AUTOMOTIVE TECHNOLOGY

Principles, Diagnosis, and Service, 7th Edition

JAMES HALDERMAN | CURT WARD

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AUTOMOTIVE TECHNOLOGY

Principles, Diagnosis, and Service

SEVENTH EDITION

James Halderman | Curt Ward

Pearson

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PREFACE

NEW TO THIS EDITION Based on the suggestions and recommendations from automotive instructors and reviewers who said about the awesome seventh edition:

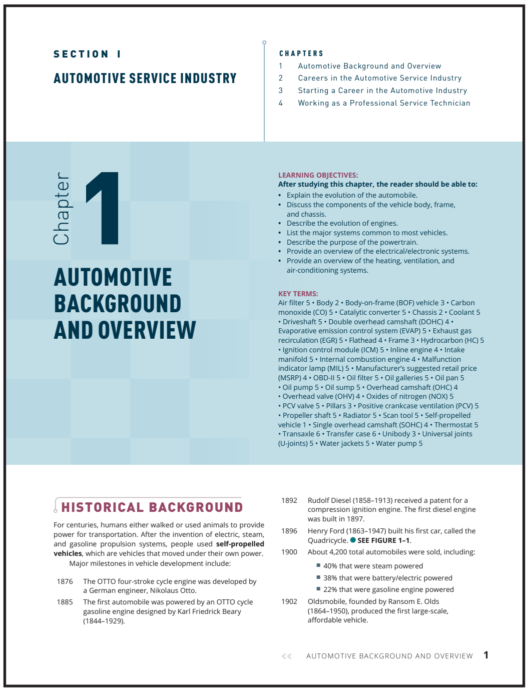
> "Hands down, the best automotive textbook on the market."

The following changes have been made to the new edition:

1. All the content meets and has been correlated to the latest ASE Education Foundation tasks.
    - **A0 - Fundamentals and Basic Skills** (including soft skills) – Chapters 1 through 14
    - **A1 - Engine Repair** – Chapters 15 through 35
    - **A2 - Automatic Transmissions/Transaxles** – Chapters 128 through 133
    - **A3 - Manual Drivetrains and Axles** – Chapters 121 through 127
    - **A4 - Steering and Suspension** – Chapters 108 through 120
    - **A5 - Brakes** – Chapters 93 through 107
    - **A6 - Electrical/Electronic Systems** – Chapters 36 through 59
    - **A7 - Heating and Air-Conditioning** – Chapters 60 through 66
    - **A8 - Engine Performance** – Chapters 67 through 85
    - **G1 - Maintenance and Light Repair** – Selected content from many chapters
    - **P2 - Parts Specialist** – Chapter 134
    - **C1 - Service Consultant** – Chapter 135
    - **X1 - Exhaust Systems** – Chapter 136
    - **L3 - Electric and Hybrid Electric Vehicles** – Chapters 86 through 92
2. All chapters have been updated and older content replaced with the latest technologies.
3. The new seventh edition has 3,792 color photos and line drawings, of which 584 are new or updated.
4. Concisely written.
5. Easy to read.
6. Includes well-defined major headings (H1s) and sub-headings (H2s), making it easy to find exactly what is needed within a chapter.
7. Case studies are included in many chapters that include the three Cs (Complaint, Cause, and Correction).
8. All terminology adheres to the SAE J1930 standard.
9. New and high-technology topics have been added including
    - Health and Environmental Issues – Chapter 7
    - Digital Storage Oscilloscope (DSO) – Chapter 40
    - BCM coding – Chapter 57
    - Advanced Driver Assist Systems (ADAS) – Chapter 58
    - Heat Pump Systems – Chapter 63
    - Gasoline Direct Injection (GDI) System – Chapter 76
    - Electronic Throttle Control (ETC) System – Chapter 77
    - Module Programming – Chapter 84
    - Strategy-Based Diagnosis – Chapter 85
    - Electric and Hybrid Electric Vehicles – Chapters 86 through 90
    - Acoustical foam in tires – Chapter 87
    - Fuel Cells and Advanced Technologies – Chapter 92
    - Electronic Stability Control Systems – Chapter 107
    - Vibration and Noise Diagnosis and Correction – Chapter 127
    - Continuously Variable and Dual-Clutch Automatic Transmissions – Chapter 129
    - EV and HEV Transmissions – Chapter 131
    - Parts Specialist (P2) – Chapter 134
    - Service Consultant (C1) – Chapter 135
    - Exhaust Systems (X1) – Chapter 136

IN-TEXT FEATURES

The following highlights the unique core features that set the Professional Technician Series textbook apart from other automotive textbooks.



SECTION I

AUTOMOTIVE SERVICE INDUSTRY

CHAPTERS

1 Automotive Background and Overview
2 Careers in the Automotive Service Industry
3 Starting a Career in the Automotive Industry
4 Working as a Professional Service Technician

Chapter 1

AUTOMOTIVE BACKGROUND AND OVERVIEW

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the evolution of the automobile.
- Discuss the components of the vehicle body, frame, and chassis.
- Describe the evolution of engines.
- List the major systems common to most vehicles.
- Describe the purpose of the powertrain.
- Provide an overview of the electrical/electronic systems.
- Provide an overview of the heating, ventilation, and air-conditioning systems.

KEY TERMS:

Air filter 5 • Body 2 • Body-on-frame (BOF) vehicle 3 • Carbon monoxide (CO) 5 • Catalytic converter 5 • Chassis 2 • Coolant 5 • Driveshaft 5 • Double overhead camshaft (DOHC) 4 • Evaporative emission control system (EVAP) 5 • Exhaust gas recirculation (EGR) 5 • Flathead 4 • Frame 3 • Hydrocarbon (HC) 5 • Ignition control module (ICM) 5 • Inline engine 4 • Intake manifold 5 • Internal combustion engine 4 • Malfunction indicator lamp (MIL) 5 • Manufacturer's suggested retail price (MSRP) 4 • OBD-II 5 • Oil filter 5 • Oil galleries 5 • Oil pan 5 • Oil pump 5 • Oil sump 5 • Overhead camshaft (OHC) 4 • Overhead valve (OHV) 4 • Oxides of nitrogen (NOX) 5 • PCV valve 5 • Pillars 3 • Positive crankcase ventilation (PCV) 5 • Propeller shaft 5 • Radiator 5 • Scan tool 5 • Self-propelled vehicle 1 • Single overhead camshaft (SOHC) 4 • Thermostat 5 • Transaxle 6 • Transfer case 6 • Unibody 3 • Universal joints (U-joints) 5 • Water jackets 5 • Water pump 5

HISTORICAL BACKGROUND

For centuries, humans either walked or used animals to provide power for transportation. After the invention of electric, steam, and gasoline propulsion systems, people used **self-propelled vehicles**, which are vehicles that moved under their own power.

Major milestones in vehicle development include:

1876 The OTTO four-stroke cycle engine was developed by a German engineer, Nikolaus Otto.
1885 The first automobile was powered by an OTTO cycle gasoline engine designed by Karl Friedrick Beary (1844–1929).
1892 Rudolf Diesel (1858–1913) received a patent for a compression ignition engine. The first diesel engine was built in 1897.
1896 Henry Ford (1863–1947) built his first car, called the Quadricycle. ● **SEE FIGURE 1–1**.
1900 About 4,200 total automobiles were sold, including:

- 40% that were steam powered
- 38% that were battery/electric powered
- 22% that were gasoline engine powered

1902 Oldsmobile, founded by Ransom E. Olds (1864–1950), produced the first large-scale, affordable vehicle.

<< AUTOMOTIVE BACKGROUND AND OVERVIEW 1

OBJECTIVES AND KEY TERMS appear at the beginning of each chapter to help students and instructors focus on the most important material in each chapter. The chapter objectives are based on specific ASE tasks.

TECH TIP

Treat a Vehicle Body with Respect

Do not sit on a vehicle. The metal can easily be distorted, which could cost hundreds of dollars to repair. This includes sitting on the hood, roof, and deck (trunk) lid, as well as fenders. Also, do not hang on any opened door as this can distort the hinge area causing the door not to close properly.

TECH TIPS feature real-world advice and "tricks of the trade" from ASE-certified master technicians.

SAFETY TIP

Compressed Air Safety

Improper use of an air nozzle can cause blindness or deafness. Compressed air must be reduced to less than 30 PSI (206 kPa). ● **SEE FIGURE 5–11**. If an air nozzle is used to dry and clean parts, make sure the air stream is directed away from anyone else in the immediate area. Always use an OSHA-approved nozzle with side slits that limit the maximum pressure at the nozzle to 30 PSI. Coil and store air hoses when they are not in use.

SAFETY TIPS alert students to possible hazards on the job and how to avoid them.

CASE STUDY

The Case of the No-Crank Camaro

The owner of a Camaro SS equipped with a 6.2 liter V-8 and a six-speed manual transmission had the car towed to a shop for a no crank, no start condition. The technician used a scan tool and was able to retrieve a stored diagnostic trouble code (DTC) P0807. This code indicated a fault with the clutch pedal position (CPP) sensor. The clutch pedal position sensor was removed and it was found to be internally shorted. A new sensor was installed and the technician performed a relearn procedure as specified in service information. The car was then able to crank and start and verified that no codes were present.

Summary:

Complaint—The customer stated that the engine would not crank or start.
Cause—A shorted clutch pedal position (CPP) sensor.
Correction—The clutch pedal position sensor was replaced and a relearn procedure was performed.

CASE STUDIES present students with actual automotive scenarios and show how these common (and sometimes uncommon) problems are diagnosed and repaired. These scenarios "Use the Three Cs approach" (Complaint, Cause, and Correction).

FREQUENTLY ASKED QUESTION

Why Is Windshield Washer Fluid Regulated?

Automotive windshield washer fluid (AWWF) is a source of pollution because it can contain high levels of methanol, a volatile organic compound (VOC), which is a component of ground-level ozone, one of the main pollutants in smog. The VOC content (methanol) in automotive windshield washer fluid is regulated/limited by federal and, in some cases, by state and local regulation. At the federal level, VOC content is limited to 35% by weight. State and local regulations are more restrictive than the federal regulation, restricting the sale of windshield washer fluid to a VOC weight content that is lower than the 35% federal standard.

FREQUENTLY ASKED QUESTIONS are based on the author's own experience and provide answers to many of the most common questions asked by students and beginning service technicians.

NOTE: Even though DOT 5 does not normally absorb water, it is still tested using standardized SAE procedures in a humidity chamber. After a fixed amount of time, the brake fluid is measured for boiling point. Because it has had a *chance* to absorb moisture, the boiling point after this sequence is called the minimum wet boiling point.

NOTES provide students with additional technical information to give them a greater understanding of a specific task or procedure.

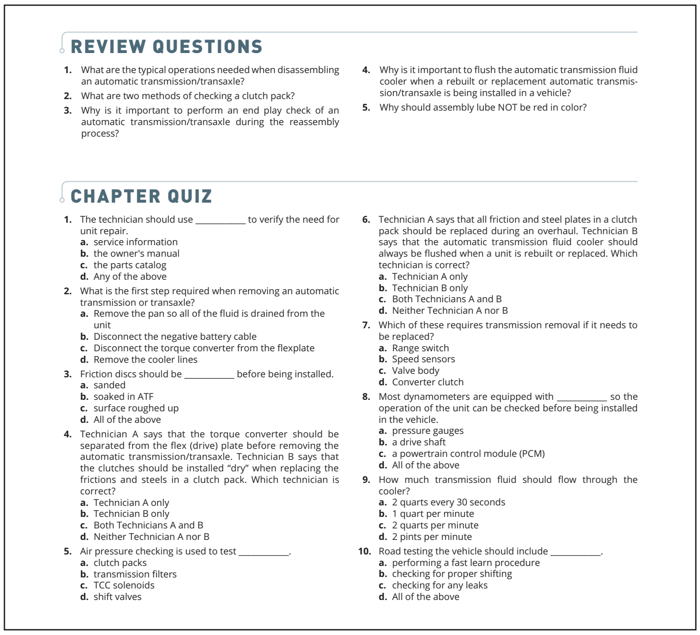
CAUTION: Do not use fluid that is labeled for all vehicles as this type may not be compatible with the seals used in the power steering system or provide the specified friction additives needed to provide the proper steering feel to the driver.

CAUTIONS alert students about potential damage to the vehicle that can occur during a specific task or service procedure.

WARNING

Windshield washer fluid usually contains methanol, a poisonous chemical that can cause blindness if ingested.

WARNINGS alert students to potential dangers to themselves during a specific task or service procedure.



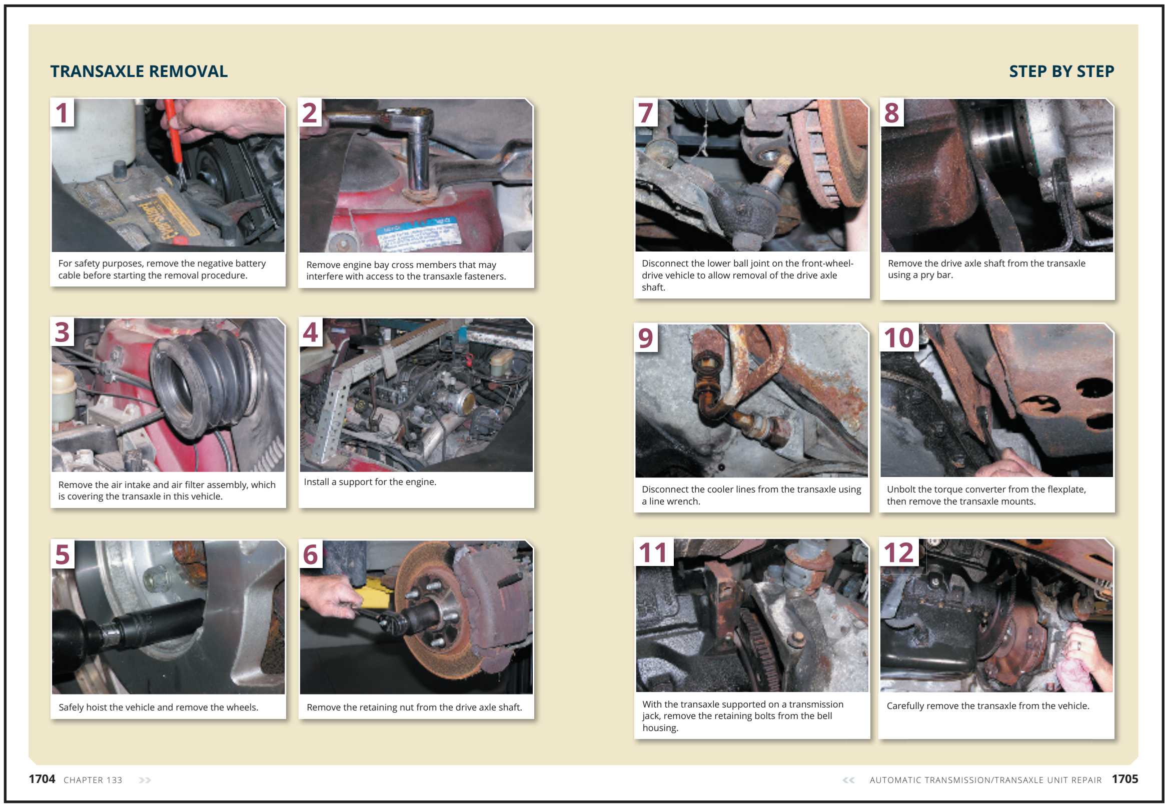
REVIEW QUESTIONS

1. What are the typical operations needed when disassembling an automatic transmission/transaxle?
2. What are two methods of checking a clutch pack?
3. Why is it important to perform an end play check of an automatic transmission/transaxle during the reassembly process?
4. Why is it important to flush the automatic transmission fluid cooler when a rebuilt or replacement automatic transmission/transaxle is being installed in a vehicle?
5. Why should assembly lube NOT be red in color?

CHAPTER QUIZ

1. The technician should use __________ to verify the need for unit repair.
   - **a.** service information
   - **b.** the owner's manual
   - **c.** the parts catalog
   - **d.** Any of the above
2. What is the first step required when removing an automatic transmission or transaxle?
   - **a.** Remove the pan so all of the fluid is drained from the unit
   - **b.** Disconnect the negative battery cable
   - **c.** Disconnect the torque converter from the flexplate
   - **d.** Remove the cooler lines
3. Friction discs should be __________ before being installed.
   - **a.** sanded
   - **b.** soaked in ATF
   - **c.** surface roughed up
   - **d.** All of the above
4. Technician A says that the torque converter should be separated from the flex (drive) plate before removing the automatic transmission/transaxle. Technician B says that the clutches should be installed "dry" when replacing the frictions and steels in a clutch pack. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Air pressure checking is used to test __________.
   - **a.** clutch packs
   - **b.** transmission filters
   - **c.** TCC solenoids
   - **d.** shift valves
6. Technician A says that all friction and steel plates in a clutch pack should be replaced during an overhaul. Technician B says that the automatic transmission fluid cooler should always be flushed when a unit is rebuilt or replaced. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Which of these requires transmission removal if it needs to be replaced?
   - **a.** Range switch
   - **b.** Speed sensors
   - **c.** Valve body
   - **d.** Converter clutch
8. Most dynamometers are equipped with __________ so the operation of the unit can be checked before being installed in the vehicle.
   - **a.** pressure gauges
   - **b.** a drive shaft
   - **c.** a powertrain control module (PCM)
   - **d.** All of the above
9. How much transmission fluid should flow through the cooler?
   - **a.** 2 quarts every 30 seconds
   - **b.** 1 quart per minute
   - **c.** 2 quarts per minute
   - **d.** 2 pints per minute
10. Road testing the vehicle should include __________.
   - **a.** performing a fast learn procedure
   - **b.** checking for proper shifting
   - **c.** checking for any leaks
   - **d.** All of the above

REVIEW QUESTIONS AND CHAPTER QUIZ at the end of each chapter help students review the material presented in the chapter and test to see how much they have learned.



TRANSAXLE REMOVAL **STEP BY STEP**

1. For safety purposes, remove the negative battery cable before starting the removal procedure.
2. Remove engine bay cross members that may interfere with access to the transaxle fasteners.
3. Remove the air intake and air filter assembly, which is covering the transaxle in this vehicle.
4. Install a support for the engine.
5. Safely hoist the vehicle and remove the wheels.
6. Remove the retaining nut from the drive axle shaft.
7. Disconnect the lower ball joint on the front-wheel-drive vehicle to allow removal of the drive axle shaft.
8. Remove the drive axle shaft from the transaxle using a pry bar.
9. Disconnect the cooler lines from the transaxle using a line wrench.
10. Unbolt the torque converter from the flexplate, then remove the transaxle mounts.
11. With the transaxle supported on a transmission jack, remove the retaining bolts from the bell housing.
12. Carefully remove the transaxle from the vehicle.

1704 CHAPTER 133 >>

<< AUTOMATIC TRANSMISSION/TRANSAXLE UNIT REPAIR 1705

STEP-BY-STEP PHOTO SEQUENCES show in detail the steps involved in performing a specific task or service procedure.

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REVEL FOR AUTOMOTIVE TECHNOLOGY, 7E

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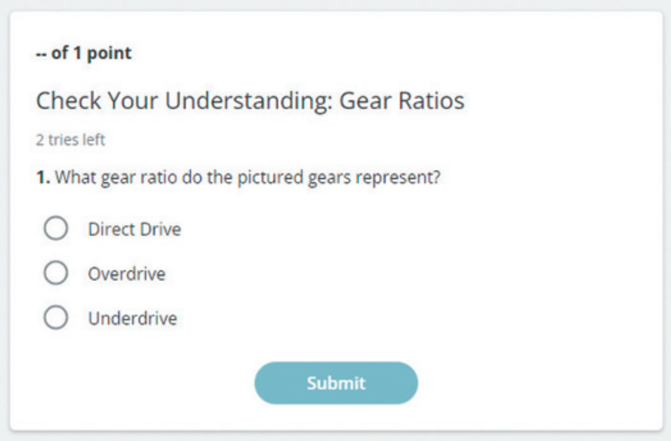
KEY FEATURES

- **Full chapter audio** allows students to listen and learn in an alternative format.
- **Interactive exercises** such as, multiple-choice questions, fill-in-the blank, and others are integrated throughout the narrative so students can self-check their understanding at regular intervals before moving on.



-- of 1 point

Check Your Understanding: Gear Ratios

2 tries left

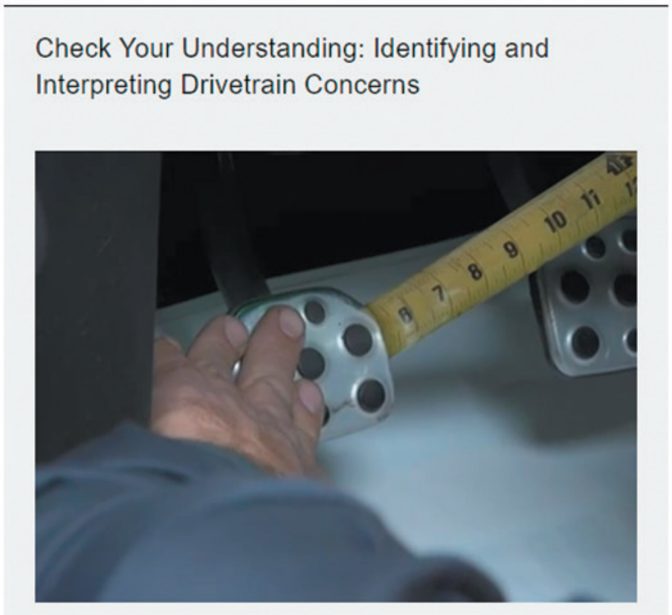
1. What gear ratio do the pictured gears represent?

○ Direct Drive

○ Overdrive

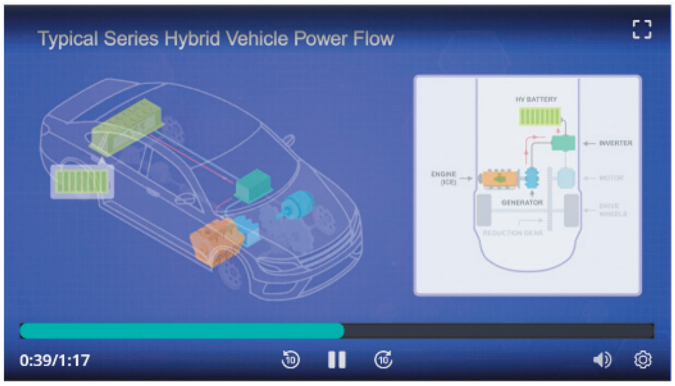
○ Underdrive

- **More than 280 videos with questions** appear inline next to corresponding narrative. These video segments feature author and expert presentations of key concepts and skills demonstrations.



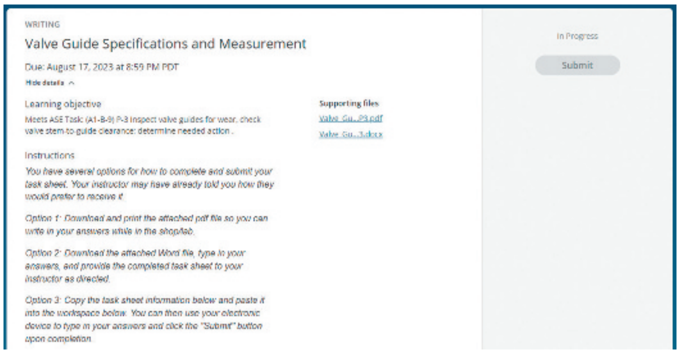
Check Your Understanding: Identifying and Interpreting Drivetrain Concerns

- **More than 500 animations**, including 48 new, that have been exclusively created for the 7th edition! These instructive videos enhance the text narrative and static images by depicting skills and key concepts not possible with a photograph or traditional video.



Typical Series Hybrid Vehicle Power Flow

- **ASE Task Sheets** are now delivered through Revel in an all-new format. Students can download, print, or complete them electronically on their mobile device (without downloading) and easily submit for grading once complete.



WRITING

Valve Guide Specifications and Measurement

Due: August 17, 2023 at 8:59 PM PDT

Hide details ^

Learning objective

Meets ASE Task: (A1-B-9) P-3 Inspect valve guides for wear; check valve stem-to-guide clearance; determine needed action.

Supporting files

Valve_Gu...P3.pdf

Valve_Gu...3.docx

Instructions

You have several options for how to complete and submit your task sheet. Your instructor may have already told you how they would prefer to receive it.

Option 1: Download and print the attached pdf file so you can write in your answers while in the shop/lab.

Option 2: Download the attached Word file, type in your answers, and provide the completed task sheet to your instructor as directed.

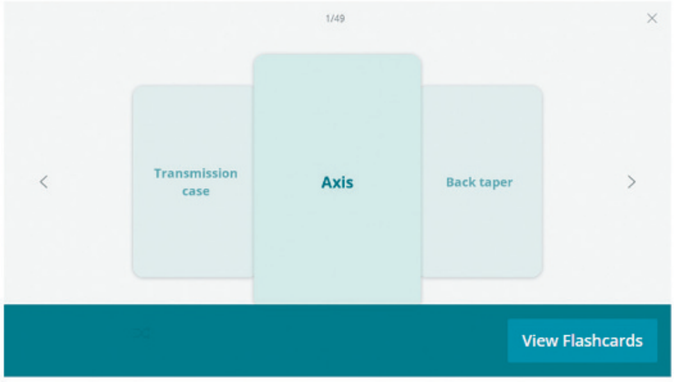
Option 3: Copy the task sheet information below and paste it into the workspace below. You can then use your electronic device to type in your answers and click the "Submit" button upon completion.

In Progress

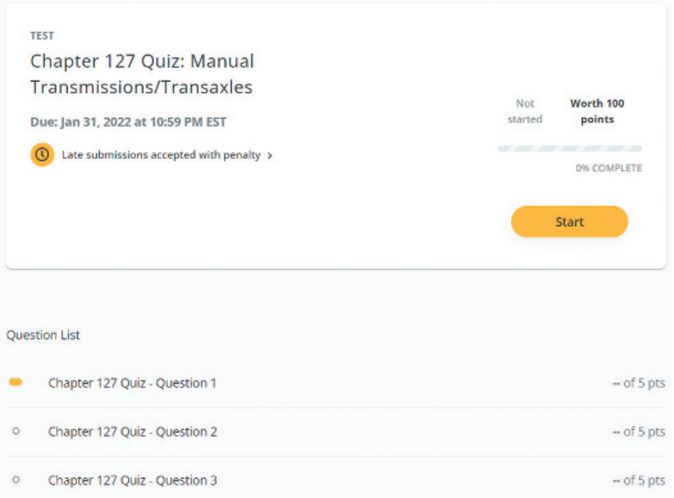
Submit

- **Flashcards and study tools** provide practice with all of the important key terms.

Chapter 127 Key Terms



- **Learning Objective quizzes and comprehensive Chapter quizzes** test students' knowledge. These are graded instantly for immediate feedback and scores are tracked in the instructor dashboard.



TEST

Chapter 127 Quiz: Manual Transmissions/Transaxles

Due: Jan 31, 2022 at 10:59 PM EST

Late submissions accepted with penalty >

Not started

Worth 100 points

0% COMPLETE

Start

Question List

●	Chapter 127 Quiz - Question 1	-- of 5 pts
○	Chapter 127 Quiz - Question 2	-- of 5 pts
○	Chapter 127 Quiz - Question 3	-- of 5 pts

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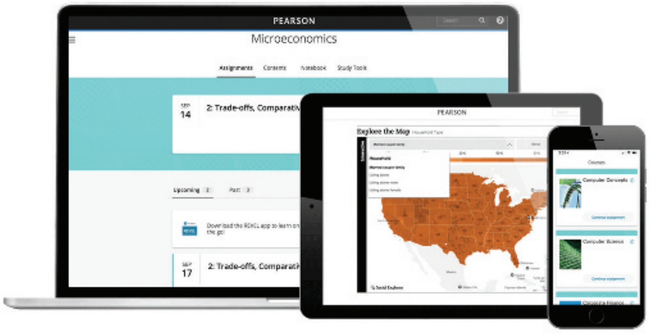
- **Highlighting, note taking, and a glossary** let students read and study in a variety of ways.
- **The Revel mobile app** lets students read, practice, and study—anywhere, anytime, on any device. Content is available both online and offline, and the app syncs work across all registered devices automatically, giving students great flexibility to toggle between phone, tablet, and laptop.



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- **The Performance dashboard** enables instructors to view assignment completion, time on task, points earned on chapter quizzes, how the class is trending, student performance by learning outcome, and more.
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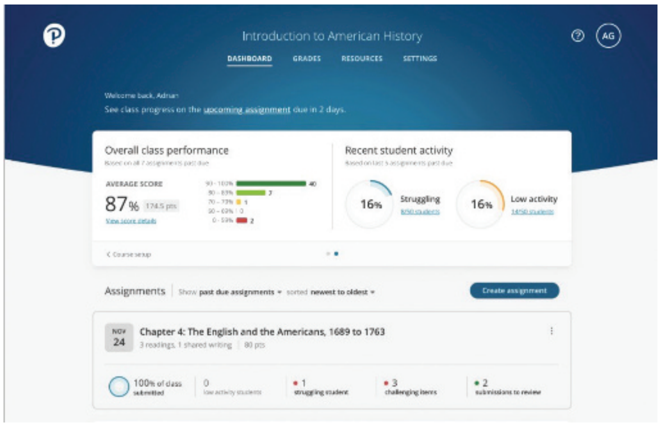

Introduction to American History

DASHBOARD GRADES RESOURCES SETTINGS

Welcome back, Adnan

See class progress on the upcoming assignment due in 2 days.

Overall class performance

AVERAGE SCORE

87% 174.5 pts

View score details

Recent student activity

16% Struggling

16% Low activity

< Course setup

Assignments Show past due assignments ▾ sorted newest to oldest ▾

Create assignment

NOV 24 Chapter 4: The English and the Americans, 1689 to 1763

3 readings, 1 shared writing | 80 pts

100% of class submitted | 0 low activity students | 1 struggling student | 3 challenging items | 2 submissions to review

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- Image Bank of all images from the text
- TestGen Computerized Testbank
- ASE Correlated Task Sheets (downloaded only by instructors)

Student Supplements (for purchase): *ASE Correlated Task Sheets for Automotive Technology: Principles, Diagnosis, and Service*, 7th edition, ISBN: 9780137854950

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Automatic Transmission Rebuilders Association (ATRA)
Battery Council International (BCI)
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SECTION I

AUTOMOTIVE SERVICE INDUSTRY

CHAPTERS

1 Automotive Background and Overview
2 Careers in the Automotive Service Industry
3 Starting a Career in the Automotive Industry
4 Working as a Professional Service Technician

Chapter 1

AUTOMOTIVE BACKGROUND AND OVERVIEW

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the evolution of the automobile.
- Discuss the components of the vehicle body, frame, and chassis.
- Describe the evolution of engines.
- List the major systems common to most vehicles.
- Describe the purpose of the powertrain.
- Provide an overview of the electrical/electronic systems.
- Provide an overview of the heating, ventilation, and air-conditioning systems.

KEY TERMS:

Air filter 5 • Body 2 • Body-on-frame (BOF) vehicle 3 • Carbon monoxide (CO) 5 • Catalytic converter 5 • Chassis 2 • Coolant 5 • Driveshaft 5 • Double overhead camshaft (DOHC) 4 • Evaporative emission control system (EVAP) 5 • Exhaust gas recirculation (EGR) 5 • Flathead 4 • Frame 3 • Hydrocarbon (HC) 5 • Ignition control module (ICM) 5 • Inline engine 4 • Intake manifold 5 • Internal combustion engine 4 • Malfunction indicator lamp (MIL) 5 • Manufacturer’s suggested retail price (MSRP) 4 • OBD-II 5 • Oil filter 5 • Oil galleries 5 • Oil pan 5 • Oil pump 5 • Oil sump 5 • Overhead camshaft (OHC) 4 • Overhead valve (OHV) 4 • Oxides of nitrogen (NOX) 5 • PCV valve 5 • Pillars 3 • Positive crankcase ventilation (PCV) 5 • Propeller shaft 5 • Radiator 5 • Scan tool 5 • Self-propelled vehicle 1 • Single overhead camshaft (SOHC) 4 • Thermostat 5 • Transaxle 6 • Transfer case 6 • Unibody 3 • Universal joints (U-joints) 5 • Water jackets 5 • Water pump 5

HISTORICAL BACKGROUND

For centuries, humans either walked or used animals to provide power for transportation. After the invention of electric, steam, and gasoline propulsion systems, people used **self-propelled vehicles**, which are vehicles that moved under their own power.

Major milestones in vehicle development include:

1876	The OTTO four-stroke cycle engine was developed by a German engineer, Nikolaus Otto.
1885	The first automobile was powered by an OTTO cycle gasoline engine designed by Karl Friedrick Beary (1844–1929).
1892	Rudolf Diesel (1858–1913) received a patent for a compression ignition engine. The first diesel engine was built in 1897.
1896	Henry Ford (1863–1947) built his first car, called the Quadricycle. ● **SEE FIGURE 1–1**.
1900	About 4,200 total automobiles were sold, including: ■ 40% that were steam powered ■ 38% that were battery/electric powered ■ 22% that were gasoline engine powered
1902	Oldsmobile, founded by Ransom E. Olds (1864–1950), produced the first large-scale, affordable vehicle.

FIGURE 1–1 A model of the Quadricycle, a car built by Henry Ford in 1896.

1908	William Durant (1861–1947) formed General Motors.
1908	The Ford Model T was introduced.
1912	The electric starter was invented by Charles F. Kettering (1876–1958) of Dayton, Ohio, first used on a Cadillac. The starter was produced by a new company called Delco, which stood for Dayton Engineering Laboratories Company.
1914	First car with a 100% steel body was made by the Budd Corporation for Dodge. Before 1914, all car bodies had wood components in them.
1922	The first vehicle to have four-wheel hydraulically operated brakes was a Duesenberg built in Indianapolis, Indiana.
1940	The first fully automatic transmission was introduced by Oldsmobile.
1973	Airbags were offered as an option on some General Motors vehicles.
1985	Lincoln offers the first four-wheel antilock braking system.
1997	The first vehicle with electronic stability control was offered by Cadillac.

BODIES, CHASSIS SYSTEMS, AND FRAMES

BODIES Early motor vehicles evolved from horse-drawn carriages. The engine and power train were attached to a modified carriage leading to the term "horseless carriage."

The bodies evolved until in the 1930s, all-steel-enclosed bodies became the most used type. All bodies depended on a frame of wood or steel to support the chassis components. ● **SEE FIGURE 1–2**.

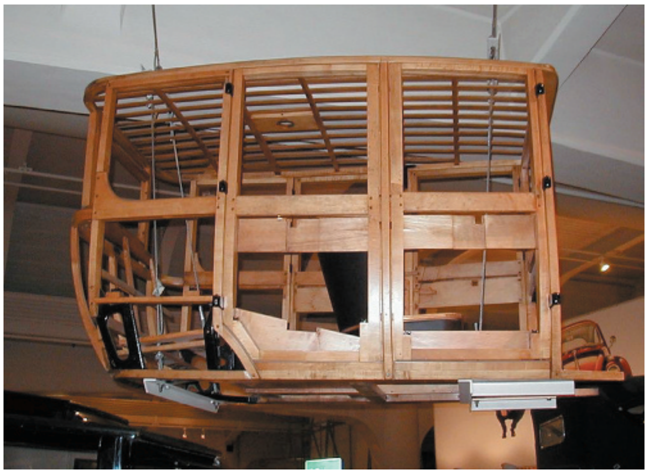


FIGURE 1–2 Most vehicle bodies were constructed with a wood framework until the 1920s.

CHASSIS SYSTEMS OVERVIEW The **chassis** system of the vehicle includes the following components:

1. Frame or **body** of the vehicle, which is used to provide the support for the suspension and steering components as well as the powertrain.
2. The suspension system of the vehicle provides a smooth ride to the driver and passengers and helps the tires remain on the road even when the vehicle is traveling over rough roads. The suspension system includes springs and control arms that allow the wheel to move up and down and keep the tires on the road.
3. The braking system of the vehicle is used to slow and stop the rotation of the wheels, which in turn stops the vehicle. The braking system includes the brake pedal, master cylinder, plus wheel brakes at each wheel. Two types of wheel brakes are used. Disc brakes include a caliper, which applies force to brake pads on both sides of a rotating disc or rotor. Drum brakes use brake shoes, which are applied by hydraulic pressure outward against a rotating brake drum. The brake drum is attached to and stops the rotation of the wheels. Drum brakes are used on the rear of many vehicles.
4. Wheels and tires—The wheels are attached to the bearing hubs on the axles. The tires must provide traction for accelerating, braking, and cornering, as well as provide a comfortable ride. Wheels are constructed of steel or aluminum alloy and mount to the hubs of the vehicle using lug nuts, which must be tightened correctly to the proper torque.

Vehicle manufacturers can design a platform that can use different powertrains. ● **FIGURE 1–3**.

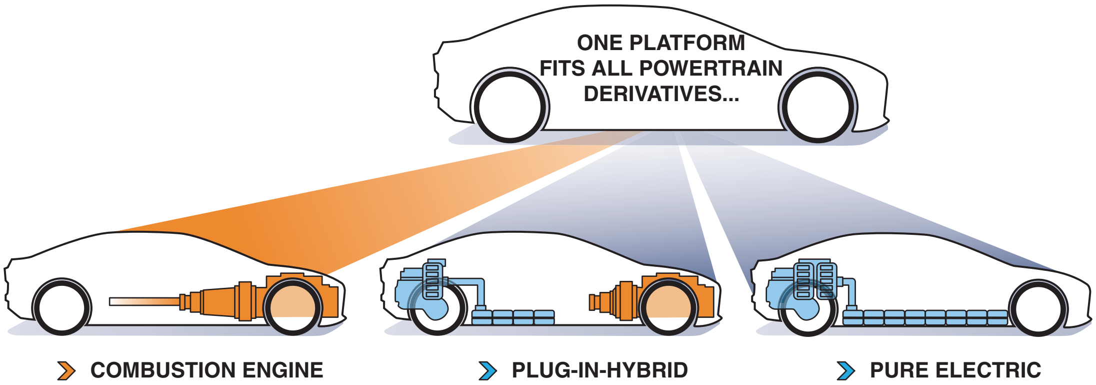


FIGURE 1–3 Some vehicle manufacturers are able to manufacture one platform that can be used with an internal combustion engine, a plug-in hybrid powertrain, or a full electric powertrain.

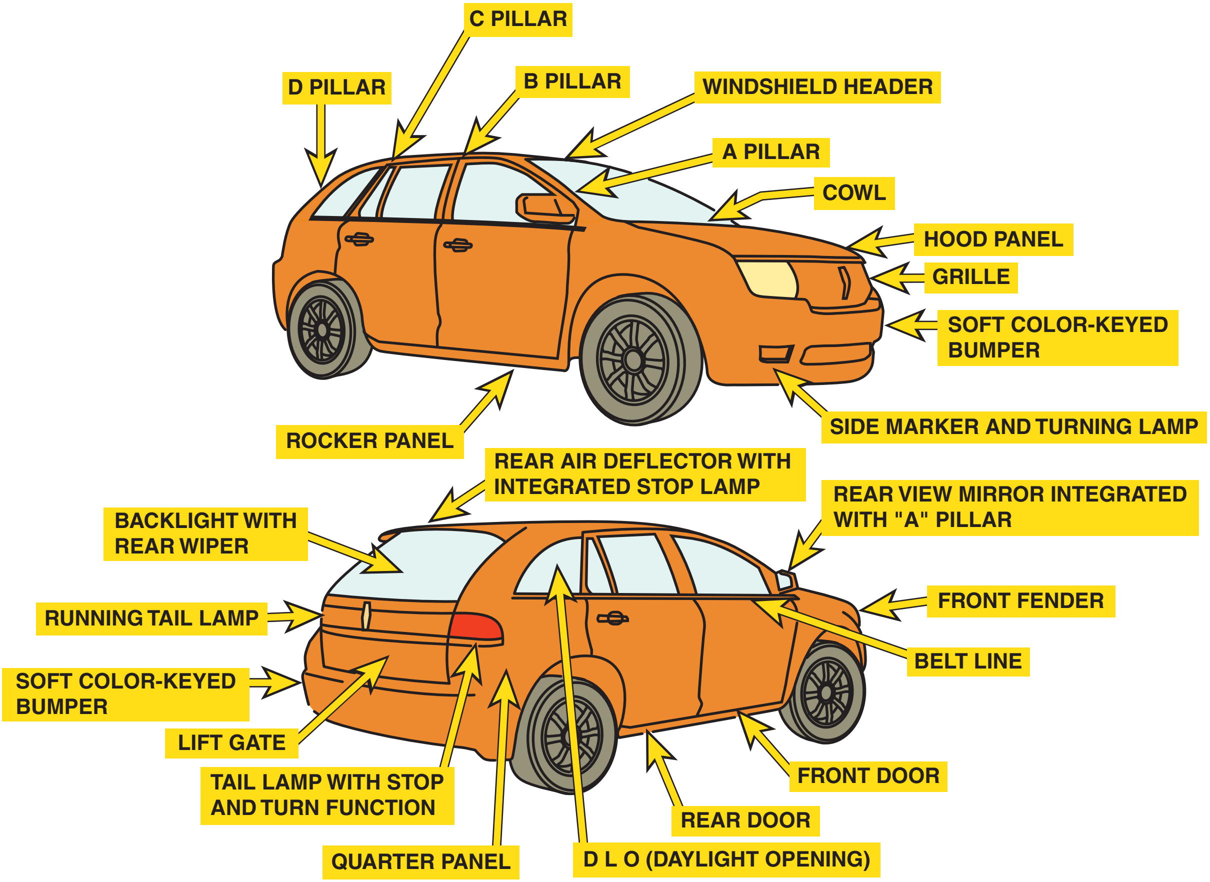

C PILLAR
D PILLAR
B PILLAR
WINDSHIELD HEADER
A PILLAR
COWL
HOOD PANEL
GRILLE
SOFT COLOR-KEYED BUMPER
SIDE MARKER AND TURNING LAMP
ROCKER PANEL
REAR AIR DEFLECTOR WITH INTEGRATED STOP LAMP
REAR VIEW MIRROR INTEGRATED WITH "A" PILLAR
BACKLIGHT WITH REAR WIPER
RUNNING TAIL LAMP
FRONT FENDER
BELT LINE
SOFT COLOR-KEYED BUMPER
LIFT GATE
FRONT DOOR
TAIL LAMP WITH STOP AND TURN FUNCTION
REAR DOOR
QUARTER PANEL
D L O (DAYLIGHT OPENING)

FIGURE 1–4 Body and terms.

Many of the expensive automakers in the 1920s and 1930s had bodies built by another company. Eventually, most bodies were constructed of steel and many without the need for a frame to support the drivetrain and suspension.

BODY TERMS The roof of a vehicle is supported by **pillars** and they are labeled A, B, C, and D from the front to the rear of the vehicle. All vehicles have an A pillar at the windshield but many, such as a hardtop, do not have a B pillar. Station wagons and sport utility vehicles (SUVs) often have a D pillar at the rear of the vehicle. ● **SEE FIGURE 1–4**.

FRAMES **Frame** construction usually consists of channel-shaped steel beams welded and/or fastened together. Vehicles with a separate frame and body are usually called **body-on-frame (BOF) vehicles.** Many terms are used to label or describe the frame of a vehicle including:

UNIT-BODY CONSTRUCTION Unit-body construction (sometimes called **unibody**) is a design that combines the body with the structure of the frame. The body is composed of many individual stamped-steel panels welded together. The strength of this type of construction lies in the *shape* of the assembly. The typical vehicle uses 300 separate stamped-steel panels that are spot-welded together to form a vehicle's body. ● **SEE FIGURE 1–5**.

NOTE: A typical vehicle contains about 10,000 separate individual parts.

SPACE-FRAME CONSTRUCTION Some vehicles use space-frame construction, which consists of formed sheet steel that is used to construct a framework for the entire vehicle. The vehicle then has plastic or steel panels to cover the steel framework. ● **SEE FIGURE 1–6**.

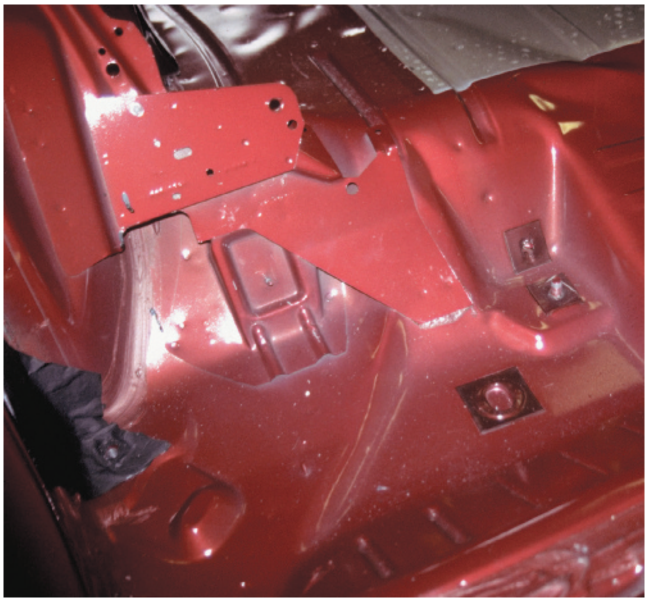


FIGURE 1–5 Note the ribbing and the many different pieces of sheet metal used in the construction of this body.

TECH TIP

Treat a Vehicle Body with Respect

Do not sit on a vehicle. The metal can easily be distorted, which could cost hundreds of dollars to repair. This includes sitting on the hood, roof, and deck (trunk) lid, as well as fenders. Also, do not hang on any opened door as this can distort the hinge area causing the door not to close properly.

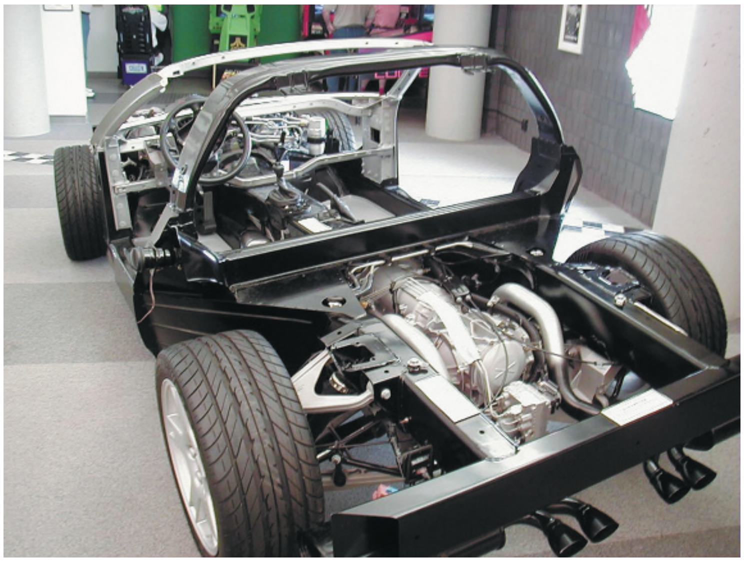


FIGURE 1–6 A Corvette without the body. Notice that the vehicle is complete enough to be driven.

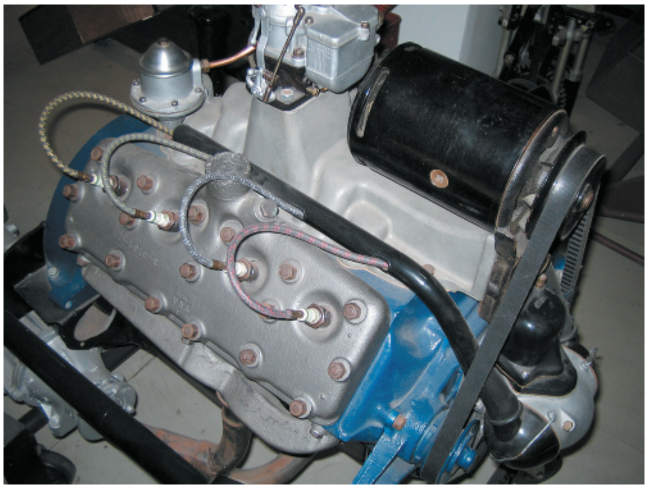


FIGURE 1–7 A Ford flathead V-8 engine. This engine design was used by Ford Motor Company from 1932 through 1953. In a flathead design, the valves are located next to (beside) the cylinders.

ENGINE DESIGN EVOLUTION

All gasoline and diesel engines are called **internal combustion engines** and are designed to compress an ignitable mixture. This mixture is ignited by using a spark (gasoline) or by heat of compression (diesel). The pistons are connected to a crankshaft, which converts the up-and-down motion of the pistons to a rotary force that is used to propel the vehicle.

INLINE VERSUS V-TYPE DESIGN Most early engines used four or six cylinders arranged inline. These are called **inline engines** and are still produced today. Some engines with 4, 6, 8, 10, 12, or 16 cylinders are arranged with half of the cylinders on each set of a "V" and connected to a common crankshaft in the bottom of the "V." The crankshaft changed the up-and-down motion of the piston to rotary motion, allowing the engine to power the drive wheels.

VALVE LOCATION DESIGN The design where the valves are located in the engine block is called **flathead** design because the cylinder head simply covers the combustion chamber and includes a hole for the spark plug. The engine block contains passages for coolant as well as lubricating oil and is the support for all other engine systems. ● **SEE FIGURE 1–7**.

By the 1950s, most engine designs placed the valves in the cylinder head. This is called an **overhead valve** *or* **OHV** design.

Even newer engine designs feature **overhead camshafts (OHC)** called **single overhead camshaft (SOHC)** designs and engines that use two overhead camshafts per bank of cylinders called **double overhead camshaft (DOHC)** designs. The placement of the camshaft results in better flow of intake air into and exhaust out of the engine.

The need for reduced emissions and greater fuel economy led to advances in engine design. These changes include:

- Electronic ignition systems
- Electronic fuel injection
- Computerized engine controls
- Emission control devices, including the catalytic converter used in the exhaust system to reduce emissions
- Improved engine oils that help reduce friction and reduce emissions

FREQUENTLY ASKED QUESTION

What Is the Monroney Label?

The Monroney label is the sticker on the vehicle that lists the **manufacturer's suggested retail price**, usually abbreviated **MSRP.** The law that requires this label on all vehicles is called the Monroney Law, named for the congressman who sponsored the bill, Almer S. Monroney (1902–1980), a U.S. farm representative from Oklahoma from 1939 to 1951 and a U.S. Senator from 1951 to 1969.

Before the Monroney label law was passed in 1958, the price of a vehicle was unknown to new vehicle buyers who had to rely on the dealer for pricing. Besides all of the standard and optional equipment on the vehicle, the Monroney label also includes fuel economy and exhaust emission information. ● **SEE FIGURE 1–8**.

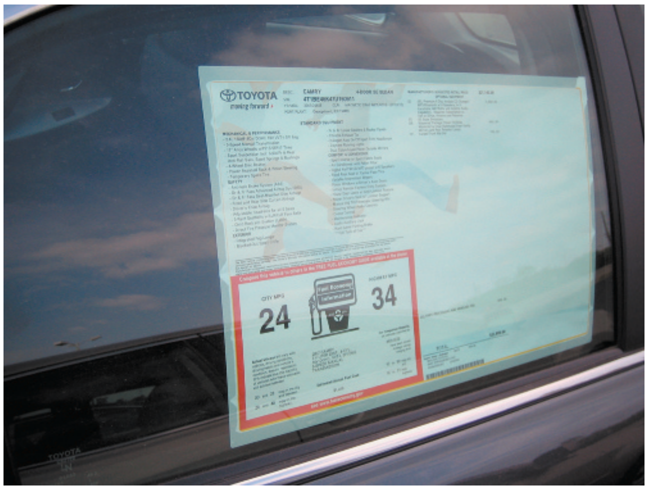


FIGURE 1–8 A Monroney label as shown on the side window of a new vehicle.

ENGINE SYSTEMS OVERVIEW

Every engine requires many systems to function correctly.

COOLING SYSTEM While some older engines were air cooled, all engines currently in production are liquid cooled. Coolant is circulated by a **water pump** through passages in the cylinder block and head called **water jackets**. The **coolant** is a mixture of antifreeze and water to provide corrosion and freezing protection. After the coolant picks up the heat from the engine, it flows through a **radiator**, which cools the coolant by releasing the heat into the air. The temperature of the coolant is maintained by using a **thermostat** located in the coolant passage, which opens to allow coolant to flow to the radiator or closes until the coolant is hot enough to need cooling.

LUBRICATION SYSTEM All engines need a supply of lubricating oil to reduce friction and help to cool the engine. Most engines are equipped with an **oil pan**, also called an **oil sump**, containing 3 to 7 quarts (liters) of oil. An engine-driven **oil pump** forces the oil under pressure through an **oil filter**, then to passages in the block and head called **oil galleries**, and then to all of the moving parts.

AIR INTAKE SYSTEM All engines, both gasoline and diesel engines, draw air from the atmosphere. It requires about 9,000 gallons of air for each gallon of gasoline used. The air must be drawn where deep water in the road cannot be drawn into the engine. The air is then filtered by a replaceable **air filter**. After the air is filtered, it passes through a throttle valve and then into the engine through an **intake manifold**.

FUEL SYSTEM The fuel system includes the following components and systems:

- Fuel tank
- Fuel lines and filter(s)
- Fuel injectors
- Electronic control of the fuel pump and fuel injection

The fuel injectors are designed to atomize the liquid gasoline into small droplets so they can be mixed with the air entering the engine. This mixture of fuel and air is then ignited by the spark plug.

STARTING AND CHARGING SYSTEM Engine starting and charging systems include the battery, starting (cranking) system, charging system components, and circuits.

IGNITION SYSTEM The ignition system includes the **ignition control module (ICM)** and ignition coil(s), which create a high-voltage spark by stepping up battery voltage. The arc across the electrodes of the spark plug ignites the air–fuel mixture in the combustion chamber and the resulting pressure pushes the piston down on the power stroke.

EMISSION CONTROL SYSTEM The control of vehicle emissions includes controlling gasoline vapors from being released into the atmosphere in addition to reducing the emissions from the exhaust. Emissions that are controlled include unburned gasoline, called **hydrocarbons (HCs)**, and exhaust gases, **carbon monoxide (CO)** and **oxides of nitrogen (NOX)**. The **evaporative emission control system**, usually called the **EVAP system,** is designed to prevent gasoline fumes and vapors from being released. Other emission control systems include:

- **Positive crankcase ventilation (PCV).** This system uses a valve called a **PCV valve** to regulate the flow of gases created in the crankcase of a running engine, which are routed back into the intake manifold. The engine will then draw these gases into the combustion chamber where they are burned to help prevent the release of the gases into the atmosphere.
- **Exhaust gas recirculation (EGR).** The EGR system meters about 3% to 7% of the exhaust gases back into the intake where the gases reduce the peak combustion temperature and prevent the oxygen (O_2) and nitrogen (NO) from the air from combining to form oxides of nitrogen.
- **Catalytic converter.** The catalytic converter is a unit located in the exhaust system usually close to the engine, which causes chemical changes in the exhaust gases.
- **On-board diagnostics.** This means that the engine, as well as the engine management systems can test itself, for proper operation and alert the driver if a fault is detected. The warning lamp is called the **malfunction indicator light (MIL)** and is labeled "Check Engine" or "Service Engine Soon." The on-board diagnostic system is currently in the second generation and is called **OBD-II**. Electronic hand-held testers, called **scan tools**, are needed to access (retrieve) stored diagnostic trouble codes (DTCs) and view sensor and system data.

POWERTRAIN OVERVIEW

The purpose of the powertrain is to transfer the torque output of the engine to the drive wheels.

REAR-WHEEL-DRIVE POWERTRAIN A rear-wheel-drive vehicle uses the following components to transfer engine torque to the rear drive wheels:

- **Transmission.** An automatic transmission usually uses planetary gearsets and electronic controls to change gear ratios. In a manually shifted transmission, the drivetrain contains a clutch assembly, which allows the driver to disengage engine torque from the transmission to allow the driver to shift from one gear ratio to another. The transmission contains gears and other assemblies that provide high torque output at low speeds for acceleration and lower torque output but at higher speeds for maximum fuel economy at highway speeds.
- **Driveshaft.** A **driveshaft**, also called a **propeller shaft**, is used to connect and transmit engine torque from the transmission to the rear drive axle. **Universal joints (U-joints)** are used to allow the rear drive axle to move up and down on the rear suspension and still be able to transmit engine torque.
- **Drive axle.** A drive axle is used at the rear of some vehicles and performs three functions:
  - It contains a differential that allows for different axle speeds when cornering.
  - It increases the torque applied to the rear drive wheels by the use of a reduction gear set (ring and pinion gear).
  - It changes the direction of the applied engine torque and uses axle shafts to transfer the torque to the drive wheels.

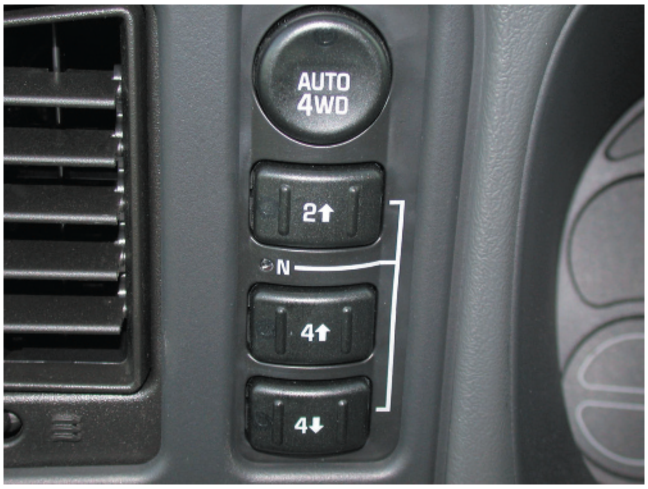


FIGURE 1–9 A dash control panel used by the driver to control the four-wheel-drive system.

FIGURE 1–10 The alternator is responsible for supplying the electrical needs of the vehicle and to keep the battery charged.

FRONT-WHEEL-DRIVE POWERTRAIN A front-wheel-drive vehicle uses a **transaxle**, which is a combination of a transmission and differential in one assembly. Drive axle shafts then transfer the engine torque to the front drive wheels from the output of the transaxle.

FOUR-WHEEL-DRIVE SYSTEM There are many types of methods of powering all four wheels. Many include a **transfer case** to split engine torque to both the front and the rear wheels. ● **SEE FIGURE 1–9**.

ELECTRICAL/ELECTRONIC SYSTEMS OVERVIEW

Early vehicles did not have an electrical system because even the ignition did not require a battery. Early engines used a magneto to create a spark instead of using electrical power from a battery as used today.

The first electrical components on vehicles were battery-powered lights, not only for the driver to see the road, but also so others could see an approaching vehicle at night.

Only after 1912 and the invention of the self-starter did the use of a battery become commonplace. Charles F. Kettering also invented the point-type ignition system about the same time as the self-starter. Therefore, the early batteries were often referred to as SLI batteries, meaning starting, lighting, and ignition. From the 1920s into the 1950s other electrical components were added, such as radios, defroster fans, and horns. It was not until the 1960s that electrical accessories, such as air conditioning, power seats, and power windows, became common.

Today's vehicles require alternators that are capable of producing a higher amount of electricity than was needed in the past, and the number of electronic components has grown to include every system in the vehicle, including:

- A tire pressure monitoring system for the tires
- Heated and cooled seats
- Automatic climate control
- Power windows
- Security systems
- Electric power steering
- Electronic suspension

● **SEE FIGURE 1–10**.

HEATING, VENTILATION, AND AIR CONDITIONING OVERVIEW

Early model vehicles did not include heaters or other methods to provide comfort for the driver and passengers. Most early vehicles were open with a simple removable top. Some had optional side curtains that provided all-weather protection. In the 1930s and 1940s when fully enclosed bodies became common, the vehicle manufacturers started to include heaters, which were small radiators with engine coolant flowing through them. About the same time and into the 1950s, the only options that many vehicles had were a radio and heater, abbreviated R & H.

Today, air-conditioning systems are on most vehicles and incorporate defrosters and passenger compartment heating, often in two zones for maximum comfort of the driver and passenger. Additional related comfort options today include heated and cooled seats, and heated steering wheels.

REVIEW QUESTIONS

1. In 1900, what was the most produced vehicle powered by?
2. What parts are included in the vehicle chassis?
3. Why were early engines called flatheads?
4. What is the difference between a unit-body and body-on-frame vehicle?
5. The powertrain consists of what components?

CHAPTER QUIZ

1. The first self-propelled vehicle that used an OTTO cycle four-stroke gasoline engine was produced in ____________.
   - **a.** 1885
   - **b.** 1900
   - **c.** 1902
   - **d.** 1908
2. Early vehicles were constructed mostly of what material?
   - **a.** Steel
   - **b.** Cast iron
   - **c.** Wood
   - **d.** Tin
3. Which component is *not* part of the chassis system?
   - **a.** Frame
   - **b.** Electrical system
   - **c.** Suspension
   - **d.** Brakes
4. Early engines were called flathead designs because they ____________.
   - **a.** were only inline engines
   - **b.** did not include valves
   - **c.** used valves beside the cylinder
   - **d.** used spark plugs at the top of the cylinders
5. A V-type engine could have how many cylinders?
   - **a.** 4
   - **b.** 6
   - **c.** 8
   - **d.** Any of the above
6. What component regulates the temperature of the coolant in an engine?
   - **a.** Cooling (water) jackets
   - **b.** Thermostat
   - **c.** Cooling fan(s)
   - **d.** Radiator
7. A malfunction indicator light (MIL) on the dash may be labeled ____________.
   - **a.** check engine
   - **b.** service vehicle soon
   - **c.** MIL
   - **d.** MAL
8. To retrieve stored diagnostic trouble codes, a service technician needs a ____________.
   - **a.** paper clip
   - **b.** desktop computer
   - **c.** wireless connection to an electronic tester
   - **d.** scan tool
9. A four-wheel-drive vehicle often uses a ____________ to transmit torque to all four wheels.
   - **a.** driveshaft
   - **b.** U-joint
   - **c.** transaxle
   - **d.** transfer case
10. Vehicles require alternators that are capable of producing electricity to power ________.
    - **a.** heated and cooled seats
    - **b.** power windows
    - **c.** electric power steering
    - **d.** All of the above

Chapter 2

CAREERS IN THE AUTOMOTIVE SERVICE INDUSTRY

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the need for automotive technicians.
- Discuss the need for servicing vehicles.
- Discuss the sites at which servicing is performed.
- Describe the various technician job classifications.
- Explain the relationship of the service advisor and the service manager to others in a shop.
- Discuss parts-related positions.
- Discuss sales jobs in the automotive service industry.
- List other careers in the automotive industry.
- Explain the typical automotive organization arrangement.

KEY TERMS:

Entrepreneur 13 • On-the-job training (OJT) 10 • Parts counter person 13 • Service advisor 12 • Service consultant 12 • Service manager 12 • Service writer 12 • Shop supervisor 12 • Team leader 12 • Technician 8 • vehicle identification number (VIN) 11 • Work order 11

THE NEED FOR AUTOMOTIVE TECHNICIANS

The need for trained and skilled automotive **technicians** is greater than ever for several reasons, including:

- Vehicles are becoming more complex and require a higher level of knowledge and skills.
- Electrical and electronic components and sensors are included throughout the vehicle.
- Construction of parts and materials being used has changed over the last few years, requiring that all service work must be done to specified procedures to help avoiding damage to the vehicle.
- Increasing numbers of different types of lubricants and coolants make even routine service challenging.

All of the above issues require proper training and the ability to follow factory specified procedures to ensure customer satisfaction. The number of service technicians needed is increasing due to more vehicles on the road. A good service technician can find work in almost any city or town in the country, making the career as a professional service technician an excellent choice.

THE NEED FOR CONTINUOUS VEHICLE SERVICE

Vehicles are lasting longer due to improved materials and more exacting tolerances. Every year, vehicles are being driven farther than ever before. It used to be (in the 1950s) that the life of a vehicle was considered to be 100,000 miles or 10 years. Now achieving 200,000 miles without a major repair is common with proper maintenance and routine service. However, even the amount of needed routine service has been reduced due to changes in vehicle manufacturing and materials.

WARRANTIES A warranty is a guarantee to the purchaser of a vehicle that it will function as specified. The warranty covers the quality and performance of the product and states the conditions under which the warranty will be honored. Vehicle warranties vary, but all warranties indicate a time and mileage restriction. The expressed warranties often include the following areas:

- New vehicle limited warranty that covers most components and is commonly called a bumper-to-bumper policy.
- Powertrain warranty covers the engine, transmission/transaxle, and final drive units. This coverage usually is longer than the bumper-to-bumper coverage.

- Sheet metal rust through warranty is usually longer than the bumper-to-bumper and powertrain warranty and covers rust if a hole occurs starting from inside the outer metal surface of the body.
- Emission control device warranties depend on the emission rating, the warranty coverage of the powertrain control module (PCM), and the catalytic converter and are covered for 8 years and 80,000 miles up to 10 years and 150,000 miles.

Vehicle warranties, unless an emergency repair, must be performed at a dealership, which is certified by the vehicle manufacturer to perform the repairs. At the dealership, the technician performing the repair must also be certified by the vehicle manufacturer.

All technicians should be familiar with what may be covered by the factory warranties to help ensure that the customer does not have to pay for a repair that may be covered. While warranties do cover many components of the vehicle, wear and service items are not covered by a warranty in most cases and, therefore, offer excellent opportunity for additional service work for trained automotive technicians.

TECHNICIAN WORK SITES

Service technician work takes place in a variety of work sites including:

NEW VEHICLE DEALERSHIPS Most dealerships handle one or more brands of vehicle, and the technician employed at dealerships usually has to meet minimum training standards. The training is usually provided at no cost online or at regional training centers. The dealer usually pays the service technician for the day(s) spent in training as well as provides or pays for transportation, meals, and lodging. Most dealerships offer in-house on-line training with minimum off-site training. ● **SEE FIGURE 2–1**.

INDEPENDENT SERVICE FACILITIES These small- to medium-size repair facilities usually work on a variety of vehicles. Technicians employed at independent service facilities usually have to depend on aftermarket manufacturers' seminars or the local vocational school or college to keep technically up-to-date. ● **SEE FIGURE 2–2**.

MASS MERCHANDISER Large national chains of vehicle repair facilities are common in most medium- and large-size cities. Some examples of these chains include, Goodyear, Firestone, and NAPA, as shown in ● **FIGURE 2–3**. Technicians employed by these chains usually work on a wide variety of vehicles. Many of the companies have their own local or regional training sites designed to train beginning service technicians and to provide update training for existing technicians.

FIGURE 2–1 Most large dealerships are busy in the morning with customers dropping off their vehicle and in the evening when they are being picked up.

AL'S SERVICE CENTER
COOLING
ALIGNMENT
AIR CONDITIONING
OIL CHANGE

FIGURE 2–2 A typical independent service facility. Independent garages often work on a variety of vehicles and perform many different types of vehicle repairs and service. Some independent garages specialize in just one or two areas of service work or in just one or two makes of vehicles.

NAPA
THE PARTS STORE

FIGURE 2–3 This NAPA parts store also performs service work from the garage area on the side of the building.

SPECIALTY SERVICE FACILITIES Specialty service facilities usually limit their service work to selected systems or components of the vehicle and/or to a particular brand of vehicle. Examples of specialty service facilities include Midas, Speedy, and AAMCO Transmissions. Many of the franchised specialty facilities have their own technician training for both beginning and advanced technicians. ● **SEE FIGURE 2–4**.

MIDAS
AUTO SERVICE
MIDAS

FIGURE 2–4 Midas is considered to be a specialty service shop.

FIGURE 2–5 A school bus garage is a typical fleet operation shop that needs skilled service technicians.

FLEET FACILITIES Many city, county, and state governments have their own vehicle service facilities for the maintenance and repair of their vehicles. Service technicians are usually employees of the city, county, or state and are usually paid by the hour rather than on a commission basis. ● **SEE FIGURE 2–5**.

TECHNICIAN JOB CLASSIFICATIONS

LUBE TECH/QUICK SERVICE TECHNICIAN A lubrication technician should be trained in the proper use of hand tools and instructed how to properly service various types of vehicles. The training could be **on-job training (OJT)** or could be the result of high school or college automotive training. Some larger companies provide in-house training for new technicians and as a result they are trained to perform according to a specified standard. It is important that the lubrication technician double-check the work to be certain that the correct viscosity oil has been installed and to the specified level. The oil plug and oil filter must also be checked for leakage.

Lubrication technicians are trained to perform routine services including:

- Oil and oil filter change
- Chassis lubrication
- Fluids check and refill
- Tire inflation checks
- Accessory drive belt inspection
- Air filter check and replacement
- Cabin filter replacement
- Windshield wiper blade replacement

As a result of these tasks, the lubrication technician should be skilled in hoisting the vehicle and able to handle the tasks efficiently and in minimum time.

NEW VEHICLE PREPARATION FOR DELIVERY A new entry-level position at a dealership often includes preparing new vehicles for delivery to the customer. This is often referred to as "new car prep." The duties performed for new vehicle preparation are generally learned on the job. The vehicle manufacturer publishes guidelines that should be followed, and it is the responsibility of the new vehicle preparation person to see that all items are checked and serviced and all associated paperwork is completed. The activities normally associated with preparing a new vehicle for delivery include:

- Installing wheel center caps or wheel covers (if used)
- Installing roof racks, running boards, and other dealer-installed options
- Checking and correcting tire pressures

NOTE: Many vehicle manufacturers ship the vehicles to the dealer with the tires overinflated to help prevent movement of the vehicle during shipping.

- Checking all fluids
- Checking that everything works, including the remote key fob and all accessories

- Ordering any parts found to be broken, missing, and damaged in transit
- Removing all protective covering and plastic from the seats, carpet, and steering wheel
- Washing the vehicle

GENERAL SERVICE TECHNICIAN A general service technician usually has been trained by one or more of the following methods:

- High school—Technical or vocational school or a comprehensive high school that has an Automotive Youth Education System (AYES) program or NATEF certification.
- College or technical school—Usually a two-year program that can earn the student an associate's degree.
- Career college or institute—Usually a 6-month to 12-month program earning the graduate a certificate.

Automotive service technicians begin by reading the work order and examining the vehicle. To locate the cause of faulty operation and repair it, a technician will:

- Verify the customer concern
- Use testing equipment, take the vehicle for a test-drive, and/or refer to manufacturer's specifications and manuals
- Dismantle faulty assemblies, repair, or replace worn or damaged parts
- Reassemble, adjust, and test the repaired mechanism

Automotive service technicians also may:

- Perform scheduled maintenance services, such as oil changes, lubrications, and filter replacement
- Advise customers on work performed, general vehicle conditions, and future repair requirements

WORKING CONDITIONS Most automotive service technicians work a 40-hour, five-day week. Some evening, weekend, or holiday work may be required. The work is sometimes noisy and dirty. There is some risk of injury involved in working with power tools and near exhaust gases.

SKILLS AND ABILITIES The work is most rewarding for those who enjoy doing precise work that is varied and challenging. Also, technicians usually achieve job security and a feeling of independence.

To be successful in the trade, automotive service technicians need:

- Good hearing, eyesight, and manual dexterity (ability to work with their hands)
- Mechanical aptitude and interest
- The ability to lift between 25 and 50 pounds (11 and 25 kilograms)
- The willingness to keep up-to-date with changing technology

A working knowledge of electricity, electronics, and computers is also required for many service procedures.

EMPLOYMENT AND ADVANCEMENT Automotive service technicians are employed by automotive repair shops, specialty repair shops, service facilities, car and truck dealerships, and by large organizations that own fleets of vehicles.

FREQUENTLY ASKED QUESTION

Why Is the Work Order Important?

The **work order** is a legal document that includes the description of the vehicle and the work requested by the customer. The customer signs the work order authorizing that the stated work be performed. If there are additional faults found, the shop must notify the customer and get permission to change the amount or extent of the work originally authorized. As work is performed on the vehicle, the parts used and the labor operation performed are added. This creates a complete file on the repair. This means that the vehicle has to be properly identified by including the **vehicle identification number (VIN)** on the work order. There is only one vehicle with that VIN, yet there may be many "white Chevrolet pickup trucks."

The work order is the paper trail that shows all operations, labor times, and parts used when the vehicle is in control of the shop. A work order is often required even when the technician is working on his or her own vehicle.

Experienced automotive service technicians may advance to service manager or shop supervisor; some automotive service technicians open their own repair facilities.

Many technicians can also start work in a shop or dealership and learn on the job. Most technicians keep up-to-date by attending update seminars or training classes on specific topics throughout the year.

Specific tasks performed by a general service technician can include the following:

- All of the tasks performed by the lubrication technician
- Engine repairs, including intake manifold gasket replacement, cylinder head replacement, and oil and water pump replacement plus other engine-related tasks
- Brake system service and repair, including disc brakes, drum brakes, parking brake, and antilock brake (ABS) diagnosis and service
- Suspension-related service, including tire inspection and replacement, shock and strut replacement, servicing or replacing wheel bearings, performing steering component inspection and parts replacement, and performing wheel alignment and vibration diagnosis
- Electrical-related diagnosis and repair, including starting and charging problems, correcting lighting and accessory faults, and general service, such as light bulb replacement and key fob reprogramming
- Heating, ventilation, and air conditioning work, involving the use of diagnostic and service equipment that requires special training and certification if working with refrigerants
- Engine performance-related diagnosis and repair, including replacing fuel pumps and filters, cleaning or replacing fuel injectors, service ignition system components, solving emissions-related failures, and determining the cause and correcting "Check Engine" lights
- Manual transmission service and repairs, including replacing clutches, adjusting, or replacing clutch linkage,

and performing four-wheel-drive diagnosis and service procedures

- Automatic transmission service and repairs, including performing routine automatic transmission service, removing and replacing automatic transmissions, servicing differentials, transmissions/transaxles, and performing diagnosis and service checks including fluid pressure and scan tool diagnosis

The vehicle is then driven by the service technician to verify the repair.

TECHNICIAN TEAMS Some shops use a team system. The **team leader** is an experienced service technician who can perform most, if not all, of the work that the shop normally handles. The team leader assigns work to others in the group based on the experience or competency of the technician. The team leader then checks the work after it has been completed to be sure that it has been performed correctly.

The number of hours of labor for each member of the team is totaled each pay period. Each member of the team is paid an equal share of the time but at different rates. The team leader gets a higher per-hour rate than the others on the team. The rate of pay per hour is based on the level of training and experience.

While some shops do not use teams, many large shops or dealerships have two or more teams. The advantage of a team-type organization is that everyone on the team looks out and helps each other if needed because they are all paid based on the number of hours the team generates.

The team leader performs the duties of a shop supervisor, but only for those members on the team and not the entire shop. The team leader is under the direction and control of the service manager.

SERVICE MANAGEMENT JOB CLASSIFICATIONS

SHOP SUPERVISOR A **shop supervisor** (usually employed in larger dealerships and vehicle repair facilities) is an experienced service technician who is usually paid a salary (so much a week, month, or year). A shop supervisor is a knowledgeable and experienced service technician who keeps up-to-date with the latest vehicle systems, tools, and equipment. Typically, a shop supervisor's duties include:

- Test-driving the customer's vehicle to verify the customer concern (complaint)
- Assigning work to the service technicians
- Assisting the service technicians
- Helping to maintain the shop and shop equipment
- Assisting the service manager
- Verifying that the repair is completed satisfactorily

The shop supervisor is under the direction and control of the service manager.

SERVICE ADVISOR A **service advisor**, also called a **service writer** or **service consultant**, is the person at the dealership or shop designated to communicate the needs of the customer and accurately complete a work order.

A service advisor should:

- Have a professional appearance
- Be able to speak clearly
- Be able to listen carefully to the customer
- Write neatly and/or type accurately
- Be familiar with industry and shop standards and procedures

Most service advisors would benefit from taking a short course on service advising skill development and interpersonal relationship building. A service advisor should be familiar with the operation of the vehicle, but not to the same level as a service technician. A service advisor should not diagnose the problem, but rather state clearly on the work order what, when, and where the problem occurs so that the service technician has all the needed information to make an accurate diagnosis.

The service advisor's duties include:

1. Recording the vehicle identification number (VIN) of the vehicle on the work order
2. Recording the make, model, year, and mileage on the work order
3. Carefully recording what the customer's complaint (concern) is so that the service technician can verify the complaint and make the proper repair
4. Reviewing the customer's vehicle history file and identifying additional required service
5. Keeping the customer informed as to the progress of the service work

A service advisor must be at the shop early in the morning to greet the customers and often needs to stay after the shop closes to be available when the customer returns at the end of the day.

SERVICE MANAGER The **service manager** rarely works on a vehicle, but instead organizes the service facility and keeps it operating smoothly. A service manager can be a former service technician or, in many larger dealerships, a business major graduate who is skilled at organization and record keeping. The service manager handles all of the paperwork associated with operating a service department.

NOTE: In a small shop, the shop owner usually performs all of the duties of a shop supervisor and service manager, as well as the lead technician in many cases.

Typical duties of a service manager include:

- Establishing guidelines to determine the technicians' efficiency
- Supervising any warranty claims submitted to the vehicle manufacturer or independent insurer
- Evaluating and budgeting for shop tools and equipment
- Establishing service department hours of operation and employee schedules

TECH TIP

Check the Vehicle before Work Is Started

As part of the work order writing process, the service advisor should look over the vehicle and make a written note of any body damage that may already exist. If any damage is noted, it should be mentioned to the customer and noted on the work order. Often the customer is not aware of any damage, especially on the passenger side, and thus would blame the shop for the damage after the service work was performed.

- Assigning working hours and pay for technicians and others in the service department
- Establishing procedures and policies to keep the service area clean and properly maintained

PARTS-RELATED POSITIONS

PARTS COUNTER PERSON The parts manager and other parts personnel, such as the **parts counter person**, are responsible for getting the correct part for the service technician. A parts counter person often learns job skills by on-the-job training. A good parts counter person must be able to greet and easily talk to customers and technicians. A parts counter person must also have computer skills and the willingness to help others.

The parts counter person usually has the following duties:

- Greet the customer or technician
- Locate the correct parts for the service technician or customer
- Suggest related parts (retail customers)
- Stock shelves
- Check in delivered parts
- Take inventory
- Keep the parts department clean
- Help the parts manager

PARTS MANAGER The specific duties of a parts manager usually include:

- Ordering parts from the vehicle manufacturers and aftermarket companies
- Stocking parts
- Organizing the parts department in a clear and orderly fashion
- Locating parts quickly within the parts department
- Developing contacts with parts departments in other local dealerships so that parts that are not in stock can be purchased quickly and at a reasonable cost

VEHICLE SALES JOBS

SALESPERSON When a vehicle is sold, it generates a potential customer for the service department. New and many used vehicle sales dealerships employ salespeople to help the customer select and purchase a vehicle. The salesperson should have excellent interpersonal skills, as well as be familiar with the local and regional laws and taxes to be able to complete all of the paperwork associated with the sale of a vehicle. The usual duties of a vehicle salesperson include:

- Greet the customer
- Introduce yourself and welcome the customer to the store
- Qualify the customer as to the ability to purchase a vehicle
- Demonstrate and ride with the customer on a test-drive
- Be able to find the answer to any question the customer may ask about the vehicle and/or financing
- Be able to complete the necessary paperwork
- Follow up the sale with a telephone call or card

SALES MANAGER A sales manager is an experienced salesperson who is able to organize and manage several individual salespeople. The duties of a sales manager include:

- Establish a schedule where salespeople will be available during all hours of operation
- Consult with salespeople as needed on individual sales
- Train new salespeople
- Conduct sales promotion activities
- Attend or assign someone to attend vehicle auctions to sell and/or purchase vehicles
- Keep up-to-date with the automotive market
- Purchase vehicles that sell well in the local market
- Answer to the general manager or dealership principal

FREQUENTLY ASKED QUESTION

What Is an Entrepreneur?

An **entrepreneur** is a person who starts and operates a business. Many service technicians want to eventually own their own shop and become an entrepreneur. However, operating a shop involves many duties and responsibilities that many service technicians lack, including:

- Bookkeeping and accounting skills
- Tax preparation (local, state, and federal)
- Sales tax collection and payment
- Health insurance arrangements for employees
- Unemployment compensation payments
- Workers' compensation payments
- Uniform payment
- Real estate taxes
- Garage keepers liability insurance

While at first it may seem like owning your own shop would be great, a good technician can often make more money, and have fewer headaches, by simply working for someone else.

OTHER CAREERS IN THE AUTOMOTIVE INDUSTRY

Other careers in the automotive industry include:

- Sales representative for automotive tools and equipment
- Technical trainers
- Technical school instructors
- Wholesale parts warehouse management
- Insurance adjuster
- Automotive technical writer
- Warranty claim examiner

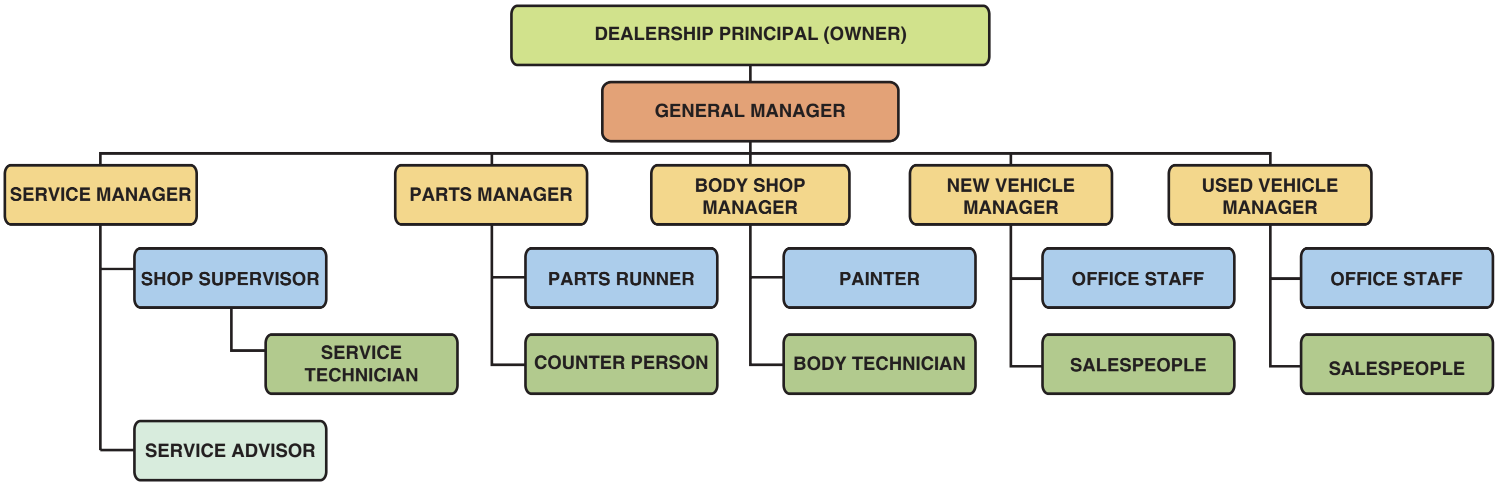

DEALERSHIP PRINCIPAL (OWNER)
GENERAL MANAGER
SERVICE MANAGER
PARTS MANAGER
BODY SHOP MANAGER
NEW VEHICLE MANAGER
USED VEHICLE MANAGER
SHOP SUPERVISOR
SERVICE TECHNICIAN
SERVICE ADVISOR
PARTS RUNNER
COUNTER PERSON
PAINTER
BODY TECHNICIAN
OFFICE STAFF
SALESPEOPLE
OFFICE STAFF
SALESPEOPLE

FIGURE 2–6 A typical large new vehicle dealership organizational chart.

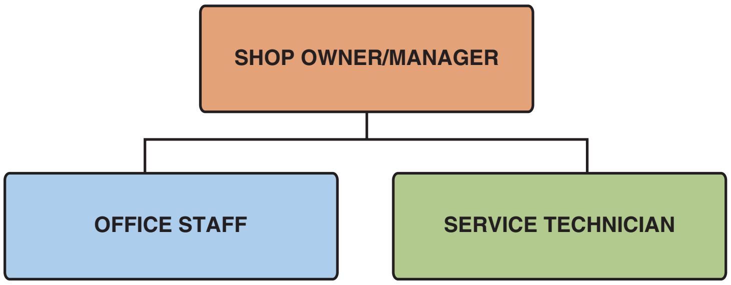

SHOP OWNER/MANAGER
OFFICE STAFF
SERVICE TECHNICIAN

FIGURE 2–7 A typical independent shop organizational chart.

TYPICAL AUTOMOTIVE ORGANIZATION ARRANGEMENT

LARGE COMPREHENSIVE NEW VEHICLE DEALER A typical dealership includes many levels because there are many departments such as sales (new and used) as well as the service, parts and body shops to manage. ● **SEE FIGURE 2–6**.

INDEPENDENT SHOP An independent shop may or may not have a shop supervisor, depending on the number of technicians and the volume of work. Larger independent shops have a shop supervisor, whereas at smaller shops, the owner is the shop supervisor. ● **SEE FIGURE 2–7**.

REVIEW QUESTIONS

1. What should be included on a work order?
2. What are some examples of mass merchandiser facilities?
3. What tasks are usually performed by a general service technician?
4. What duties are performed by the shop supervisor and service manager?
5. What duties are performed by a parts counter person?

CHAPTER QUIZ

1. A vehicle needs a repair while still under warranty. Who is most likely to perform the repair?
   a. Any technician at the vehicle dealership
   b. A trained technician at any repair shop
   c. Any ASE-certified technician
   d. A certified technician at the vehicle dealership
2. A service advisor is called a ________________.
   a. shop supervisor
   b. service manager
   c. service writer
   d. service technician

3. All of the following are usual duties of a lube technician *except* ________________.
   a. oil change
   b. air filter replacement
   c. water pump replacement
   d. accessory drive belt inspection

4. New vehicle preparation is usually an entry-level vehicle service position and usually involves what duties?
   a. Installing dealer-installed options
   b. Correcting tire pressures
   c. Removal of all protective coverings and plastic
   d. Any of the above

5. What is *not* a duty of a general service technician?
   a. Have the customer sign the work order
   b. Order the parts needed
   c. Diagnose the customer's concern
   d. Perform vehicle repair procedures

6. Two technicians are discussing the duties of a shop supervisor and a service manager. Technician A says that a shop supervisor diagnoses vehicle problems. Technician B says that the service manager usually repairs vehicles. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Who greets the service customer and completes the work order?
   a. Service manager
   b. Service advisor
   c. Service writer
   d. Either b or c

8. Which job would be concerned with the maintenance of the shop equipment?
   a. Service manager
   b. Shop supervisor
   c. Shop owner
   d. Any of the above

9. Which job would be concerned with assigning working hours and pay?
   a. Service manager
   b. Shop supervisor
   c. Service advisor
   d. Service technician

10. Who is responsible for finding the correct part needed by the service technician?
    a. Counter person
    b. Service technician
    c. Shop supervisor
    d. Service advisor

Chapter 3

STARTING A CAREER IN THE AUTOMOTIVE INDUSTRY

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the options and preparations for applying for a job.
- Discuss the development of an employment plan.
- Describe what the resume should include.
- Describe what the cover letter should include.
- Discuss the process of applying for employment, interviewing, and accepting employment.
- Explain how the flat-rate pay plan works.
- Discuss payroll deductions.
- Discuss the expenses of an employee working in the automotive industry.
- Discuss becoming a shop owner.

KEY TERMS:

Apprentice program 17 • Clock-in 20 • Clock time 20 • Commission pay 21 • Cooperative education 17 • Federal tax 21 • FICA 21 • Flat-rate 21 • Gross 21 • Housing expense 22 • Incentive pay 21 • Job shadowing 17 • Net 21 • Part-time employment 17 • Reference 19 • Resume 18 • Soft skills 17 • State tax 21 • Straight time 20

PREPARING FOR AN AUTOMOTIVE SERVICE CAREER

DESIRE AND INTEREST If a person has an interest in automobiles and trucks and likes computers, the automotive service field may be a good career choice. Computer skills are needed in addition to hands-on skills for several reasons, including:

- Service information, such as diagnostic procedures and specifications, is commonly available in electronic format.
- Work orders are commonly written and sent to the technician electronically. The technician needs typing skills to type the steps taken during the service or repair procedures.
- Warranty claims are often submitted by the Internet and computer skills are needed to quickly and accurately submit claims and answer questions from the insurance company.

Interest in vehicles is also very important toward being successful as a professional service technician. Most technicians enjoy working on vehicles, not only professionally, but also during their spare time. Many technicians own a project vehicle, which could include:

- Drag race vehicle
- Race vehicle used in road racing
- A fun vehicle used on sunny weekend days and evenings
- Motorcycle
- Snowmobile or jet ski
- Truck for rock crawling

TECHNICAL KNOWLEDGE AND SKILLS The enjoyment of being involved with vehicles is very important because the job of servicing and repairing automobiles and trucks can be hard and dirty work. Many men and women enjoy being around and learning about the details of vehicle operation. With these desires and interest, working in the automotive service field is a great career. Technical information, skills, and tools needed include:

- **Hand tools and tool usage.** Owning and experience using hand tools is important for a service technician. All service technicians are expected to be able to remove and replace parts and components as needed in a timely manner using proper tools and techniques.
- **Technical knowledge.** While knowing how all aspects of the vehicle works is not expected of a beginning service technician, it is important that the technician have a basic understanding of the parts and procedures needed, at least, for routine service procedures.

TECH TIP

If in Doubt, Ask

No one expects a beginning service technician to know everything, but other technicians do not know what you do or do not know. It is usually assumed that the beginning technician will ask for help if they think they need the help. However, asking for help is very rare and requires the beginning technician to admit that they do not know something. Not asking for help can cause harm to the vehicle or the service technician. If in doubt—always ask. No one will be upset, and learning the answer to your question will help in the learning experience.

JOB SHADOWING A great way to see what it is really like to work as a service technician is to follow a professional around for a day or more. **Job shadowing** is usually arranged through an automotive program, and the shop or dealership has agreed to allow someone into the shop area to observe.

While it does allow the student to observe, job shadowing does not allow the person to perform any work or help the technician in any way. During the day, the person who is job shadowing has to wear all personal protective equipment as required by the technician and must observe all safety regulations. The advantages of job shadowing include:

- Being able to observe a typical day in the life of an automotive technician
- Being able to talk to the working technician about what is being done and why
- Being able to observe other technicians and seeing the various skill levels that often exist in a shop

COOPERATIVE EDUCATION PROGRAMS **Cooperative education** programs are formal programs of study at a high school or college where the student attends classes at the school, and also works at a local shop or dealership.

If a cooperative education program is held at the high school level, the work at the shop or dealership occurs during the afternoon or evening and during the summer between the junior and senior year.

If the cooperative education program is held at a community college, the work at the dealership occurs around the training sessions, usually the first or second half of a semester or on alternative semesters. The most common college programs include:

- General Motors ASEP (Automotive Service Educational Program) (see *www.gmasepbsep.com*)
- Ford ASSET (Automotive Student Service Educational Training) (see *www.fordasset.com*)
- Chrysler CAP (College Automotive Program) (see *www.chryslercap.com*)
- Toyota T-TEN (Toyota Technician Education Network) (see *www.toyota.com/about/tten/index.html*)

Another factory sponsored program open to those who have already completed a postsecondary automotive program is BMW STEP (Service Technician Education Program) (see *www.bmwusa.com/about/techtraining.html*).

APPRENTICE PROGRAMS An **apprentice program** involves a beginning service technician working at a shop or dealership during the day and attending training classes in the evening. The key advantage to this type of program is that money is being earned due to full-time employment and getting on-the-job training (OJT) during the day. Often the shop or dealership will help pay for training. While this program usually takes more than two years to complete, the work performed at the shop or dealership usually becomes more technical as the apprentice becomes more knowledgeable and gets more experienced.

PART-TIME EMPLOYMENT Working part time in the automotive service industry is an excellent way to get hands-on experience, which makes it easier to relate classroom knowledge to everyday problems and service issues. Working part time gives the student technician some flexibility as to college schedules and provides an income needed for expenses. Often **part-time employment** becomes full-time employment so it is important to keep attending technical classes toward becoming an asset to the company.

DEVELOPING AN EMPLOYMENT PLAN

An employment plan is an evaluation of your skills, interest, and talents. Selecting a career is different than getting a job. A typical job, while it does involve some training, usually can be learned in a few days to several months. However, a career requires many years to achieve competence. Therefore, selecting a career should require a thorough self-examination to determine what your true interest is in a particular career field. Some items that you should enjoy or would be willing and able to learn include:

- Working with your hands, using tools and equipment
- Computer usage, including typing skills
- Working in an area where lifting is often required
- Being able to read, understand, and follow service information, technical service bulletins, and work orders
- Being able to perform diagnostic work and figure out the root cause of a problem

SOFT SKILLS In addition, any career, including being a service technician, requires many people skills, often called **soft skills**. These people-related skills include:

- Working cooperatively with other people
- Communicating effectively with others verbally (speech) and in writing
- Working as a member of a team for the benefit of all
- Being able to work by yourself to achieve a goal or complete a job assignment
- Being able to lead or supervise others
- Willingness to work with others with a different background or country of origin
- Being a good citizen (citizenship) within the community by participating in local and regional activities and showing leadership within your profession

LOCATING EMPLOYMENT POSSIBILITIES Locating where you wish to work is a very important part of your career. Of course, where you would like to work may not have an opening and you may have to work hard to locate a suitable employer. First, try to select a shop or dealership where you think you would like to work because of location, vehicles serviced, or other factors. Ask other technicians who have worked or are presently working there to be sure that the location would meet your needs.

If looking for employment through a want ad in a newspaper or employment Web site, check the following:

- **Job description.** Is this a position that could advance into a more technical position?
- **Tools needed.** Most professional service technician positions require that the technician provide their own tools. (The shop or dealership provides the shop equipment.) Do you have the tools needed to do the job?
- **Hours needed.** Are you available during the hours specified in the ad?
- **Drug testing.** Is a drug test needed for employment and are you prepared to pass?

PREPARING A RESUME

A **resume** is usually a one-page description of your skills, talents, and education. It is used by prospective employers to help narrow the field of applicants for a job or position. The number one purpose of a resume is to obtain a job interview. A good resume should include the following items:

Personal Information

- Full given name (avoid nicknames)
- Mailing address (do not use a post office [PO] box)

Sample Resume

Personal Information:

James Hartman
301 Main Street
City, State 40005
Telephone: (555) 555-0170
Cell: (555) 555-1139

Career Goal:

To become a certified ASE master technician and work at a new vehicle dealership.

Experience:

2018 to present—I work part time (20 hours per week) at Miller Service performing routine vehicle service, including oil changes, tire balancing, brake repairs, timing belt replacement, and intake manifold gasket replacement. I have assisted with suspension and air-conditioning repairs and own a basic set of hand tools.

Education:

High school diploma from Central High School, City, State 40010. I am finishing a two-year automotive technician training program at City College, City, State 40010 (to be completed May 15).

Additional Training and Certification:

ASE certified in Brakes and Engine Repair.
Attended a seminar on wide-band oxygen sensors and electronic throttle control at a local automotive service exposition.

Other Skills and Interests:

I am restoring a 1969 Chevrolet Camaro, including all mechanical repairs and upgraded suspension system.

References:

Available upon request.

- Telephone and/or cell phone number
- E-mail address
- Avoid using dates that could indicate your age

Educational Information

- Highest education level achieved
- Major, if in a college or in a training program

Experience and Skills

- Work or volunteer experience that may be helpful or useful to an employer. For example, if you took a course in welding, this may be useful to a shop owner who is looking for a service technician who could do welding, even though this fact was not included in the job posting.
- A valid driver's license is a must for most professional service technicians.
- A good driving record. Often the shop insurance company will not allow a shop owner to hire a technician with a poor driving record.

REFERENCES A **reference** is someone who is willing to tell a possible employer about you, including your skills and talents, as well as your truthfulness and work habits.

Most employers would like to see someone who is familiar with your work ethic, such as a teacher or coach. Always ask the person for approval before including the person on your list of references. Ask the reference to supply you with a written recommendation. Some references prefer to simply fill out a reference questionnaire sent by many companies. If a reference sends you a written recommendation have copies made so they can be included with your resume.

Sample Cover Letter

301 Main Street
City, State 40005
Telephone: (555) 555-0170
Cell: (555) 555-1139

Date

Mr. John Smith
Smith Dealership
800 North Street
City, State 40010

Dear Mr. Smith:

I am applying for the position of general service technician at your dealership as advertised in the Sunday, January 7, edition of the Daily News.

I am currently finishing my studies in Automotive Technology at City College and have worked part time at Miller Service for the past two years. I am ASE certified in Brakes and Engine Repair and plan to become certified in all eight areas.
I have my own tools and currently can work in the afternoons and evenings. After May 15, I will be able to work full time after completing my automotive courses.

I look forward to the opportunity to discuss my skills and resume in an interview. Thank you for your consideration.

Sincerely,

James Hartman

Enclosure (1)

TECH TIP

Always Be Truthful

No one is smart enough to be a liar. If you say something that is not true, then you have to remember what was said forever or your lie will often be discovered. If asked about your experience or knowledge, try to be as truthful as possible. Facts and skills can be learned, and not knowing how to do everything that a shop may be involved with is not an indication that you will be rejected from the job opening.

PREPARING A COVER LETTER

When answering an advertisement in a newspaper or magazine, be sure to include the details of where you saw the ad in your cover letter to the employer. For example: "I am applying for the position as an entry-level service technician, as published in the August 15, edition of the Daily News."

If the requirements for the position are listed, be sure to include that you do have the specified training and/or experience and the tools needed for the job.

If calling about a position, be sure to state that you are applying for the position posted and ask to speak to the correct person or to the person mentioned in the ad.

APPLYING AND INTERVIEWING FOR EMPLOYMENT

CONTACTING POTENTIAL EMPLOYERS When a job opening is posted in a newspaper or it is mentioned by a friend, most experts recommend that you visit the shop or dealership in person to see where the job is located, the condition of the buildings, and the surrounding areas. This trip could also be used for you to submit your resume and cover letter in person unless the company indicates otherwise. Be prepared to be interviewed when submitting your resume. Even if the position has already been filled, the trip gives you experience in meeting people and seeing the shop, which helps increase your confidence during the job search. Searching for a job is a full-time job in itself. Be prepared every day to answer ads, search employment Web sites, and travel to shops or dealerships.

COMPLETING THE EMPLOYMENT APPLICATION Most businesses require that an employment application be completed because it not only asks for all necessary personal information needed, but also references and emergency contacts. Most employment application forms ask for previous employers, the names and telephone numbers of contact people, and other information that you may not remember. It is wise to have all of the information written down ahead of time and take it with you for reference when completing the application. Always answer questions honestly and as thoroughly as possible. Never lie on an employment application.

THE INTERVIEW When meeting for the job interview, be sure to dress appropriately for the position. For example, a suit and tie would not be appropriate for an interview for a service technician position. However, the following may be a helpful guide:

- Wear shoes that are not sneakers and be sure they are clean
- Wear slacks, not jeans
- Wear a shirt with a collar
- Do not wear a hat
- Have clean hair
- Avoid facial jewelry
- Men: Be clean shaven or have beard/mustache neatly trimmed
- Women: Keep makeup and jewelry to a minimum

During the interview, try to answer every question honestly. Emphasize what you are capable of providing to the shop including:

- Enthusiasm
- Experience
- Willingness to work
- Willingness to work long hours and/or long weeks

AFTER THE INTERVIEW After the interview, follow up with a letter thanking the shop for the interview. In the letter include when the interview occurred and that from the information you received, that you are very interested in becoming a part of the organization (shop or dealership). Also include contact information, such as your cell phone number and e-mail address, so the service manager can easily get in contact with you. A quick review of your skills and talent will also be helpful to the shop owner or service manager.

ACCEPTING EMPLOYMENT When a job is offered, there will likely be some paperwork that needs to be filled out and decisions made. Some of the requested information could include:

- Social security number (social insurance number in Canada)
- W-4 tax withholding form
- Emergency contact people
- Retirement plan selection (This is usually given to you to study and return at a later date.)
- Other information that may be unique to the shop or dealership

After accepting the employment position, be sure to determine exactly what day and time you should report to work and try to determine where your tools should be placed. Most places will show you around and introduce you to others you will work with.

TECHNICIAN PAY METHODS

STRAIGHT-TIME PAY METHODS When the particular service or repair is not covered or mentioned in a flat-rate guide, it is common practice for the technician to **clock-in** and use the actual time spent on the repair as a basis for payment. The technician uses a flat-rate time ticket and a time clock to record the actual time. Being paid for the actual time spent is often called **straight time** or **clock time**. Difficult engine performance repairs are often calculated using the technician's straight time.

FLAT-RATE PAY METHODS Beginning service technicians are usually paid by the hour. The hourly rate can vary greatly depending on the experience of the technician and type of work being performed. Most experienced service technicians are paid by a method called **flat-rate**. The flat-rate method of pay is also called **incentive** or **commission pay**. "Flat-rate" means that the technician is paid a set amount of time (flat-rate) for every service operation. The amount of time allocated is published in a flat-rate manual. For example, if a bumper requires replacement, the flat-rate manual may call for 1.0 hour (time is always expressed in tenths of an hour). Each hour has 60 minutes. Each tenth of an hour is 1/10 of 60 or 6 minutes.

0.1 hour = 6 minutes
0.2 hour = 12 minutes
0.3 hour = 18 minutes
0.4 hour = 24 minutes
0.5 hour = 30 minutes
0.6 hour = 36 minutes
0.7 hour = 42 minutes
0.8 hour = 48 minutes
0.9 hour = 54 minutes
1.0 hour = 60 minutes

Many service operations are greater than 1 hour and are expressed as such:

2.4 hours = 2 hours and 24 minutes
3.6 hours = 3 hours and 36 minutes

The service technician would therefore get paid the flat-rate time regardless of how long it actually took to complete the job. Often, the technician can "beat flat-rate" by performing the operation in less time than the published time. It is therefore important that the technician not waste time and work efficiently to get paid the most for a day's work. The technician also has to be careful to perform the service procedure correctly because if the job needs to be done again due to an error, the technician does the repair at no pay. Therefore, the technician needs to be fast and careful at the same time.

The vehicle manufacturer determines the flat-rate for each labor operation by having a team of technicians perform the operation several times. The average of all of these times is often published as the allocated time. The flat-rate method was originally developed to determine a fair and equitable way to pay dealerships for covered warranty repairs. Because the labor rate differs throughout the country, a fixed dollar amount would not be fair compensation. However, if a time could be established for each operation, then the vehicle manufacturer could reimburse the dealership for the set number of hours multiplied by the labor rate approved for that dealership. For example, if the approved labor rate is $60.00 per hour and:

Technician A performed 6.2 hours × $60.00 = $372.00
Technician B performed 4.8 hours × $60.00 = $288.00
The total paid to the dealership by the manufacturer = $660.00

This does not mean that the service technician gets paid $60.00 per hour. Sorry, no! This means that the dealership gets reimbursed for labor at the $60.00 per hour rate. The service technician usually gets paid a lot less than half of the total labor charge.

Depending on the part of the country and the size of the dealership and community, the technician's flat-rate per hour income can vary from minimum wage to $20.00 or more per flat-rate hour. Remember, a high pay rate ($20 for example) does not necessarily mean that the service technician will be earning $800.00 per week (40 hours × $20.00 per hour = $800.00). If the dealership is not busy or it is a slow time of year, maybe the technician will only have the opportunity to "turn" 20 hours per week. So it is not really the pay rate that determines what a technician will earn, but rather a combination of all of the following:

- Pay rate
- Number of service repairs performed
- Skill and speed of the service technician
- Type of service work (A routine brake service may be completed faster and easier than a difficult engine performance problem.)

A service technician earns more at a busy dealership with a lower pay rate than at a smaller or less busy dealership with a higher pay rate.

PAYROLL DEDUCTIONS

GROSS VERSUS NET COMPENSATION Most beginning technicians start by receiving a certain amount of money per hours worked. **Gross** earnings are the total amount you earned during the pay period. The paycheck you receive will be for an amount called **net** earnings. Taxes and deductions that are taken from your paycheck may include all or most of the following:

- **Federal** income **tax**
- **State** income **tax** (not all states)
- Social Security taxes (labeled **FICA**, which stands for Federal Insurance Contribution Act)
- Health/dental/eye insurance deductions

In addition to the above, uniform costs, savings plan deductions, parts account deductions, as well as weekly payments for tools, may also reduce the amount of your net or "take-home" pay.

RETIREMENT INFORMATION AND PAYMENTS Some shops or dealerships offer some retirement savings plan, but the most commonly used is an employer-sponsored 401(k) account named after a section of the U.S. Internal Revenue Code. A 401(k) account allows a worker to save for retirement while deferring taxes on the saved money and earnings until withdrawal. Most 401(k) plans allow the employer to select from stock mutual funds or other investments. A 401(k) retirement plan offers two advantages compared to a simple savings account.

- The contributions (money deposited into the account) are tax deferred. The amount will increase due to interest and no taxes are due until the money is withdrawn.
- Many employers provide matching contributions to your 401(k) account which can range from 0% (no matching contributions) to 100%.

The savings really add up over time. For example, if you start saving at age 25 and your income averages $3,000 per month

TECH TIP

Hourly Rate to Annual Income

To calculate the amount of income that will be earned using an hourly rate, do the following:

Multiply the hourly rate times 2 and then times 1,000.

For example:
$10 per hour × 2 × 1,000 = $20,000 per year.

This easy-to-use formula assumes working eight hours a day, five days a week for 50 weeks (instead of 52 weeks in the year).

The reverse can also be easily calculated:

Divide the yearly income by 2 and then by 1,000 = hourly rate

For example: $36,000 per year ÷ 2 = $18,000 ÷ 1,000 = $18 per hour

($36,000 per year) and you contribute 6% of your pay and the employer contributes 3%, after 40 years at age 65, the account will be worth $1,700,000 (one million, seven hundred thousand dollars) assuming a 10% average return.

In retirement, most experts agree that 4% of the total can be withdrawn each year and not reduce the capital investment. Four percent of $1,700,000 is $68,000 per year or over $5,600 per month every month for the rest of your life.

ADDITIONAL SERVICE TECHNICIAN BENEFITS Many larger dealerships and service facilities often offer some or all of the following:

- Paid uniforms/cleaning
- Vacation time
- Update training (especially new vehicle dealerships)
- Some sort of retirement (usually a contributing 401(k)) program
- Health and dental insurance (usually not fully paid)
- Discounts on parts and vehicles purchased at the dealership or shop

Not all service facilities offer all of these additional benefits.

HOUSING AND LIVING EXPENSES

As a general guideline, **housing expenses**, such as rent or a mortgage payment, should not exceed 30% of the gross monthly income. For example,

Ten dollars per hour times 40 hours per week = $400 per week times 4 weeks in a month = $1,600 per month. Thirty percent of $1,600 is $480 per month for rent or a mortgage payment.

A vehicle payment should not exceed 25% of the gross earnings. In the example where the pay was $10 per hour, the maximum recommended vehicle payment should be $400 per month.

FREQUENTLY ASKED QUESTION

Where Does All the Money Go?

Money earned does seem to quickly disappear. For example, if a soft drink and a bag of chips were purchased every day at work for $2.50, this amounts to $12.50 per week or $50 per month, which is $600 per year. Use the following chart to see where the money goes.

Income

Labor rate per hour × number of hours worked = ______
Overtime pay, if applicable = ______
Part-time work on weekends = ______
TOTAL WEEKLY INCOME = ______
Multiply by 4.3 to get the **MONTHLY INCOME** = ______

Monthly Expenses

Car/truck payment = ______
Rent/mortgage = ______
Gasoline = ______
Food (groceries) = ______
Fast food or restaurants = ______
Heat and electric (heat/air conditioning) = ______
Water and sewer = ______
Telephone (cell) = ______
Cable TV/Internet access = ______
Clothing (including cleaning) = ______
Credit card payment = ______
TOTAL MONTHLY EXPENSES = ______

Hopefully, the total income is more than the total expenses!

FREQUENTLY ASKED QUESTION

Employee or Contract Labor?

Most shops and dealerships hire service technicians as employees. However, some shops or businesses will pay a technician for services performed on a contract basis. This means that they are not hiring you as an employee, but simply paying for a service similar to having a plumber repair a toilet. The plumber is performing a service and is paid for the job rather than as an employee of the shop. An employer/employee relationship exists if the shop meets two factors:

1. **Direction—**This means that the employer can direct the technician to report to work to perform service work.
2. **Control—**This means that the employer can direct the hours and days when the work is to be performed and at the employer's location.

A contract labor association exists if the repairs are performed without both direction and control of the shop.

If a contract labor basis is established, then no taxes are withheld. It is then the responsibility of the technician to make the necessary and required general tax payments and pay all taxes on time.

BECOMING A SHOP OWNER

Many service technicians want to start and operate their own shop. Becoming a shop owner results in handling many non-automotive-related duties that some technicians do not feel qualified to handle, including:

- Handling customers
- Ordering and paying for shop equipment and supplies
- Bookkeeping, including payroll
- Budgeting for and paying for garage owner's insurance and workers' compensation
- Paying rent, as well as heat/air-conditioning bills
- Advertising expenses
- Hiring and firing employees

TECH TIP

Find Three Key People

An entrepreneur is a person who organizes and manages their own business assuming the risk for the sake of a profit. Many service technicians have the desire to own their own repair facility. The wise business owner (entrepreneur) seeks the advice of the following people when starting and operating their own business.

1. **Attorney (lawyer)—**This professional will help guide you to make sure that your employees and your customers are protected by the laws of your community, state, and federal regulations.
2. **Accountant—**This professional will help you with the journals and records that must be kept by all businesses and to help with elements, such as payroll taxes, unemployment taxes, and worker's compensation that all businesses have to pay.
3. **Insurance Agent—**This professional will help you select the coverage needed to protect you and your business from major losses.

REVIEW QUESTIONS

1. What facts should be included on the resume?
2. What are five interviewing tips?
3. What is the difference between gross pay and net pay?
4. What taxes are usually withheld from a paycheck?
5. What are five duties of a shop owner?

CHAPTER QUIZ

1. A resume should be how many pages long?
a. 1
b. 2
c. 3
d. 4 or more

2. What personal information should *not* be included on the resume?
a. Address
b. Cell or telephone number
c. Age
d. Work experience

3. Why is having a good driving record good for the shop?
a. Allows the use of a company vehicle
b. Lowers insurance costs
c. Allows you to drive customer's vehicles
d. Permits you to use your vehicle to get parts

4. Which is *not* recommended during an interview?
a. Wear shoes that are not sneakers
b. Wear a shirt with a collar
c. Have clean hair
d. Wear jeans

5. During an interview, try to ___________.
a. show enthusiasm
b. explain your work experience
c. state your willingness to work
d. All of the above

6. Flat-rate time is expressed in tenths of an hour. Each tenth of an hour is ___________ minutes.
a. 60
b. 16
c. 30
d. 6

7. One of the deductions from a paycheck is for Social Security. This item is usually shown on the pay stub as ___________.
a. Social Security
b. SSA
c. FICA
d. U.S. government deduction

8. Technician A says that the net pay amount is usually higher than the gross pay amount. Technician B says that the gross pay amount is usually higher than the net pay. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

9. A beginning service technician earns $400 per week. How much should the technician spend on a vehicle payment?
a. $400 per month
b. $800 per month
c. $500 per month
d. $1,000 per month

10. Which activity does a shop owner perform?
a. Handling customers
b. Ordering and paying for shop equipment
c. Paying for the rent and heat bills for the shop
d. All of the above

Chapter

4

WORKING AS A PROFESSIONAL SERVICE TECHNICIAN

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss aspects of professionalism and ethics.
- Discuss how to start a new job and be a good employee.
- Describe a service technician's duties.
- Describe the use of work orders.
- Describe the types and pricing of parts.
- Describe the advantages of having a mentor.
- Describe the role of teamwork for service technicians.
- Describe the role of goal setting and business meetings for service technicians.
- List useful business skills for service technicians to develop.
- List housekeeping duties service technicians typically perform.
- Explain formal and informal evaluations.
- Discuss ASE technician certification.

KEY TERMS:

Advisor 29 • Advocate 29 • Aftermarket parts 28 • Coach 29 • Core 28 • Core charge 28 • Counselor 29 • Critical thinking 30 • Customer pay (CP) 26 • Formal evaluation 31 • Informal evaluation 31 • Jobber 28 • Mentor 29 • Original equipment (OE) 28 • Rebuilt 28 • Remove and inspect (R & I) 28 • Remove and replace (R & R) 28 • Renewal parts 28 • Repair order (RO) 25 • Role model 29 • Service bay 25 • Stall 25 • Teacher 29 • Three Cs (concern, cause, correction) 25 • Trainee 29 • Warehouse distributor 28

PROFESSIONALISM

Professionalism and personal credibility are important and can determine success as a service technician or as a customer service provider. A true professional does the following on a regular basis:

1. **Practice consistency.** Be positive, professional, and warm at all times.
2. **Keep your word.** Follow through with the commitments that you make. People will not have faith in you if you break your promises.
3. **Develop technical expertise.** Become very knowledgeable about the vehicles being serviced. Attend regular update training classes to keep up with the latest technical information and equipment.
4. **Become a teammate with your coworkers.** Working successfully with others shows that you have common goals and can benefit from the specific skills of others.
5. **Be accountable.** Practice honesty all of the time, admit mistakes, and take responsibility for actions. Apologize if you are wrong.

ETHICS Ethics are a set of principles that govern the conduct of an individual or group. Sometimes ethical decisions are easy to recognize and are perceived as popular choices of behavior by the people around us. At other times, the spectrum of potential choices falls into gray areas in which the "right" or "wrong" course of action is difficult or nearly impossible to identify. When faced with an ethically challenging situation, ask yourself the following questions:

- Is it legal? (Is it against local, state, or federal laws?)
- Is it fair? (Is it harmful to me or to others?)

TECH TIP

Clean Clothes Are a Must

Anyone who meets the public in any business must not only be dressed appropriately, but the clothing should be clean. Service advisors and others that greet the public should also be sure that their shoes are shined. Dull, dirty, or scuffed shoes or a messy appearance reflects an unprofessional look.

TECH TIP

Never Use Profanity

Regardless of the situation, a true professional never resorts to the use of profanity. If tensions are high and the discussion becomes heated, try to defuse the situation by turning the situation over to someone else.

- How do I feel about it? (Is it against the teachings of my parents or my religion?)
- Would the court of public opinion find my behavior incorrect? (Would it disappoint my family?)
- Am I fearful of what those I trust would say about my actions? (Would I be hurt or upset if someone did this to me?)

The above questions can be quite revealing when attempting to choose an ethical course of action.

WHAT HAPPENS THE FIRST DAY?

The first day on the job, someone, usually the shop owner or shop supervisor, should:

- Introduce the new technician to key people at the shop.
- Show the new technician the facility, parking, rules, and regulations of the organization.
- Establish the new technician's work area.
- Ask questions of the new technician regarding their skills and talents.

The shop owner or supervisor should:

- Review the training tasks that were completed in school.
- Try to direct work to the new technician that covers the new training material.

The first day on the job the beginning technician should:

- Smile and ask questions if needed to clarify procedures and regulations.
- Be prepared to take and pass a drug test.
- Assure the service manager or shop owner that you are serious about a career as an automotive technician.

TECH TIP

Don't Touch Other Technician's Tools

A beginning technician seldom has all of the tools needed to perform all of the service and repair tasks. A technician's tools are very important. If a tool needs to be borrowed, the beginning technician should ask for permission to borrow a tool. Then when the tool is returned, it should be clean and replaced back exactly where the technician asks for it to be returned.

TECH TIP

Regulated Terms to Use

In some states or areas where automotive service is regulated, such as in California or Michigan, it is important that the term used to describe a labor operation is the term defined by the state agency. This means that some terms used in parts and time guides may not be the same terms used by the state. Always check that the terms used are in compliance with all regulations. Some terms that could be affected include rebuild, repair, overhaul, inspection and R & R (remove and replace), and safety inspection.

A work order, also called a **repair order** or **RO**, is assigned to a technician who is best qualified to perform the work. The technician gets the keys and drives the vehicle to an assigned **service bay** (also called a **stall**), performs the proper diagnosis, gets the necessary parts from the parts department, and completes the repair.

After the service work has been performed, the service technician should then fill out the work order and describe what work was performed. These are called the "**three Cs**."

1. **Concern—**Write on the work order what was done to confirm the customer's concern. For example, "Drove the vehicle at highway speed and verified a vibration."
2. **Cause—**The service technician should write the cause of the problem. For example, "Used a scan tool and discovered that cylinder #3 was misfiring."
3. **Correction—**The service technician should write what was done to correct the problem. For example, "Removed the spark plug wire from cylinder number three and by visual inspection found that the boot had been arcing to the cylinder head. Replaced the spark plug wire and verified that the misfire was corrected."

DUTIES OF A SERVICE TECHNICIAN

READING THE WORK ORDER A work order is selected or assigned to a service technician who then performs the listed tasks. The work order should be written so that the technician knows exactly what needs to be done. However, if there is any doubt, the technician should clarify the needed task with the service advisor or the person who spoke to the customer.

TALKING TO CUSTOMERS The typical service technician usually does not talk directly to a customer except in some smaller shops. However, there may be causes where the technician will

TECH TIP

If Late—Call

When running late, you may know that you will be just a few minutes late, but your boss does not know how late you will be. If you are going to be late, even by a few minutes, call the shop and let them know. This does not eliminate your being late from your record but does demonstrate your concern to your service manager and other technicians who are counting on you to be on time to work every day.

be asked to clarify a procedure or repair to a customer. Many technicians do not like to talk to the customers and fear that they may say too much or not enough. If a technician is asked to talk to a customer, try to keep the discussion to the following without being too technical:

- The service technician should repeat the original concern. This is to simply verify to the customer and the technician the goal of the service or repair.
- The cause of the fault should be mentioned. If further diagnostic steps needed to find the cause are requested, discuss the steps followed and the equipment or tools used.
- Discuss what was done to solve the concern, including what part or parts were replaced. This step may also include what other service operations were needed to complete the repair, such as reprogramming the computer.

NOTE: If the customer speaks a language that you do not understand, excuse yourself and locate someone in the shop who can assist you with communicating with the customer. Avoid using slang or abbreviations of technical terms. Ask the person if they understand and be willing to restate, if needed, until the situation is understood.

ESTIMATING A REPAIR Sometimes a service technician is asked to help create an estimate for the customer. It is usually the responsibility of the service advisor or shop owner to create estimates. The technician may be helpful by pointing out all of the operations that need to be performed to achieve a repair. The estimate for a repair includes:

- **Parts needed—**This list would also include any gaskets and/or supplies needed. The technician can help identify if extra supplies may be needed.
- **Labor—**A published time guide is usually used, but many times options, such as rear air conditioning or four-wheel drive, may add substantial time to the operation. The technician can help with the estimate by making sure that the options are pointed out to the service advisor or shop owner.

TECH TIP

Car, Truck, or Vehicle?

When discussing a vehicle with a customer, it is best to avoid creating problems. For example, if a technician asked about a customer's "car," the customer could become concerned because they drive a truck and many owners of trucks do not want their vehicle called a car. Use of the term "vehicle," a generic term, is often recommended when talking to customers to avoid possible concerns.

DOCUMENTING THE WORK ORDER The service technician must document the work order. This means that the service technician must write (or type) what all was done to the vehicle, including documenting defective components or conditions that were found in the course of the diagnosis. The documentation is often called "telling the story" and should include the following:

- The test equipment used to diagnose the problem. For example: Used a Tech 2 scan tool to retrieve P0300 random misfire diagnostic trouble code.
- Used a digital multimeter to determine a spark plug wire was defective.
- List what parts or service operations were performed. For example: Replaced the spark plug wire on cylinder number 3. Used a scan tool to clear the diagnostic trouble codes and verify that the engine is operating correctly.

FOLLOWING RECOMMENDED PROCEDURES All service technicians should follow the diagnostic and service procedures specified by the vehicle manufacturer. Following service information procedures includes:

- Follow and document the diagnostic procedure. Writing down the test results helps the customer see all that was involved in the procedure and creates the proper paper trail for future reference, if needed.
- Follow the recommended removal and reinstallation (R & R) procedures. This step helps prevent the possibility of doing harm to the vehicle if an alternative method is attempted.
- Always torque fasteners to factory specifications. This step is very important because under- or overtightened fasteners can cause problems that were not present until after the repair. The wise technician will document torque specifications on the work order.

CUSTOMER PAY **Customer pay (CP)** means that the customer will be paying for the service work at a dealership rather than the warranty. Often the same factory flat-rate number of hours is used to calculate the technician's pay, but customer pay often pays the service technician at a higher rate. For example, a service technician earning $15.00 per flat-rate hour for warranty work may be paid $18.00 per hour for customer-pay work. Obviously, service technicians prefer to work on vehicles that require customer-pay service work rather than factory-warranty service work.

NONDEALERSHIP FLAT-RATE Technicians who work for independent service facilities or at other nondealership locations use one or both of the following to set rates of pay:

- Mitchell, Motors, or Chilton parts and time guides
- Alldata, Shop-Key, Car-Quest, Auto Value, Mitchell, AC Delco, or other shop management software program.

These guides contain service operation and flat-rate times. Generally, these are about 20% higher (longer) than those

FREQUENTLY ASKED QUESTION

What Can a Service Technician Do to Earn More Money?

Because service technicians are paid on a commission basis (flat-rate), the more work that is completed, the more hours the technician can "turn." Therefore, to earn the most money, the service technician could do the following to increase the amount of work performed:

- Keep up-to-date and learn the latest technical information.
- Practice good habits that help avoid errors or incomplete repairs.
- Learn from experienced and successful fellow technicians and try to approach the repair the same way the successful technician does.
- Purchase the proper tools to do the work efficiently.

NOTE: This does not mean that every technician needs to purchase all possible tools. Purchase only those tools that you know you will need and use.

specified by the factory flat-rate to compensate for rust or corrosion and other factors of time and mileage that often lengthen the time necessary to complete a repair. Again, the service technician is usually paid a dollar amount per flat-rate hour based on one of these aftermarket flat-rate guides. The guides also provide a list price for the parts for each vehicle. This information allows the service advisor to accurately estimate the total cost of the repair.

CASE STUDY

The Case of the Flat-Rate Technician

A technician was new to flat-rate after working at a shop by the hour for six weeks. The technician seemed overwhelmed and was not able to make as much money as when working by the hour. The shop supervisor noticed that the technician was not working efficiently. The supervisor saw that the technician was working on the rear tail lights of a pickup truck and asked "Did you know that you were going to be working on the rear of the truck when you drove it into your stall?" The technician said yes. The supervisor suggested that the truck should have been backed into the stall making the rear of the truck closer to the tool box, saving a lot of walking and unnecessary time. The technician learned that planning ahead for a job by placing the tools needed on a tool cart and taking them to the vehicle saved a lot of time.

Summary:

Complaint—A technician new to flat-rate was overwhelmed and not making much money.
Cause—The technician was not working efficiently.
Correction—The technician learned to become more organized, which greatly improved the amount of work that could be achieved in a day.

FLAGGING A WORK ORDER

When a service technician completes a service procedure or repair, a sticker or notification on the work order indicates the following:

- Technician number (number, rather than a name) is often used not only to shorten the identification, but also to shield the actual identity of the technician from the customer
- Work order number
- Actual clock time from a time clock record for certain jobs, as needed
- Amount of time allocated to the repair expressed in hours and tenths of an hour

TECH TIP

Technician Skill Level and Severe Service

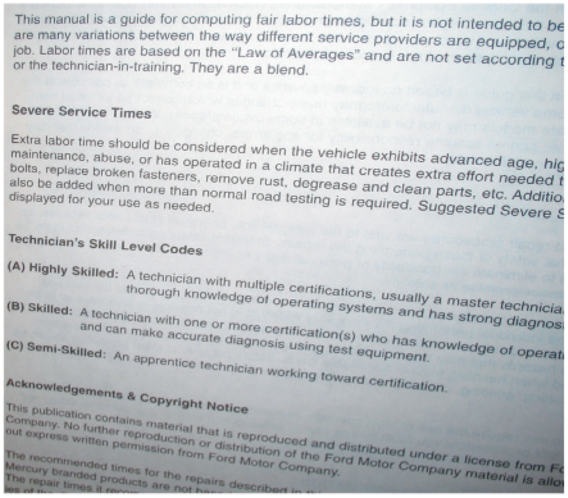
Most aftermarket service information includes a guideline for the relative level of the technician's skill required to perform the listed service procedures. These include:

A = Highly skilled and experienced technician

B = Skilled technician who is capable of performing diagnosis of vehicle systems

C = Semi-skilled technician who is capable of performing routine service work without direct supervision

Many time guides provide additional time for vehicles that may be excessively rusted due to climate conditions or have been subjected to abuse. Be sure to quote the higher rate if any of these conditions are present on the customer's vehicle. ● **SEE FIGURE 4–1**.



This manual is a guide for computing fair labor times, but it is not intended to be
are many variations between the way different service providers are equipped, c
job. Labor times are based on the "Law of Averages" and are not set according t
or the technician-in-training. They are a blend.

Severe Service Times

Extra labor time should be considered when the vehicle exhibits advanced age, hig
maintenance, abuse, or has operated in a climate that creates extra effort needed t
bolts, replace broken fasteners, remove rust, degrease and clean parts, etc. Additio
also be added when more than normal road testing is required. Suggested Severe S
displayed for your use as needed.

Technician's Skill Level Codes

(A) Highly Skilled: A technician with multiple certifications, usually a master technicia
thorough knowledge of operating systems and has strong diagnos
(B) Skilled: A technician with one or more certification(s) who has knowledge of operat
and can make accurate diagnosis using test equipment.
(C) Semi-Skilled: An apprentice technician working toward certification.

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Company. No further reproduction or distribution of the Ford Motor Company material is allo
out express written permission from Ford Motor Company.

The recommended times for the repairs described in
Mercury branded products are not
The repair times it

FIGURE 4–1 Note the skill levels of the technician and the extra time that should be added if work is being performed on a vehicle that has excessive rust or other factors as stated in the time guide.

The application of the service technician's sticker to the back of the work order or completing the details of the repair into the electronic service record is called **flagging the work order**.

NOTE: The actual assignment of the time is often done by another person at the dealership or service facility. This procedure assures that the correct number of hours is posted to the work order and to the technician's ticket.

SUBLET REPAIRS Often a repair (or a part of a repair) is performed by another person or company outside of the dealership or service facility. For example, an engine needing repair that also has a defective or leaking radiator would be repaired by the original repair facility, but the radiator may be sent to a specialty radiator repair shop. The radiator repair cost is then entered on the work order as a sublet repair.

PARTS REPLACEMENT

Parts replacement is often called **R & R,** meaning **remove and replace**.

NOTE: R & R can also mean remove and repair, but this meaning is generally not used as much now as it used to be when components such as starters and air-conditioning compressors were repaired rather than replaced as an assembly.

R & I is often used to indicate **remove and inspect** to check a component for damage. The old replaced part is often returned for remanufacturing and is called a **core**. A **core charge** is often charged by parts stores when a new (or remanufactured) part is purchased. This core charge usually represents the value of the old component. Because it is needed by the remanufacturer as a starting point for the remanufacturing process, the core charge is also an incentive to return the old part for credit (or refund) of the core charge.

NOTE: Most parts stores today require that all cores be returned in the original boxes. Be sure to place the defective part into the same box that was used for the new or remanufactured part to be sure that the shop gets the proper credit for the core.

ORIGINAL EQUIPMENT PARTS Parts at a new vehicle dealership come either directly from the vehicle manufacturer or a regional dealership. If one dealership purchases from another dealership, the cost of the part is higher, but no waiting is required. If a dealership orders a part from the manufacturer directly, the cost is lower, but there is often a 7- to 10-day waiting period. **Original equipment** parts, abbreviated **OE,** are generally of the highest quality because they have to meet performance and durability standards not required of replacement parts manufacturers.

NOTE: Many service technicians will use only OE parts for certain critical systems, such as fuel injection and ignition system components because, in their experience, even though the price is often higher, the extra quality seems to be worth the cost, not only to the owner of the vehicle, but also to the service technician, who does not have to worry about having to replace the same part twice.

AFTERMARKET PARTS Parts manufactured to be sold for use after the vehicle is made are often referred to as **aftermarket parts** or **renewal parts**. Most aftermarket parts are sold at automotive parts stores or **jobbers**. A jobber or parts retailer usually gets parts from a large regional **warehouse distributor**. The warehouse distributor can either purchase parts directly from the manufacturer or from an even larger central warehouse. Because each business needs to make a profit (typically, 35%), the cost to the end user may not be lower than it is for the same part purchased at a dealership (two-step process instead of the typical three-step process), even though it costs more to manufacture the original equipment part. To determine what a 35% margin increase is for any product, simply divide the cost by 0.65. To illustrate how this works, compare the end cost of a part (part A) from a dealership and a parts store.

Retail Parts Store	New Vehicle Dealership
Manufacturer's selling price = $17.00	Manufacturer's selling price = $25.00
Warehouse distributor's selling price = $26.15 ($17.00 ÷ 0.65 = $26.15)	Parts department selling price = $38.46 ($25.00 ÷ 0.65 = $38.46)
Retail store selling price = $40.23 ($26.15 ÷ 0.65 = $40.23)	

NOTE: The cost of the part to the customer where service work is performed is increased about 35% over the base cost of the part. For example, a part that cost the repair facility $40.23 will be billed to the customer at about $61.00. The retail service customer at the dealer may pay $59.17 ($38.46 ÷ 0.65 = $59.17).

NEW VERSUS REMANUFACTURED PARTS New parts are manufactured from raw materials and have never been used on a vehicle. A remanufactured component (also called **rebuilt**) has been used on a vehicle until the component wore out or failed. A remanufacturer totally disassembles the component, cleans, machines, and performs all the necessary steps to restore the part to a "like new" look and function. If properly remanufactured, the component can be expected to deliver the same length of service as a new component part.

The cost of a remanufactured component is often less than the cost of a new part.

NOTE: Do not always assume that a remanufactured component is less expensive than a new component. Due to the three-step distribution process, the final cost to the end user (you) may be close to the same!

USED PARTS Used parts offer another alternative to either new or remanufactured parts. The cost of a used component is typically one-half the cost of the component if purchased new. Wrecking and salvage yards use a Hollander manual that lists original equipment part numbers and cost and cross-references them to other parts that are the same.

WORKING WITH A MENTOR

A mentor is a person at the job site who helps the beginning service technician, also called the **trainee**. The word **mentor** comes from Greek mythology. In Homer's *The Odyssey*, Mentor was the faithful companion and friend of Ulysses (Odysseus), the King of Ithaca. Before Ulysses went to the Trojan Wars, he instructed Mentor to stay and take full charge of the royal household. This meant that Mentor had to be father figure, teacher, role model, counselor, trusted advisor, challenger, and encourager to the King's son in order that he become a wise and good ruler.

TECH TIP

Work Habit Hints

The following statements reflect the expectations of service managers or shop owners for their technicians:

1. Report to work every day on time. Being several minutes early every day is an easy way to show your service manager and fellow technicians that you are serious about your job and career.
2. If you *must* be late or absent, call your service manager as soon as possible.
3. Keep busy. If not assigned to a specific job, ask what activities the service manager or supervisor wants you to do.
4. Report any mistakes or accidents *immediately* to your supervisor or team leader. *Never* allow a customer to be the first to discover a mistake.
5. Never lie to your employer or to a customer.
6. Always return any borrowed tools as soon as you are done with them and in *clean* condition. *Show* the person you borrowed the tools from that you are returning them to the toolbox or workbench.
7. Keep your work area neat and orderly.
8. Always use fender covers when working under the hood.
9. Double-check your work to be sure that everything is correct.
    a. Remember: "If you are forcing something, you are probably doing something wrong."
    b. Ask for help if unclear as to what to do or how to do it.
10. Do not smoke in a customer's vehicle.
11. Avoid profanity.
12. DO NOT TOUCH THE RADIO! If the radio is turned on and prevents you from hearing noises, turn the volume down. Try to return the vehicle to the owner with the radio at the same volume as originally set.

NOTE: Some shops have a policy that requires employees to turn the radio off.

13. Keep yourself neatly groomed, including:
    a. Shirttail tucked into pants (unless shirt is designed to be worn outside)
    b. Daily bathing and use of deodorant
    c. Clean hair, regular haircuts, and hair tied back if long
    d. Men: daily shave or keep beard and/or mustache neatly trimmed
    e. Women: makeup and jewelry kept to a minimum

Therefore, a good definition of a mentor would be, "A highly qualified individual who is entrusted with the protection and development of an inexperienced technician."

A mentor therefore fulfills many roles, such as:

- **Teacher—**helps teach information and procedures
- **Coach—**has the trainee practice service procedures
- **Counselor—**concerned about, but not trained to offer advice on personal life decisions
- **Advisor—**helps with career-type decisions, such as what tools are needed
- **Advocate** (stands up for the trainee)—represents and helps the trainee's concerns be expressed to others
- **Role model—**presents a positive role model every day

QUALIFICATIONS OF A GOOD MENTOR A good mentor should be assigned to a new technician. Qualifications of a good mentor include:

- **Trade proficiency—**The person selected should be a highly skilled technician.
- **Good coaching/mentoring skills and techniques—**The mentor has to have patience and be willing to help the trainee by explaining each step needed to complete a service procedure.
- **Leadership/role model—**The mentor should take pride in being a professional service technician and have high ethical and professional standards.

Mentoring a trainee can be frustrating for an experienced technician. This occurs because the mentor needs to verify almost everything the trainee does until satisfied that competence has been achieved. Even very basic procedures need to be watched, such as hoisting the vehicle, changing the oil and oil filter, plus many other operations. As a result, the time taken to help the beginning technician will reduce the efficiency, and therefore, the pay of the mentor. However, after several weeks, the trainee can start helping the mentor, thereby increasing efficiency.

TECH TIP

Adhere to the Times

When starting a new job at a shop or dealership, be sure to ask about the following:

- **What time should I arrive at work?** This may be different than the scheduled work starting time. For example, the work day could start at 8 a.m. but the shop owner or service manager may want all technicians to arrive and start to get ready to work at 7:50 a.m.
- **When is break time?** Breaks may or may not be regularly scheduled and it is important for the beginning technician to know and adhere to break times.
- **When is lunch time?** In some busy shops, the lunch period is staggered to be sure that some technicians are always available for work. Always be willing to adhere to the requested lunch period.

TEAMWORK

TEAM BUILDING A team is a group of individuals working together to achieve a common goal. Even shops or service departments that do not use a team system with a group of technicians is still a team. All members of the service department are really part of a team effort working together to achieve efficient vehicle service and customer satisfaction. The key to building a team that works together is selecting employees that are willing to work together. While the shop owner or service manager at a dealership has hiring authority, every technician should consider what is best for the entire group to help increase repeat business and satisfied customers.

LEADERSHIP ROLES As technicians gain experience, they often ask for guidance, not only for technical answers, but also for how to handle other issues in the shop, such as paperwork, use of aftermarket parts, and other issues. Therefore, the more experience that technicians have, the more likely they will be placed in a leadership and role model position.

GOAL SETTING AND BUSINESS MEETINGS

GOAL SETTING The wise service technician sets goals to achieve during a career and life. The purpose of goal setting is to focus efforts on improving your personal and professional life. Goals can include aspects of career, physical, family, education, financial and public service. There are many helpful web sites that can be used to help set and track progress toward achieving goals. The hardest part of any goal is to write it down. Until it is written down, a goal is not real.

BUSINESS MEETINGS All service technicians attend business (shop) meetings. A good business meeting will have the following features:

1. An agenda (list of topics to be discussed) will be given out or displayed.
2. The meeting should start on time and end on time.
3. If someone is to give a report or be asked to do a project, this topic should be discussed with the designated person before the meeting to avoid that person being surprised and made to feel uncomfortable.
4. The meeting should be held following the "Robert's Rule of Order" guidelines.
5. Often meetings include others from inside or outside the company or shop, so try to look your best and smile to make the best impression.

ADVANCEMENT SKILLS

The job of a service technician becomes more valuable to the shop or dealership if work can be accomplished quickly and without any mistakes. Therefore, being careful to avoid errors is the first consideration for any service technician. Then, with experience, the speed of accomplishing tasks can and will increase.

More than speed is needed to become a master technician. It requires problem solving and critical thinking skills, too. While beginning technicians are usually not required to diagnose problems, troubleshooting skills are very important toward becoming a master technician. Most master technicians follow a plan that includes:

- Always verify the customer concern.
- Perform a thorough visual inspection and check for possible causes of the problem, including damage from road debris or accidents.
- Use a scan tool and check for stored diagnostic trouble codes (DTCs).
- Check service information for technical service bulletins (TSBs).
- Check service information and follow all diagnostic trouble charts.
- Locate and correct the root cause of the problem.
- Verify the repair and document the work order.

The hardest part of the diagnostic process is to locate the root cause of the problem. The process of analyzing and evaluating information and making a conclusion is called **critical thinking**.

HOUSEKEEPING DUTIES

A professional service technician is usually responsible for keeping his or her work area clean and tidy. Good housekeeping includes all of the following:

- **Clean floor—**If coolant or oil is spilled on the floor during a repair procedure, it should be cleaned before starting another job.
- **Tool box—**Keep work area and tool box clean and organized.
- **Items kept off the floor—**It is easy to allow parts and other items to be stored in and around the toolbox and in corners. However, having items on the floor makes keeping the area clean and neat-looking very difficult.

TECH TIP

Keeping "Things" Off the Floor

To make cleaning easier and for a more professional shop appearance, keep only those items on the floor that have to be on the floor and find a place off the floor for all other items.

TECH TIP

Look at the Shop from a Customer's Point of View

To determine if the shop and other technicians look professional, step outside and enter the shop through the same door as a customer. Now look around. Look at the shop and the other technicians. Does the shop give the appearance of a professional service facility? If not, try to improve the look by asking the shop owner or service manager to do the same thing in an attempt to create a more professional-looking shop.

- **Keep areas around exits and fire extinguishers clear.** Do not store or place parts, boxes, or shop equipment, such as floor jacks and testers, near exits and fire extinguishers. This helps ensure that people can have easy access to exits or the fire extinguishers in the event of an emergency.
- **Avoid spraying chemicals in the air.** To help keep the air in the shop clean, keep the use of spray chemicals, such as brake cleaner, to a minimum and avoid spraying where it could result in affecting the air others breathe.

JOB EVALUATION

In most jobs, there is an evaluation of performance. A beginning technician is not expected to perform at the same level as an experienced master technician but should be able to do the following:

- **Follow instructions.** The trainee should follow the instructions of the mentor or service manager. This includes making sure that the person is notified when the job has been completed and if there were any problems.
- **Do no harm.** Avoid exerting a lot of force to door panels or other components to help avoid breaking clips or components. Always use the right tool for the job. For example, never use pliers to remove a bolt or nut, which could round off the flats of the fastener. Always think before acting, "Am I going to hurt something by doing this?"
- **Keep a neat and clean appearance.** It is normal to get dirty while performing service work on a vehicle. However, after each job is completed or even during the repair, try to keep as clean as possible. A professional service technician should try to maintain a professional appearance at all times. For example, if coolant or automatic transmission fluid (ATF) gets onto a shirt or pants, the wise technician would change into a clean uniform before working on another vehicle. Many shop owners and service managers recommend that shirttails always be tucked into pants to ensure a more professional appearance.
- **Ask that your work be checked.** Even though the trainee thinks that the service or repair was done correctly, until confidence has been established, it is wise to ask to have all work double-checked.

CAUTION: Never allow a mistake to reach the customer. It is only a problem if it cannot be corrected.

TECH TIP

Write It Down

If a technician needs to have another technician finish a repair due to illness or some other reason, be sure to write down exactly what was done and what needs to be done. Verbal communication, while very effective, is often not a good way to explain multiple steps or processes. For example, the other technician could easily forget that the oil had not yet been added to the engine, which could cause a serious problem if the engine were to be started. If in doubt, write it down.

TECH TIP

Don't Cover Up Mistakes

Everyone makes mistakes. While a damaged component or vehicle is never a good thing to have happen, the wise technician should notify the service manager or other person in charge as soon as a problem or accident occurs. Only then can work begin to correct the problem. If a mistake is hidden, eventually someone will learn about the error and then people will not think it was wise to ignore or to cover up the situation.

FORMAL EVALUATION The mentor and/or service manager may or may not conduct a written evaluation on a regular basis. If a written evaluation is performed, this is called a **formal evaluation**. A formal evaluation usually includes many points of discussion. See the sample evaluation form.

INFORMAL EVALUATION In many cases, a beginning technician's activities are simply observed and noted, which is a type of **informal evaluation**. Both are usually done and both can influence the technician's pay.

NOTE: Most employees are fired from a job as the result of not being able to get along with others, rather than a lack of technical skills.

CERTIFICATION TESTS

ASE TEST AREAS

A1	Engine Repair
A2	Automatic Transmission/Transaxle
A3	Manual Drive Train and Axles
A4	Suspension and Steering
A5	Brakes
A6	Electrical/Electronic Systems
A7	Heating and Air Conditioning
A8	Engine Performance

If a technician takes and passes all eight of the automobile tests and has achieved two or more years of work experience, ASE will award the designation of *ASE Certified Master Automobile Technician*. Contact ASE for other certification areas.

PROCEDURE TO FOLLOW

STEP 1 Go to *www.ase.com* and register to take the test(s). They are offered most days and at various times, which change frequently because sessions fill up and other times and days become open.

STEP 2 Arrive at the test site prepared to take the test. Bring a photo ID and the test registration paper.

STEP 3 Before being assigned a computer on which you will take the test, the following will be performed:

1. You will be issued a locker where you will place everything that is in your pockets except for your photo ID.
2. You will be asked to turn all of your pockets inside out to verify that there is nothing left in your pockets.

Technician Evaluation

Please check one of the spaces to the left of each characteristic which best expresses your judgment of the technician:

ATTITUDE-APPLICATION TO WORK
_____outstanding in enthusiasm
_____very interested and industrious
_____average in diligence and interest
_____somewhat indifferent
_____definitely not interested

DEPENDABILITY
_____completely dependable
_____above average in dependability
_____usually dependable
_____sometimes neglectful or careless
_____unreliable

QUALITY OF WORK
_____excellent
_____very good
_____average
_____below average
_____very poor

MATURITY
_____shows confidence
_____has good self-assurance
_____average maturity
_____seldom assertive
_____timid
_____brash

ABILITY TO LEARN
_____learned work exceptionally well
_____learned work readily
_____average in understanding work
_____rather slow in learning
_____very slow to learn

INITIATIVE
_____proceeds well on his or her own
_____proceeds independently at times
_____does all assigned work
_____hesitates
_____must be pushed frequently

RELATIONS WITH OTHERS
_____exceptionally well accepted
_____works well with others
_____gets along satisfactorily
_____has difficulty working with others
_____works very poorly with others

QUANTITY OF WORK
_____usually high output
_____more than average
_____normal amount
_____below average
_____low output, slow

JUDGMENT
_____exceptionally mature
_____above average
_____usually makes the right decision
_____often uses poor judgment

ATTENDANCE
_____regular
_____irregular

PUNCTUALITY
_____regular
_____irregular

3. You will be asked to stand on a line with your arms outstretched and a sensor wand will be used to check for anything on your body. You will be asked to turn around and again the wand will be used to check your other side.
4. You will then be asked to lift up your pants so the inspector can see your ankles.

STEP 4 After being checked, you will be given your photo ID and the key to the locker.

STEP 5 The inspector will ask you to wait while he/she starts the computer that you will use for your test.

NOTE: The testing area is under video surveillance at all times.

STEP 6 After the computer has been setup, you will be escorted to the computer cubical and instructed to place your photo ID on a holder and the key to your locker on the desk in front of you.

STEP 7 At this time, you click on the screen and the test opens. Click start and the questions are displayed. Each test has a time limit and the time remaining is displayed on the upper left corner. The number of the test question is shown at the upper right corner of the screen, such as 17/50.

HINT: If you are spending too much time on one question, skip it and go on to keep on task. The program will display and allow you to go back and answer the question you skipped if there is time remaining at the end.

STEP 8 After the last question has been displayed and answered, you will be shown a screen showing any skipped questions. You can click to exit and you have completed the test. Exit the test area.

STEP 9 When you exit the testing area, you will be asked to sign out and show your photo ID. Your test score will be printed out and given to you before you retrieve your belongings and then you are free to leave the testing center.

REVIEW QUESTIONS

1. What factors are part of being a professional service technician?
2. What is a mentor?
3. A formal evaluation could include what items?
4. What are the three Cs?
5. What should be included on the work order after the repair has been completed?

CHAPTER QUIZ

1. Professionalism includes which factor?
   - **a.** Keeping your word
   - **b.** Becoming a teammate with your coworkers
   - **c.** Apologizing if you are wrong
   - **d.** All of the above
2. Which of the following characteristics is evaluated under "maturity," on a technician evaluation form?
   - **a.** Completely dependable
   - **b.** Has difficulty working with others
   - **c.** Very slow to learn
   - **d.** Seldom assertive
3. The three Cs include ________, ________, and ________.
   - **a.** correction, correct torque, customer name
   - **b.** concern, cause, correction
   - **c.** cause, cost, caller name
   - **d.** captured data, cause, cost (of the repair)
4. When documenting the work order, what things should be listed?
   - **a.** The test equipment used in the diagnosis
   - **b.** The test procedure that was followed
   - **c.** The parts that were replaced
   - **d.** All of the above
5. Technician A says that customer-pay rate is sometimes higher than the factory flat-rate. Technician B says that the factory flat-rate times are usually longer (given more time) compared to aftermarket flat-rate time guides. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Housekeeping duties of a technician can include ____________.
   - **a.** cleaning the floor
   - **b.** keeping the work area clean and organized
   - **c.** keeping items off the floor whenever possible
   - **d.** All of the above
7. A repair shop pays $22.50 for an aftermarket water pump. With a shop margin of 35%, how much will the customer be charged for the water pump?
   - **a.** $22.50
   - **b.** $22.50 plus 10%
   - **c.** $34.62
   - **d.** $38.50
8. Which of the following is a characteristic of good business meetings?
   - **a.** The meetings should start on time and can be easily extended beyond the decided end time.
   - **b.** The meetings should not include anyone outside the company or shop.
   - **c.** The meetings should follow "Robert's Rules of Order."
   - **d.** The agenda of the meeting should be displayed at the end.
9. A mentor performs all of the following *except* ____________.
   - **a.** helps guide diagnosis of a problem
   - **b.** signs paychecks
   - **c.** offers advice on how to do a job
   - **d.** advises on professional behavior
10. What is/are true about the ASE certification tests?
    - **a.** It is a test given at a testing center
    - **b.** It includes a section of hands-on activities
    - **c.** They are offered two times a year
    - **d.** It is a test taken over the Internet

SECTION II

SAFETY AND HEALTH ISSUES

CHAPTERS

5 Shop Safety
6 Hazardous Materials
7 Health and Environmental Concerns

Chapter 5

SHOP SAFETY

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the personal protective equipment used by technicians.
- Explain the safety tips for technicians.
- Discuss electrical cord safety, jump-starting, and battery safety.
- Discuss the purpose of fire extinguishers and fire blankets.
- Discuss the purpose of first aid and eye wash stations.
- Discuss the purpose of evacuation routes.

KEY TERMS:

ANSI 34 • Bump cap 35 • Decibel (dB) 35 • Eye wash station 38 • Fire blankets 38 • PASS 38 • Personal protective equipment (PPE) 34 • Spontaneous combustion 36

PERSONAL PROTECTIVE EQUIPMENT

Safety is not just a buzzword on a poster in the work area. Safe work habits can reduce accidents and injuries, ease the workload, and keep employees pain free.

SAFETY GLASSES The most important **personal protective equipment (PPE)** a technician should wear all the time are safety glasses, which meet standard **ANSI** Z87.1. ● **SEE FIGURE 5–1**.

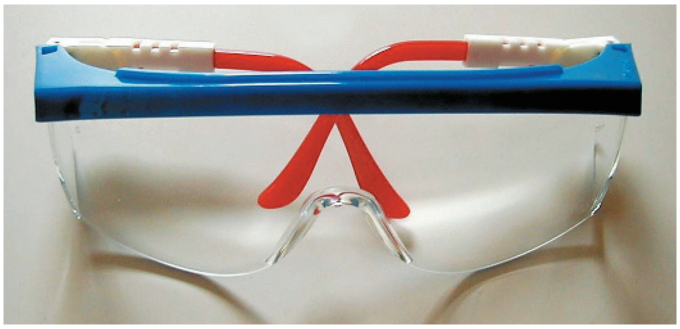


FIGURE 5–1 Safety glasses should be worn at all times when working on or around any vehicle or servicing any component.

STEEL-TOED SHOES Steel-toed safety shoes are also a good investment. ● **SEE FIGURE 5–2**. If safety shoes are not available, leather-topped shoes offer more protection than canvas or cloth covered shoes.

GLOVES Wear gloves to protect your hands from rough or sharp surfaces. Thin rubber gloves are recommended when working around automotive liquids such as engine oil, antifreeze, transmission fluid, or any other liquids that may be hazardous. Several types of gloves and their characteristics include:

- **Latex surgical gloves.** These gloves are relatively inexpensive, but tend to stretch, swell, and weaken when exposed to gas, oil, or solvents.
- **Vinyl gloves.** These gloves are also inexpensive and are not affected by gas, oil, or solvents. ● **SEE FIGURE 5–3**.
- **Polyurethane gloves.** These gloves are more expensive, yet very strong. Even though these gloves are also not affected by gas, oil, or solvents, they tend to be slippery.
- **Nitrile gloves.** These gloves are exactly like latex gloves, but are not affected by gas, oil, or solvents, yet they tend to be expensive.
- **Mechanic's gloves.** These gloves are usually made of synthetic leather and spandex and provide thermo protection, as well as protection from dirt and grime.

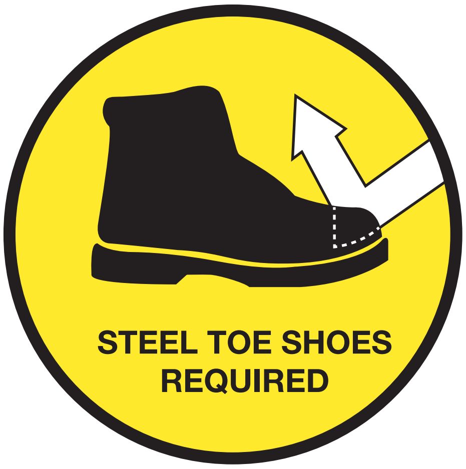


FIGURE 5–2 Steel-toed shoes are a worthwhile investment to help prevent foot injury due to falling objects.

FIGURE 5–3 Protective gloves such as these vinyl gloves are available in several sizes. Select the size that allows the gloves to fit snugly. Vinyl gloves last a long time and often can be worn all day to help protect your hands from dirt and possible hazardous materials.

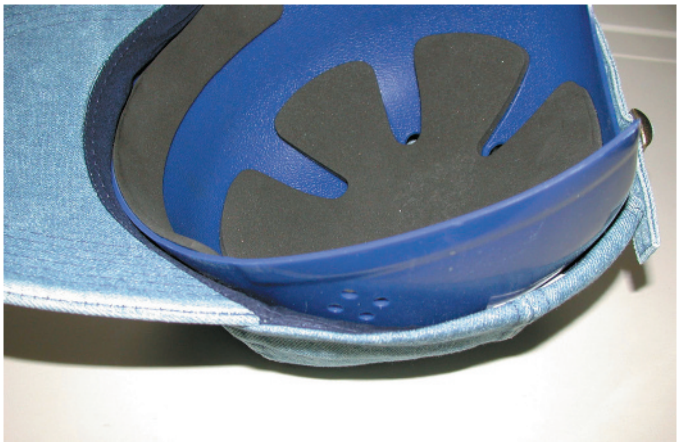


FIGURE 5–4 One version of a bump cap is this padded plastic insert that is worn inside a regular cloth cap.

BUMP CAP Service technicians working under a vehicle should wear a **bump cap** to protect the head against under-vehicle objects and the pads of the lift. ● **SEE FIGURE 5–4**.

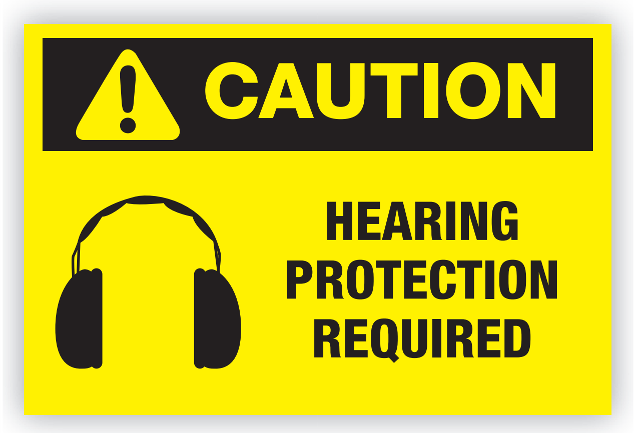


FIGURE 5–5 Hearing protection is recommended for use if the noise level exceeds 90 dB, which is often the case in a noisy automotive shop if air tools or grinders are being used.

TECH TIP

Professional Behavior in the Shop Is a Must

To be respected as a professional service technician and for safety, always behave in a professional manner. These behaviors include, but are not limited to, the following:

- Show respect to other technicians and employees. For example, the shop owner or service manager may not always be right, but they are always the boss.
- Avoid horseplay or practical jokes.
- Act as if a customer is observing your behavior at all times because this is often the case.

HANDS, JEWELRY, AND CLOTHING Remove jewelry that may get caught on something or act as a conductor to an exposed electrical circuit.

Take care of your hands. Keep your hands clean by washing with soap and hot water that is at least 110°F (43°C). Avoid loose or dangling clothing. Also, ear protection should be worn if the sound around you requires that you raise your voice (sound level higher than 90 **decibels [dB]**). ● **SEE FIGURE 5–5**.

NOTE: A typical lawnmower produces noise at a level of about 110 dB. This means that everyone who uses a lawnmower or other lawn or garden equipment should wear ear protection.

SAFETY TIPS FOR TECHNICIANS

- When lifting any object, get a secure grip with solid footing. Keep the load close to your body to minimize the strain. Lift with your legs and arms, not your back.
- Do not twist your body when carrying a load. Instead, pivot your feet to help prevent strain on the spine.
- Ask for help when moving or lifting heavy objects.
- Push a heavy object rather than pull it. (This is opposite to the way you should work with tools—never push a wrench! If you do and a bolt or nut loosens, your entire weight is

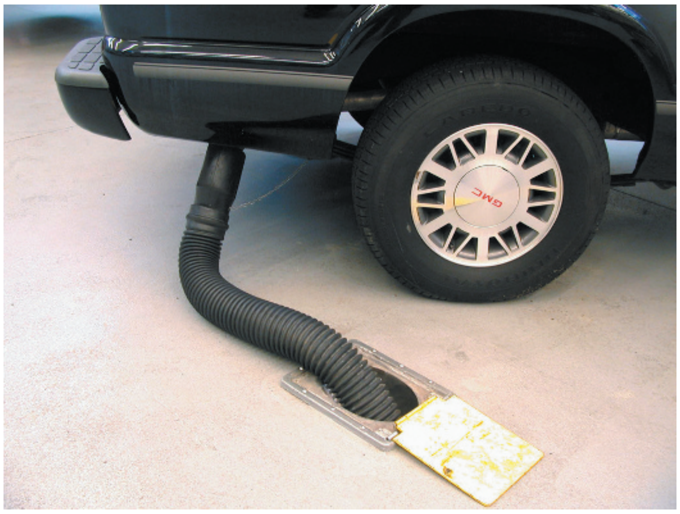


FIGURE 5–6 Always connect an exhaust hose to the tailpipe of the engine of a vehicle to be run inside a building.

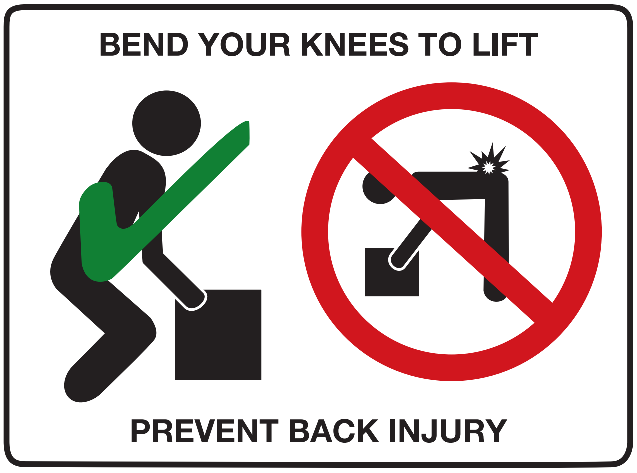

BEND YOUR KNEES TO LIFT
PREVENT BACK INJURY

FIGURE 5–7 When lifting heavy objects, lift using your legs instead of your back to help avoid strain and injury.

used to propel your hand(s) forward. This usually results in cuts, bruises, or other painful injury.)

- Always connect an exhaust hose to the tailpipe of any running vehicle to help prevent the buildup of carbon monoxide (CO) inside a closed garage space. ● **SEE FIGURE 5–6**.
- When standing, keep objects, parts, and tools with which you are working between chest height and waist height. If seated, work at tasks that are at elbow height. ● **SEE FIGURE 5–7**.
- Always be sure the hood is securely held open.
- Ask for help when pushing a vehicle or use a motorized pusher. ● **SEE FIGURE 5–8**.

SAFETY TIP

Shop Cloth Disposal

Always dispose of oily shop cloths in an enclosed container to prevent a fire. ● **SEE FIGURE 5–9**. Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur which can ignite the cloth even without an open flame. This process of ignition without an open flame is called **spontaneous combustion**.

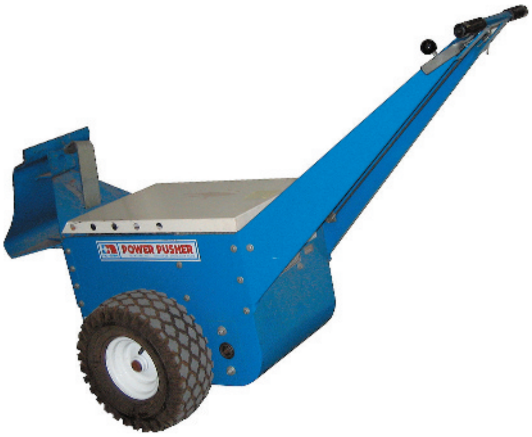


FIGURE 5–8 An electric pusher used to push vehicles into or around the shop.

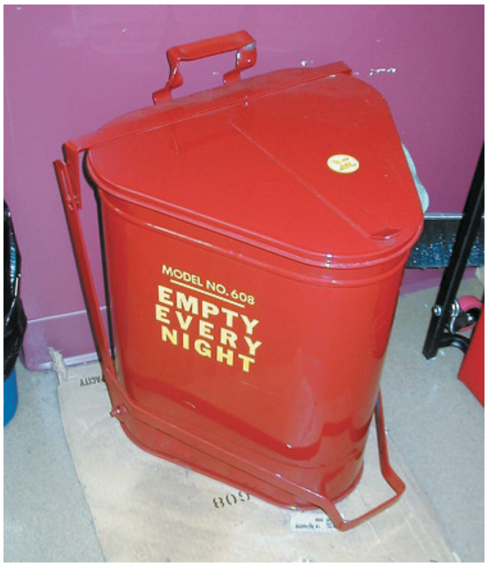


FIGURE 5–9 All oily shop cloths should be stored in a metal container equipped with a lid to help prevent spontaneous combustion.

TECH TIP

Pound with Something Softer

If you must pound on something, be sure to use a tool that is softer than what you are about to pound on to avoid damage. Examples are given in the following table.

The Material Being Pounded	What to Pound With
Steel or cast iron	Brass or aluminum hammer or punch
Aluminum	Plastic or rawhide mallet or plastic-covered dead-blow hammer
Plastic	Rawhide mallet or plastic dead-blow hammer

ELECTRICAL SAFETY

ELECTRICAL CORD SAFETY Use correctly grounded three-prong sockets and extension cords to operate power tools. Some tools use only two-prong plugs. Make sure these are double insulated and repair or replace any electrical cords that are cut or damaged to prevent the possibility of an electrical shock. When not in use, keep electrical cords off the floor to prevent tripping over them. Tape the cords down if they are placed in high foot traffic areas.

JUMP-STARTING AND BATTERY SAFETY To jump-start another vehicle with a dead battery, connect good-quality copper jumper cables as indicated in ● **FIGURE 5–10** or use a jump box. The last connection made should always be on the engine block or an engine bracket as far from the battery as possible. It is normal for a spark to be created when the jumper cables finally complete the jumper cable connections, and this spark could cause an explosion of the gases around the battery. Many newer vehicles have special ground connections built away from the battery just for the purpose of jump-starting. Check the owner manual or service information for the exact location.

SAFETY TIP

Compressed Air Safety

Improper use of an air nozzle can cause blindness or deafness. Compressed air must be reduced to less than 30 PSI (206 kPa). ● **SEE FIGURE 5–11**. If an air nozzle is used to dry and clean parts, make sure the air stream is directed away from anyone else in the immediate area. Always use an OSHA-approved nozzle with side slits that limit the maximum pressure at the nozzle to 30 PSI. Coil and store air hoses when they are not in use.

Batteries contain acid and should be handled with care to avoid tipping them greater than a 45-degree angle. Always remove jewelry when working around a battery to avoid the possibility of electrical shock or burns, which can occur when the metal comes in contact with a 12 volt circuit and ground, such as the body of the vehicle.

FIRE EXTINGUISHERS

There are four classes of fire extinguishers. Each class should be used on specific fires only.

- *Class A* is designed for use on general combustibles, such as cloth, paper, and wood.
- *Class B* is designed for use on flammable liquids and greases, including gasoline, oil, thinners, and solvents.
- *Class C* is used only on electrical fires.
- *Class D* is effective only on combustible metals such as powdered aluminum, sodium, or magnesium.

The class rating is clearly marked on the side of every fire extinguisher. Many extinguishers are good for multiple types of fires. ● **SEE FIGURE 5–12**.

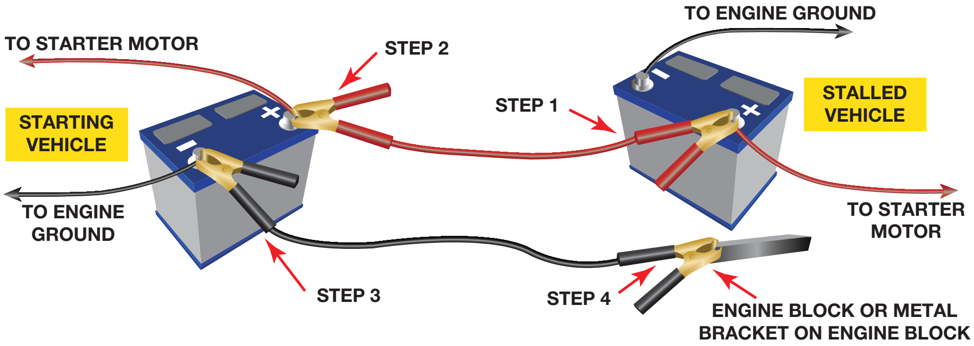

TO ENGINE GROUND
TO STARTER MOTOR
STEP 2
STEP 1
STALLED VEHICLE
STARTING VEHICLE
TO ENGINE GROUND
TO STARTER MOTOR
STEP 3
STEP 4
ENGINE BLOCK OR METAL BRACKET ON ENGINE BLOCK

FIGURE 5–10 Jumper cable usage guide. Follow the same connections if using a portable jump box.

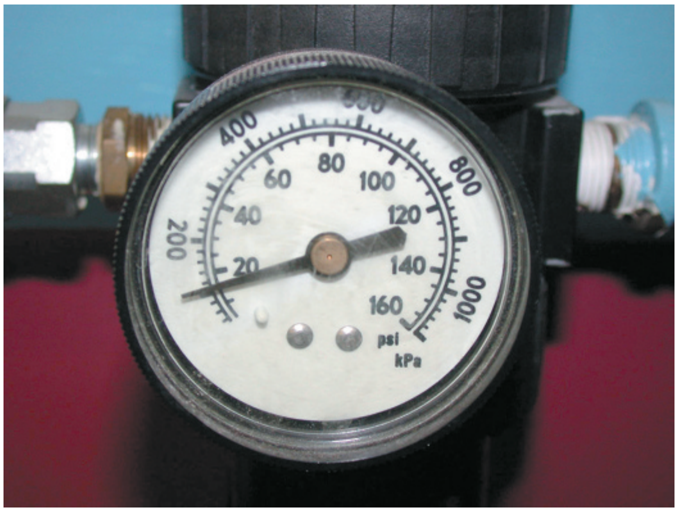


FIGURE 5–11 The air pressure going to the nozzle should be reduced to 30 PSI or less.

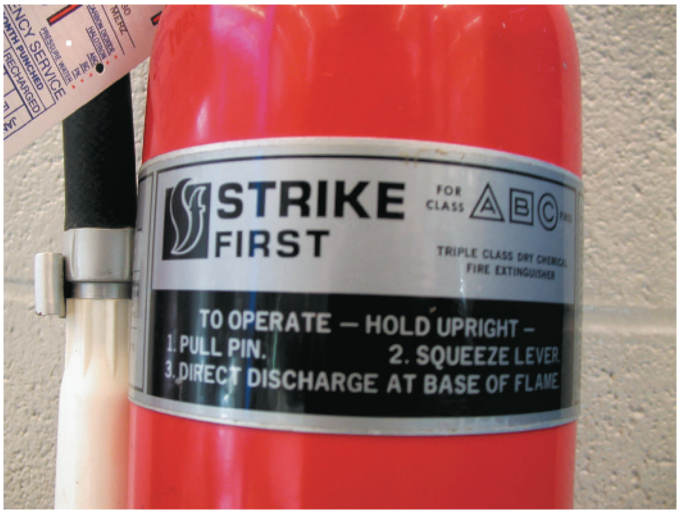

STRIKE FIRST
FOR CLASS A B C
TRIPLE CLASS DRY CHEMICAL FIRE EXTINGUISHER
TO OPERATE – HOLD UPRIGHT –
1. PULL PIN.
2. SQUEEZE LEVER
3. DIRECT DISCHARGE AT BASE OF FLAME

FIGURE 5–12 A typical fire extinguisher designed to be used on type class A, B, or C fires.

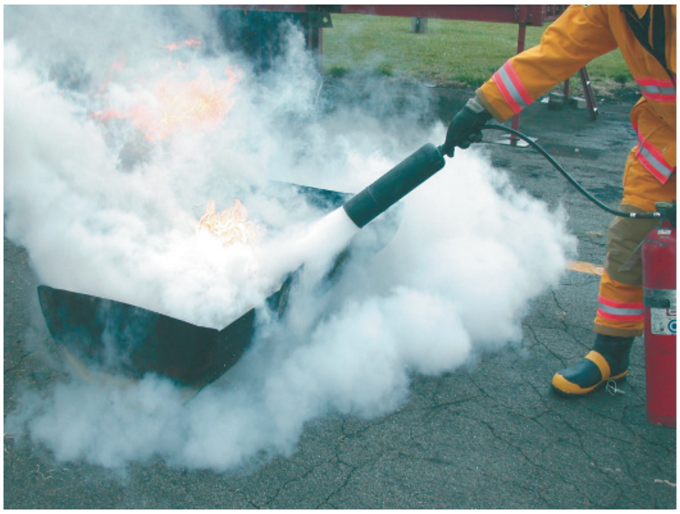


FIGURE 5–13 A CO_2 fire extinguisher being used on a fire set in an open steel drum during a demonstration at a fire department training center.

When using a fire extinguisher, remember the word **"PASS."**

P = Pull the safety pin.
A = Aim the nozzle of the extinguisher at the base of the fire.
S = Squeeze the lever to actuate the extinguisher.
S = Sweep the nozzle from side to side.

● **SEE FIGURE 5–13**.

TYPES OF FIRE EXTINGUISHERS Types of fire extinguishers include the following:

- **Water.** A water fire extinguisher, usually in a pressurized container, is good to use on Class A fires by reducing the temperature to the point where a fire cannot be sustained.
- **Carbon dioxide (CO_2).** A carbon dioxide fire extinguisher is good for almost any type of fire, especially Class B or Class C materials. A CO_2 fire extinguisher works by removing the oxygen from the fire and the cold CO_2 also helps reduce the temperature of the fire.
- **Dry chemical (yellow).** A dry chemical fire extinguisher is good for Class A, B, or C fires by coating the flammable materials, which eliminates the oxygen from the fire. A dry chemical fire extinguisher tends to be very corrosive and will cause damage to electronic devices.

FIRE BLANKETS **Fire blankets** are required to be available in the shop areas. If a person is on fire, a fire blanket should be removed from its storage bag and thrown over and around the victim to smother the fire. ● **SEE FIGURE 5–14** showing a typical fire blanket.

FIRST AID AND EYE WASH STATIONS

All shop areas must be equipped with a first aid kit and an eye wash station centrally located and kept stocked with emergency supplies.

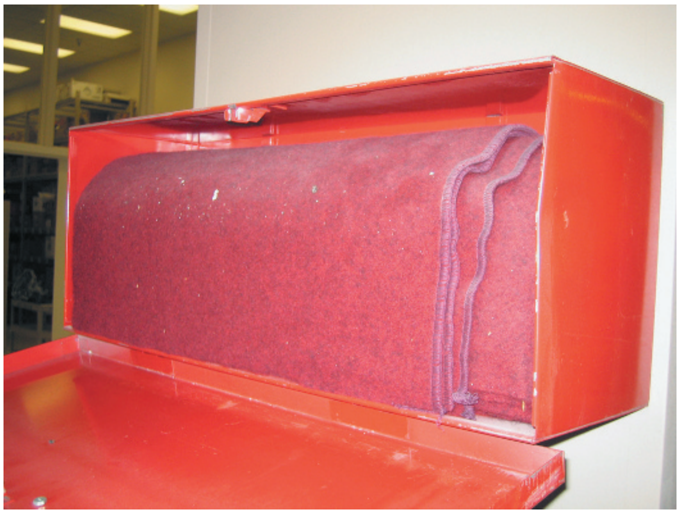


FIGURE 5–14 A treated wool blanket is kept in this easy-to-open wall-mounted holder and should be placed in a centralized location in the shop.

FIRST AID KIT A first aid kit should include:

- Bandages (variety)
- Gauze pads
- Roll gauze
- Iodine swab sticks
- Antibiotic ointment
- Hydrocortisone cream
- Burn gel packets
- Eye wash solution
- Scissors
- Tweezers
- Gloves
- First aid guide

● **SEE FIGURE 5–15**. Every shop should have a person trained in first aid. If there is an accident, call for help immediately.

EYE WASH STATION An **eye wash station** should be centrally located and used whenever any liquid or chemical gets into the eyes. If such an emergency does occur, keep eyes in a constant

Afassco
First Aid
CARSON CITY, NV 89721

FIGURE 5–15 A first aid box should be centrally located in the shop and kept stocked with the recommended supplies.

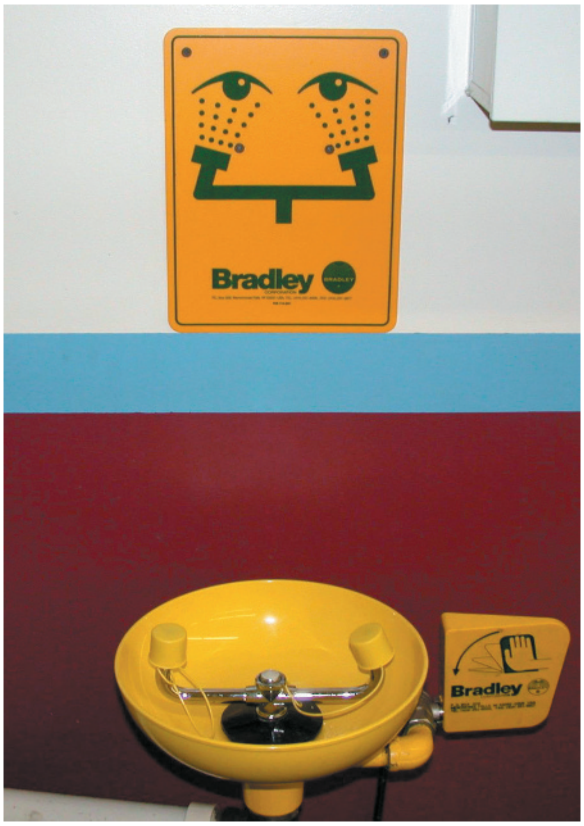


FIGURE 5–16 A typical eye wash station. Often a thorough flushing of the eyes with water is the best treatment in the event of eye contamination.

stream of water and call for professional assistance. ● **SEE FIGURE 5–16**.

EVACUATION ROUTES

POSTED MAPS Check the location of posted evacuation routes and be sure to read, understand, and follow the instructions for evacuating the area in case of an emergency. The evacuation routes are commonly posted throughout the building and often include the location of the nearest fire extinguisher and other safety related items. ● **SEE FIGURE 5–17**.

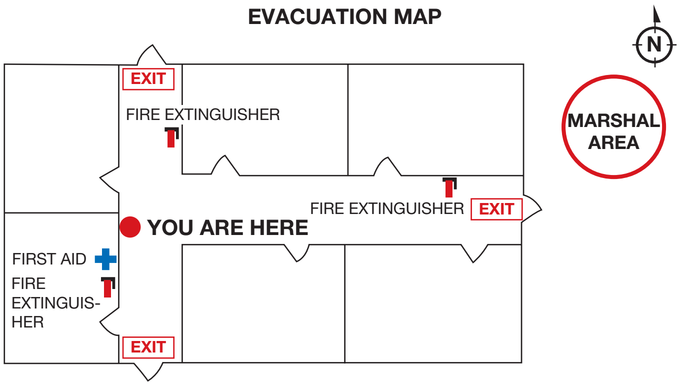


FIGURE 5–17 The evacuation routes from where you are in the building is shown on maps that are attached to the walls in schools and commercial buildings.

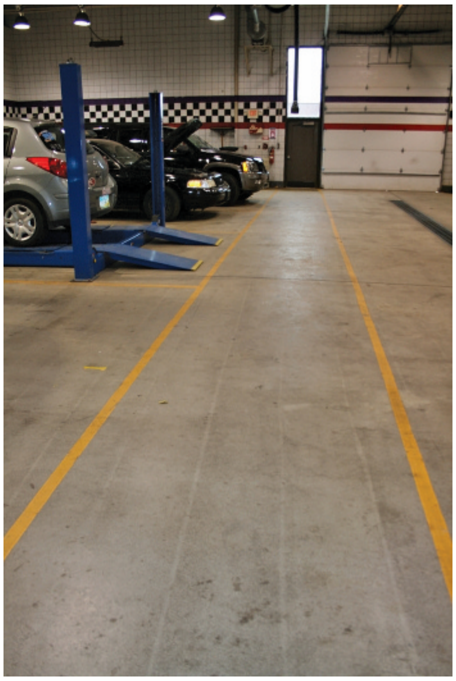


FIGURE 5–18 A properly marked aisle using yellow paint stripes leading to an exit.

AISLE MARKINGS Aisles leading to the emergency exit must be marked with yellow paint or tape at least 2 inches (5 cm) wide. The aisles should also be 40 to 48 inches (102 to 122 cm) wide. Aisles should lead to exits as directly as possible. ● **SEE FIGURE 5–18**.

SAFETY TIP

Infection Control Precautions

Working on a vehicle can result in personal injury including the possibility of being cut or hurt enough to cause bleeding. Some infections such as hepatitis B, HIV (which can cause acquired immunodeficiency syndrome, or AIDS), and hepatitis C virus are transmitted through blood. These infections are commonly called blood-borne pathogens. Report any injury that involves blood to your supervisor and take the necessary precautions to avoid coming in contact with blood from another person.

REVIEW QUESTIONS

1. What are four items that are personal protective equipment (PPE)?
2. What are the types of fire extinguishers and their usage?
3. What items are included in a typical first aid box?
4. What infection control precautions should be followed in the shop?
5. Why should oily shop cloths be kept in a metal covered container?

CHAPTER QUIZ

1. What do you call the service technician's protective head cover?
   - **a.** Cap
   - **b.** Hat
   - **c.** Bump cap
   - **d.** Helmet
2. All safety glasses should meet the standards set by ______________.
   - **a.** ANSI
   - **b.** SAE
   - **c.** ASE
   - **d.** DOT
3. When washing hands, the water should be at what temperature?
   - **a.** 98°F (37°C)
   - **b.** 110°F (43°C)
   - **c.** 125°F (52°C)
   - **d.** 135°F (57°C)
4. Hearing protection should be worn anytime the noise level exceeds ______________.
   - **a.** 60 dB
   - **b.** 70 dB
   - **c.** 80 dB
   - **d.** 90 dB
5. What precautions should be adhered to when using an electrical power tool?
   - **a.** Make sure the outlet has a ground
   - **b.** Use double-insulated power tools
   - **c.** Replace any extension cords that are damaged
   - **d.** All of the above
6. Exhaust hoses should be used because one of the exhaust gases is deadly in high concentration. This gas is ______________.
   - **a.** carbon monoxide (CO)
   - **b.** carbon dioxide (CO_2)
   - **c.** a hydrocarbon (HC)
   - **d.** an oxide of nitrogen (NOX)
7. The process of combustion occurring without an open flame is called ______________.
   - **a.** direct ignition
   - **b.** non open flame combustion
   - **c.** spontaneous combustion
   - **d.** cold fusion
8. When using a fire extinguisher, what word can be used to remember what to do?
   - **a.** PASS
   - **b.** FIRE
   - **c.** RED
   - **d.** LEVER
9. Evacuation routes should include ______________.
   - **a.** aisle markings
   - **b.** leads to an assembly area
   - **c.** wide aisles
   - **d.** All of the above
10. Which item is usually *not* included in a first aid kit?
    - **a.** Eye wash solution
    - **b.** Antibiotic cream
    - **c.** Fire blanket
    - **d.** Bandages

Chapter 6

HAZARDOUS MATERIALS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Define hazardous waste materials.
- Describe federal and state laws regarding hazardous waste materials.
- Discuss asbestos hazards and asbestos handling guidelines.
- Explain the storage and disposal of brake fluid.
- Explain the storage and disposal of used oil.
- Explain the characteristics of hazardous solvents.
- Describe coolant disposal.
- Discuss lead-acid battery waste.
- Discuss fuel safety and storage.
- Discuss airbag handling.
- Discuss used tire disposal.
- Discuss air-conditioning refrigerant oil disposal.
- Describe typical waste materials generated at auto repair shops and disposal methods.

KEY TERMS:

Aboveground storage tank (AGST) 44 • Asbestosis 43 • BCI 46 • CAA 43 • CFR 42 • EPA 42 • Hazardous waste material 41 • HEPA 43 • Mercury 48 • SDS 42 • OSHA 41 • RCRA 42 • Right-to-know laws 42 • Solvent 43 • Underground storage tank (UST) 44 • Used oil 44 • WHMIS 42

HAZARDOUS WASTE

DEFINITION OF HAZARDOUS WASTE **Hazardous waste materials** are chemicals, or components, that the shop no longer needs that pose a danger to the environment and people if they are disposed of in ordinary garbage cans or sewers. However, no material is considered hazardous waste until the shop has finished using it and is ready to dispose of it. ● **SEE FIGURE 6–1**.

PERSONAL PROTECTIVE EQUIPMENT (PPE) When handling hazardous waste material, one must always wear the proper protective clothing and equipment detailed in the right-to-know laws. This includes respirator equipment. All recommended procedures must be followed accurately. Personal injury may result from improper clothing, equipment, and procedures when handling hazardous materials.

FEDERAL AND STATE LAWS

OCCUPATIONAL SAFETY AND HEALTH ACT The United States Congress passed the **Occupational Safety and Health Act (OSHA)** in 1970. This legislation was designed to assist and

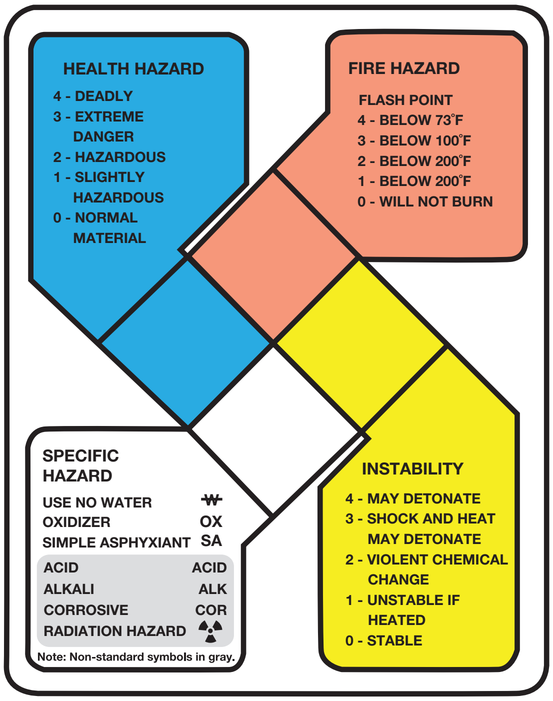

HEALTH HAZARD
4 - DEADLY
3 - EXTREME DANGER
2 - HAZARDOUS
1 - SLIGHTLY HAZARDOUS
0 - NORMAL MATERIAL
FIRE HAZARD
FLASH POINT
4 - BELOW 73°F
3 - BELOW 100°F
2 - BELOW 200°F
1 - BELOW 200°F
0 - WILL NOT BURN
SPECIFIC HAZARD
USE NO WATER ~~W~~
OXIDIZER OX
SIMPLE ASPHYXIANT SA
ACID ACID
ALKALI ALK
CORROSIVE COR
RADIATION HAZARD ☢
Note: Non-standard symbols in gray.
INSTABILITY
4 - MAY DETONATE
3 - SHOCK AND HEAT MAY DETONATE
2 - VIOLENT CHEMICAL CHANGE
1 - UNSTABLE IF HEATED
0 - STABLE

FIGURE 6–1 Hazardous material classification.

WARNING

Hazardous waste disposal laws include serious penalties for anyone responsible for breaking these laws.

encourage the citizens of the United States in their efforts to assure:

- Safe and healthful working conditions by providing research, information, education, and training in the field of occupational safety and health.
- Safe and healthful working conditions for workers by authorizing enforcement of the standards developed under the Act.

Because about 25% of workers are exposed to health and safety hazards on the job, the OSHA standards are necessary to monitor, control, and educate workers regarding health and safety in the workplace.

EPA The **Environmental Protection Agency (EPA)** publishes a list of hazardous materials that is included in the **Code of Federal Regulations (CFR)**. The EPA considers waste hazardous if it is included on the EPA list of hazardous materials, or it has one or more of the following characteristics:

- **Reactive.** Any material that reacts violently with water or other chemicals is considered hazardous.
- **Corrosive.** If a material burns the skin, or dissolves metals and other materials, a technician should consider it hazardous. A pH scale is used, with the number 7 indicating neutral. Pure water has a pH of 7. Lower numbers indicate an acidic solution and higher numbers indicate a caustic solution. If a material releases cyanide gas, hydrogen sulfide gas, or similar gases when exposed to low pH acid solutions, it is considered hazardous.
- **Toxic.** Materials are hazardous if they leak one or more of eight different heavy metals in concentrations greater than 100 times the primary drinking water standard.
- **Ignitable.** A liquid is hazardous if it has a flash point below 140°F (60°C), and a solid is hazardous if it ignites spontaneously.
- **Radioactive.** Any substance that emits measurable levels of radiation is radioactive. When individuals bring containers of a highly radioactive substance into the shop environment, qualified personnel with the appropriate equipment must test them.

RIGHT-TO-KNOW LAWS The **right-to-know laws** state that employees have a right to know when the materials they use at work are hazardous. Under the right-to-know laws, the employer has responsibilities regarding the handling of hazardous materials by their employees. All employees must be trained about the types of hazardous materials they will encounter in the workplace.

SAFETY DATA SHEETS (SDS). All hazardous materials must be properly labeled, and information about each hazardous material must be posted on **safety data sheets (SDS)**, formally called *material safety data sheets* (MSDS) available from the manufacturer. In Canada, MSDS information is called **Workplace Hazardous Materials Information Systems (WHMIS)**.

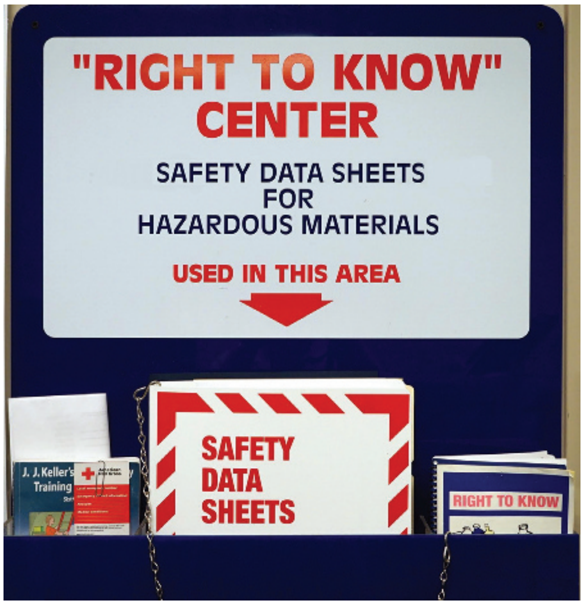


FIGURE 6–2 Safety Data Sheets (SDS) should be readily available for use by anyone in the area who may come into contact with hazardous materials.

The employer has a responsibility to place MSDS information where they are easily accessible by all employees.

The manufacturer must supply all warning and precautionary information about hazardous materials. This information must be read and understood by the employee before handling the material. ● **SEE FIGURE 6–2**.

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)

Federal and state laws control the disposal of hazardous waste materials and every shop employee must be familiar with these laws. Hazardous waste disposal laws include the **Resource Conservation and Recovery Act (RCRA)**. This law states that hazardous material users are responsible for hazardous materials from the time they become a waste until the proper waste disposal is completed. Many shops hire an independent hazardous waste hauler to dispose of hazardous waste material. The shop owner, or manager, should have a written contract with the hazardous waste hauler. The RCRA controls the following types of automotive waste:

- Paint and body repair products waste
- Solvents for parts and equipment cleaning
- Batteries and battery acid
- Mild acids used for metal cleaning and preparation
- Waste oil, and engine coolants or antifreeze
- Air-conditioning refrigerants and oils
- Engine oil filters

LOCKOUT/TAGOUT According to OSHA Title 29, code of Federal Regulations (CPR), part 1910.147, machinery must be locked out to prevent injury to employees when maintenance or repair work is being performed. Any piece of equipment that should not be used must be tagged and the electrical power disconnected to prevent it from being used. Always read, understand, and follow all safety warning tags. ● **SEE FIGURE 6–3**.

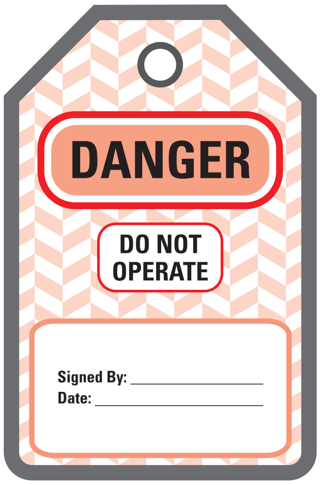


FIGURE 6–3 Tag that identifies the electrical power has been removed and service work is being done.

CLEAN AIR ACT Air-conditioning (A/C) systems and refrigerants are regulated by the **Clean Air Act (CAA)**, Title VI, Section 609. Technician certification and service equipment are also regulated. Any technician working on automotive A/C systems must be certified. A/C refrigerants must not be released or vented into the atmosphere, and used refrigerants must be recovered.

ASBESTOS HAZARDS

Friction materials such as brake and clutch linings often contain asbestos. While asbestos has been eliminated from most original equipment friction materials, the automotive service technician cannot know whether the vehicle being serviced is or is not equipped with friction materials containing asbestos. It is important that all friction materials be handled as if they do contain asbestos.

Asbestos exposure can cause scar tissue to form in the lungs. This condition is called **asbestosis**. It gradually causes increasing shortness of breath, and the scarring to the lungs is permanent.

Even low exposures to asbestos can cause *mesothelioma*, a type of fatal cancer of the lining of the chest or abdominal cavity. Asbestos exposure can also increase the risk of *lung cancer* as well as cancer of the voice box, stomach, and large intestine. It usually takes 15 to 30 years or more for cancer or asbestos lung scarring to show up after exposure. Scientists call this the *latency period*.

ASBESTOS OSHA STANDARDS The Occupational Safety and Health Administration (OSHA) has established three levels of asbestos exposure. Any vehicle service establishment that does either brake or clutch work must limit employee exposure to asbestos to less than 0.2 fibers per cubic centimeter (cc) as determined by an air sample.

If the level of exposure to employees is greater than specified, corrective measures must be performed and a large fine may be imposed.

NOTE: Research has found that worn asbestos fibers such as those from automotive brakes or clutches may not be as hazardous as first believed. Worn asbestos fibers do not have sharp flared ends that can latch onto tissue, but rather are worn down to a dust form that resembles talc. Grinding or sawing operations on unworn brake shoes or clutch discs will contain harmful asbestos fibers. To limit health damage, always use proper handling procedures while working around any component that may contain asbestos.

ASBESTOS EPA REGULATIONS The federal Environmental Protection Agency (EPA) has established procedures for the removal and disposal of asbestos. The EPA procedures require that products containing asbestos be "wetted" to prevent the asbestos fibers from becoming airborne. According to the EPA, asbestos-containing materials can be disposed of as regular waste. Only when asbestos becomes airborne is it considered to be hazardous.

ASBESTOS HANDLING GUIDELINES The air in the shop area can be tested by a testing laboratory, but this can be expensive. Tests have determined that asbestos levels can easily be kept below the recommended levels by using a liquid, like water, or a special vacuum.

NOTE: The service technician cannot tell whether the old brake pads, shoes, or clutch discs contain asbestos. Therefore, to be safe, the technician should assume that all brake pads, shoes, or clutch discs contain asbestos.

HEPA VACUUM. A special **high-efficiency particulate air (HEPA)** vacuum system has been proven to be effective in keeping asbestos exposure levels below 0.1 fibers per cubic centimeter.

SOLVENT SPRAY. Many technicians use an aerosol can of brake cleaning solvent to wet the brake dust and prevent it from becoming airborne. A **solvent** is a liquid that is used to dissolve dirt, grime, or solid particles. Commercial brake cleaners are available that use a concentrated cleaner that is mixed with water. ● **SEE FIGURE 6–4**. The waste liquid is filtered, and when dry, the filter can be disposed of as solid waste.

DISPOSAL OF BRAKE DUST AND BRAKE SHOES. The hazard of asbestos occurs when asbestos fibers are airborne. Once the asbestos has been wetted down, it is then considered to be solid waste, rather than hazardous waste. Old brake shoes and pads should be enclosed, preferably in a plastic bag, to help prevent any of the brake material from becoming airborne. *Always follow current federal and local laws concerning disposal of all waste.*

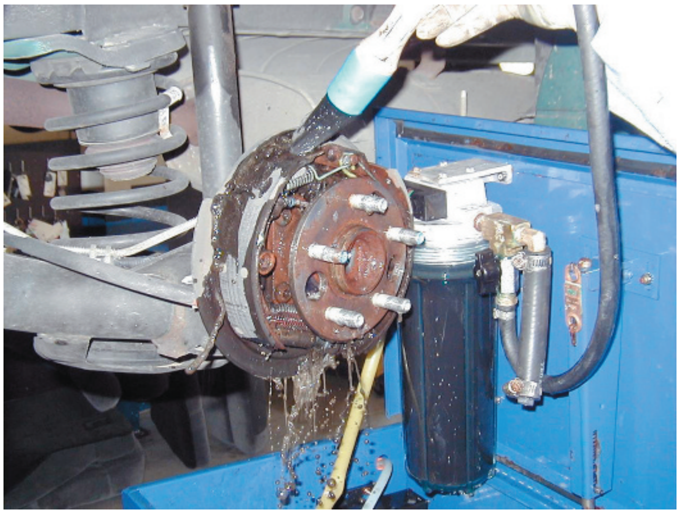


FIGURE 6–4 All brakes should be moistened with water or solvent to help prevent brake dust from becoming airborne.

WARNING

Never use compressed air to blow brake dust. The fine talc-like brake dust can create a health hazard even if asbestos is not present or is present in dust rather than fiber form.

USED BRAKE FLUID

Most brake fluid is made from polyglycol, is water soluble, and can be considered hazardous if it has absorbed metals from the brake system.

STORAGE AND DISPOSAL OF BRAKE FLUID

- Collect brake fluid in a container clearly marked to indicate that it is designated for that purpose.
- If the waste brake fluid is hazardous, be sure to manage it appropriately and use only an authorized waste receiver for its disposal.
- If the waste brake fluid is nonhazardous (such as old, but unused), determine from your local solid waste collection provider what should be done for its proper disposal.
- Do not mix brake fluid with used engine oil.
- Do not pour brake fluid down drains or onto the ground.
- Recycle brake fluid through a registered recycler.

USED OIL

DEFINITIONS **Used oil** is any petroleum-based or synthetic oil that has been used. During normal use, impurities such as dirt, metal scrapings, water, or chemicals can get mixed in with the oil. Eventually, this used oil must be replaced with virgin or re-refined oil. The EPA's used oil management standards include a three-pronged approach to determine if a substance meets the definition of *used oil*. To meet the EPA's definition of used oil, a substance must meet each of the following three criteria:

- **Origin.** The first criterion for identifying used oil is based on the oil's origin. Used oil must have been refined from crude oil or made from synthetic materials. Animal and vegetable oils are excluded from the EPA's definition of used oil.
- **Use.** The second criterion is based on whether and how the oil is used. Oils used as lubricants, hydraulic fluids, heat transfer fluids, and for other similar purposes are considered used oil. The EPA's definition also excludes products used as cleaning agents, as well as certain petroleum-derived products like antifreeze and kerosene.
- **Contaminants.** The third criterion is based on whether the oil is contaminated with either physical or chemical impurities. In other words, to meet the EPA's definition, used oil must become contaminated as a result of being used. This aspect of the EPA's definition includes residues and contaminants generated from handling, storing, and processing used oil.

NOTE: The release of only 1 gallon of used oil (a typical oil change) can make 1 million gallons of fresh water undrinkable.

If used oil is dumped down the drain and enters a sewage treatment plant, concentrations as small as 50 to 100 parts per million (ppm) in the wastewater can foul sewage treatment processes. Never mix a listed hazardous waste, gasoline, wastewater, halogenated solvent, antifreeze, or an unknown waste material with used oil. Adding any of these substances will cause the used oil to become contaminated, which classifies it as hazardous waste.

STORAGE AND DISPOSAL OF USED OIL Once oil has been used, it can be collected, recycled, and used over and over again. An estimated 380 million gallons of used oil are recycled each year. Recycled used oil can sometimes be used again for the same job or can take on a completely different task. For example, used engine oil can be re-refined and sold at some discount stores as engine oil or processed for furnace fuel oil. After collecting used oil in an appropriate container such as a 55 gallon steel drum, the material must be disposed of in one of two ways:

- Shipped offsite for recycling
- Burned in an onsite or offsite EPA-approved heater for energy recovery

Used oil must be stored in compliance with an existing **underground storage tank (UST)** or an **aboveground storage tank (AGST)** standard, or kept in separate containers. ● **SEE FIGURE 6–5**. Containers are portable receptacles, such as a 55 gallon steel drum.

KEEP USED OIL STORAGE DRUMS IN GOOD CONDITION. This means that they should be covered, secured from vandals, properly labeled, and maintained in compliance with local fire codes. Frequent inspections for leaks, corrosion, and spillage are an essential part of container maintenance.

NEVER STORE USED OIL IN ANYTHING OTHER THAN TANKS AND STORAGE CONTAINERS. Used oil may also be stored in units that are permitted to store regulated hazardous waste.

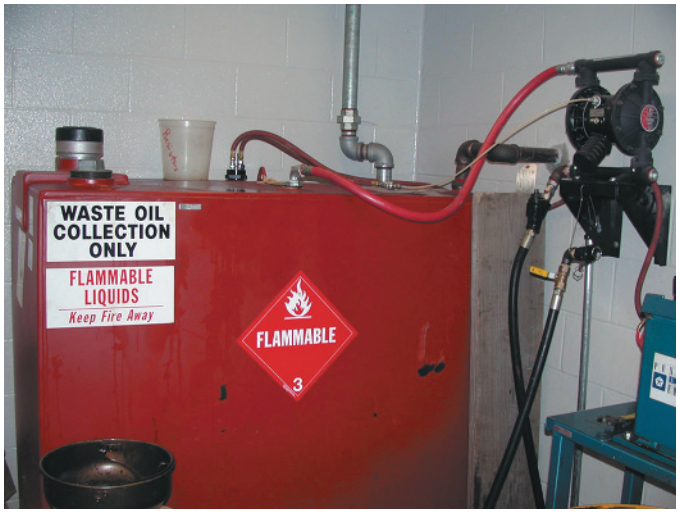


FIGURE 6–5 A typical aboveground oil storage tank.

USED OIL FILTER DISPOSAL REGULATIONS Used oil filters contain used engine oil that may be hazardous. Before an oil filter is placed into the trash or sent to be recycled, it must be drained using one of the following hot-draining methods approved by the EPA:

- Puncture the filter antidrainback valve or filter dome end and hot drain for at least 12 hours
- Hot draining and crushing
- Dismantling and hot draining
- Any other hot-draining method, which will remove all the used oil from the filter

After the oil has been drained from the oil filter, the filter housing can be disposed of in any of the following ways:

- Sent for recycling
- Picked up by a service contract company
- Disposed of in regular trash

FIGURE 6–6 Washing hands and removing jewelry are two important safety habits all service technicians should practice.

SOLVENTS

DEFINITIONS The major sources of chemical danger are liquid and aerosol brake cleaning fluids that contain chlorinated hydrocarbon solvents. Several other chemicals that do not deplete the ozone, such as heptane, hexane, and xylene, are now being used in nonchlorinated brake cleaning solvents. Some manufacturers are also producing solvents they describe as environmentally responsible, which are biodegradable and noncarcinogenic (not cancer causing).

There is no specific standard for physical contact with chlorinated hydrocarbon solvents or the chemicals replacing them. All contact should be avoided whenever possible. The law requires an employer to provide appropriate protective equipment and ensure proper work practices by an employee handling these chemicals.

EFFECTS OF CHEMICAL POISONING The effects of exposure to chlorinated hydrocarbon and other types of solvents can take many forms. Short-term exposure at low levels can cause symptoms such as:

- Headache
- Nausea
- Drowsiness
- Dizziness
- Lack of coordination
- Unconsciousness

It may also cause irritation of the eyes, nose, and throat, and flushing of the face and neck. Short-term exposure to higher concentrations can cause liver damage with symptoms such as yellow jaundice or dark urine. Liver damage may not become evident until several weeks after the exposure.

HAZARDOUS SOLVENTS AND REGULATORY STATUS Most solvents are classified as hazardous wastes. Other characteristics of solvents include the following:

- Solvents with flash points below 140°F (60°C) are considered flammable and, like gasoline, are federally regulated by the Department of Transportation (DOT).
- Solvents and oils with flash points above 140°F (60°C) are considered combustible and, like engine oil, are also regulated by the DOT. All flammable items must be stored in a fireproof container. ● **SEE FIGURE 6–7**.

It is the responsibility of the repair shop to determine if its spent solvent is hazardous waste. Solvent reclaimers are available that clean and restore the solvent so it lasts indefinitely.

SAFETY TIP

Hand Safety

Service technicians should wash their hands with soap and water after handling engine oil, differential oil, or transmission fluids or wear protective rubber gloves. Another safety hint is that the service technician should not wear watches, rings, or other jewelry that could come in contact with electrical or moving parts of a vehicle. ● **SEE FIGURE 6–6**.

FREQUENTLY ASKED QUESTION

How Can You Tell If a Solvent Is Hazardous?

If a solvent or any of the ingredients of a product contains “fluor” or “chlor,” it is likely to be hazardous. Check the instructions on the label for proper use and disposal procedures.

USED SOLVENTS Used or spent solvents are liquid materials that have been generated as waste and may contain xylene, methanol, ethyl ether, and methyl isobutyl ketone (MIBK). These materials must be stored in OSHA-approved safety containers with the lids or caps closed tightly. Additional requirements include the following:

- Containers should be clearly labeled “Hazardous Waste” and the date the material was first placed into the storage receptacle should be noted.
- Labeling is not required for solvents being used in a parts washer.

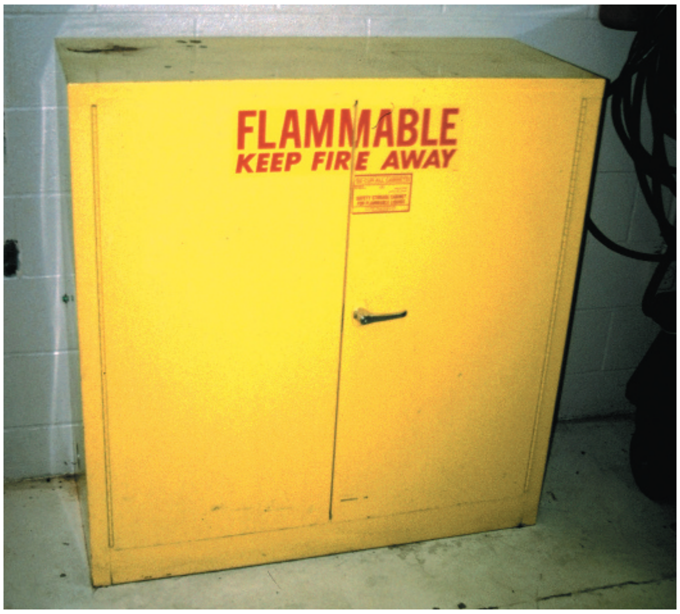


FIGURE 6–7 Typical fireproof flammable storage cabinet.

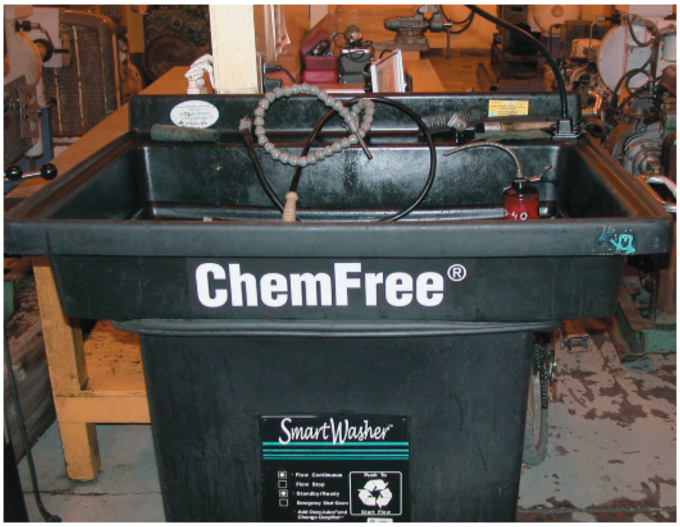


FIGURE 6–8 Using a water-based cleaning system helps reduce the hazards from using strong chemicals.

- Used solvents will not be counted toward a facility's monthly output of hazardous waste if the vendor under contract removes the material.
- Used solvents may be disposed of by recycling with a local vendor, such as SafetyKleen®, to have the used solvent removed according to specific terms in the vendor agreement.
- Use aqueous-based (nonsolvent) cleaning systems to help avoid the problems associated with chemical solvents. ● **SEE FIGURE 6–8**.

COOLANT DISPOSAL

Coolant is a mixture of antifreeze and water. New antifreeze is not considered to be hazardous even though it can cause death if ingested. Used antifreeze may be hazardous due to dissolved metals from the engine and other components of the cooling system. These metals can include iron, steel, aluminum, copper, brass, and lead (from older radiators and heater cores). Coolant should be disposed of in one of the following ways:

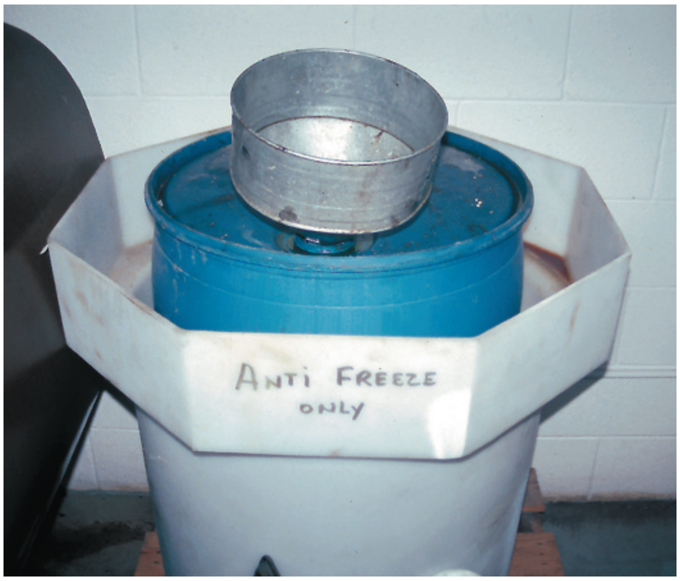


FIGURE 6–9 Used antifreeze coolant should be kept separate and stored in a leakproof container until it can be recycled or disposed of according to federal, state, and local laws. Note that the storage barrel is placed inside another container to catch any coolant that may spill out of the inside barrel.

- Coolant should be recycled either onsite or offsite.
- Used coolant should be stored in a sealed and labeled container. ● **SEE FIGURE 6–9**.
- Used coolant can often be disposed of into municipal sewers with a permit. Check with local authorities and obtain a permit before discharging used coolant into sanitary sewers.

LEAD-ACID BATTERY WASTE

About 70 million spent lead-acid batteries are generated each year in the United States alone. Lead is classified as a toxic metal and the acid used in lead-acid batteries is highly corrosive. The vast majority (95% to 98%) of these batteries are recycled through lead reclamation operations and secondary lead smelters for use in the manufacture of new batteries.

BATTERY DISPOSAL Used lead-acid batteries must be reclaimed or recycled in order to be exempt from hazardous waste regulations. Leaking batteries must be stored and transported as hazardous waste. Some states have more strict regulations, which require special handling procedures and transportation. According to the **Battery Council International (BCI)**, battery laws usually include the following rules:

1. Lead-acid battery disposal is prohibited in landfills or incinerators. Batteries are required to be delivered to a battery retailer, wholesaler, recycling center, or lead smelter.
2. All retailers of automotive batteries are required to post a sign that displays the universal recycling symbol and indicates the retailer's specific requirements for accepting used batteries.

3. Battery electrolyte contains sulfuric acid, which is a very corrosive substance capable of causing serious personal injury, such as skin burns and eye damage. In addition, the battery plates contain lead, which is highly poisonous. For this reason, disposing of batteries improperly can cause environmental contamination and lead to severe health problems.

BATTERY HANDLING AND STORAGE Batteries, whether new or used, should be kept indoors if possible. The storage location should be an area specifically designated for battery storage and must be well ventilated (to the outside). If outdoor storage is the only alternative, a sheltered and secured area with acid-resistant secondary containment is strongly recommended. It is also advisable that acid-resistant secondary containment be used for indoor storage. In addition, batteries should be placed on acid-resistant pallets and never stacked.

FUEL SAFETY AND STORAGE

Gasoline is a very explosive liquid. The expanding vapors that come from gasoline are extremely dangerous. These vapors are present even in cold temperatures. Vapors formed in gasoline tanks on many vehicles are controlled, but vapors from gasoline storage may escape from the can, resulting in a hazardous situation. Therefore, place gasoline storage containers in a well-ventilated space. Although diesel fuel is not as volatile as gasoline, the same basic rules apply to diesel fuel and gasoline storage. These rules include the following:

1. Use storage cans that have a flash-arresting screen at the outlet. These screens prevent external ignition sources from igniting the gasoline within the can when someone pours the gasoline or diesel fuel.
2. Use only a red-approved gasoline container to allow for proper hazardous substance identification. ● **SEE FIGURE 6–10**.

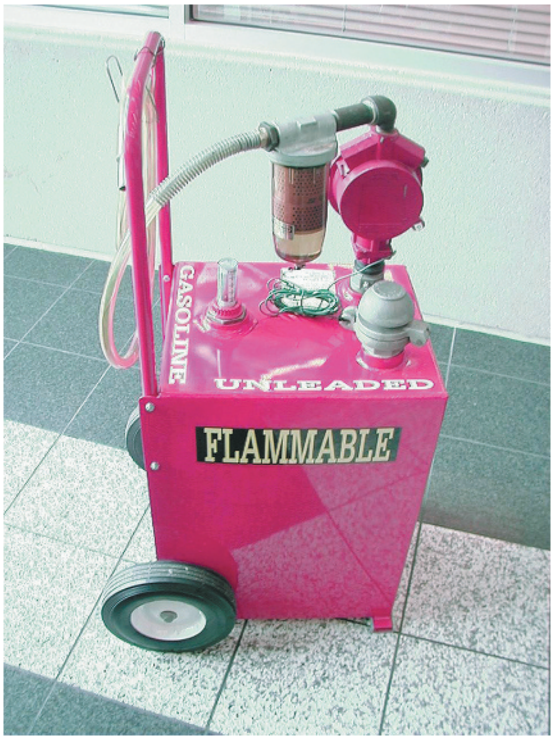


FIGURE 6–10 This red gasoline container holds about 30 gallons of gasoline and is used to fill vehicles used for training.

3. Do not fill gasoline containers completely full. Always leave the level of gasoline at least 1 inch from the top of the container. This action allows expansion of the gasoline at higher temperatures. If gasoline containers are completely full, the gasoline will expand when the temperature increases. This expansion forces gasoline from the can and creates a dangerous spill. If gasoline or diesel fuel containers must be stored, place them in a designated storage locker or facility.
4. Never leave gasoline containers open, except while filling or pouring gasoline from the container.
5. Never use gasoline as a cleaning agent.
6. Always connect a ground strap to containers when filling or transferring fuel or other flammable products from one container to another to prevent static electricity that could result in explosion and fire. These ground wires prevent the buildup of a static electric charge, which could result in a spark and disastrous explosion.

AIRBAG HANDLING

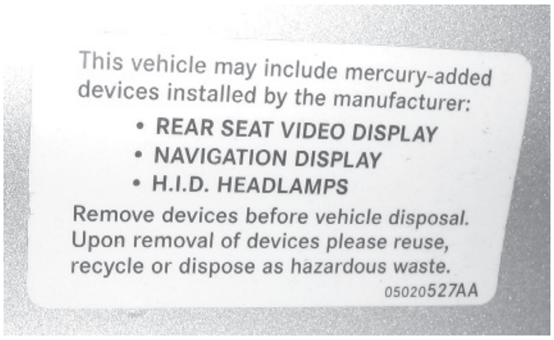
Airbag modules are pyrotechnic devices that can be ignited if exposed to an electrical charge or if the body of the vehicle is subjected to a shock. Airbag safety should include the following precautions:

1. Disarm the airbag(s) if you will be working in the area where a discharged bag could make contact with any part of your body. Consult service information for the exact procedure to follow for the vehicle being serviced.
2. If disposing of an airbag, the usual procedure is to deploy the airbag using a 12 volt power supply, such as a jump-start box, using long wires to connect to the module to ensure a safe deployment.
3. Do not expose an airbag to extreme heat or fire.
4. Always carry an airbag pointing away from your body.
5. Place an airbag module facing upward.
6. Always follow the manufacturer's recommended procedure for airbag disposal or recycling, including the proper packaging to use during shipment.
7. Wear protective gloves if handling a deployed airbag.
8. Always wash your hands or body well if exposed to a deployed airbag. The chemicals involved can cause skin irritation and possible rash development.

USED TIRE DISPOSAL

Used tires are an environmental concern because of several reasons, including the following:

1. In a landfill, they tend to "float" up through the other trash and rise to the surface.
2. The inside of tires traps and holds rainwater, which is a breeding ground for mosquitoes. Mosquito-borne diseases include encephalitis, malaria, and dengue fever.
3. Used tires present a fire hazard and, when burned, create a large amount of black smoke that contaminates the air.



This vehicle may include mercury-added devices installed by the manufacturer:

- REAR SEAT VIDEO DISPLAY
- NAVIGATION DISPLAY
- H.I.D. HEADLAMPS

Remove devices before vehicle disposal. Upon removal of devices please reuse, recycle or dispose as hazardous waste.

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FIGURE 6–11 Placard near driver's door, including what devices in the vehicle contain mercury.

TECH TIP

Remove Components That Contain Mercury

Some vehicles have a placard near the driver's side door that lists the components that contain the heavy metal, mercury. **Mercury** can be absorbed through the skin and is a heavy metal that once absorbed by the body does not leave. ● **SEE FIGURE 6–11.**

These components should be removed from the vehicle before the rest of the body is sent to be recycled to help prevent releasing mercury into the environment.

Used tires should be disposed of in one of the following ways:

1. Used tires can be reused until the end of their useful life.
2. Tires can be retreaded.
3. Tires can be recycled or shredded for use in asphalt.
4. Unmounted tires can be sent to a landfill (most landfill operators will shred the tires because it is illegal in many states to landfill whole tires).
5. Tires can be burned in cement kilns or other power plants where the smoke can be controlled.
6. A registered scrap tire handler should be used to transport tires for disposal or recycling.

AIR-CONDITIONING REFRIGERANT OIL DISPOSAL

Air-conditioning refrigerant oil contains dissolved refrigerant and is therefore considered to be hazardous waste. This oil must be kept separated from other waste oil or the entire amount of oil must be treated as hazardous. Used refrigerant oil must be sent to a licensed hazardous waste disposal company for recycling or disposal.

WASTE CHART

All automotive service facilities create some waste and while most of it is handled properly, it is important that all hazardous and nonhazardous waste be accounted for and properly disposed. ● **SEE CHART 6–1** for a list of typical wastes generated at automotive shops, plus a checklist for keeping track of how these wastes are handled.

TECH TIP

What Every Technician Should Know

OSHA has adopted new hazardous chemical labeling requirements making it agree with global labeling standards established by the United Nations. As a result, workers will have better information available on the safe handling and use of hazardous chemicals, allowing them to avoid injuries and possible illnesses related to exposures to hazardous chemicals. ● **SEE FIGURE 6–12.**

WASTE STREAM	TYPICAL CATEGORY IF NOT MIXED WITH OTHER HAZARDOUS WASTE	IF DISPOSED IN LANDFILL AND NOT MIXED WITH A HAZARDOUS WASTE	IF RECYCLED
Used oil	Used oil	Hazardous waste	Used oil
Used oil filters	Nonhazardous solid waste, if completely drained	Nonhazardous solid waste, if completely drained	Used oil, if not drained
Used transmission fluid	Used oil	Hazardous waste	Used oil
Used brake fluid	Used oil	Hazardous waste	Used oil
Used antifreeze	Depends on characterization	Depends on characterization	Depends on characterization
Used solvents	Hazardous waste	Hazardous waste	Hazardous waste
Used citric solvents	Nonhazardous solid waste	Nonhazardous solid waste	Hazardous waste
Lead-acid automotive batteries	Not a solid waste if returned to supplier	Hazardous waste	Hazardous waste
Shop rags used for oil	Used oil	Depends on used oil characterization	Used oil

WASTE STREAM	TYPICAL CATEGORY IF NOT MIXED WITH OTHER HAZARDOUS WASTE	IF DISPOSED IN LANDFILL AND NOT MIXED WITH A HAZARDOUS WASTE	IF RECYCLED
Shop rags used for solvent or gasoline spills	Hazardous waste	Hazardous waste	Hazardous waste
Oil spill absorbent material	Used oil	Depends on used oil characterization	Used oil
Spill material for solvent and gasoline	Hazardous waste	Hazardous waste	Hazardous waste
Catalytic converter	Not a solid waste if returned to supplier	Nonhazardous solid waste	Nonhazardous solid waste
Spilled or unused fuels	Hazardous waste	Hazardous waste	Hazardous waste
Spilled or unusable paints and thinners	Hazardous waste	Hazardous waste	Hazardous waste
Used tires	Nonhazardous solid waste	Nonhazardous solid waste	Nonhazardous solid waste

CHART 6–1

Typical waste materials generated at auto repair shops and typical category (hazardous or nonhazardous) by disposal method.

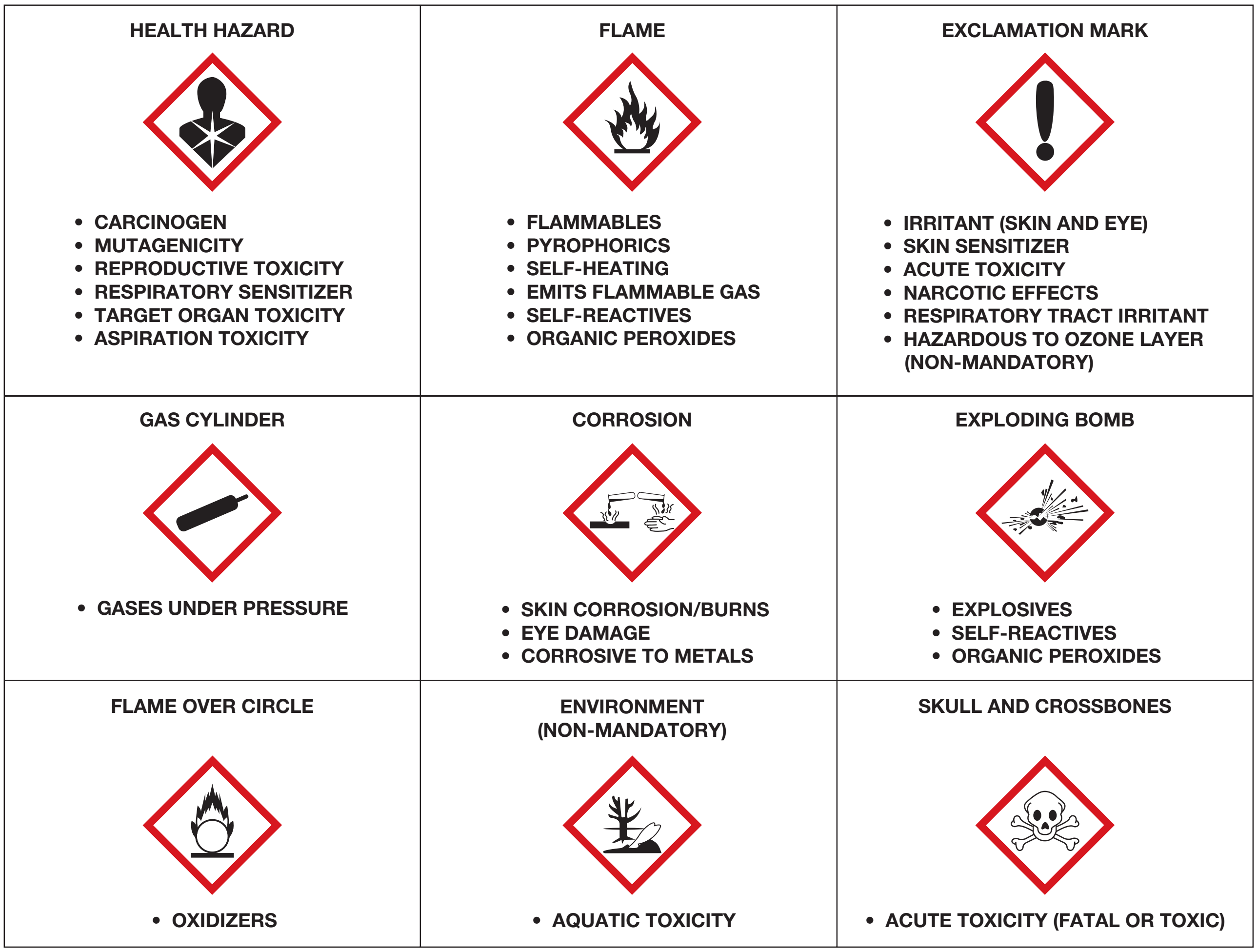

HEALTH HAZARD
• CARCINOGEN
• MUTAGENICITY
• REPRODUCTIVE TOXICITY
• RESPIRATORY SENSITIZER
• TARGET ORGAN TOXICITY
• ASPIRATION TOXICITY
FLAME
• FLAMMABLES
• PYROPHORICS
• SELF-HEATING
• EMITS FLAMMABLE GAS
• SELF-REACTIVES
• ORGANIC PEROXIDES
EXCLAMATION MARK
• IRRITANT (SKIN AND EYE)
• SKIN SENSITIZER
• ACUTE TOXICITY
• NARCOTIC EFFECTS
• RESPIRATORY TRACT IRRITANT
• HAZARDOUS TO OZONE LAYER (NON-MANDATORY)
GAS CYLINDER
• GASES UNDER PRESSURE
CORROSION
• SKIN CORROSION/BURNS
• EYE DAMAGE
• CORROSIVE TO METALS
EXPLODING BOMB
• EXPLOSIVES
• SELF-REACTIVES
• ORGANIC PEROXIDES
FLAME OVER CIRCLE
• OXIDIZERS
ENVIRONMENT (NON-MANDATORY)
• AQUATIC TOXICITY
SKULL AND CROSSBONES
• ACUTE TOXICITY (FATAL OR TOXIC)

FIGURE 6–12 The OSHA global hazardous materials labels.

REVIEW QUESTIONS

1. What are five common automotive chemicals or products that may be considered hazardous materials?
2. The Resource Conservation and Recovery Act (RCRA) controls what types of automotive waste?
3. What methods need to be used when handling products that may contain asbestos?
4. How should used engine oil be disposed?
5. What precautions are needed to be taken when handling an airbag?

CHAPTER QUIZ

1. Hazardous materials include all of the following *except* __________.
   - **a.** engine oil
   - **b.** asbestos
   - **c.** water
   - **d.** brake cleaner
2. To determine if a product or substance being used is hazardous, consult __________.
   - **a.** a dictionary
   - **b.** SDS
   - **c.** SAE standards
   - **d.** EPA guidelines
3. Exposure to asbestos dust can cause what condition?
   - **a.** Asbestosis
   - **b.** Mesothelioma
   - **c.** Lung cancer
   - **d.** All of the above
4. Wetted asbestos dust is considered to be __________.
   - **a.** solid waste
   - **b.** hazardous waste
   - **c.** toxic
   - **d.** poisonous
5. How should coolant be disposed?
   - **a.** Poured down the sanitary sewer
   - **b.** Placed in a plastic container and disposed of in regular trash
   - **c.** Sent to an authorized recycling center or vendor
   - **d.** Mixed with and disposed with waste engine oil
6. Used engine oil can be disposed of by any of the following methods *except* __________.
   - **a.** disposed of in regular trash
   - **b.** shipped offsite for recycling
   - **c.** burned onsite in a waste oil-approved heater
   - **d.** burned offsite in a waste oil-approved heater
7. What is proper airbag handling?
   - **a.** Disarm the airbag(s) if you will be working in the area
   - **b.** Do not expose an airbag to extreme heat or fire
   - **c.** Always carry an airbag pointing away from your body
   - **d.** All of the above
8. Which act or organization regulates air-conditioning refrigerant?
   - **a.** Clean Air Act (CAA)
   - **b.** SDS
   - **c.** WHMIS
   - **d.** Code of Federal Regulations (CFR)
9. Gasoline should be stored in approved containers that include what color(s)?
   - **a.** A red container with yellow lettering
   - **b.** A red container
   - **c.** A yellow container
   - **d.** A yellow container with red lettering
10. How should tires, brake fluid, and batteries be properly disposed?
    - **a.** In regular trash
    - **b.** Sealed in a plastic bag
    - **c.** Buried
    - **d.** According to federal, state, and local laws

Chapter 7

HEALTH AND ENVIRONMENTAL CONCERNS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Identify carbon-based fuels and greenhouse gases.
- Explain how ozone affects our environment.
- Explain how ultraviolet radiation affects our environment.
- Describe the health effects of air pollution.
- Describe the health effects of acid rain.
- List the factors that will be needed to reduce the carbon footprint.

KEY TERMS:

Carbohydrates 51 • Carbon (C) 51 • Carbon footprint 55 • Greenhouse gases (GHG) 52 • Irradiance 54 • Ozone 53 • Ozone-depleting substances (ODS) 53 • Sequestration 56 • Smog 51 • Stratosphere 54 • Ultraviolet (UV) radiation 54 • Volatile organic compounds (VOC) 53

CARBON-BASED FUELS

BACKGROUND Throughout history, most of the energy used in the world has been generated by burning organic fuel that contains **carbon (C)**. An economy that uses only carbon-based fuels is often referred to as a *carbon-based society*. Carbon is formed from materials that were once alive on the earth, including:

- Plants that die and eventually are turned into coal, oil, and natural gas.
- Animal life of all types that also dies and decays to form carbon-fuels.

The source of carbon-based fuels is limited to the remains of dead plants and animals and is therefore not a limitless resource. ● **SEE FIGURE 7–1**.

CARBOHYDRATES All life-forms are able to collect, store, and use energy from their environment. In carbon-based biology, the basic energy storage compounds are in **carbohydrates**, where the carbon atoms are linked by single bonds into a chain. For example, carbon dioxide (CO_2) plus water (H_2O), when combined with chlorophyll in the plant and sunlight, produces glucose and oxygen (O_2). A carbohydrate is oxidized (combined with O_2) to release energy (and waste products of H_2O and CO_2). The carbon atoms are attached to hydrogen atoms to form hydrocarbons (abbreviated HC).

There are literally thousands of hydrocarbons, and they differ not only by the number of carbon atoms, but also by the way they are attached to each other. The various bonds by which the molecule is constructed results in a change in the physical characteristics of the hydrocarbon. Molecules that have a high number of carbon atoms release more energy when burned, which translates into more power from the fuel and from the engine. Gasoline is composed of hundreds of different hydrocarbons that are blended together to create the specified volatility and other physical characteristic for use in an engine. ● **SEE CHART 7–1**.

CHEMISTRY OF CARBON-BASED EMISSIONS When carbon-based fuels are burned, the carbon and the hydrogen from the fuel combine with the 21% oxygen and the 78% nitrogen in the air to create many new and often dangerous compounds, including:

- Carbon monoxide (CO)—This colorless, odorless, poisonous gas is a result of incomplete combustion.
- Carbon dioxide (CO_2)—An inert greenhouse gas, which is thought to cause climate change.
- Hydrocarbons (HC)—This is simply unburned fuel and is one of the components of smog. **Smog** is a term used to describe a condition that looks like smoke and/or fog.

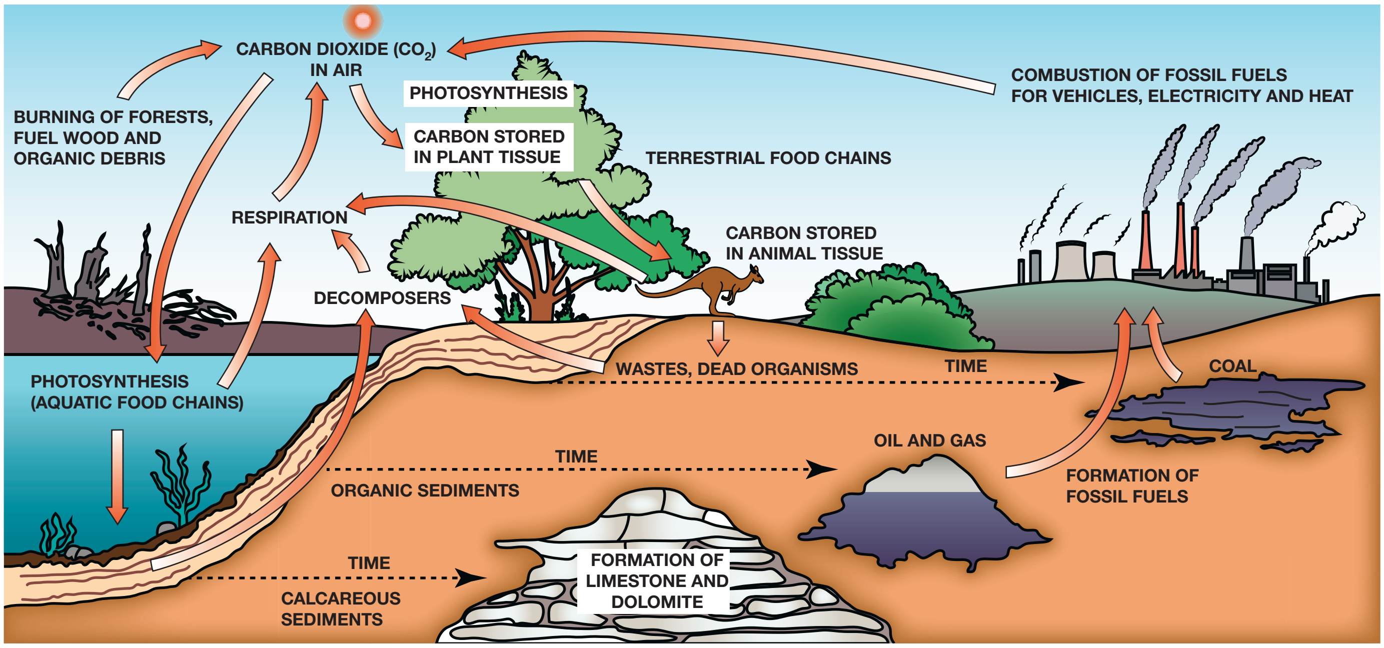

CARBON DIOXIDE (CO_2) IN AIR
PHOTOSYNTHESIS
CARBON STORED IN PLANT TISSUE
COMBUSTION OF FOSSIL FUELS FOR VEHICLES, ELECTRICITY AND HEAT
BURNING OF FORESTS, FUEL WOOD AND ORGANIC DEBRIS
TERRESTRIAL FOOD CHAINS
RESPIRATION
CARBON STORED IN ANIMAL TISSUE
DECOMPOSERS
WASTES, DEAD ORGANISMS
TIME
COAL
PHOTOSYNTHESIS (AQUATIC FOOD CHAINS)
OIL AND GAS
TIME
ORGANIC SEDIMENTS
FORMATION OF FOSSIL FUELS
TIME
FORMATION OF LIMESTONE AND DOLOMITE
CALCAREOUS SEDIMENTS

FIGURE 7–1 Carbon-based fuels are limited to the remains of dead plants and animals and their fossil remains create the carbon-based fuels used today.

FUEL	STATE	% OF CARBON	% OF HYDROGEN
Hydrogen	Gas	0%	100%
Methane	Gas	20%	80%
Gasoline	Liquid	31%	69%
Oil	Liquid	36%	64%
Coal	Solid	62%	36%
Wood	Solid	90%	10%

CHART 7–1

Carbon and hydrogen content of various fuels.

GREENHOUSE GASES **Greenhouse gases (GHG)** are those gases in our atmosphere that, if in too great a concentration, can prevent heat from escaping the surface, leading to an increase in the temperature on earth. In a nursery greenhouse, the glass panes are painted white to reflect the heat back into the greenhouse.

The ultraviolet light can penetrate through the paint and warms the interior so plants can be grown in colder periods of the year or in colder climates. Therefore, the gases in our atmosphere that act like the white paint on the glass panes of a greenhouse are called greenhouse gases. ● **SEE FIGURE 7–2**.

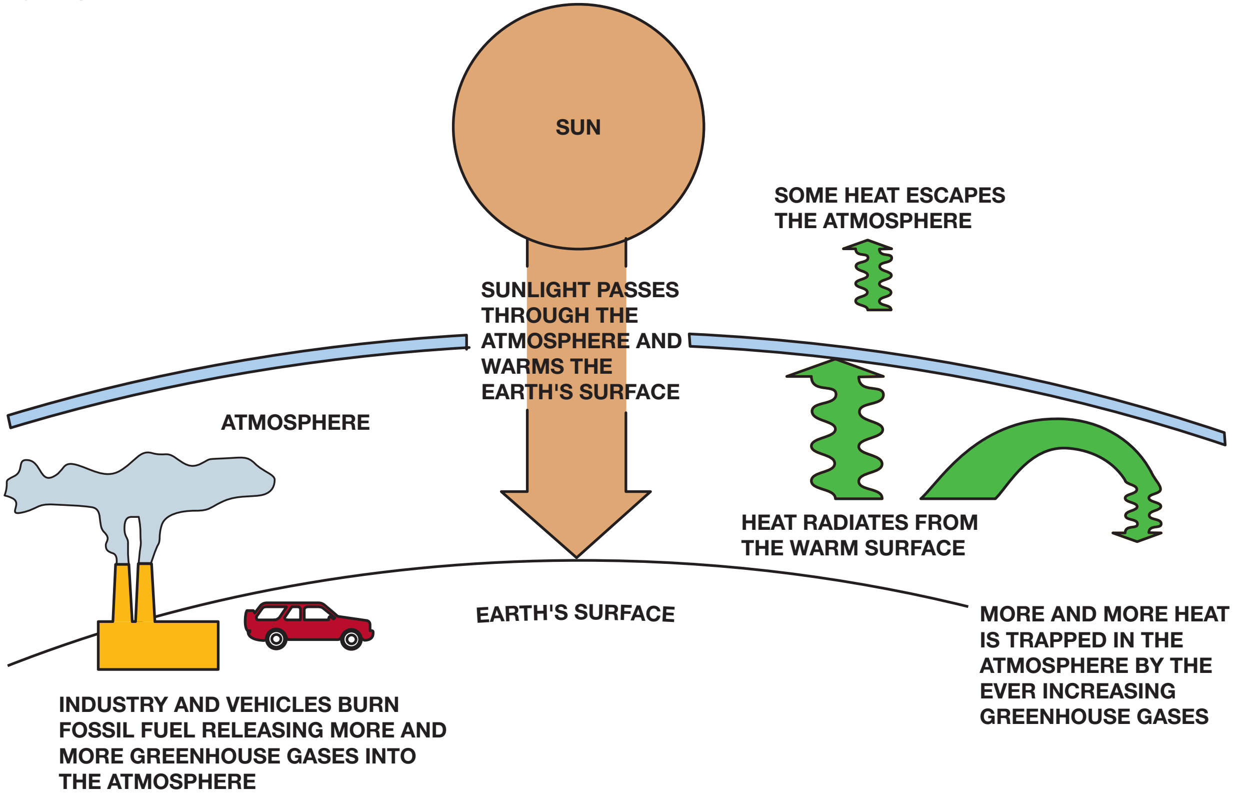

SUN
SOME HEAT ESCAPES THE ATMOSPHERE
SUNLIGHT PASSES THROUGH THE ATMOSPHERE AND WARMS THE EARTH'S SURFACE
ATMOSPHERE
HEAT RADIATES FROM THE WARM SURFACE
EARTH'S SURFACE
MORE AND MORE HEAT IS TRAPPED IN THE ATMOSPHERE BY THE EVER INCREASING GREENHOUSE GASES
INDUSTRY AND VEHICLES BURN FOSSIL FUEL RELEASING MORE AND MORE GREENHOUSE GASES INTO THE ATMOSPHERE

FIGURE 7–2 The atmosphere allows radiation to pass through to the earth's surface and blocks the release of heat back into space if there is too high a concentration of greenhouse gases.

GHG tend to absorb this infrared radiation as it is reflected back toward space, trapping the heat in the atmosphere. Atmospheric concentrations of several important GHG (carbon dioxide, methane, nitrous oxide, and most man-made gases) have increased by about 25% since large-scale industrialization began some 150 years ago. The growth in the concentration of these gases is believed to be caused by human activity. Carbon dioxide that is generated as a result of human activity is known an anthropogenic greenhouse gas. In particular, anthropogenic carbon dioxide emissions have greatly increased since the beginning of the industrial age, due largely to the burning of fossil fuels and cutting down of forests for timber and other uses, such as paper and chemicals.

OZONE

DEFINITION **Ozone** is composed of three atoms of oxygen and is abbreviated O_3. Ozone occurs naturally in the atmosphere and can be detected by smell after a thunderstorm. Ozone has a strong clean smell, and in high concentrations, it can be a lung and respiratory irritant. Ozone can be created by lightning, which breaks the molecular structure of oxygen (O_2) into atoms (O), which then combine back into oxygen or combine to create ozone. ● **SEE FIGURE 7–3**.

GROUND-LEVEL OZONE Ozone that is located at ground level or in the atmosphere close to the earth is a health concern to humans because it causes health problems, including:

- Eye irritation
- Asthma
- Shortness of breath
- Chest tightness
- Wheezing

VEHICLES AND OZONE Exhaust from vehicles causes ground-level-ozone levels to increase because unburned hydrocarbons (HC) and oxides of nitrogen (NO_X), in the presence of sunlight, combine to create ozone, also called smog, which is a term used to describe the smoky or fog-like appearance of ground-level ozone.

UPPER-LEVEL OZONE Ozone located in the upper atmosphere (called the ozone layer) is helpful because it helps to block harmful ultraviolet rays from the sun from entering the lower atmosphere. Therefore, ozone is not a health concern when it is located in the upper regions of the atmosphere.

Depletion of the earth's upper ozone layer due to the release of man-made chemicals threatens human health and damages plant life. Certain man-made chemicals used in refrigeration, air conditioning, fire and explosion prevention, and as solvents can trigger reactions in the atmosphere that destroy the ozone layer. **Ozone-depleting substances (ODS)** include:

- Chlorofluorocarbons (CFCs)
- Hydrochlorofluorocarbons (HCFCs)
- Halons
- Methyl bromide

● **SEE FIGURE 7–4**.

FREQUENTLY ASKED QUESTION

What Are Volatile Organic Compounds?

Volatile organic compounds (VOC) are gases emitted by paints, solvents, aerosol sprays, cleaners, glues, permanent markers, pesticides, and fuels. Health effects of VOC emissions into the atmosphere include:

- Eye, nose, and throat irritation
- Headaches
- Nausea

To reduce the levels of VOC released, always follow the manufacturer's directions for use of household and industrial products.

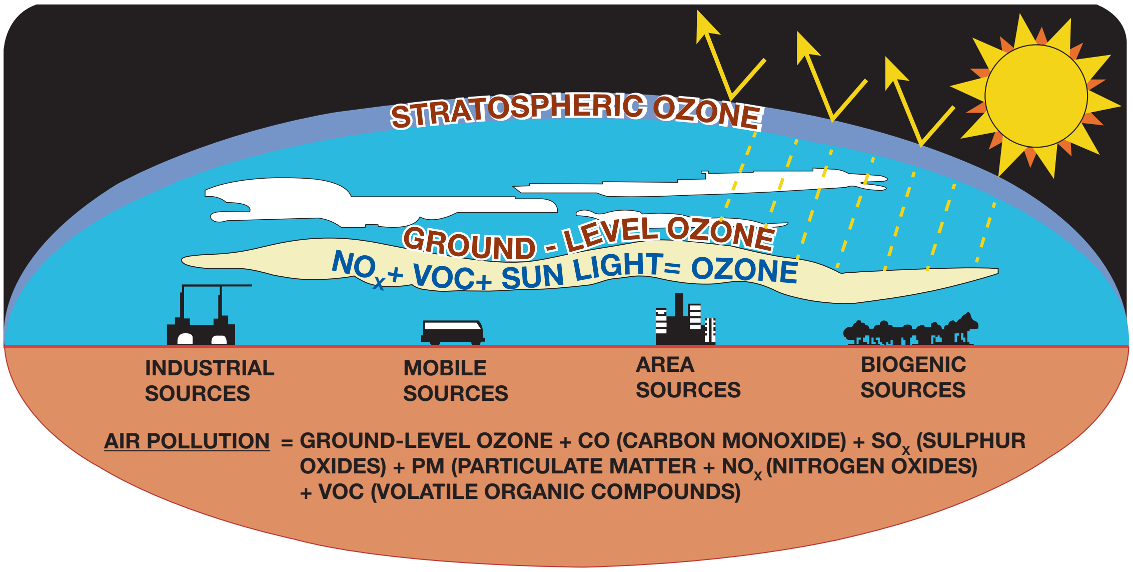

STRATOSPHERIC OZONE
GROUND - LEVEL OZONE
NO$_X$+ VOC+ SUN LIGHT= OZONE
INDUSTRIAL SOURCES
MOBILE SOURCES
AREA SOURCES
BIOGENIC SOURCES
AIR POLLUTION = GROUND-LEVEL OZONE + CO (CARBON MONOXIDE) + SO$_X$ (SULPHUR OXIDES) + PM (PARTICULATE MATTER + NO$_X$ (NITROGEN OXIDES) + VOC (VOLATILE ORGANIC COMPOUNDS)

FIGURE 7–3 Ground-level ozone is created by pollutants, such as nitrogen oxides and volatile organic compounds reacting together by sunlight. Ozone in the upper atmosphere is good but ozone near the earth's surface is bad.

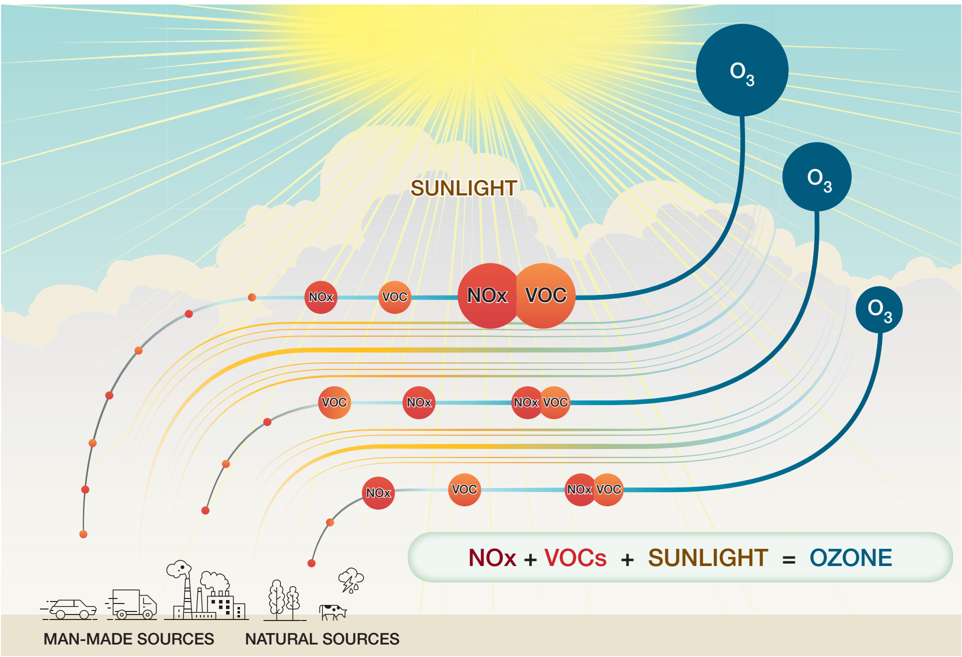


FIGURE 7–4 NO$_x$ plus VOCs interact with sunlight to create ozone.

ULTRAVIOLET RADIATION ABSORPTION

TYPES OF UV RADIATION **Ultraviolet (UV) radiation** is divided into three designations based on its impact on living organisms. The designations include:

- Designation "A," abbreviated UVA, is not absorbed by the ozone layer and generally is not damaging to biological organisms.
- Designation "B," abbreviated UVB, is only partially absorbed by the ozone layer and can cause damage to biological organisms.
- Designation "C," abbreviated UVC, is almost completely absorbed by the ozone layer and represents little, if any, health concerns.

INTENSITY OF RADIATION Another consideration in evaluating the effects of UV radiation is the intensity at the earth's surface—that is, how much radiation is reaching the earth's surface. For example, consider the difference in radiation between a 20-watt light bulb and a 100-watt bulb.

There is a large difference in intensity and thus in the amount of light or radiation. The term used to define the amount of solar radiation is **irradiance**. The solar irradiance at the earth's surface varies greatly depending on factors such as:

- Latitude
- Time of day
- Time of year
- Cloud cover
- Haze

In the case of the UV irradiance, additional factors are ozone density and elevation above sea level.

OZONE CONTROL OF UVB IRRADIANCE The protection of the earth's living systems from UVB and UVC radiation is a result of the absorption of this radiation by ozone. While there is some ozone in the lower atmosphere, called the troposphere, it is small compared to the amount in the upper atmosphere, called the **stratosphere**.

TECH TIP

Watch for Sunburn When at High Altitude

When at a location that is above 1,000 feet, and especially if above 5,000 feet, consider that there is much less atmosphere above to block the UV radiation. This means that sunburn and eye damage, such as cataracts, can more easily occur at high altitude compared to areas that are at or near sea level.

The most important factor is the total amount of ozone that solar radiation encounters before reaching the earth's surface. This is referred to as column ozone since it is the total amount of ozone in a column between the earth's surface and the top of the stratosphere. ● **SEE FIGURE 7–5**.

HEALTH EFFECTS OF AIR POLLUTION

TYPICAL HEALTH ISSUES According to medical experts, almost every disease has an environmental element, either minor or major. Skin cancer is largely thought to be caused by severe sunburn, often in childhood.

Unburned hydrocarbon (HC) emissions along with oxides of nitrogen (NO$_x$) combine in the atmosphere in the presence of sunlight to generate ground-level ozone (O$_3$). High levels of ozone, a respiratory irritant, can cause respiratory problems, including inflammation of the lungs.

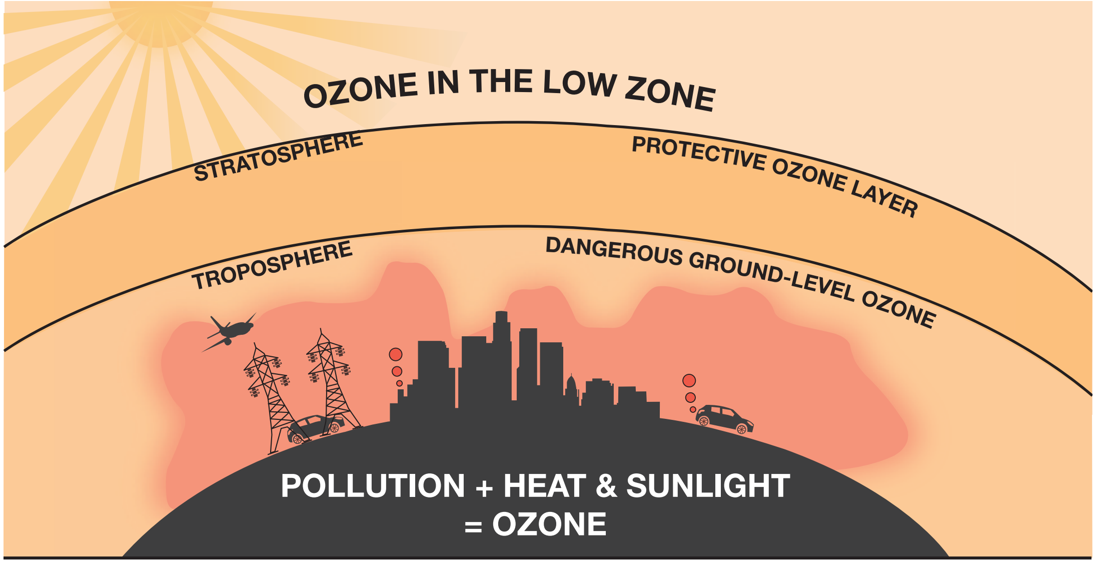


FIGURE 7–5 Column ozone is the total amount of ozone between the earth's surface and the top of the stratosphere.

Ozone exposure may lead to the following conditions:

- Premature death (due to long-term exposure to high levels of ozone)
- Shortness of breath
- Chest pain when inhaling deeply
- Wheezing and coughing

Another health concern involves particulate matter (PM), also called soot, which is found in the exhaust of diesel engines. PM has been linked to respiratory disease and cancer.

ACID RAIN

pH SCALE Acid rain refers to rain that has a pH lower than 7, indicating that it is acidic. Normal rain is pure water that is neither acidic (a pH of less than 7) nor alkaline (a pH greater than 7). Acid rain usually has a pH of 5.5 but can be as low as 4.3, according to the Environmental Protection Agency (EPA). The rain becomes acidic due to gases in the atmosphere, such as sulfur dioxide (SO_2) and oxides of nitrogen (NO_X). SO_2 combines with the rain water to form mild sulfuric acid. NO_X combine with rain water to form nitric acid. ● **SEE FIGURE 7–6**.

Both acids are harmful to the environment and can cause the following problems:

- Damage to forests and soils
- Damage to fish because the acid rain makes lakes and streams more acidic
- Damage to buildings and paint on vehicles
- Damage to roads and sidewalks. ● **SEE FIGURE 7–7**.

CARBON FOOTPRINT

DEFINITION Total **carbon footprint** includes energy-related emissions from human activities, including heat, light, power, refrigeration, and all transport-related emissions from vehicles, freight, and distribution. The carbon footprint is a representation of the effect a person or organization has on the climate in terms of the total volume of GHG (mostly CO_2) produced.

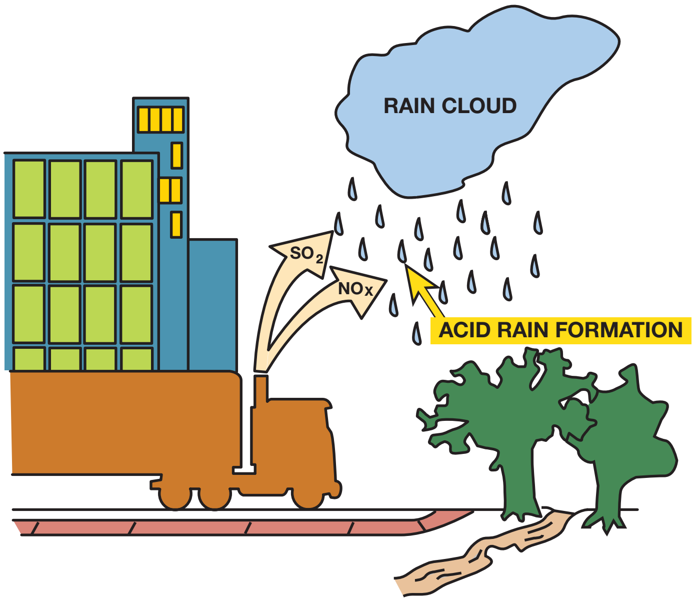


FIGURE 7–6 Acid rain is formed when sulfur dioxide (SO_2) and oxides of nitrogen (NO_X) combine with rain, forming acids.

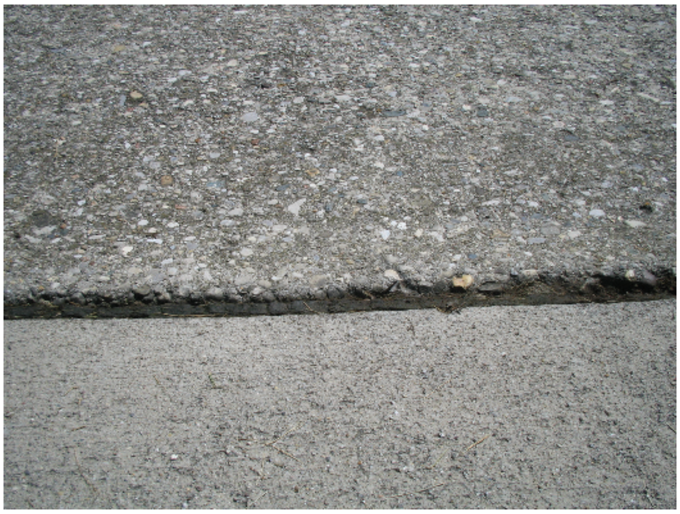


FIGURE 7–7 The sidewalk section at the top is about 20 years old and shows the effects of acid rain, as compared to the lower section, which is about five years old. Notice that the acid rain has eroded the cement, leaving the aggregate (stones) exposed on the upper section.

CASE STUDY

The Case of the Wrong pH

A museum was using a spray polish on an original paint blue 1937 Ford. After a few minutes, they noticed that the paint started to look purple. They immediately stopped using the spray polish and started to investigate the product they were using by checking with restoration experts. What they discovered was that the polish they were using was slightly acidic and this was causing the original old paint to change color. While the product was okay to use on modern paints, it was not suitable for use on older original paint used before modern paint technology. To avoid causing damage or a color change on older paint, restoration experts recommend using a "pH balanced" product.

The pH is measured on a scale from 1 to 14 and is used to indicate the amount of chemical activity. The term pH is from the French word *pouvoir hydrogine*, meaning "hydrogen power."

Alkaline materials and acid materials neutralize each other, such as when baking soda (a caustic) is used to clean the outside of the battery (an acid surface). The caustic baking soda neutralizes any sulfuric acid that has been spilled or splashed on the outside of the battery. Most car shampoos are slightly alkaline with a pH of ranging from 7.1 to 8.5. Many car polishes are slightly acidic with a pH of 5 or 6. To check if the polish is acidic or is pH balanced, visit a parts store and ask that the safety data sheet (SDS) be printed out for the product being considered. The parts store counterperson will use the bar code to access the product information and from there, the SDS should be available and can be printed. Check the listed pH, and if the pH is 7, it is usable for all paints and finishes. However, if the pH is 4 to 6, most experts recommend that these not be used on old vehicles with their original paint.

Summary:

Complaint—Using a spray polish, it was discovered to be the cause of turning the blue paint to purple on an old car.

Cause—The spray polish was slightly acidic and this caused the blue paint to turn purple.

Correction—The museum switched brands of spray polish to ones that were "pH balanced," meaning that the pH was 7 or about 7 (neutral).

Many actions generate carbon emissions, which contribute to accelerating climate change. For example, when gasoline is burned in a vehicle, it produces carbon in the form of carbon dioxide. Depending on the fuel efficiency of the vehicle and the miles traveled, a gasoline powered vehicle can easily generate its own weight in carbon dioxide each year. To prevent these conditions from occurring, GHG must be reduced by 60%, or a method must be used where CO_2 can be stored below the earth's surface. The process of storing carbon dioxide underground is called **sequestration**. ● **SEE FIGURE 7–8**.

REDUCING THE CARBON FOOTPRINT The following is a list of simple things that can be done immediately that will start to reduce the contribution to climate change. The items in this list will cost no money at all and will in fact save money.

1. Turn electrical devices off when not in use, such as lights, television, and computer.
2. Turn down the central heating slightly (try just 1 to 2 degrees).
3. Turn down the water heating setting (just 2 degrees will make a significant saving).
4. Check the central heating timer setting—there is no point in heating the house if everyone is at work during the day.
5. Fill the dishwasher and washing machine with a full load—this will save water and electricity, as well as detergent.
6. Unplug the cell phone as soon as it has finished charging.
7. Defrost the freezer regularly; if not done automatically, consider disabling the automatic function to save electricity.
8. Do shopping in a single trip.
9. Travel less and travel more using carbon-footprint-friendly vehicles.
10. Purchase a fuel-efficient vehicle, such an electric vehicle (EV) or hybrid electric vehicle (HEV).

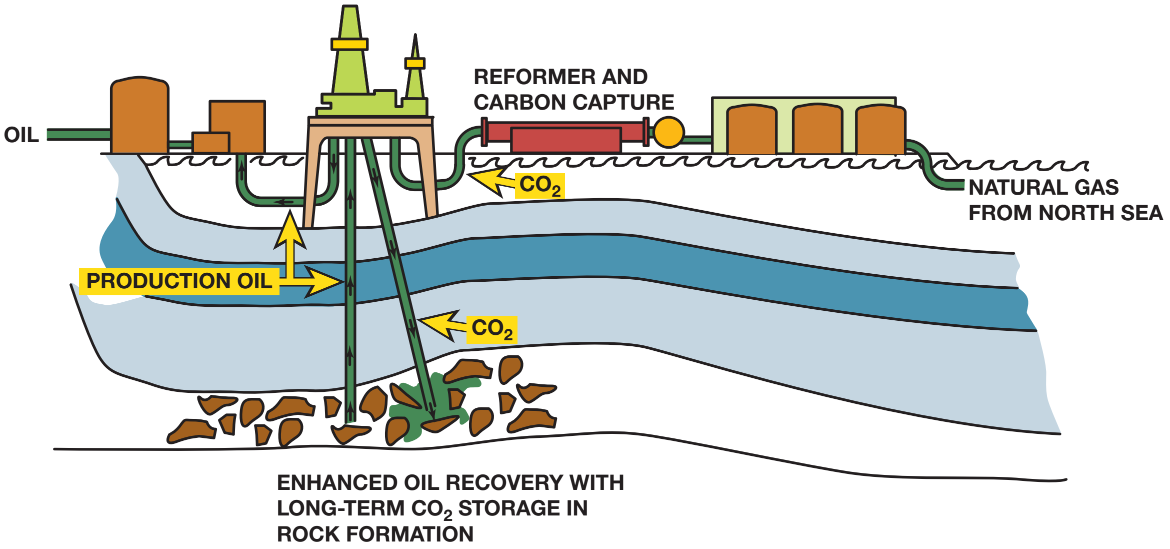

REFORMER AND CARBON CAPTURE
OIL
CO_2
NATURAL GAS FROM NORTH SEA
PRODUCTION OIL
CO_2
ENHANCED OIL RECOVERY WITH LONG-TERM CO_2 STORAGE IN ROCK FORMATION

FIGURE 7–8 Pumping carbon dioxide back into the earth not only reduces the amount released to the atmosphere, but also helps force more crude oil to the surface, thereby increasing the efficiency of existing wells.

REVIEW QUESTIONS

1. What is meant by the term “carbon-based society"?
2. What are hydrocarbons?
3. Which type of UV radiation is the most harmful to living organisms on earth?
4. What does carbon footprint mean?
5. What are six things people can do to reduce their individual carbon footprint?

CHAPTER QUIZ

1. Which fuel contains the least amount of carbon?
   - **a.** Methane
   - **b.** Hydrogen
   - **c.** Coal
   - **d.** Gasoline
2. What does the word organic mean?
   - **a.** Any fuel
   - **b.** Anything that was once alive
   - **c.** Stone or rock
   - **d.** Any part of the atmosphere above the ozone layer
3. The major greenhouse gas from gasoline-powered vehicles is ____________.
   - **a.** carbon monoxide (CO)
   - **b.** carbon dioxide (CO_2)
   - **c.** oxides of nitrogen (NO_X)
   - **d.** unburned hydrocarbons (HCs)
4. The earth’s upper ozone layer ____________.
   - **a.** is harmful to plants and animals, including humans
   - **b.** helps reduce UV radiation from reaching the earth’s surface
   - **c.** Both a and b
   - **d.** Neither a nor b
5. Which of the following result in smog when exposed to sunlight?
   - **a.** Unburned hydrocarbon (HC)
   - **b.** Oxides of nitrogen (NO_X)
   - **c.** Carbon dioxide (CO_2)
   - **d.** Both a and b
6. What is ozone?
   - **a.** O_3
   - **b.** CO_2
   - **c.** NO_X
   - **d.** H_2O
7. Which of the following UV radiation types is the most harmful to living organisms?
   - **a.** UVA
   - **b.** UVB
   - **c.** UVC
   - **d.** None of the above
8. Why is sunburn more likely to occur at high altitudes as compared to sea level?
   - **a.** There is less ozone above to block the UV rays
   - **b.** You are closer to the sun
   - **c.** There is less oxygen
   - **d.** It is colder at high altitudes and sunburn is therefore less likely
9. To reduce your carbon footprint, what action(s) can be performed?
   - **a.** Drive a hybrid electric vehicle instead of a conventional gasoline-engine vehicle
   - **b.** Drive fewer miles
   - **c.** Insulate homes
   - **d.** All of the above
10. Carbon dioxide ____________.
    - **a.** is manufactured gas
    - **b.** occurs in our atmosphere normally
    - **c.** is produced by plants and trees
    - **d.** Both a and b

SECTION III

FASTENERS, TOOLS AND SHOP EQUIPMENT

CHAPTERS

8 Fasteners and Thread Repair
9 Hand and Power Tools
10 Vehicle Lifting and Hoisting

Chapter 8

FASTENERS AND THREAD REPAIR

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the strength ratings of threaded fasteners.
- Discuss metric bolts and grades of bolts.
- Define tensile strength.
- Discuss the purpose of nuts.
- Discuss how taps and dies are used.
- Discuss how sheet metal screws are used.
- Discuss how washers are used.
- Discuss how snap rings and clips are used.
- Explain how to avoid broken fasteners.
- Compare the different types of thread repair inserts.

KEY TERMS:

Bolts 58 • Cap screws 58 • Capillary action 64 • Christmas tree clips 63 • Cotter pins 63 • Crest 58 • Die 61 • Grade 59 • Helical insert 65 • Heli-Coil® 66 • Metric bolts 59 • Penetrating oil 64 • Pitch 58 • Pop rivet 64 • Prevailing torque nuts 60 • Self-tapping screw 62 • Snap ring 63 • Stud 58 • Tap 61 • Tensile strength 59 • Threaded insert 66 • UNC (Unified National Coarse) 58 • UNF (Unified National Fine) 58 • Washers 63

THREADED FASTENERS

Most of the threaded fasteners used on vehicles are cap screws. They are called **cap screws** when they are threaded into a casting. Automotive service technicians usually refer to these fasteners as **bolts**, regardless of how they are used. In this chapter, they are called bolts. Sometimes, studs are used for threaded fasteners. A **stud** is a short rod with threads on both ends. Often, a stud will have coarse threads on one end and fine threads on the other end. The end of the stud with coarse threads is screwed into the casting. A nut is used on the opposite end to hold the parts together.

The fastener threads *must* match the threads in the casting or nut. The threads may be measured either in fractions of an inch (called fractional) or in metric units. The size is measured across the outside of the threads, called the **crest** of the thread. ● **SEE FIGURE 8–1**.

Fractional threads are either coarse or fine. The coarse threads are called **Unified National Coarse (UNC)**, and the fine threads are called **Unified National Fine (UNF)**. Standard combinations of sizes and number of threads per inch (called **pitch**) are used. Pitch can be measured with a thread pitch gauge as shown in ● **SEE FIGURE 8–2**.

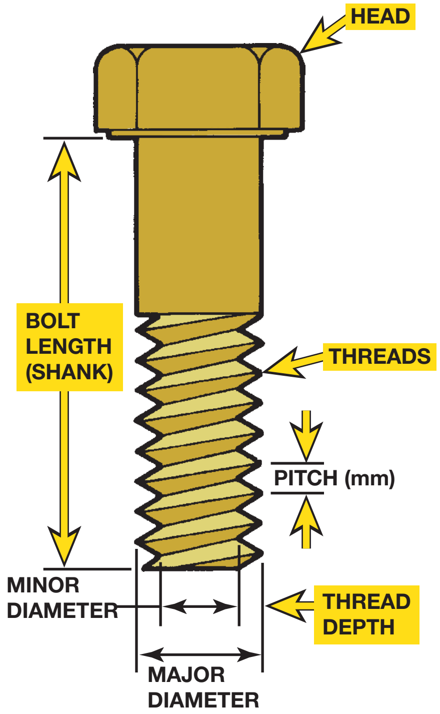


FIGURE 8–1 The dimensions of a typical bolt showing where sizes are measured. The major diameter is called the crest.

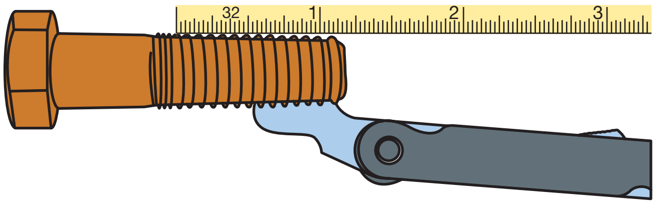


FIGURE 8–2 Thread pitch gauge used to measure the pitch of the thread. This bolt has 13 threads to the inch.

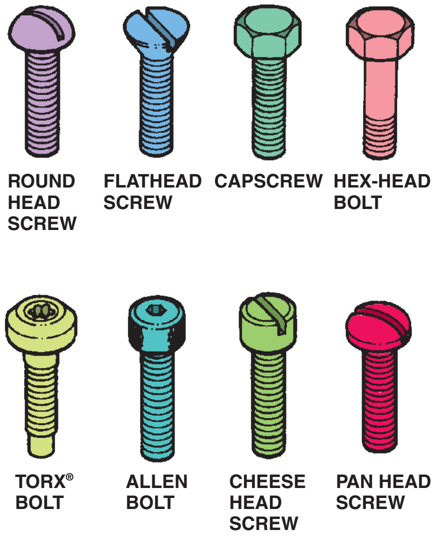


FIGURE 8–3 Bolts and screws have many different heads, which determine what tool must be used.

Bolts are identified by their diameter and length as measured from below the head, and not by the size of the head or the size of the wrench used to remove or install the bolt. Bolts and screws have many different-shaped heads. ● **SEE FIGURE 8–3**.

Fractional thread sizes are specified by the diameter in fractions of an inch and the number of threads per inch. Typical UNC thread sizes would be 5/16-18 and 1/2-13. Similar UNF thread sizes would be 5/16-24 and 1/2-20. ● **SEE CHART 8–1**.

BOLTS

METRIC BOLTS The size of a **metric bolt** is specified by the letter *M* followed by the diameter in millimeters (mm) across the outside (crest) of the threads. Typical metric sizes would be M8 and M12. Fine metric threads are specified by the thread diameter followed by *X* and the distance between the threads measured in millimeters (M8 × 1.5). ● **SEE FIGURE 8–4**.

GRADES OF BOLTS Bolts are made from many different types of steel, and for this reason some are stronger than others. The strength or classification of a bolt is called the **grade**. The bolt heads are marked to indicate their grade strength. Graded bolts are commonly used in the suspension parts of the vehicle but can be used almost anywhere in the vehicle.

The actual grade of bolts is two more than the number of lines on the bolt head. Metric bolts have a decimal number to indicate the grade. More lines or a higher grade number indicate a stronger bolt. Higher grade bolts usually have threads that are rolled rather than cut, which also makes them stronger. ● **SEE FIGURE 8–5**. In some cases, nuts and machine screws have similar grade markings.

	THREADS PER INCH		OUTSIDE DIAMETER
SIZE	NC UNC	NF UNF	(INCHES)
0	. .	80	0.0600
1	64	. .	0.0730
1	. .	72	0.0730
2	56	. .	0.0860
2	. .	64	0.0860
3	48	. .	0.0990
3	. .	56	0.0990
4	40	. .	0.1120
4	. .	48	0.1120
5	40	. .	0.1250
5	. .	44	0.1250
6	32	. .	0.1380
6	. .	40	0.1380
8	32	. .	0.1640
8	. .	36	0.1640
10	24	. .	0.1900
10	. .	32	0.1900
12	24	. .	0.2160
12	. .	28	0.2160
1/4	20	. .	0.2500
1/4	. .	28	0.2500
5/16	18	. .	0.3125
5/16	. .	24	0.3125
3/8	16	. .	0.3750
3/8	. .	24	0.3750
7/16	14	. .	0.4375
7/16	. .	20	0.4375
1/2	13	. .	0.5000
1/2	. .	20	0.5000

CHART 8–1

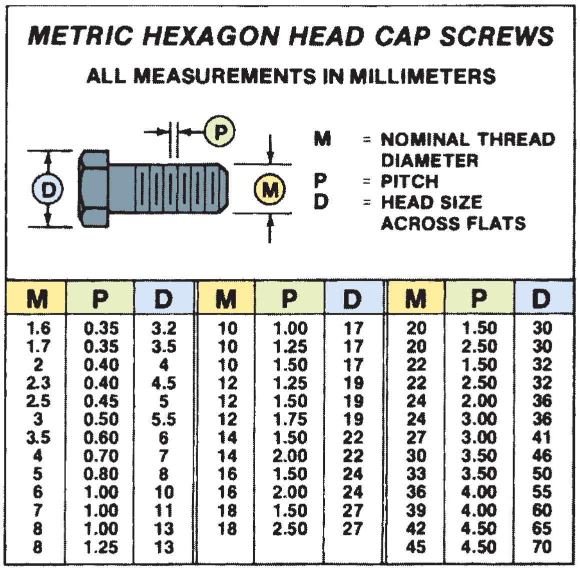
The American national system is one method of sizing fasteners.

CAUTION: *Never* use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

TENSILE STRENGTH

Graded fasteners have a higher tensile strength than nongraded fasteners. **Tensile strength** is the maximum stress used under tension (lengthwise force) without causing failure of the fastener. Tensile strength is specified in pounds per square inch (PSI). See the following chart that shows the grade and specified tensile strength.

The strength and type of steel used in a bolt is supposed to be indicated by a raised mark on the head of the bolt. The type of mark depends on the standard to which the bolt was manufactured. Most often, bolts used in machinery are made to SAE Standard J429.


METRIC HEXAGON HEAD CAP SCREWS

ALL MEASUREMENTS IN MILLIMETERS

M = NOMINAL THREAD DIAMETER
P = PITCH
D = HEAD SIZE ACROSS FLATS

M	P	D	M	P	D	M	P	D
1.6	0.35	3.2	10	1.00	17	20	1.50	30
1.7	0.35	3.5	10	1.25	17	20	2.50	30
2	0.40	4	10	1.50	17	22	1.50	32
2.3	0.40	4.5	12	1.25	19	22	2.50	32
2.5	0.45	5	12	1.50	19	24	2.00	36
3	0.50	5.5	12	1.75	19	24	3.00	36
3.5	0.60	6	14	1.50	22	27	3.00	41
4	0.70	7	14	2.00	22	30	3.50	46
5	0.80	8	16	1.50	24	33	3.50	50
6	1.00	10	16	2.00	24	36	4.00	55
7	1.00	11	18	1.50	27	39	4.00	60
8	1.00	13	18	2.50	27	42	4.50	65
8	1.25	13				45	4.50	70

FIGURE 8–4 The metric system specifies fasteners by diameter, length, and pitch.

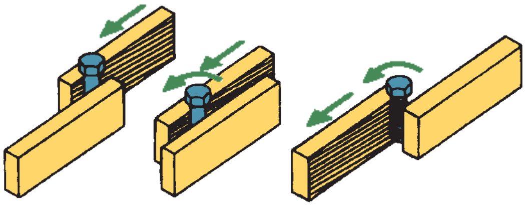


FIGURE 8–5 Stronger threads are created by cold-rolling a heat-treated bolt blank instead of cutting the threads using a die.

TECH TIP

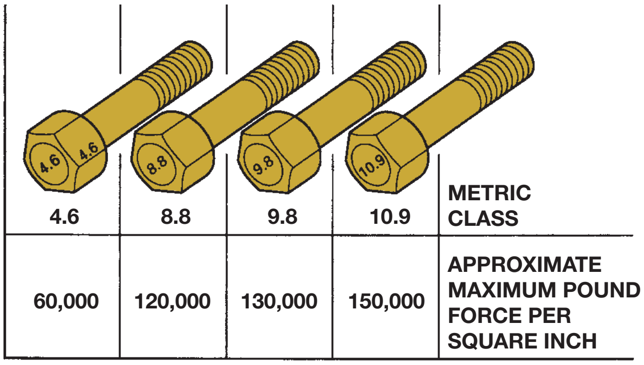
A 1/2 Inch Wrench Does Not Fit a 1/2 Inch Bolt

A common mistake made by persons new to the automotive field is to think that the size of a bolt or nut is the size of the head. The size of the bolt or nut (outside diameter of the threads) is usually smaller than the size of the wrench or socket that fits the head of the bolt or nut. Examples are given in the following table.

Wrench Size	Thread Size
7/16 inch	1/4 inch
1/2 inch	5/16 inch
9/16 inch	3/8 inch
5/8 inch	7/16 inch
3/4 inch	1/2 inch
10 mm	6 mm
12 mm or 13 mm*	8 mm
14 mm or 17 mm*	10 mm

*European (Système International d'Unités-SI) metric.

NOTE: An open-end wrench can be used to gauge bolt sizes. A 3/8 inch wrench will fit the threads of a 3/8 inch bolt.



4.6	8.8	9.8	10.9	METRIC CLASS
60,000	120,000	130,000	150,000	APPROXIMATE MAXIMUM POUND FORCE PER SQUARE INCH

FIGURE 8–6 Metric bolt (cap screw) grade markings and approximate tensile strength.

Metric bolt tensile strength property class is shown on the head of the bolt as a number, such as 4.6, 8.8, 9.8, and 10.9; the higher the number, the stronger the bolt. ● **SEE FIGURE 8–6**.

NUTS

Most nuts used on cap screws have the same hex size as the cap screw head. Metric nuts are often marked with dimples to show their strength. More dimples indicate stronger nuts. Some nuts, called locking nuts, use interference fit threads to keep them from accidentally loosening. This means that the shape of the nut is slightly distorted or that a section of the threads are deformed. Nuts can also be kept from loosening with a nylon washer fastened in the nut or with a nylon patch or strip on the threads. Some nuts, called jam nuts, are used to keep bolts and screws from loosening. Jam nuts screw on top of a regular nut and jam against the regular nut to prevent loosening. Jam nuts are also called pal nuts. ● **SEE FIGURES 8–7 AND 8–8**.

NOTE: Locking nuts are commonly referred to as prevailing torque nuts. This means that the nut will hold its tightness or torque and not loosen with movement or vibration. Most prevailing torque nuts should be replaced whenever removed to ensure that the nut will not loosen during service. Always follow the manufacturer's recommendations.

One of the oldest types of retaining nuts is the castle nut. It looks like a small castle, with slots for a cotter pin. A castellated nut is used on a bolt that has a hole for the cotter pin. ● **SEE FIGURE 8–9**.

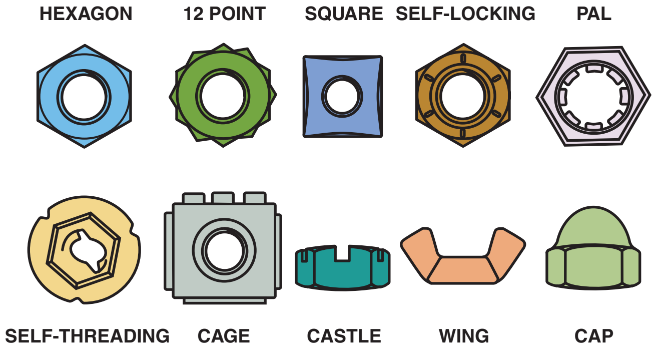
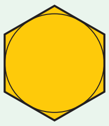
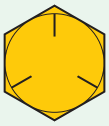
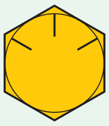
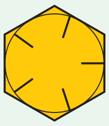
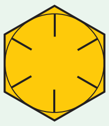
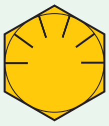


FIGURE 8–7 All of the nuts shown are used by themselves except for the pal nut, which is used to lock another nut to a threaded fastener so they will not be loosened by vibration.

SAE BOLT DESIGNATIONS

SAE GRADE NO.	SIZE RANGE	TENSILE STRENGTH, PSI	MATERIAL	HEAD MARKING
1	1/4 through 1-1/2	60,000	Low or medium carbon steel	
2	1/4 through 3/4	74,000		
	7/8 through 1-1/2	60,000		
5	1/4 through 1 1-1/8 through 1-1/2	120,000 105,000	Medium carbon steel, quenched & tempered	
5.2	1/4 through 1	120,000	Low carbon martensite steel*, quenched & tempered	
7	1/4 through 1-1/2	133,000	Medium carbon alloy steel, quenched & tempered	
8	1/4 through 1-1/2	150,000	Medium carbon alloy steel, quenched & tempered	
8.2	1/4 through 1	150,000	Low carbon Martensite steel*, quenched & tempered	

*Martensite steel is steel that has been cooled rapidly, thereby increasing its hardness. It is named after a German metallurgist, Adolf Martens.

CHART 8–2

SAE bolt grades.

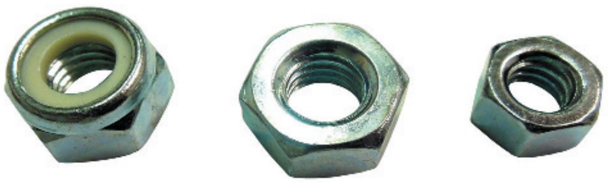


FIGURE 8–8 Types of lock nuts. On the left, a nylon ring; and the other two use a distorted shape to keep the nut from loosening.

TAPS AND DIES

Taps and dies are used to cut threads. **Taps** are used to cut threads in holes drilled to an exact size depending on the size of the tap. A **die** is used to cut threads on round rods or studs. Most taps and dies come as a complete set for the most commonly used fractional and metric threads.

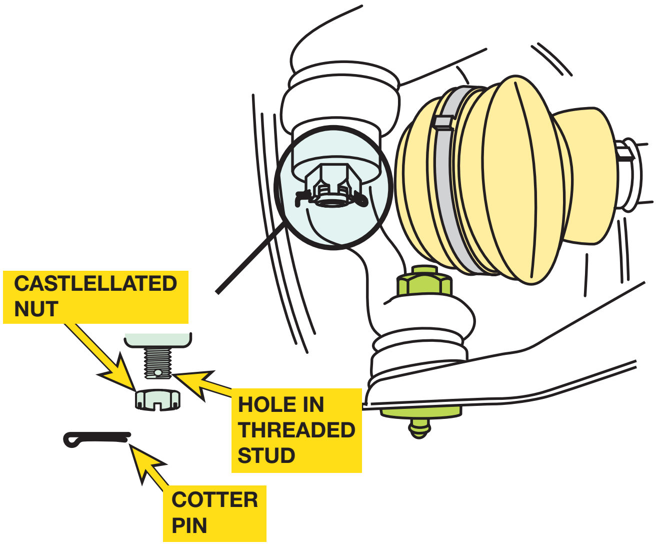


FIGURE 8–9 A castellated nut is locked in place with a cotter pin.

TAPS There are two commonly used types of taps, including:

- **Taper tap.** This is the most commonly used tap and is designed to cut threads by gradually enlarging the threaded hole.
- **Bottoming tap.** This tap has a flat bottom instead of a tapered tip to allow it to cut threads to the bottom of a drilled hole. ● **SEE FIGURE 8–10**.

All taps must be used in the proper size hole called a "tap drill size." This information is often stamped on the tap itself or in a chart that is included with a tap and die tool set. ● **SEE FIGURE 8–11**.

DIES A die is a hardened steel round cutter with teeth on the inside of the center hole. ● **SEE FIGURE 8–12**. A die is rotated using a die handle over a rod to create threads.

PROPER USE OF TAPS AND DIES Taps and dies are used to cut threads on rods in the case of a die or in a hole for a tap. A small tap can be held using a T-handle tap wrench, but for larger taps, a tap handle is needed to apply the needed force to cut threads. ● **SEE FIGURE 8–13A AND 8–13B**.

TAP USAGE. Be sure that the hole is the correct size for the tap and start by inserting the tap straight into the hole. Lubricate the tap using tapping lubricant. Rotate the tap about one full turn clockwise, then reverse the direction of the tap one-half turn to break the chip that was created. Repeat the procedure until the hole is completely threaded.

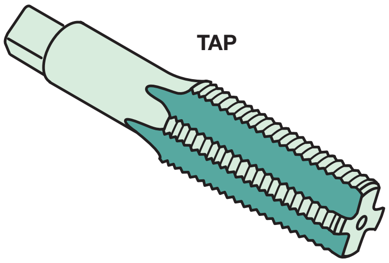


FIGURE 8–10 A typical bottoming tap used to create threads in holes that are not open, but stop in a casting, such as an engine block.

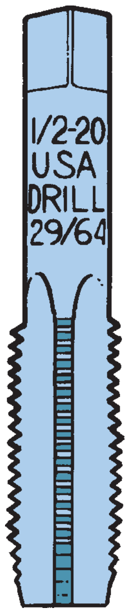


FIGURE 8–11 Many taps, especially larger ones, have the tap drill size printed on the top.

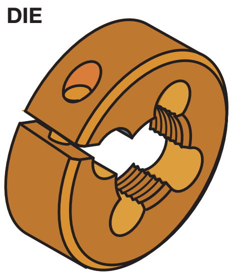


FIGURE 8–12 A die is used to cut threads on a metal rod.

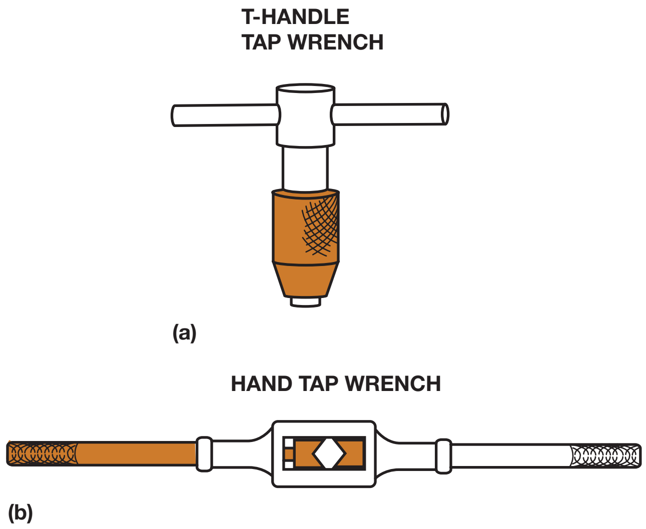


FIGURE 8–13 (a) A T-handle is used to hold and rotate small taps. (b) A tap wrench is used to hold and drive larger taps.

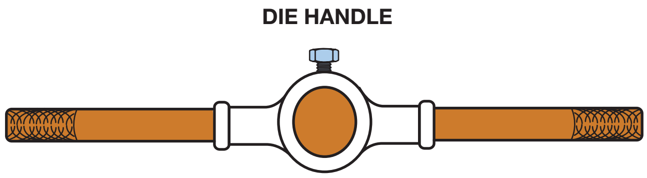


FIGURE 8–14 A die handle used to rotate a die while cutting threads on a metal rod.

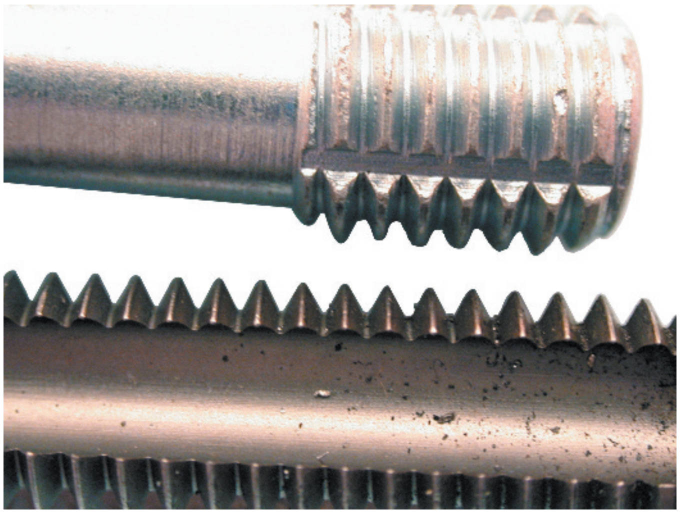


FIGURE 8–15 A thread chaser is shown at the top compared to a tap on the bottom. A thread chaser is used to clean threads without removing metal.

FREQUENTLY ASKED QUESTION

What Is the Difference between a Tap and a Thread Chaser?

A tap is a cutting tool and is designed to cut new threads. A thread chaser has more rounded threads and is designed to clean dirty threads without removing metal. Therefore, when cleaning threads, it is best to use a thread chaser rather than a tap to prevent the possibility of removing metal, which would affect the fit of the bolt being installed. ● **SEE FIGURE 8–15**.

DIE USAGE. A die should be used on the specified diameter rod for the size of the thread. Install the die securely into the die handle. ● **SEE FIGURE 8–14**.

Lubricate the die and the rod and place the die onto the end of the rod to be threaded. Rotate the die handle one full turn clockwise, then reverse the direction and rotate the die handle about a half turn counterclockwise to break the chip that was created. Repeat the process until the threaded portion has been completed.

SHEET METAL SCREWS

Sheet metal screws are fully threaded screws with a point for use in sheet metal. Also called **self-tapping screws**, they are used in many places on the vehicle, including fenders, trim, and door panels. ● **SEE FIGURE 8–16**.

These screws are used in unthreaded holes and the sharp threads cut threads as they are installed. This makes for a quick and easy installation when installing new parts, but the sheet metal screw can easily strip out the threads when used on the same part over and over, so care is needed.

When reinstalling self-tapping screws, first turn the screw lightly backwards until you feel the thread drop into the existing

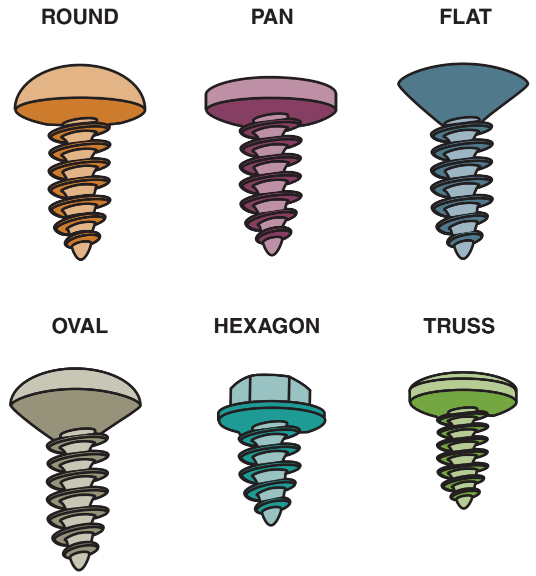


FIGURE 8–16 Sheet metal screws come with many head types.

thread in the screw hole. Then, turn the screw in; if it threads in easily, continue to tighten the screw. If the screw seems to turn hard, stop and turn it backwards about another half turn to locate the existing thread and try again. This technique can help prevent stripped holes in sheet metal and plastic parts.

Sheet metal screws are sized according to their major thread diameter.

WASHERS

Washers are often used under cap screw heads and under nuts. ● **SEE FIGURE 8–17**.

Plain flat washers are used to provide an even clamping load around the fastener. Lock washers are added to prevent accidental loosening. In some accessories, the washers are locked onto the nut to provide easy assembly.

Flat washers are placed underneath a nut to spread the load over a wide area and prevent gouging of the material. However, flat washers do not prevent a nut from loosening.

Lock washers are designed to prevent a nut from loosening. Spring-type lock washers resemble a loop out of a coil spring. As the nut or bolt is tightened, the washer is compressed. The tension of the compressed washer holds the fastener firmly against the threads to prevent it from loosening. Lock washers should not be used on soft metal, such as aluminum. The sharp ends of the steel washers would gouge the aluminum badly, especially if they are removed and replaced often.

Another type of locking washer is the star washer. The teeth on a star washer can be external or internal, and they bite into the metal because they are twisted to expose their edges. Star washers are used often on sheet metal or body parts. They are seldom used on engines. The spring steel lock washer also uses the tension of the compressed washer to prevent the fastener from loosening. The waves in this washer make it look like a distorted flat washer.

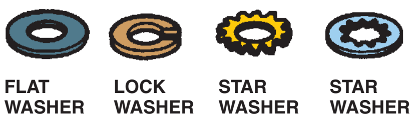


FIGURE 8–17 Various types washers serve different purposes and all are used to secure bolts or cap screws.

SIZE	DIAMETER DECIMAL (INCH)	DIAMETER NEAREST FRACTION INCH
4	0.11	7/64
6	0.14	9/64
8	0.17	11/64
10	0.19	3/16
12	0.22	7/32
14	0.25	1/4

CHART 8–3

Sheet metal screw sizes.

SNAP RINGS AND CLIPS

SNAP RINGS **Snap rings** are not threaded fasteners, but instead attach with a spring-like action. Snap rings are constructed of spring steel and are used to attach parts without using a threaded fastener. There are several different types of snap rings and most require the use of a special pair of pliers, called snap ring pliers, to release or install. The types of snap rings include:

- Expanding (internal)
- Contracting (external)
- E-clip
- C-clip
- Holeless snap rings in both expanding and contracting styles

● **SEE FIGURE 8–18**.

DOOR PANEL CLIPS Interior door panels and other trim pieces are usually held in place with plastic clips. Due to the tapered and fluted shape, these clips are often called **Christmas tree clips**. ● **SEE FIGURE 8–19**.

A special tool is often used to remove interior door panels without causing any harm. ● **SEE FIGURE 8–20**.

CAUTION: Use extreme care when removing panels that use plastic or nylon clips. It is very easy to damage the door panel or the clip during removal.

PINS **Cotter pins**, also called a cotter key, are used to keep linkage or a threaded nut in place or to keep it retained. The word *cotter* is an Old English verb meaning "to close or fasten." There are many other types of pins used in vehicles, including clevis pins, roll pins, and hair pins. ● **SEE FIGURE 8–21**.

Pins are used to hold together shafts and linkages, such as shift linkages and cable linkages. The clevis pin is held in place

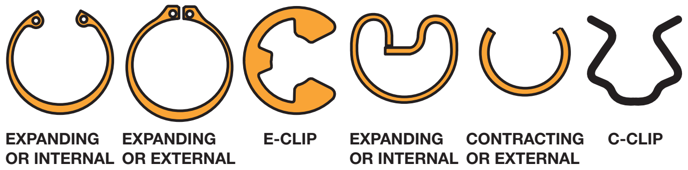


FIGURE 8–18 Some different types of snap rings. An internal snap ring fits inside of a housing or bore, into a groove. An external snap ring fits into a groove on the outside of a shaft or axle. An E-clip fits into a groove in the outside of a shaft. A C-clip shown is used to retain a window regulator handle on its shaft.

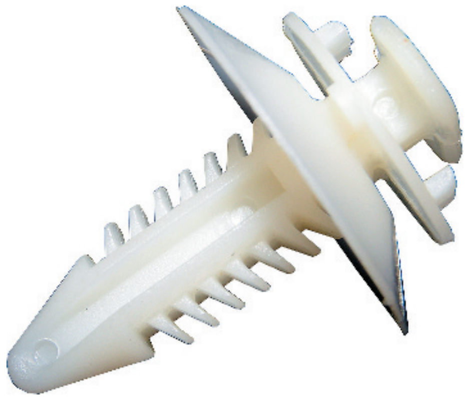


FIGURE 8–19 A typical door panel retaining clip.

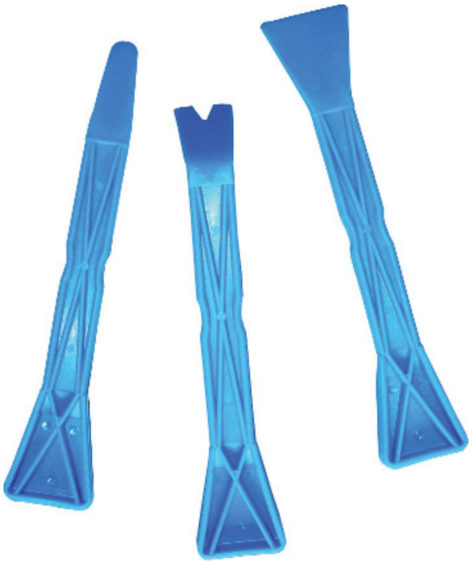


FIGURE 8–20 Plastic or metal trim tools are available to help the technician remove interior door panels and other trim without causing harm.

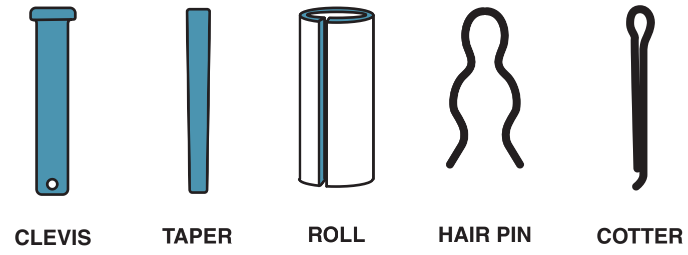


FIGURE 8–21 Pins come in various types.

with a cotter pin, while the taper and roll pins are driven in and held by friction. The hair pin snaps into a groove on a shaft.

RIVETS Rivets are used in many locations to retain components, such as window mechanisms, that do not require routine removal and/or do not have access to the back side for a nut. A drill is usually used to remove a rivet and a rivet gun is needed to properly install a rivet. Some rivets are plastic and are used to hold some body trim pieces. The most common type of rivet is called a **pop rivet** because, as the rivet tool applies a force to the shaft of the pop rivet, it causes the rivet to expand and tighten the two pieces together. When the shaft of the rivet, which looks like a nail, is pulled to its maximum, the shaft breaks, causing a "pop" sound.

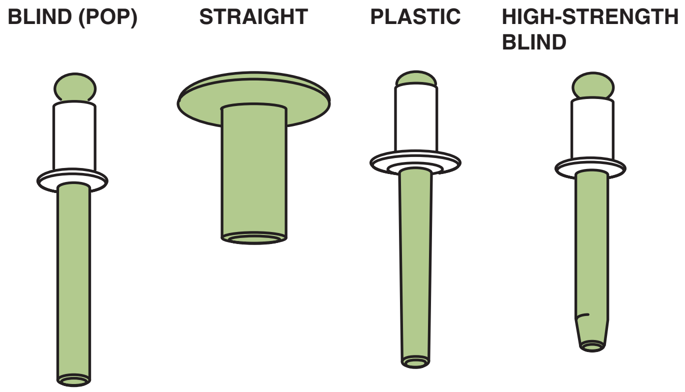


FIGURE 8–22 Various types of rivets.

Rivets may be used in areas of the vehicle where a semi-permanent attachment is needed and in places where there is no access to the back side of the workpiece. They are installed using a rivet gun or by peening with a ball-peen hammer. ● **SEE FIGURE 8–22**.

Both types of blind rivets require the use of a rivet gun to install. The straight rivet is placed through the workpieces and then peened over with a ball-peen hammer or an air-operated tool. The plastic rivet is used with a rivet gun to install some body trim parts.

BROKEN FASTENER REMOVAL

Try not to break, strip, or round off fasteners in the first place. There are several ways that you can minimize the number of fasteners you damage. First, never force fasteners loose during disassembly. Taking a few precautionary steps will often prevent damage. If a bolt or nut will not come loose with normal force, try tightening it in slightly and backing it out. Sometimes turning the fastener the other way will break corrosion loose, and the fastener will then come out easily. Another method that works well is to rest a punch on the head of a stubborn bolt and strike it with a sharp blow with a hammer. Often this method will break the corrosion loose.

LEFT-HANDED THREADS Although rare, left-handed fasteners are occasionally found on engine assemblies. These fasteners will loosen when you turn them clockwise and tighten when you turn them counterclockwise. Left-handed fasteners are used to fasten parts to the ends of rotating assemblies that turn counterclockwise, such as crankshafts and camshafts. Most automobile engines do not use left-handed threads; however, they will be found on many older motorcycle engines. Some left-handed fasteners are marked with an "L" on the bolt head for easy identification, others are not. Left-handed threads are also found inside some transaxles.

PENETRATING OIL **Penetrating oil** is a lightweight lubricant similar to kerosene, which soaks into small crevices in the threads by **capillary action**. The chemical action of penetrating oils helps to break up and dissolve rust and corrosion. The oil forms a layer of boundary lubrication on the threads to reduce friction and make the fastener easier to turn.

For best results, allow the oil time to soak in before removing the nuts and bolts. To increase the effectiveness of penetrating oil, tap on the bolt head or nut with a hammer, or alternately work the fastener back and forth with a wrench. This movement weakens the bond of the corrosion and lets more of the lubricant work down into the threads.

PROPER TIGHTENING Proper tightening of bolts and nuts is critical for proper clamping force, as well as to prevent breakage. All fasteners should be tightened using a torque wrench. A torque wrench allows the technician to exert a known amount of torque to the fasteners. However, rotating torque on a fastener does not mean clamping force because up to 80% of the torque used to rotate a bolt or nut is absorbed by friction by the threads. Therefore, for accurate tightening, two things must be performed:

- The threads must be clean and lubricated if service information specifies that they be lubricated.
- Always use a torque wrench to not only ensure proper clamping force, but also to ensure that all fasteners are tightened the same.

THREAD REPAIR INSERTS

Thread repair inserts are used to replace the original threaded hole when it has become damaged beyond use. The original threaded hole is enlarged and tapped for threads, and a threaded insert is installed to restore the threads to the original size.

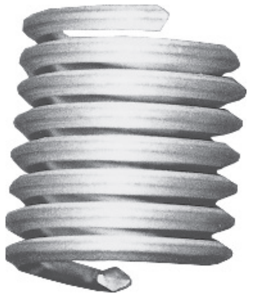
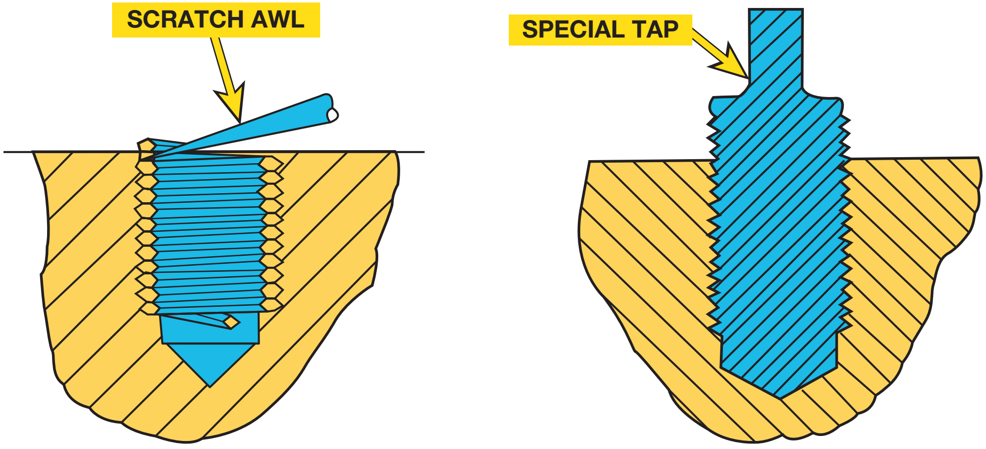


FIGURE 8–23 Helical inserts look like small, coiled springs. The outside is a thread to hold the coil in the hole, and the inside is threaded to fit the desired fastener.

HELICAL INSERTS A **helical insert** looks like a small, stainless-steel spring. ● **SEE FIGURE 8–23**.

To install a helical insert, a hole must be drilled to a specified oversize, and then it is tapped with a special tap designed for the thread inserts. The insert is then screwed into the hole. ● **SEE FIGURE 8–24**.

The insert stays in the casting as a permanent repair and bolts can be removed and replaced without disturbing the insert. One advantage of a helical insert is that the original bolt can be used because the internal threads are the same size. When correctly installed, an insert is often stronger than the original threads, especially in aluminum castings. Some vehicle manufacturers, such as BMW, specify that the threads be renewed using

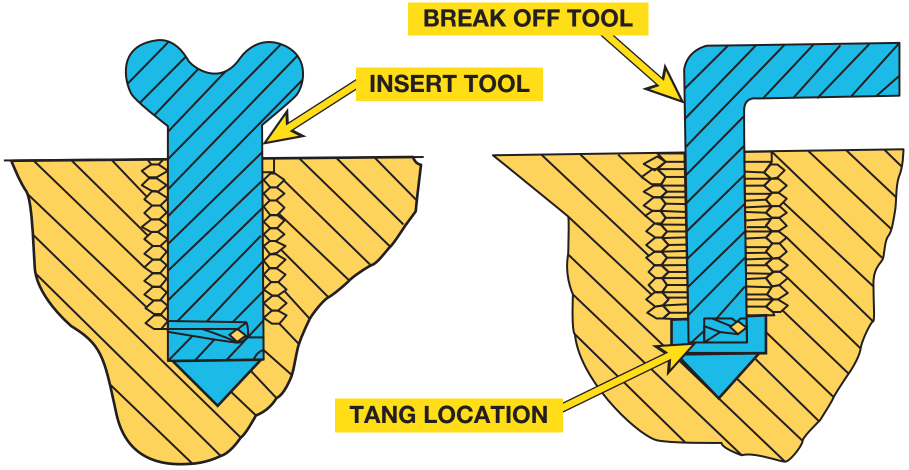


REMOVE OLD INSERT

(a)

CHASE THREADS

(b)



INSTALL INSERT

(c)

REMOVE TANG

(d)

FIGURE 8–24 The insert provides new, stock-size threads inside an oversize hole so that the original fastener can be used.

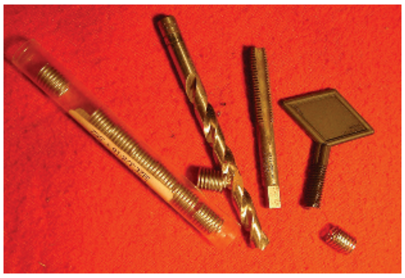


FIGURE 8–25 Heli-Coil® kits, available in a wide variety of sizes, contain everything needed to repair a damaged hole back to its original size.

an insert if the cylinder head has to be removed and reinstalled. Plus, many high-performance engine rebuilders install inserts in blocks, manifolds, and cylinder heads as a precaution.

One of the best known of the helical fasteners is the **Heli-Coil®**, manufactured by Heli-Coil® Products. To install Heli-Coil® inserts, you will need to have a thread repair kit. The kit includes a drill bit, tap, installation mandrel, and inserts. Repair kits are available for a wide variety of diameters and pitch to fit both American Standard and metric threads. A simple kit contains the tooling for one specific thread size. Master kits that cover a range of sizes are also available. Installing an insert is similar to tapping new threads. A summary of the procedures includes:

1. Select the Heli-Coil® kit designed for the specific diameter and thread pitch of the hole to be repaired. ● **SEE FIGURE 8–25**.
2. Use the drill bit supplied with the kit. The drill size is also specified on the Heli-Coil® tap, to open up the hole to the necessary diameter and depth.
3. Tap the hole with the Heli-Coil® tap, being sure to lubricate the tap. Turn it in slowly and rotate counterclockwise occasionally to break the chip that is formed.
4. Thread an insert onto the installation mandrel until it seats firmly. Apply a light coating of the recommended thread-locking compound to the external threads of the insert.
5. Use the mandrel to screw the insert into the tapped hole. Once started, spring tension prevents the insert from unscrewing. Stop when the top of the insert is 1/4 to 1/2 turn below the surface.
6. Remove the mandrel by unscrewing it from the insert and then use a small punch or needle-nose pliers to break off the tang at the base of the insert. Never leave the tang in the bore. The finished thread is ready for use immediately.

THREADED INSERTS **Threaded inserts** are tubular, case-hardened, solid steel wall pieces that are threaded inside and outside. The inner thread of the insert is sized to fit the original fastener of the hole to be repaired. The outer thread design will vary. These may be self-tapping threads that are installed in a blank hole, or machine threads that require the hole to be tapped. Threaded inserts return a damaged hole to original size by replacing part of the surrounding casting, so drilling is required. Most inserts fit into three categories.

- Self-tapping
- Solid-bushing
- Key-locking

SELF-TAPPING INSERTS The external threads of a self-tapping insert are designed to cut their own way into a casting. This eliminates the need of running a tap down the hole. To install a typical self-tapping insert, follow this procedure.

1. Drill out the damaged threads to open the hole to the proper size, using the specified size drill bit.
2. Select the proper insert and mandrel. As with Heli-Coils®, the drill bit, inserts, and mandrel are usually available as a kit.
3. Thread the insert onto the mandrel. Use a tap handle or wrench to drive the insert into the hole. Because the insert will cut its own path into the hole, it may require a considerable amount of force to drive the insert in.
4. Thread the insert in until the nut or flange at the bottom of the mandrel touches the surface of the workpiece. This is the depth stop to indicate the insert is seated.
5. Hold the nut or flange with a wrench, and turn the mandrel out of the insert. The threads are ready for immediate use.

SOLID-BUSHING INSERTS The external threads of solid-bushing inserts are ground to a specific thread pitch, so you will have to run a tap into the hole. ● **SEE FIGURE 8–26**.

Some inserts use a machine thread so a standard tap can be used; others have a unique thread and you have to use a special tap. The thread inserts come with a matching installation kit. ● **SEE FIGURE 8–27**.

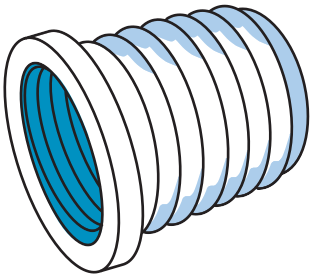


FIGURE 8–26 This solid-bushing insert is threaded on the outside, to grip the workpiece. The inner threads match the desired bolt size.

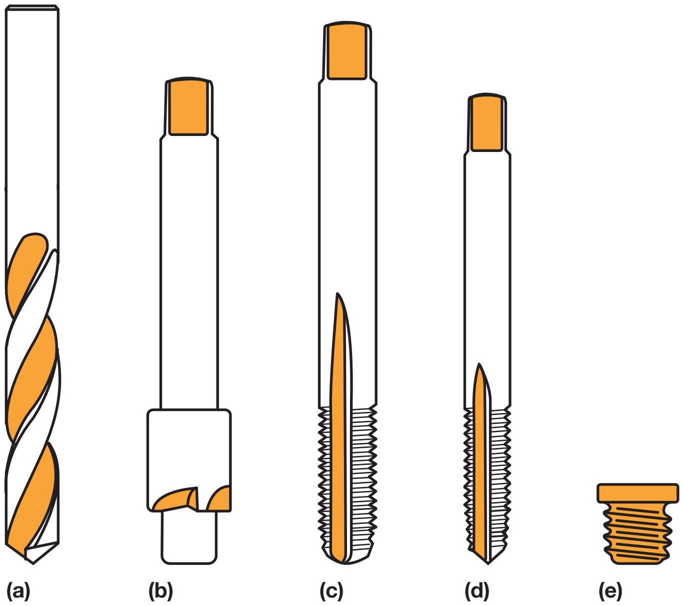


FIGURE 8–27 A Timesert® kit includes the drill (a), the recess cutter (b), a special tap (c), the installer (d), and the Timesert® threaded bushing (e).

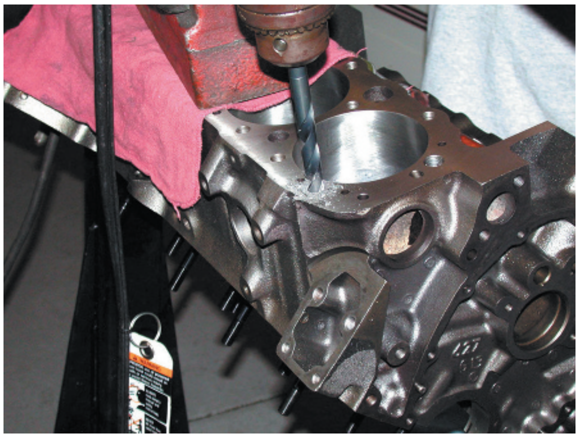


FIGURE 8–28 Drill out the damaged threads with the correct bit.

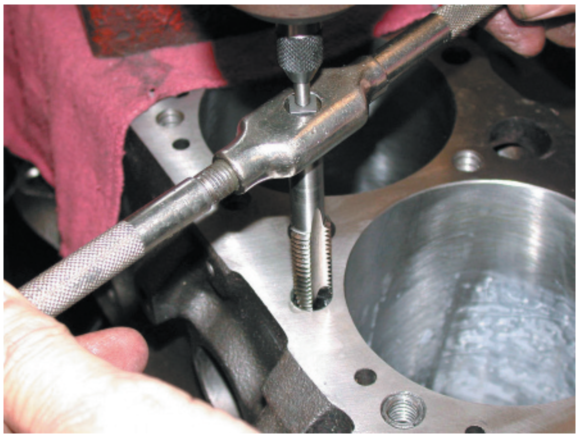


FIGURE 8–29 Use a special tap for the insert.

To install threaded inserts, follow this procedure.

1. Drill out the damaged threads to open the hole to the proper size. The drill bit supplied with the kit must be the one used because it is properly sized to the tap. ● **SEE FIGURE 8–28**.
2. Cut the recess in the top of the hole with the special tool, then clean the hole with a brush or compressed air.
3. Use the previously detailed tapping procedures to thread the hole. ● **SEE FIGURE 8–29**. Be sure to tap deep enough; the top of the insert must be flush with the casting surface.
4. Thread the insert onto the installation driver, using the driver to screw the insert into the hole. Some inserts require that a thread-locking compound be applied; others go in dry.
5. Remove the installation driver, and the new threads are ready for service with the original fastener.

KEY-LOCKING INSERTS Key-locking inserts are similar to solid-bushing inserts, but are held in place by small keys. After the insert has been installed, the keys are driven into place—perpendicular to the threads—to keep the insert from turning out. A typical installation procedure includes the following steps.

1. Drill out the damaged thread with the specified drill size.
2. Tap the drilled hole with the specified tap.
3. After putting thread-locking compound on the insert, use the mandrel to screw the insert into the tapped hole until it is slightly below the surface. ● **SEE FIGURE 8–30**. The keys act as a depth stop and prevent the insert from turning.
4. Drive the keys down using the driver supplied with the insert kit. Be sure the keys are flush with the top of the insert. ● **SEE FIGURES 8–31 AND 8–32**.

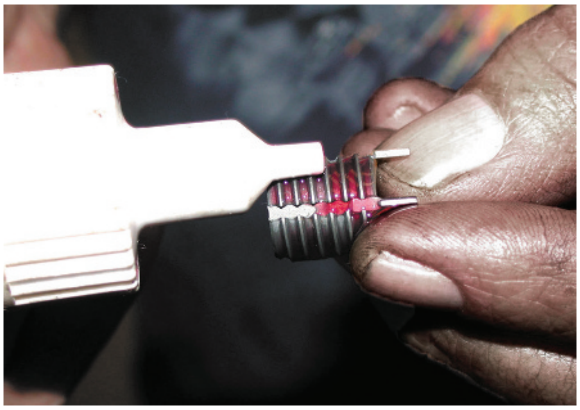


FIGURE 8–30 Put some thread-locking compound on the insert.

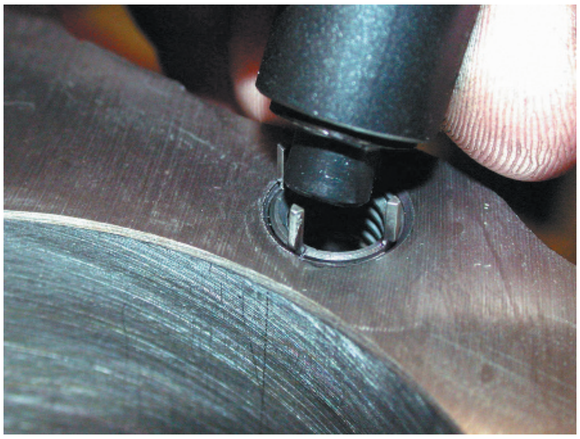


FIGURE 8–31 Use the driver to drive the keys down flush with the surface of the workpiece.

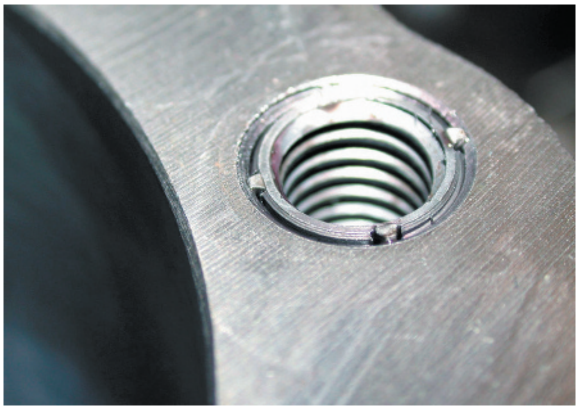


FIGURE 8–32 The insert and insert locks should be below the surface of the workpiece.

REVIEW QUESTIONS

1. What is the difference between a bolt and a stud?
2. How is the size of a metric bolt expressed?
3. What is meant by the grade of a threaded fastener?
4. How do prevailing torque nuts work?
5. How are threaded inserts installed?

CHAPTER QUIZ

1. The thread pitch of a bolt or nut is measured in what units?
   - **a.** Millimeters
   - **b.** Threads per inch
   - **c.** Fractions of an inch
   - **d.** Both a and b
2. Technician A says that the diameter of a bolt is the same as the wrench size used to remove or install the fastener. Technician B says that washers can be flat or lock-type. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. The grade of a fastener, such as a bolt, is a measure of its __________.
   - **a.** tensile strength
   - **b.** hardness
   - **c.** finish
   - **d.** color
4. Which of the following is a metric bolt?
   - **a.** 5/16-18
   - **b.** 1/2-20
   - **c.** M12 × 1.5
   - **d.** 8 millimeter
5. The marks (lines) on the heads of bolts indicate __________.
   - **a.** size
   - **b.** grade
   - **c.** tensile strength
   - **d.** Both b and c
6. A screw that can make its own threads when installed is called a __________ screw.
   - **a.** sheet metal
   - **b.** tapered
   - **c.** self-tapping
   - **d.** Both a and c
7. Which of the following statements is true of threaded inserts?
   - **a.** They look like small, stainless-steel springs.
   - **b.** They are threaded inside and outside.
   - **c.** They screw on top of a nut and prevent nut loosening.
   - **d.** They are used to hold together shafts and linkages.
8. Taps are used to create threads __________.
   - **a.** in drilled holes
   - **b.** on steel or metal rods
   - **c.** Both a and b
   - **d.** Neither a nor b
9. What type of fastener is commonly used to retain interior door panels?
   - **a.** Christmas tree clips
   - **b.** E-clips
   - **c.** External clips
   - **d.** Internal clips
10. To avoid over-tightening or breaking a bolt, _________ should always be used when tightening fasteners.
    - **a.** a torque wrench
    - **b.** a box end wrench
    - **c.** penetrating oil
    - **d.** a pitch gauge

Chapter 9

HAND AND POWER TOOLS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Compare the different types of wrenches.
- Discuss the purpose of ratchets, sockets, and extensions.
- Discuss the purpose of screwdrivers.
- Discuss the purpose of hammers and mallets.
- Discuss the purpose of pliers.
- Explain the characteristics of cutters.
- Discuss the purpose of punches and chisels.
- Discuss the purpose of removers.
- Discuss the purpose of hacksaws.
- List the basic tools a service technician should possess.
- List safety tips for using hand tools.
- Describe hand tool maintenance.
- Describe the purpose of the air compressor.
- Describe the purpose of air and electrically operated tools.
- Discuss the use of shop equipment, including grinders, bench vises, hydraulic presses, portable cranes and chain hoists, and engine stands.
- Discuss the care and maintenance of shop equipment.

KEY TERMS:

Adjustable wrench 70 • Air compressor 82 • Air drill 84 • Air ratchet 83 • Air-blow gun 84 • Aviation tin snips 77 • Beam-type torque wrench 72 • Bearing splitter 85 • Bench grinder 84 • Bench vise 85 • Box-end wrench 70 • Breaker bar (flex handle) 71 • Cheater bar 81 • Chisel 77 • Clicker-type torque wrench 71 • Cold chisel 77 • Combination wrench 70 • Crowfoot socket 71 • Dead-blow hammer 74 • Diagonal (side-cut or dikes) pliers 75 • Die grinder 84 • Double-cut file 76 • Drive size 71 • Easy out 78 • Engine stand 86 • Extension 71 • Files 76 • Fitting wrench 70 • Flare-nut wrench 70 • Flat-tip (straight blade) screwdriver 73 • Hacksaw 78 • Hydraulic press 85 • Impact wrench 83 • LED 82 • Locking pliers 76 • Multigroove adjustable pliers 75 • Needle-nose pliers 75 • Nut splitter 78 • Open-end wrench 70 • Portable crane 85 • Punch 77 • Ratchet 71 • Removers 77 • Screwdriver 73 • Single-cut file 76 • Slip-joint pliers 75 • Snap-ring pliers 76 • Socket 71 • Socket adapter 73 • Stone wheel 84 • Straight cut aviation snips 77 • Stud removal tool 78 • Stud remover 78 • Tin snips 76 • Torque wrench 71 • Trouble light 82 • Tube-nut wrench 70 • Universal joint 71 • Utility knife 77 • Vise-Grip® 76 • Water pump pliers 75 • Wire brush wheel 84 • Work light 82 • Wrench 69

WRENCHES

Wrenches are the most used hand tool by service technicians. Most wrenches are constructed of forged alloy steel, usually chrome-vanadium steel. ● **SEE FIGURE 9–1**.

After the wrench is formed, it is hardened, tempered to reduce brittleness, and chrome plated. Wrenches are available in both fractional and metric sizes. There are several types of wrenches.

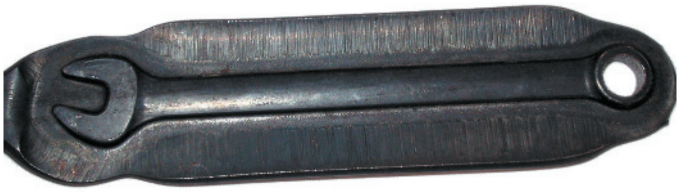


FIGURE 9–1 A forged wrench after it has been forged but before the flashing, extra material around the wrench, has been removed.

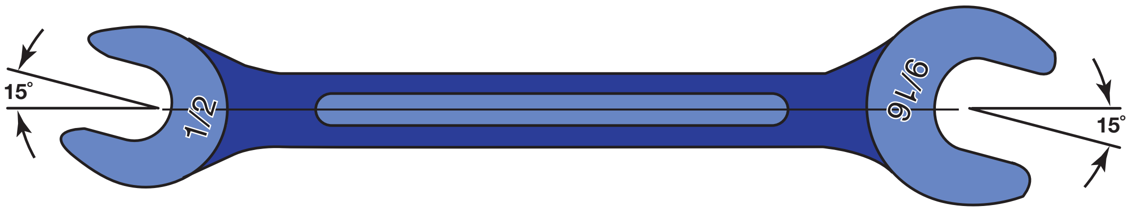


FIGURE 9–2 A typical open-end wrench. The size is different on each end and notice that the head is angled 15 degrees at each end.

OPEN-END WRENCH An **open-end wrench** is often used to loosen or tighten bolts or nuts that do not require a lot of torque. An open-end wrench can be easily placed on a bolt or nut with an angle of 15 degrees, which allows the wrench to be flipped over and used again to continue to rotate the fastener. The major disadvantage of an open-end wrench is the lack of torque that can be applied due to the fact that the open jaws of the wrench only contact two flat surfaces of the fastener. An open-end wrench has two different sizes, one at each end. ● **SEE FIGURE 9–2**.

BOX-END WRENCH A **box-end wrench** is placed over the top of the fastener and grips the points of the fastener. A box-end wrench is angled 15 degrees to allow it to clear nearby objects. ● **SEE FIGURE 9–3**.

Therefore, a box-end wrench should be used to loosen or to tighten fasteners. A box-end wrench is also called a **close-end** wrench. A box-end wrench has two different sizes, one at each end. ● **SEE FIGURE 9–4**.

COMBINATION WRENCH Most service technicians purchase **combination wrenches**, which have the open end at one end and the same size box end on the other. ● **SEE FIGURE 9–5**.

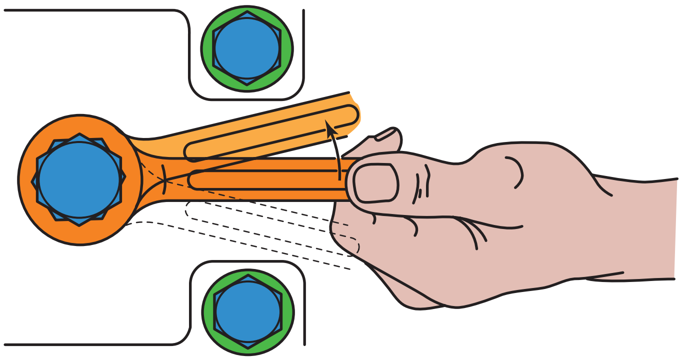


FIGURE 9–3 A typical box-end wrench is able to grip the bolt or nut at points completely around the fastener. Each end is a different size.

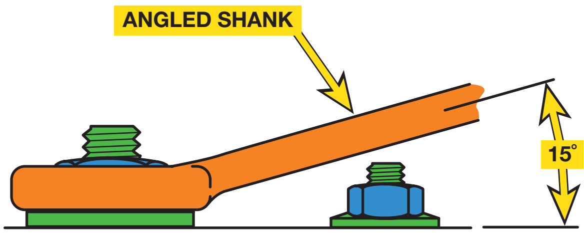


FIGURE 9–4 The end of a box-end wrench is angled 15 degrees to allow clearance for nearby objects or other fasteners.

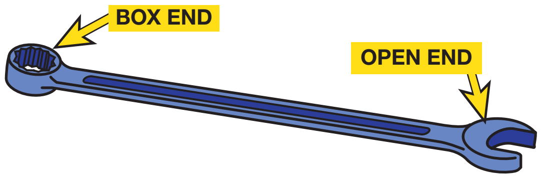


FIGURE 9–5 A combination wrench has an open end at one end and a box end at the other with the same size at each end.

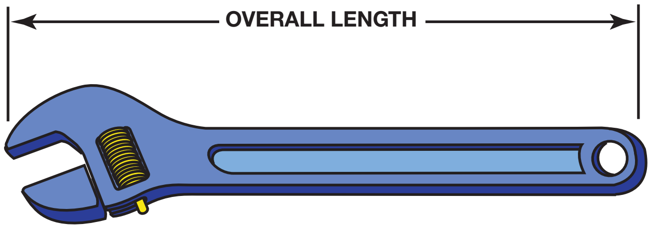


FIGURE 9–6 An adjustable wrench. Adjustable wrenches are sized by the overall length of the wrench and not by how far the jaws open. Common sizes of adjustable wrenches include 8, 10, and 12 inch.

A combination wrench allows the technician to loosen or tighten a fastener using the box end of the wrench, turn it around, and use the open end to increase the speed of rotating the fastener.

ADJUSTABLE WRENCH An **adjustable wrench** is often used where the exact size wrench is not available or when a large nut, such as a wheel spindle nut, needs to be rotated, but not tightened. An adjustable wrench should not be used to loosen or tighten fasteners because the torque applied to the wrench can cause the movable jaws to loosen their grip on the fastener, causing it to become rounded. ● **SEE FIGURE 9–6**.

LINE WRENCHES Line wrenches are also called **flare-nut wrenches**, **fitting wrenches**, or **tube-nut wrenches** and are designed to grip almost all the way around a nut used to retain a fuel or refrigerant line, and yet be able to be installed over the line. ● **SEE FIGURE 9–7**.

SAFE USE OF WRENCHES. Wrenches should be inspected before use to be sure they are not cracked, bent, or damaged. All wrenches should be cleaned after use before being returned to the toolbox. Always use the correct size of wrench for the fastener being loosened or tightened to help prevent the rounding of the flats of the fastener. When attempting to loosen a fastener, pull a wrench-do not push a wrench. If a wrench is pushed, your knuckles can be hurt when forced into another object if the fastener breaks loose.

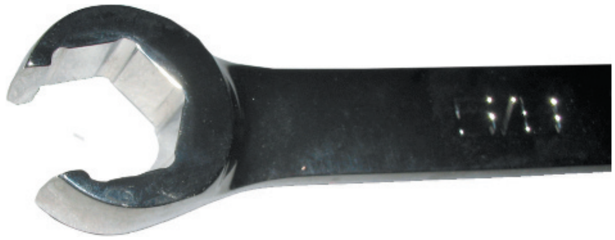


FIGURE 9–7 The end of a typical line wrench, which shows that it is capable of grasping most of the head of the fitting.

RATCHETS, SOCKETS, AND EXTENSIONS

A **socket** fits over the fastener and grips the points and/or flats of the bolt or nut. The socket is rotated (driven) using either a long bar called a **breaker bar (flex handle)** or a **ratchet**. ● **SEE FIGURES 9–8 AND 9–9**.

A ratchet turns the socket in only one direction and allows the rotating of the ratchet handle back and forth in a narrow space. Socket **extensions** and **universal joints** are also used with sockets to allow access to fasteners in restricted locations.

Sockets are available in various **drive sizes**, including 1/4 inch, 3/8 inch, and 1/2 inch sizes for most automotive use. ● **SEE FIGURES 9–10 AND 9–11**.

Many heavy-duty truck and/or industrial applications use 3/4 inch and 1 inch sizes. The drive size is the distance of each side of the square drive. Sockets and ratchets of the same size are designed to work together.

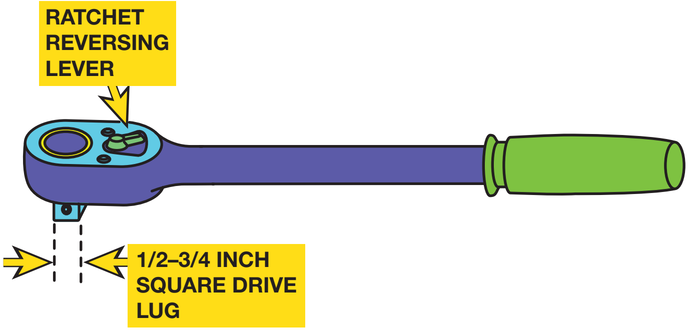


FIGURE 9–8 A typical ratchet used to rotate a socket. A ratchet makes a ratcheting noise when it is being rotated in the opposite direction from loosening or tightening. A knob or lever on the ratchet allows the user to switch directions.

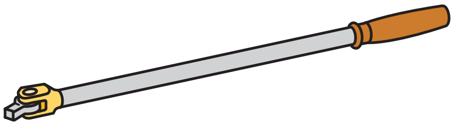


FIGURE 9–9 A typical flex handle used to rotate a socket, also called a breaker bar because it usually has a longer handle than a ratchet and, therefore, can be used to apply more torque to a fastener than a ratchet.

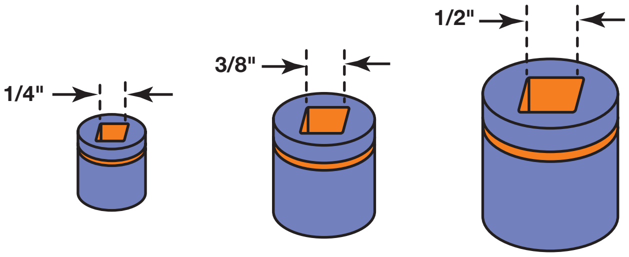


FIGURE 9–10 The most commonly used socket drive sizes include 1/4 inch, 3/8 inch, and 1/2 inch drive.

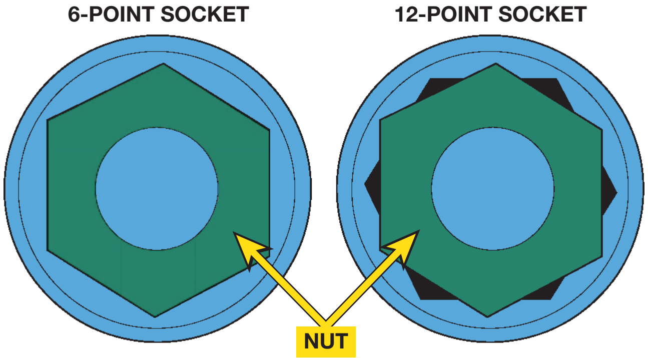


FIGURE 9–11 A 6-point socket fits the head of the bolt or nut on all sides. A 12-point socket can round off the head of a bolt or nut if a lot of force is applied.

CROWFOOT SOCKETS

A **crowfoot socket** is a socket that is an open-end or line wrench to allow access to fasteners that cannot be reached using a conventional wrench. ● **SEE FIGURE 9–12**.

Crowfoot sockets are available in the following categories.

- Fractional inch open-end wrench
- Metric open-end wrench
- Fractional line wrench
- Metric line wrench

TORQUE WRENCHES

Torque wrenches are socket turning handles that are designed to apply a known amount of force to the fastener. There are three basic types of torque wrenches.

1. A **clicker-type torque wrench** is first set to the specified torque and then it "clicks" when the set torque value has been reached. When force is removed from the torque wrench handle, another click is heard. The setting on a clicker-type torque wrench should be set back to zero

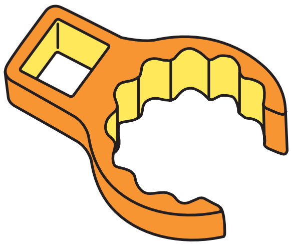


FIGURE 9–12 A crowfoot socket is designed to reach fasteners using a ratchet or breaker bar with an extension.

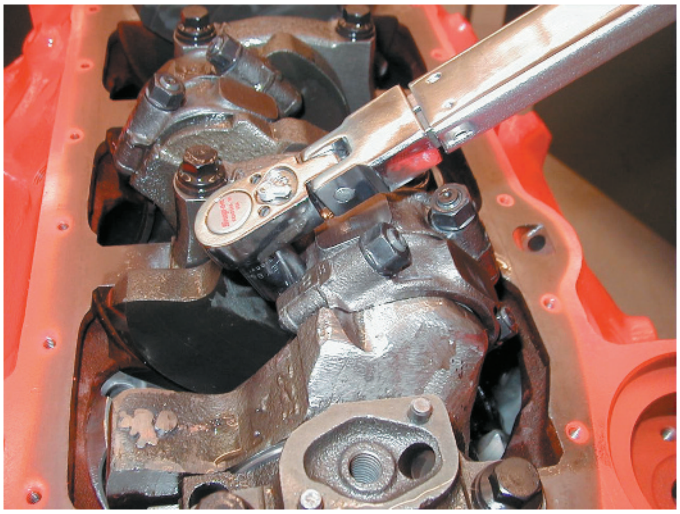


FIGURE 9–13 Using a torque wench to tighten connecting rod nuts on an engine.

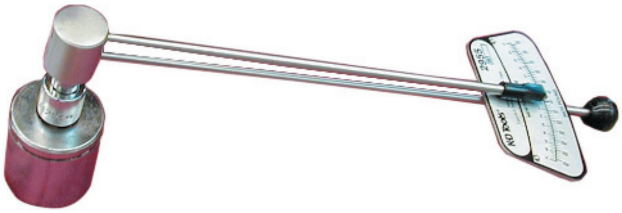


FIGURE 9–14 A beam-type torque wrench that displays the torque reading on the face of the dial. The beam display is read as the beam deflects, which is in proportion to the amount of torque applied to the fastener.

after use and checked for proper calibration regularly. ● **SEE FIGURE 9–13**.

2. **A dial-type torque wrench** is used to measure torque, but instead of presetting the value, the actual torque is displayed on the dial of the wrench as the fastener is being tightened.
3. **Beam-type torque wrenches** are available in 1/4 inch, 3/8 inch, and 1/2 inch drives and both English and metric units. ● **SEE FIGURE 9–14**.

TECH TIP

Right to Tighten

It is sometimes confusing which way to rotate a wrench or screwdriver, especially when the head of the fastener is pointing away from you. To help visualize while looking at the fastener, say “righty tighty, lefty loosey.”

TECH TIP

Check Torque Wrench Calibration Regularly

Torque wrenches should be checked regularly. For example, Honda has a torque wrench calibration setup at each of their training centers. It is expected that a torque wrench be checked for accuracy before every use. Most experts recommend that torque wrenches be checked and adjusted as needed at least every year, and more often, if possible. ● **SEE FIGURE 9–15**.

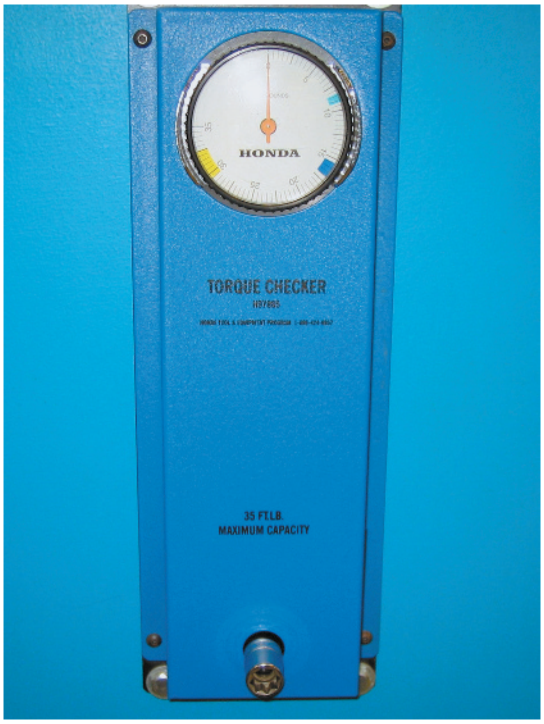


FIGURE 9–15 Torque wrench calibration checker.

FREQUENTLY ASKED QUESTION

Is It lb-ft or ft-lb of Torque?

The unit for torque is expressed as a force times the distance (leverage) from the object. Therefore, the official unit for torque is lb-ft (pound-feet) or newton-meters (a force times a distance). However, it is commonly expressed in ft-lb and even some torque wrenches are labeled with this unit.

SAFE USE OF SOCKETS AND RATCHETS. Always use the proper size socket that correctly fits the bolt or nut. All sockets and ratchets should be cleaned after use before being placed back into the toolbox. Sockets are available in short and deep well designs. ● **SEE FIGURE 9–16**.

Also select the appropriate drive size. For example, for small work, such as on the dash, select a 1/4 inch drive. For most general service work, use a 3/8 inch drive, and for suspension and steering and other large fasteners, select a 1/2 inch drive. When loosening a fastener, always pull the ratchet toward you rather than push it outward.

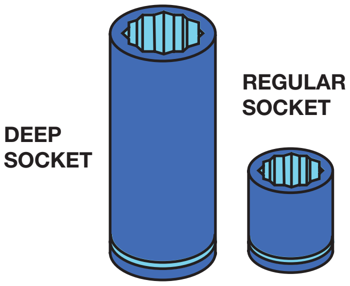


FIGURE 9–16 Deep sockets allow access to the nut that has a stud plus other locations needing great depth, such as spark plugs.

TECH TIP

Double-Check the Specifications

Misreading torque specifications is easy to do but can have serious damaging results. Specifications for fasteners are commonly expressed in pound-feet. Many smaller fasteners are tightened to specifications expressed in pound-inch

1 lb-ft = 12 lb-in.

Therefore, if a fastener were to be accidentally tightened to 24 pound-feet instead of 24 pound-inch, the actual torque applied to the fastener will be 288 lb-inch instead of the specified 24 pound-inch.

This extra torque will likely break the fastener, but it could also warp or distort the part being tightened. Always double-check the torque specifications.

TECH TIP

Use Socket Adapters with Caution

Socket adapters are available and can be used for different drive size sockets on a ratchet. Combinations include:

- 1/4 inch drive—3/8 inch sockets
- 3/8 inch drive—1/4 inch sockets
- 3/8 inch drive—1/2 inch sockets
- 1/2 inch drive—3/8 inch sockets

Using a larger drive ratchet or breaker bar on a smaller size socket can cause the application of too much force to the socket, which could crack or shatter. Using a smaller size drive tool on a larger socket will usually not cause any harm, but would greatly reduce the amount of torque that can be applied to the bolt or nut.

SCREWDRIVERS

Many smaller fasteners are removed and installed by using a **screwdriver**. Screwdrivers are available in many sizes and tip shapes. The most commonly used screwdriver is called a **flat tip** or **straight blade**.

Flat-tip screwdrivers are sized by the width of the blade and this width should match the width of the slot in the screw. ● **SEE FIGURE 9–17**.

CAUTION: Do not use a screwdriver as a pry tool or as a chisel. Always use the proper tool for each application.

Another type of commonly used screwdriver is called a Phillips screwdriver, named for Henry F. Phillips, who invented the crosshead screw in 1934. Due to the shape of the crosshead screw and screwdriver, a Phillips screw can be driven with more torque than can be achieved with a slotted screw.

A Phillips head screwdriver is specified by the length of the handle and the size of the point at the tip. A #1 tip has a sharp point, a #2 tip is the most commonly used, and a #3 tip is blunt and is only used for larger sizes of Phillips head fasteners.

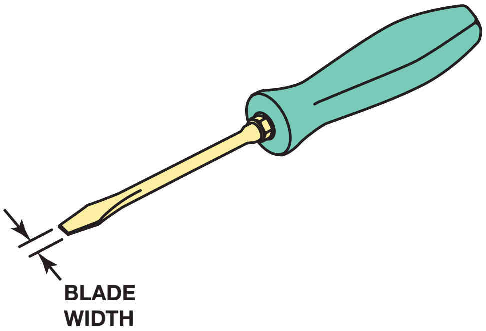


FIGURE 9–17 A **flat-tip (straight blade) screwdriver**. The width of the blade should match the width of the slot in the fastener being loosened or tightened.

TECH TIP

Avoid Using "Cheater Bars"

Whenever a fastener is difficult to remove, some technicians will insert the handle of a ratchet or a breaker bar into a length of steel pipe. The extra length of the pipe allows the technician to exert more torque than can be applied using the drive handle alone. However, the extra torque can easily overload the socket and ratchet, causing them to break or shatter, which could cause personal injury.

For example, a #2 3 3-inch Phillips screwdriver would typically measure 6 inches from the tip of the blade to the end of the handle (3-inch long handle and 3-inch long blade) with a #2 tip.

Both straight blade and Phillips screwdrivers are available with a short blade and handle for access to fasteners with limited room. ● **SEE FIGURE 9–18**.

OFFSET SCREWDRIVERS Offset screwdrivers are used in places where a conventional screwdriver cannot fit. An offset screwdriver is bent at the ends and is used similar to a wrench. Most offset screwdrivers have a straight blade at one end and a Phillips end at the opposite end.

TORX A Torx is a six-pointed star-shaped tip that was developed by Camcar (formerly Textron) to offer higher loosening

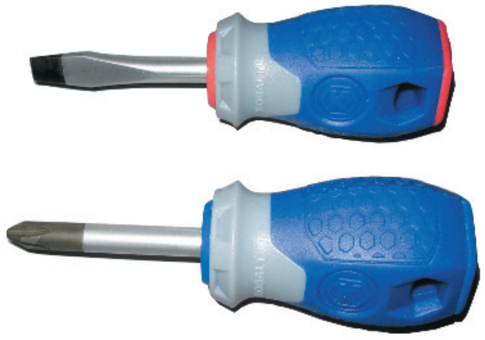


FIGURE 9–18 Two stubby screwdrivers that are used to access screws that have limited space above. A straight blade is on top and a #2 Phillips screwdriver is on the bottom.

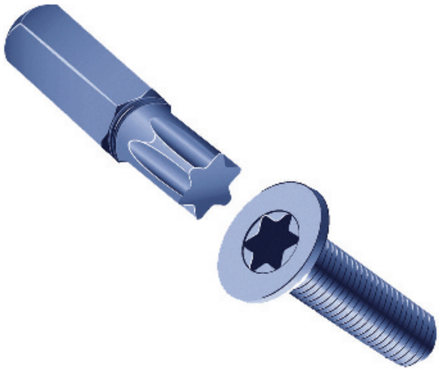


FIGURE 9–19 A Torx bit and fastener.

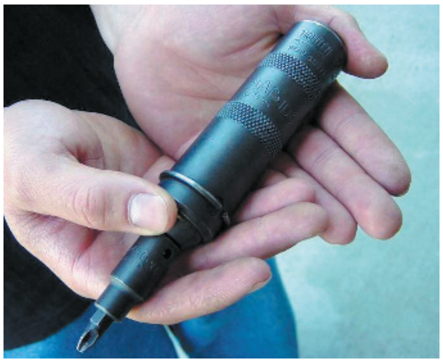


FIGURE 9–20 An impact screwdriver used to remove slotted or Phillips head fasteners that cannot be broken loose using a standard screwdriver.

and tightening torque than is possible with a straight (flat tip) or Phillips. Torx is very commonly used in the automotive field for many components. Commonly used Torx sizes from small to large include: T15, T20, T25, and T30. ● **SEE FIGURE 9–19**.

Some Torx fasteners include a round projection in the center requiring that a special version of a Torx bit be used. These are called security Torx bits that have a hole in the center to be used on these fasteners. External Torx fasteners are also used mostly as engine fasteners and are labeled E instead of T plus the size, such as E45.

IMPACT SCREWDRIVER

An impact screwdriver is used to break loose or tighten a screw. A hammer is used to strike the end after the screwdriver holder is placed in the head of the screw and rotated in the desired direction. The force from the hammer blow does two things: It applies a force downward holding the tip of the screwdriver in the slot and then applies a twisting force to loosen (or tighten) the screw. ● **SEE FIGURE 9–20**.

SAFE USE OF SCREWDRIVERS. Always use the proper type and size screwdriver that matches the fastener. Try to avoid pressing down on a screwdriver because if it slips, the screwdriver tip could go into your hand, causing serious personal injury. All screwdrivers should be cleaned after use. Do not use a screwdriver as a pry bar; always use the correct tool for the job.

HAMMERS AND MALLETS

HAMMERS

Hammers and mallets are used to force objects together or apart. The shape of the back part of the hammer head (called the *peen*) usually determines the name. For example, a ball-peen hammer has a rounded end like a ball and it is used to straighten oil pans and valve covers, using the hammer head, and for shaping metal, using the ball peen. ● **SEE FIGURE 9–21**.

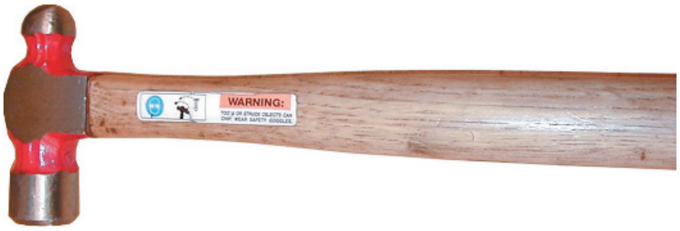


FIGURE 9–21 A typical ball-peen hammer.

NOTE: A claw hammer has a claw used to remove nails and is not used for automotive service.

A hammer is usually sized by the weight of the head of the hammer and the length of the handle. For example, a commonly used ball-peen hammer has an 8 oz head with an 11 inch handle.

MALLETS

Mallets are a type of hammer with a large striking surface, which allows the technician to exert force over a larger area than a hammer, so as not to harm the part or component. Mallets are made from a variety of materials including rubber, plastic, or wood. ● **SEE FIGURE 9–22**.

A shot-filled plastic hammer is called a **dead-blow hammer**. The small lead balls (shot) inside a plastic head prevent the hammer from bouncing off of the object when struck. ● **SEE FIGURE 9–23**.

SAFE USE OF HAMMERS AND MALLETS. All mallets and hammers should be cleaned after use and not exposed to extreme temperatures. Never use a hammer or mallet that is damaged in any way and always use caution to avoid doing damage to the components and the surrounding area. Always follow the hammer manufacturer's recommended procedures and practices.

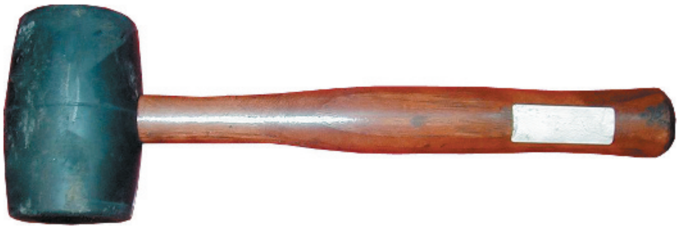


FIGURE 9–22 A rubber mallet is used to deliver a force to an object without harming the surface.

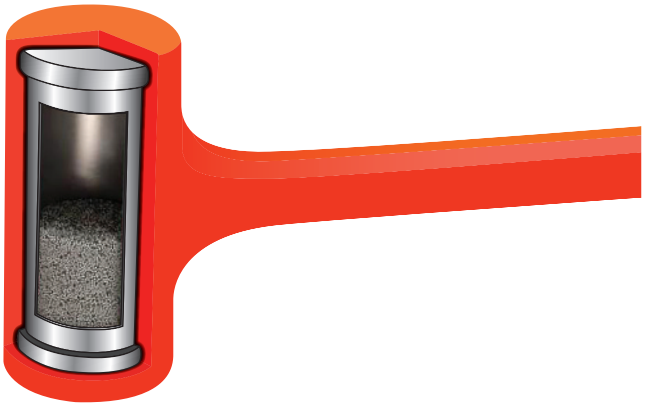


FIGURE 9–23 A dead blow hammer or mallet uses steel shot inside to provide a movable mass that helps increase the force applied.

PLIERS

SLIP-JOINT PLIERS Pliers are capable of holding, twisting, bending, and cutting objects and are an extremely useful classification of tools. The common household type of pliers is called the **slip-joint pliers**. There are two different positions where the junction of the handles meets to achieve a wide range of sizes of objects that can be gripped. ● **SEE FIGURE 9–24**.

MULTIGROOVE ADJUSTABLE PLIERS For gripping larger objects, a set of **multigroove adjustable pliers** is a commonly used tool of choice by many service technicians. Originally designed to remove the various size nuts holding rope seals used in water pumps, the name **water pump pliers** is also used. ● **SEE FIGURE 9–25**.

LINESMAN'S PLIERS Linesman's pliers are specifically designed for cutting, bending, and twisting wire. While commonly used by construction workers and electricians, linesman's pliers are very useful tools for the service technician who deals with wiring. The center parts of the jaws are designed to grasp round objects such as pipe or tubing without slipping. ● **SEE FIGURE 9–26**.

DIAGONAL PLIERS **Diagonal pliers** are designed for cutting only. The cutting jaws are set at an angle to make it easier to cut wires. Diagonal pliers are also called **side cuts** or **dikes.** These pliers are constructed of hardened steel and they are used mostly for cutting wire. ● **SEE FIGURE 9–27**.

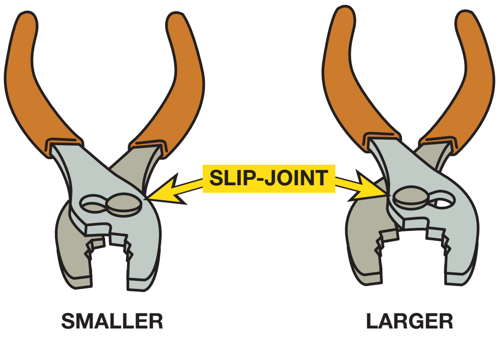


FIGURE 9–24 Typical slip-joint pliers, which are also common household pliers. The slip joint allows the jaws to be opened to two different settings.

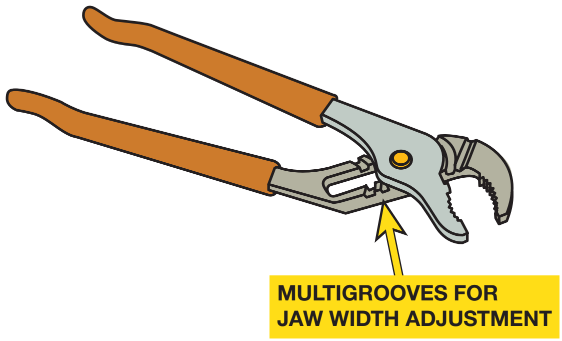


FIGURE 9–25 Multigroove adjustable pliers are known by many names, including the trade name Channel Locks.

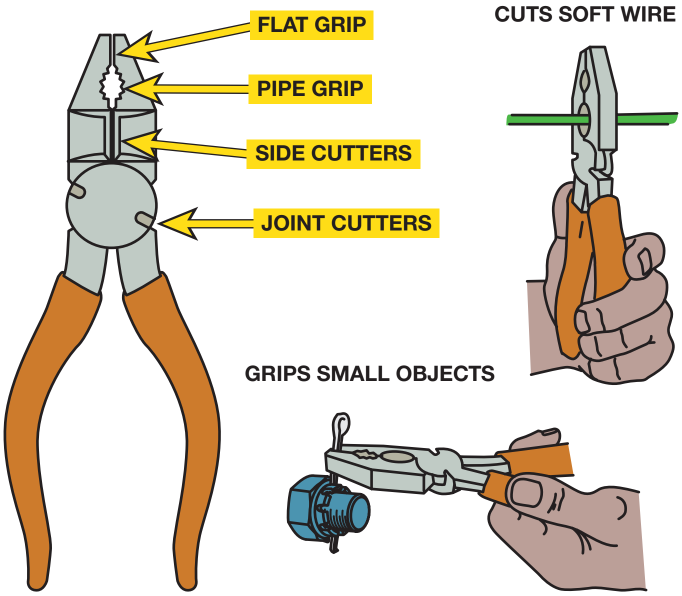


FIGURE 9–26 A linesman's pliers are very useful because they can help perform many automotive service jobs.

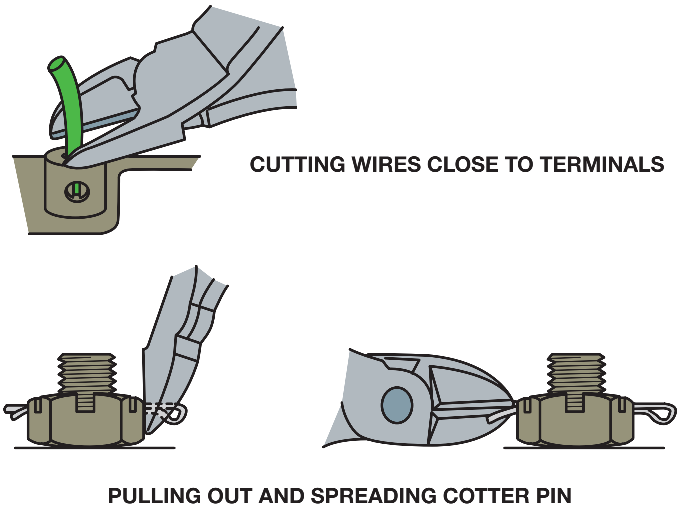

CUTTING WIRES CLOSE TO TERMINALS
PULLING OUT AND SPREADING COTTER PIN

FIGURE 9–27 Diagonal-cut pliers are another common tool that has many names.

NEEDLE-NOSE PLIERS **Needle-nose pliers** are designed to grip small objects or objects in tight locations. Needle-nose pliers have long, pointed jaws, which allow the tips to reach into narrow openings or groups of small objects. ● **SEE FIGURE 9–28**.

Most needle-nose pliers have a wire cutter located at the base of the jaws near the pivot. There are several variations of needle-nose pliers, including right angle jaws or slightly angled to allow access to certain cramped areas.

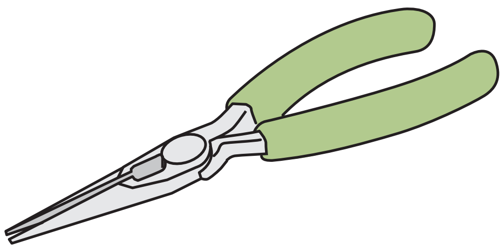


FIGURE 9–28 Needle-nose pliers are used where there is limited access to a wire or pin that needs to be installed or removed.

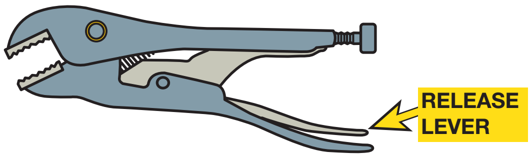


FIGURE 9–29 Locking pliers are best known by their trade name Vise-Grip®.

LOCKING PLIERS

Locking pliers are adjustable pliers that can be locked to hold objects from moving. Most locking pliers also have wire cutters built into the jaws near the pivot point. Locking pliers come in a variety of styles and sizes and are commonly referred to by their trade name **Vise-Grip®**. The size is the length of the pliers, not how far the jaws open. ● **SEE FIGURE 9–29**.

SAFE USE OF PLIERS. Pliers should not be used to remove any bolt or other fastener. Pliers should only be used when specified for use by the vehicle manufacturer.

SNAP-RING PLIERS

Snap-ring pliers are used to remove and install snap rings. Many snap-ring pliers are designed to be able to remove and install inward, as well as outward, expanding snap rings. Snap-ring pliers can be equipped with serrated-tipped jaws for grasping the opening in the snap ring, while others are equipped with points, which are inserted into the holes in the snap ring. ● **SEE FIGURE 9–30**.

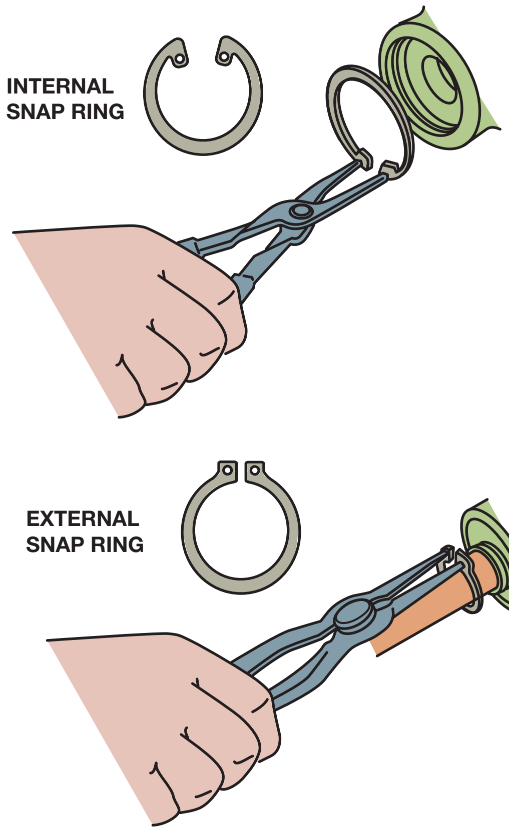


FIGURE 9–30 Snap-ring pliers are also called lock-ring pliers and are designed to remove internal and external snap rings (lock rings).

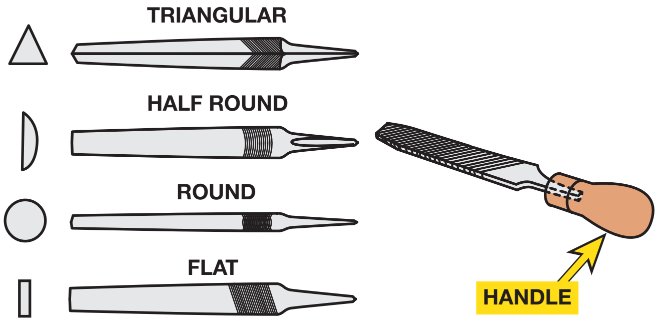


FIGURE 9–31 Files come in many different shapes and sizes. Never use a file without a handle.

FILES

Files are used to smooth metal and are constructed of hardened steel with diagonal rows of teeth. Files are available with a single row of teeth called a **single-cut file**, as well as two rows of teeth cut at an opposite angle called a **double-cut file**. Files are available in a variety of shapes and sizes from small flat files, half round files, and triangular files. ● **SEE FIGURE 9–31**.

TECH TIP

Brand Name versus Proper Term

Technicians often use slang or brand names of tools rather than the proper term. This results in some confusion for new technicians. Some examples are given in the following table.

Brand Name	Proper Term	Slang Name
Crescent wrench	Adjustable wrench	Monkey wrench
Vise Grip®	Locking pliers	
Channel Locks	Water pump pliers or multigroove adjustable pliers	Pump pliers
	Diagonal cutting pliers	Dikes or side cuts

TECH TIP

Use Chalk

Often soft metal particles can become stuck in a file, especially when using it to file aluminum or other soft metals. Rub some chalk into the file before using it to prevent this from happening.

SAFE USE OF FILES. Always use a file with a handle. Because files only cut when moved forward, a handle must be attached to prevent possible personal injury. After making a forward strike, lift the file and return the file to the starting position. Avoid dragging the file backward.

CUTTERS

SNIPS

Service technicians are often asked to fabricate sheet metal brackets or heat shields and need to use one or more types of cutters available. The simplest is called **tin snips**, which are designed to make straight cuts in a variety of materials, such

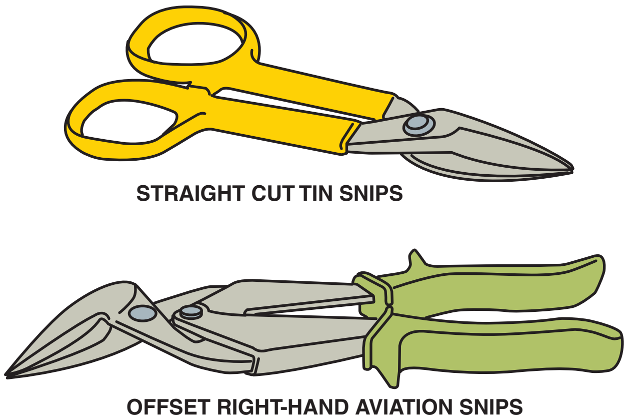


FIGURE 9–32 Tin snips are used to cut thin sheets of metal or carpet.

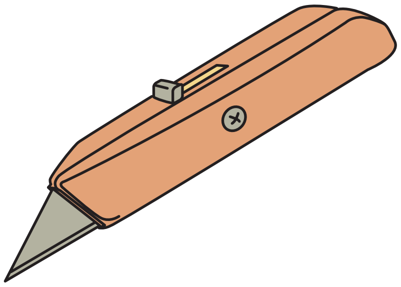


FIGURE 9–33 A utility knife uses replaceable blades and is used to cut carpet and other materials.

as sheet steel, aluminum, or even fabric. A variation of the tin snips is called **aviation tin snips**. There are three designs of aviation snips including one designed to cut straight (called **straight cut aviation snips**), one designed to cut left (called an **offset left aviation snips**), and one designed to cut right (called **offset right aviation snips**). The handles are color coded for easy identification. These include yellow for straight, red for left, and green for right. ● **SEE FIGURE 9–32**.

UTILITY KNIFE

A **utility knife** uses a replaceable blade and is used to cut a variety of materials, such as carpet, plastic, wood, and paper products, such as cardboard. ● **SEE FIGURE 9–33**.

SAFE USE OF CUTTERS. Whenever using cutters, always wear eye protection or a face shield to guard against the possibility of metal pieces being ejected during the cut. Always follow recommended procedures.

PUNCHES AND CHISELS

PUNCHES

A **punch** is a small diameter steel rod that has a smaller diameter ground at one end. A punch is used to drive a pin out that is used to retain two components. Punches come in a variety of sizes, which are measured across the diameter of the machined end. Sizes include 1/16 inch, 1/8 inch, 3/16 inch, and 1/4 inch. ● **SEE FIGURE 9–34**.

CHISELS

A **chisel** has a straight, sharp cutting end that is used for cutting off rivets or to separate two pieces of an assembly. The most common design of chisel used for automotive service work is called a **cold chisel**.

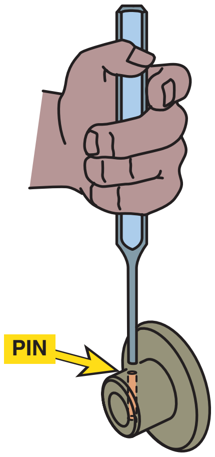


FIGURE 9–34 A punch used to drive pins from assembled components. This type of punch is also called a pin punch.

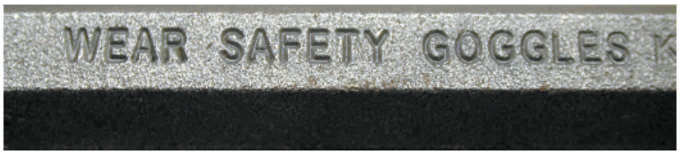


FIGURE 9–35 Warning stamped in the side of a punch warning that goggles should be worn when using this tool. Always follow safety warnings.

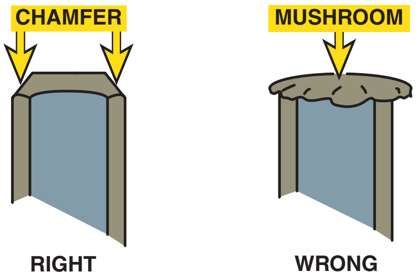


FIGURE 9–36 Use a grinder or a file to remove the mushroom material on the end of a punch or chisel.

SAFE USE OF PUNCHES AND CHISELS. Always wear eye protection when using a punch or a chisel because the hardened steel is brittle and parts of the punch could fly off and cause serious personal injury. See the warning stamped on the side of this automotive punch in ● **FIGURE 9–35**.

Punches and chisels can also have the top rounded off, which is called "mushroomed." This material must be ground off to help avoid the possibility that the overhanging material is loosened and becomes airborne during use. ● **SEE FIGURE 9–36**.

REMOVERS

Removers are tools used to remove damaged fasteners. A remover tool is not normally needed during routine service, unless the fastener is corroded or has been broken or damaged by a previous attempt to remove the bolt or nut.

To help prevent the need for a remover tool, all rusted and corroded fasteners should be sprayed with penetrating oil. Penetrating oil is a low viscosity oil that is designed to flow in between the threads of a fastener or other small separation between two parts. Commonly used penetrating oils include WD-40®, Kroil®, and CRC 5-56.

CAUTION: Do not use penetrating oil as a lubricating oil because it is volatile and will evaporate soon after usage, leaving little lubricant behind for protection.

Removers are a classification of tool used to remove stuck or broken fasteners. Over time, rust and corrosion can cause the threads of the fastener to be attached to the nut or the casting, making it very difficult to remove. There are several special tools that can be used to remove damaged fasteners. Which one to use depends on the type of damage.

DAMAGED HEADS If the bolt head or a nut becomes damaged or rounded, there are two special tools that can be used, including:

- **Stud remover.** A **stud removal tool** grips the part of the stud above the surface and uses a cam or wedge to grip the stud as it is being rotated by a ratchet or breaker bar. ● **SEE FIGURE 9–37**.
- **Nut splitter.** A **nut splitter** is used to remove the nut by splitting it from the bolt. A nut splitter is used by inserting the cutter against a flat of the nut and tightening the threaded bolt of the splitter. The nut will be split away from the bolt and can then be removed. ● **SEE FIGURE 9–38**.

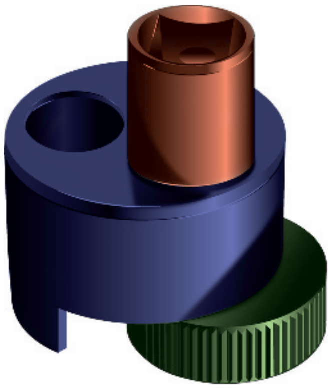


FIGURE 9–37 A stud remover uses an offset serrated wheel to grasp the stud so it will be rotated when a ratchet or breaker bar is used to rotate the assembly.

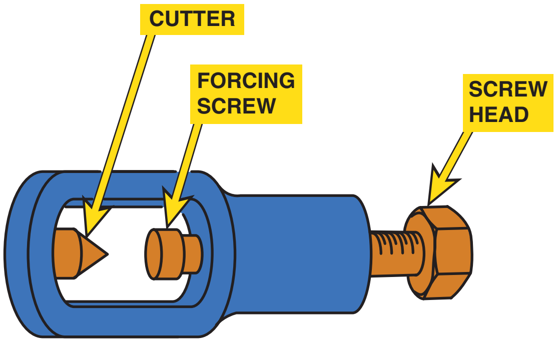


FIGURE 9–38 A nut splitter is used to split a nut that cannot be removed. After the nut has been split, a chisel is used to remove the nut.

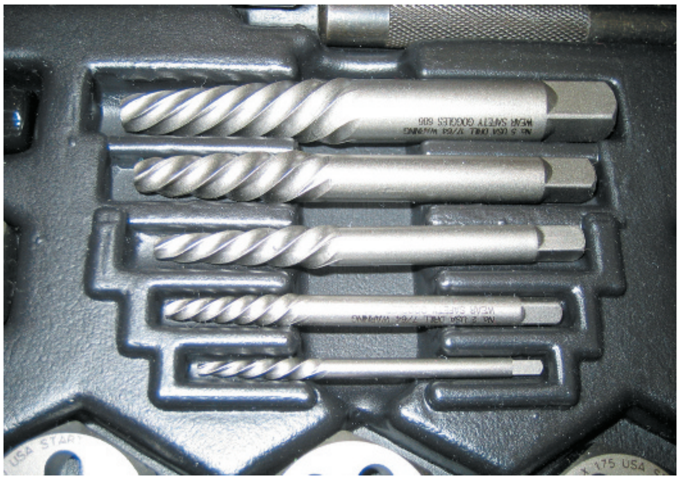


FIGURE 9–39 A set of bolt extractors, commonly called easy outs.

CAUTION: Do not rotate the entire nut splitter or damage to the cutting wedge will occur.

BROKEN BOLTS, STUDS, OR SCREWS Often, bolts, studs, or screws break within the surface, making stud removal tools impossible to use. Bolt extractors are commonly called **easy outs**. An easy out is constructed of hardened steel with flutes or edges ground into the side in the opposite direction of most threads. ● **SEE FIGURE 9–39**.

NOTE: Always select the largest extractor that can be used to help avoid the possibility of breaking the extractor while attempting to remove the bolt.

A hole is drilled into the center of a broken bolt. Then, the extractor (easy out) is inserted into the hole and rotated counterclockwise using a wrench. As the extractor rotates, the grooves grip tighter into the wall of the hole drilled in the broken bolt. As a result, most extractors are capable of removing most broken bolts.

HACKSAWS

A **hacksaw** is used to cut metals, such as steel, aluminum, brass, or copper. The cutting blade of a hacksaw is replaceable and the sharpness and number of teeth can be varied to meet

TECH TIP

The Wax Trick

Many times, rusted fasteners can be removed by using heat to expand the metal and break the rust bond between the fastener and the nut or casting. Many technicians heat the fastener using a torch and then apply paraffin wax or a candle to the heated fastener. ● **SEE FIGURE 9–40**. The wax will melt and as the part cools, will draw the liquid wax down between the threads. After allowing the part to cool, attempt to remove the fastener. It will often be removed without any trouble.

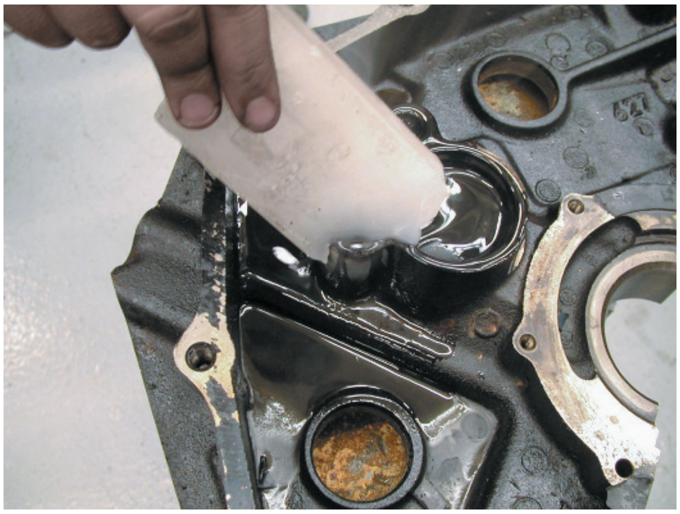


FIGURE 9–40 Removing plugs or bolts is easier if the plug is first heated to a cherry red color, using a torch, and then applying wax. During cooling, the wax flows in between the threads, making it easier to remove.

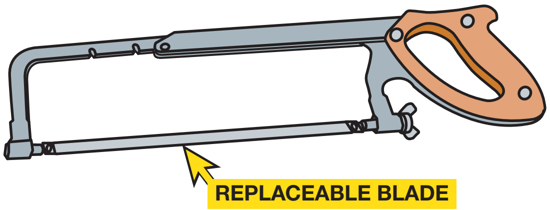


FIGURE 9–41 A typical hacksaw that is used to cut metal. If cutting sheet metal or thin objects, a blade with more teeth should be used.

the needs of the job. Use 14 or 18 teeth per inch (tpi) for cutting plaster or soft metals, such as aluminum and copper. Use 24 or 32 tpi for steel or pipe. Hacksaw blades should be installed with the teeth pointing away from the handle. This means that a hacksaw cuts while the blade is pushed in the forward direction, and then pressure should be released as the blade is pulled rearward before repeating the cutting operation. ● **SEE FIGURE 9–41**.

FREQUENTLY ASKED QUESTION

I Broke Off an Easy Out—Now What?

An extractor (easy out) is hardened steel and removing this and the broken bolt is now a job for a professional machine shop. The part, which could be as large as an engine block, needs to be removed from the vehicle and taken to a machine shop that is equipped to handle this type of job. One method involves using an electrical discharge machine (EDM). An EDM uses a high-amperage electrical current to produce thousands of arcs between the electrode and the broken tool. The part is submerged in a nonconducting liquid and each tiny spark vaporizes a small piece of the broken tool.

SAFE USE OF HACKSAWS. Check that the hacksaw is equipped with the correct blade for the job and that the teeth are pointed away from the handle. When using a hacksaw, move the hacksaw slowly away from you, then lift slightly and return for another cut.

RECOMMENDED HAND TOOLS

BASIC HAND TOOL LIST Hand tools are used to turn fasteners (bolts, nuts, and screws). The following is a list of hand tools every automotive technician should possess. Specialty tools are not included.

Safety glasses
Tool chest
1/4 inch drive socket set (1/4 to 9/16 inch standard and deep sockets; 6 to 15 mm standard and deep sockets)
1/4 inch drive ratchet
1/4 inch drive 2 inch extension
1/4 inch drive 6 inch extension
1/4 inch drive handle
3/8 inch drive socket set (3/8 to 7/8 inch standard and deep sockets; 6 to 19 mm standard and deep sockets)
3/8 inch drive Torx set (T40, T45, T50, and T55)
3/8 inch drive 13/16 inch plug socket
3/8 inch drive 5/8 inch plug socket
3/8 inch drive ratchet
3/8 inch drive 1 1/2 inch extension
3/8 inch drive 3 inch extension
3/8 inch drive 6 inch extension
3/8 inch drive 18 inch extension
3/8 inch drive universal
1/2 inch drive socket set (1/2 to 1 inch standard and deep sockets; 9 to 19 mm standard and deep metric sockets)
1/2 inch drive ratchet
1/2 inch drive breaker bar
1/2 inch drive 5 inch extension
1/2 inch drive 10 inch extension
3/8 to 1/4 inch adapter
1/2 to 3/8 inch adapter
3/8 to 1/2 inch adapter
3/8 inch and 1/2 inch torque wrench
Torque angle gauge
Crowfoot set (fractional inch)
Crowfoot set (metric)
3/8 through 1 inch combination wrench set
10 through 19 mm combination wrench set
1/16 through 1/4 inch hex (Allen) wrench set
2 through 12 mm hex (Allen) wrench set
3/8 inch hex socket
8 to 19 mm flare nut wrench set
5/16 to 3/8 inch flare nut wrench
7/16 to 1/2 inch flare nut wrench
1/2 *to* 9/16 inch flare nut wrench

Diagonal pliers
Needle pliers
Adjustable-jaw pliers
Locking pliers
Snap-ring pliers
Stripping or crimping pliers
Ball-peen hammer
Rubber hammer
Dead-blow hammer
Five-piece standard screwdriver set
Four-piece Phillips screwdriver set
#15 Torx screwdriver
#20 Torx screwdriver
File
Center punch
Pin punches (assorted sizes)
Chisel
Utility knife
Valve core tool
Filter wrench (large filters)
Filter wrench (smaller filters)
Test light
Feeler gauge
Scraper
Magnet
Tire pressure gauge

TECH TIP

Need to Borrow a Tool More Than Twice? Buy It!

Most service technicians agree that it is okay for a beginning technician to borrow a tool occasionally. However, if a tool has to be borrowed more than twice, be sure to purchase it as soon as possible. Also, whenever a tool is borrowed, be sure that you clean the tool and let the technician you borrowed the tool from know that you are returning the tool. These actions will help in any future dealings with other technicians.

TECH TIP

Hide Those from the Boss

An apprentice technician started working for a dealership and put their top tool box on a workbench. Another technician observed that, along with a complete set of good-quality tools, the box contained several adjustable wrenches. The more experienced technician said, "Hide those from the boss." If any adjustable wrench is used on a bolt or nut, the movable jaw often moves or loosens and starts to round the head of the fastener. If the head of the bolt or nut becomes rounded, it becomes that much more difficult to remove.

TOOL SETS AND ACCESSORIES A beginning service technician may wish to start with a small set of tools before spending a lot of money on an expensive, extensive tool box. ● **SEE FIGURES 9–42 AND 9–43**.

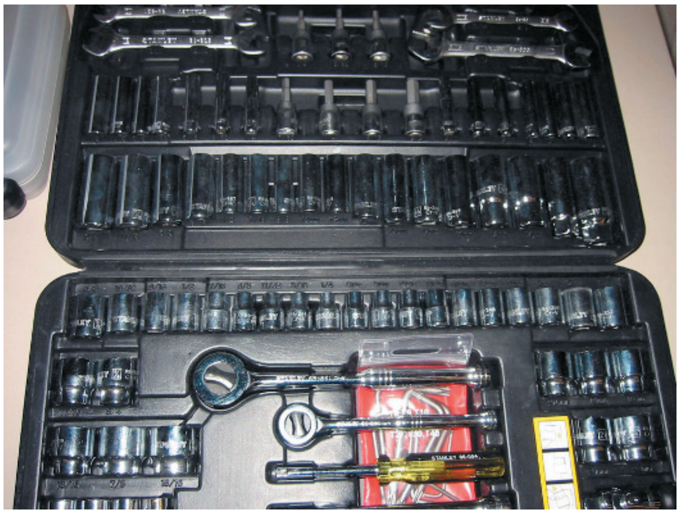


FIGURE 9–42 A typical beginning technician tool set that includes the basic tools to get started.

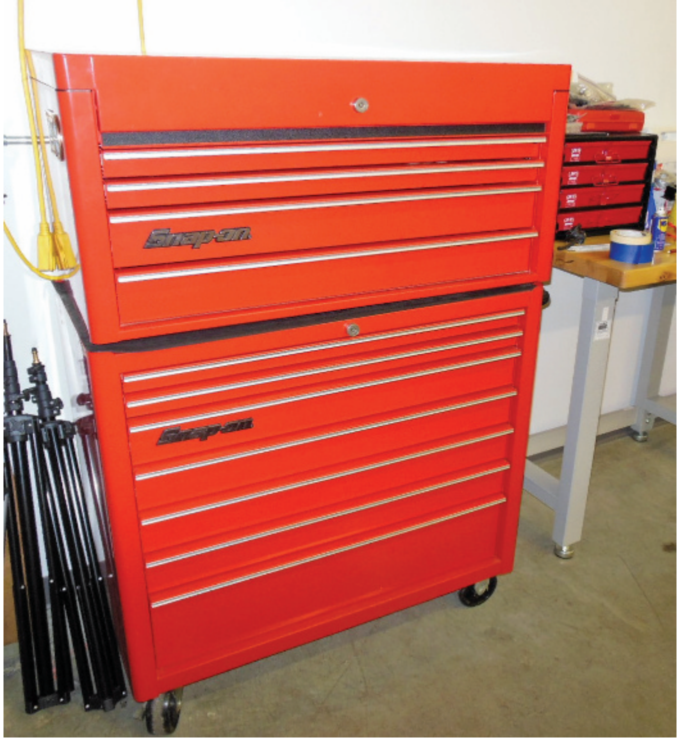


FIGURE 9–43 A typical 40-inch wide top and bottom professional tool box.

TECH TIP

The Valve Grinding Compound Trick

Apply a small amount of valve grinding compound to a Phillips or Torx screw or bolt head. The gritty valve grinding compound "grips" the screwdriver or tool bit and prevents the tool from slipping up and out of the screw head. Valve grinding compound is available in a tube from most automotive parts stores.

TECH TIP

It Just Takes a Second

Whenever removing any automotive component, it is wise to screw the bolts back into the holes a couple of threads by hand. This ensures that the right bolt will be used in its original location when the component or part is put back on the vehicle. Often, the same diameter of fastener is used on a component, but the length of the bolt may vary. Spending just a couple of seconds to put the bolts and nuts back where they belong when the part is removed can save a lot of time when the part is being reinstalled. Besides making certain that the right fastener is being installed in the right place, this method helps prevent bolts and nuts from getting lost or kicked away. How much time have you wasted looking for that lost bolt or nut?

SPECIAL SERVICE TOOLS (SSTs) Automotive dealerships have tool rooms that are supposed to have all the SSTs that are recommended by the factory. These tool rooms are for the use of the dealership technicians so that they have access to the tools needed to work on the vehicle being serviced. The tools are often sorted by content area and are identified by a tool number. SSTs are made primarily by a small group of manufacturers. They make the following SSTs:

- Miller Special Tools (Chrysler)
- Rotunda Tools (Ford, Mazda, Jaguar, Land Rover)
- Kent-Moore Tools (Detroit Diesel, General Motors, Hyundai, Lexus, Mitsubishi, Nissan, Saab, Subaru, Volvo, Kia, Toyota, Isuzu). ● **SEE FIGURE 9–44**.

Other Manufacturers of SSTs include the following:

- Sir Tools
- Assenmacher
- Baum Tools

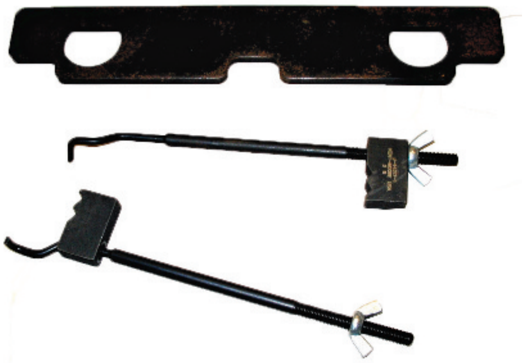


FIGURE 9–44 The special tool number is printed or stamped on the tool for easy identification. The Kent-Moore part number J-44217 indicates a tool used to hold a timing chain.

SAFETY TIPS FOR USING HAND TOOLS

The following safety tips should be kept in mind whenever you are working with hand tools.

- Always *pull* a wrench toward you for best control and safety. Never push a wrench.
- Keep wrenches and all hand tools clean to help prevent rust and to allow for a better, firmer grip.
- Always use a six-point socket or a box-end wrench to break loose a tight bolt or nut.
- Use a box-end wrench for torque and an open-end wrench for speed.
- Never use a pipe extension or other type of "**cheater bar**" on a wrench or ratchet handle. If more force is required, use a larger tool or use penetrating oil and/or heat on the frozen fastener. (If heat is used on a bolt or nut to remove it, always replace it with a new part.)
- Always use the proper tool for the job. If a specialized tool is required, use the proper tool and do not try to use another tool improperly.
- Never expose any tool to excessive heat. High temperatures can reduce the strength ("draw the temper") of metal tools.
- Never use a hammer on any wrench or socket handle unless you are using a special "staking face" wrench designed to be used with a hammer.
- Replace any tools that are damaged or worn.

TECH TIP

Use a Binder Clip

A binder clip (size 1 1/4 inch wide) is used by wise technicians to help keep fender covers in place. ● **SEE FIGURE 9–45**. Binder clips are found at office supply stores.

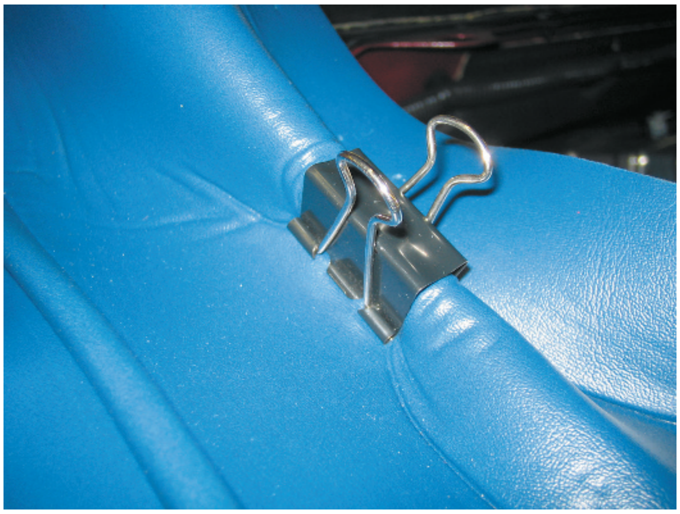


FIGURE 9–45 A binder clip being used to keep a fender cover from falling.

HAND TOOL MAINTENANCE

Most hand tools are constructed of rust-resistant metals, but they can still rust or corrode if not properly maintained. For best results and long tool life, the following steps should be taken.

- Clean each tool before placing it back into the tool box.
- Keep tools separated. Moisture on metal tools will start to rust more readily if the tools are in contact with another metal tool.
- Line the drawers of the tool box with a material that will prevent the tools from moving as the drawers are opened and closed. This helps to quickly locate the proper tool and size.
- Release the tension on all "clicker-type" torque wrenches after use.
- Keep the tool box secure.

FREQUENTLY ASKED QUESTION

What Is the Best Trouble Light to Use in the Shop?

A **trouble light**, also called a **work light** is an essential piece of shop equipment, and for safety, should be fluorescent rather than incandescent. Incandescent light bulbs can scatter or break if gasoline were to be splashed onto the bulb, creating a serious fire hazard. Fluorescent light tubes are not as likely to be broken and are usually protected by a clear plastic enclosure. Trouble lights are usually attached to a retractor, which can hold 20 to 50 ft of electrical cord.

Light-emitting diode (LED) trouble lights are excellent to use because they are shock resistant, long lasting, and do not represent a fire hazard. Some trouble lights are battery powered and therefore can be used in places where an attached electrical cord could present problems. ● **SEE FIGURE 9–46**.

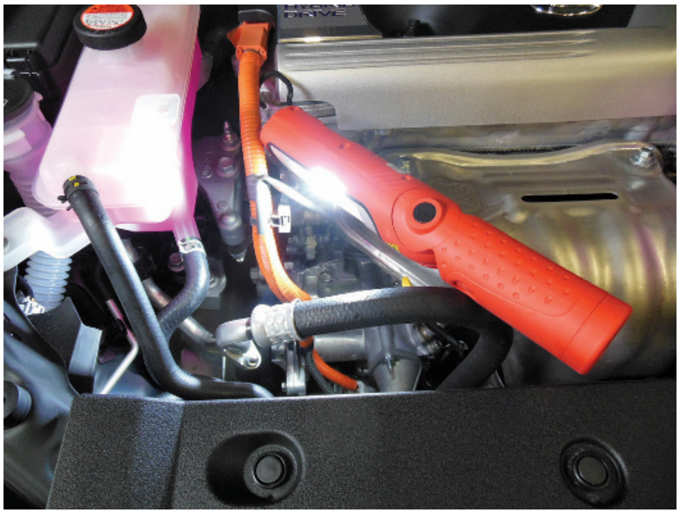


FIGURE 9–46 A battery-powered LED trouble light.

AIR COMPRESSOR

A shop air compressor is usually located in a separate room or an area away from the customer area of a shop. An **air compressor** is powered by a 220 volt AC electric motor and includes a storage tank and the compressor itself, as well as the pressure switches, which are used to maintain a certain minimum level of air pressure in the system. The larger the storage tank, expressed in gallons, the longer an air tool can be operated in the shop without having the compressor start operating. ● **SEE FIGURE 9–47**.

SAFE USE OF COMPRESSED AIR. Air under pressure can create dangerous situations. For example, an object, such as a small piece of dirt, could be forced out of an air hose blow gun with enough force to cause serious personal injury. All OSHA-approved air nozzles have air vents drilled around the outside of the main discharge hole to help reduce the force of the air blast. Also, the air pressure used by an air nozzle (blow gun) must be kept to 30 PSI (207 kPa) or less. ● **SEE FIGURE 9–48**.

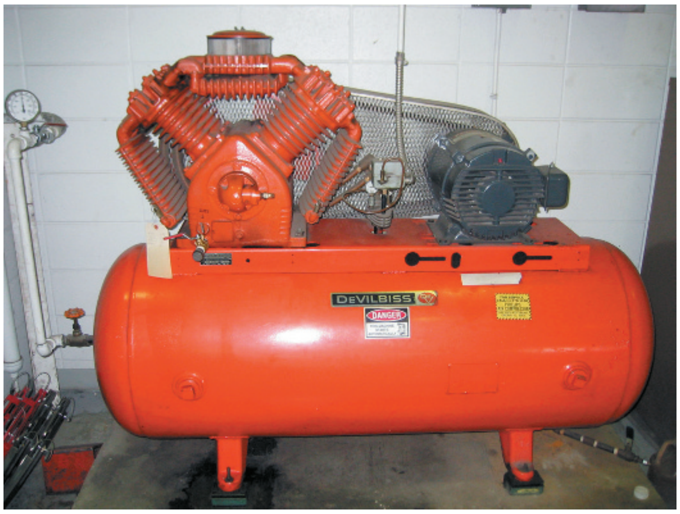


FIGURE 9–47 A typical shop compressor. It is usually placed out of the way, yet accessible to provide for maintenance to the unit.

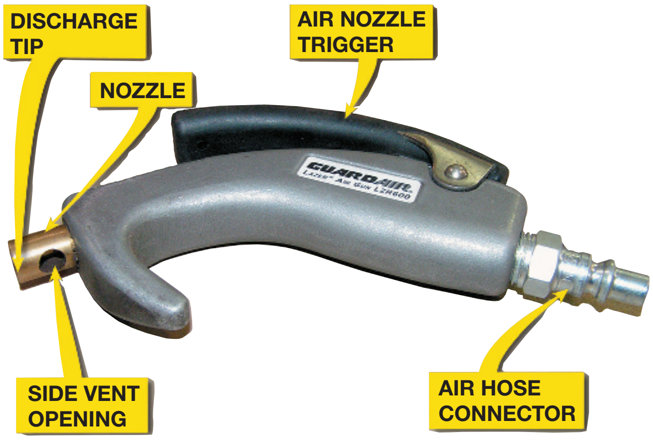


FIGURE 9–48 Always use an air nozzle that is OSHA approved. The openings in the side are used to allow air to escape if the nozzle tip were to become clogged.

AIR AND ELECTRICALLY OPERATED TOOLS

IMPACT WRENCH An **impact wrench**, either air (pneumatic) or electrically powered, is a tool that is used to remove and install fasteners. The air-operated 1/2-inch drive impact wrench is the most commonly used unit. ● **SEE FIGURE 9–49**.

The direction of rotation is controlled by a switch. ● **SEE FIGURE 9–50**.

Electrically powered impact wrenches commonly include:

- Battery-powered units. ● **SEE FIGURE 9–51**.
- 110-volt AC-powered units. This type of impact wrench is very useful, especially if compressed air is not readily available.

CAUTION: Always use impact sockets with impact wrenches, and be sure to wear eye protection in case the socket or fastener shatters. Impact sockets are thicker walled and constructed with premium alloy steel. They are hardened with a black oxide finish to help prevent corrosion and distinguish them from regular sockets. ● **SEE FIGURE 9–52**.

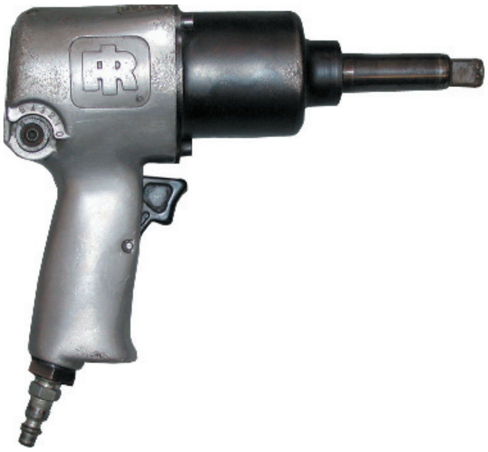


FIGURE 9–49 A typical 1/2-inch drive impact wrench.

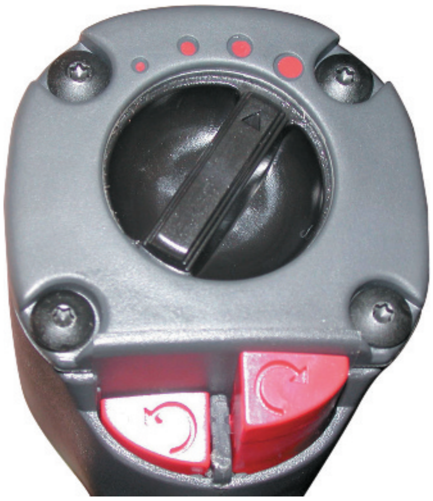


FIGURE 9–50 This impact wrench features a variable torque setting using a rotary knob. The direction of rotation can be changed by pressing the button at the bottom.

AIR RATCHET An **air ratchet** is used to remove and install fasteners that would normally be removed or installed using a ratchet and a socket. An air ratchet is much faster, yet has an air hose attached, which reduces accessibility to certain places. ● **SEE FIGURE 9–53**.

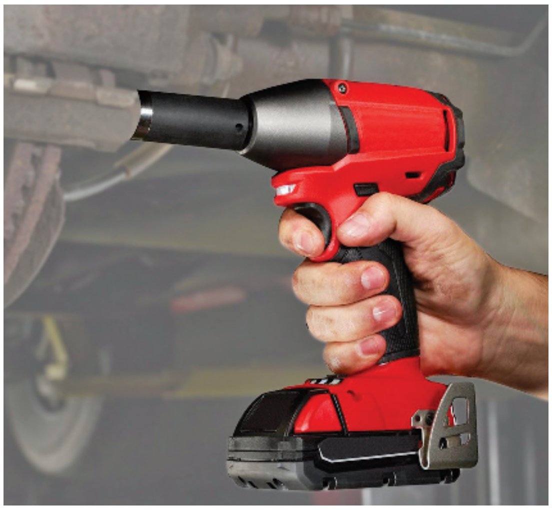


FIGURE 9–51 A typical battery-powered 1/2-inch drive impact wrench.

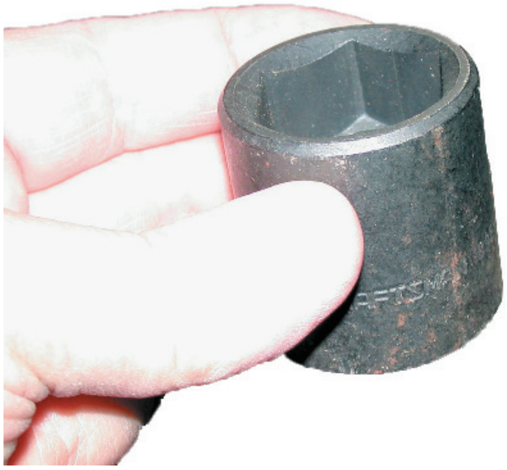


FIGURE 9–52 A black impact socket. Always use impact-type sockets whenever using an impact wrench to avoid the possibility of shattering the socket, which can cause personal injury.

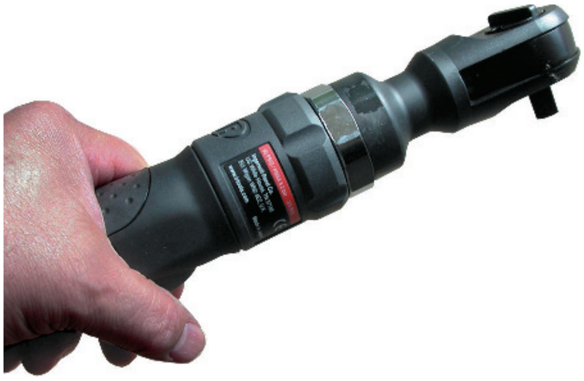


FIGURE 9–53 An air ratchet is a very useful tool that allows fast removal and installation of fasteners, especially in areas that are difficult to reach or do not have room enough to move a hand ratchet wrench.

CASE STUDY

The Case of the Rusty Air Impact Wrenches

In one busy shop, it was noticed by several technicians that water was being pumped through the air compressor lines and out of the vents of air impact wrenches whenever they were used. It is normal for moisture in the air to condense in the air storage tank of an air compressor. One of the routine service procedures is to drain the water from the air compressor. The water had been drained regularly from the air compressor at the rear of the shop, but the problem continued. Then someone remembered that there was a second air compressor mounted over the parts department. No one could remember ever draining the tank from that compressor. After that tank was drained, the problem of water in the lines was solved.

Summary:

Complaint—Water was found in the air lines in the shop.

Cause—Water was found in the second compressor above the parts department.

Correction—The service manager assigned a person to drain water from both compressors everyday. The water problem was solved.

DIE GRINDER A **die grinder** is a commonly used air-powered tool, which can also be used to sand or remove gaskets and rust. ● **SEE FIGURE 9–54**.

AIR DRILL An **air drill** is a drill that rotates faster than electric drills (up to 20,000 RPM). Air drills are commonly used in auto body work when many holes need to be drilled for plug welding.

AIR-BLOW GUN An **air-blow gun** is used to clean equipment and other purposes where a stream of air would be needed. Automotive air-blow guns should meet OSHA requirements and include passages to allow air to escape outward at the nozzle, thereby relieving pressure if the nozzle were to become blocked.

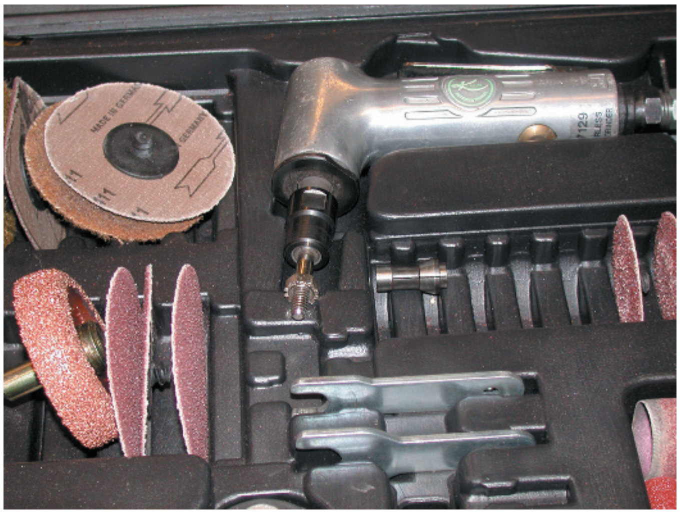


FIGURE 9–54 This typical die grinder surface preparation kit includes the air-operated die grinder, as well as a variety of sanding discs for smoothing surfaces or removing rust.

AIR-OPERATED GREASE GUN An air-operated grease gun uses shop air to operate a plunger, which then applies a force to the grease cartridge. Most air-operated grease guns use a 1/4 inch air inlet and operate on 90 PSI of air pressure.

BATTERY-POWERED GREASE GUN Battery-powered grease guns are more expensive than air-operated grease guns but offer the convenience of not having an air hose attached, making use easier. Many use rechargeable 14 to 18 volt batteries and use standard grease cartridges.

SHOP EQUIPMENT

BENCH-OR PEDESTAL-MOUNTED GRINDER These high-powered grinders can be equipped with a wire brush wheel and/or a stone wheel.

- A **wire brush wheel** is used to clean steel or sheet metal parts.
- A **stone wheel** is used to grind metal or to remove the mushroom from the top of punches or chisels. ● **SEE FIGURE 9–55**.

CAUTION: Always wear a face shield when using a wire wheel or a grinder. Also keep the part support ledge (table), also called a throat plate, within 1/16 inch (2 mm) of the stone.

Most **bench grinders** are equipped with a grinding wheel (stone) on one side and a wire brush wheel on the other side. A bench grinder is a very useful piece of shop equipment and the wire wheel end can be used for the following:

- Cleaning threads of bolts
- Cleaning gaskets from sheet metal parts, such as steel valve covers

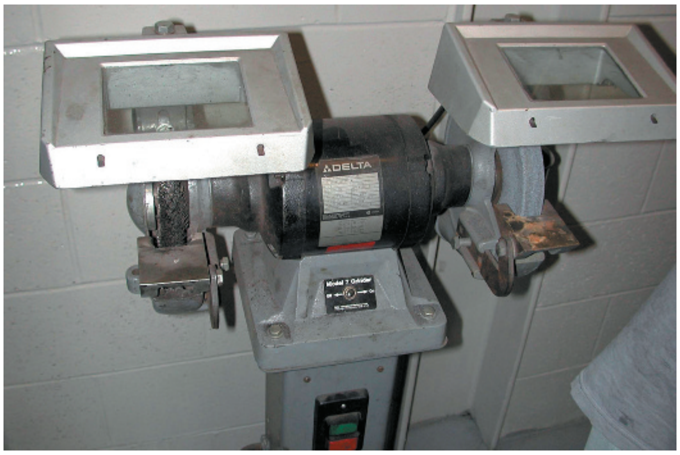


FIGURE 9–55 A typical pedestal grinder with a wire wheel on the left side and a stone wheel on the right side. Even though this machine is equipped with guards, safety glasses or a face shield should always be worn when using a grinder or wire wheel.

CAUTION: Use a steel wire brush only on steel or iron components. If a steel wire brush is used on aluminum or copper-based metal parts, it can remove metal from the part.

The grinding stone end of the bench grinder can be used for the following:

- Sharpening blades and drill bits
- Grinding off the heads of rivets or parts
- Sharpening sheet metal parts for custom fitting

BENCH VISE A **bench vise** is used to hold components so that work can be performed on the unit. The size of a vise is determined by the width of the jaws. Two common sizes of vises are 4 inch and 6 inch models. The jaws of most vises are serrated and can cause damage to some components unless protected. Many types of protection can be used, including aluminum or copper jaw covers or by simply placing wood between the vise jaws and the component being held. ● **SEE FIGURE 9–56**.

SAFE USE OF VISES. The jaws of vises can cause damage to the part or component being held. Use pieces of wood or other soft material between the steel jaws and the workpiece to help avoid causing damage. Many vises are sold with optional aluminum jaw covers. When finished using a vise, be sure to close the jaws and place the handle straight up and down to help avoid personal injury to anyone walking near the vise.

HYDRAULIC PRESSES **Hydraulic presses** are hand-operated hydraulic cylinders mounted to a stand and designed to press bearings on or off of shafts, as well as other components. To press off a bearing, a unit called a **bearing splitter** is often required to apply force to the inner race of a bearing. Hydraulic presses use a pressure gauge to show the pressure being applied. Always follow the operating instructions supplied by the manufacturer of the hydraulic press. ● **SEE FIGURE 9–57**.

PORTABLE CRANE AND CHAIN HOIST A **portable crane** is used to remove and install engines and other heavy vehicle components. Most portable cranes use a hand-operated hydraulic cylinder to raise and lower a boom that is equipped with a nylon strap or steel chain. At the end of the strap or chain is a steel hook that is used to attach around a bracket or auxiliary lifting device. ● **SEE FIGURE 9–58**.

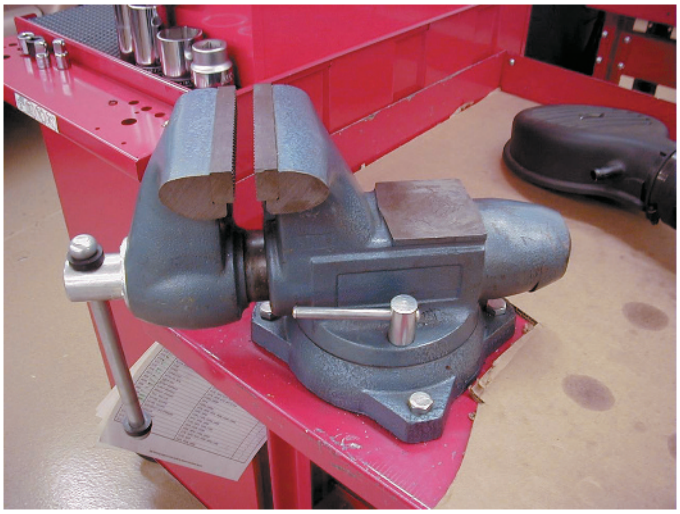


FIGURE 9–56 A typical vise mounted to a workbench.

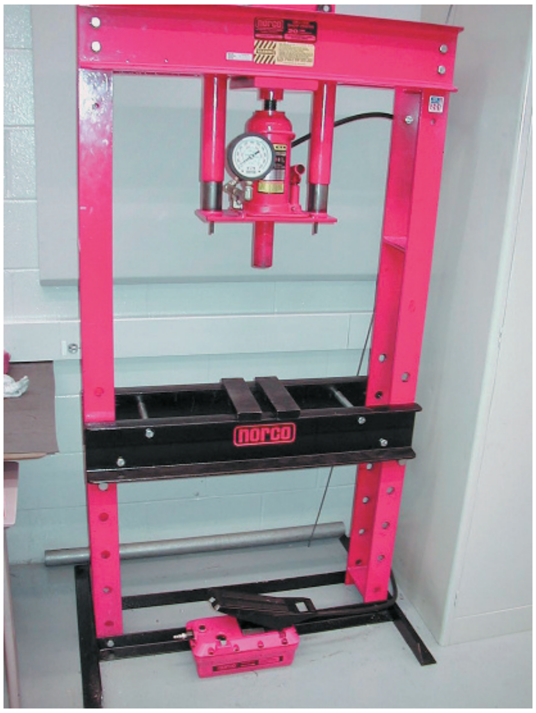


FIGURE 9–57 A hydraulic press is usually used to press bearings on and off of rear axles and transmissions.

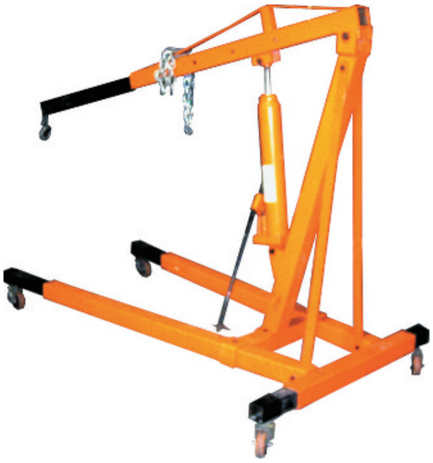


FIGURE 9–58 A typical portable crane used to lift and move heavy assemblies, such as engines and transmissions.

SAFE USE OF PORTABLE CRANES. Always be sure to attach the hook(s) of the portable crane to a secure location on the unit being lifted. The hook should also be attached to the center of the weight of the object so it can be lifted straight up without tilting.

TECH TIP

Cover Work While Pressing

Whenever pressing on a bearing or other component, use an old brake drum over the shaft and the bearing. In the event the bearing shatters during the pressing operation, the brake drum will prevent the parts of the bearing from flying outward where they could cause serious personal injury.

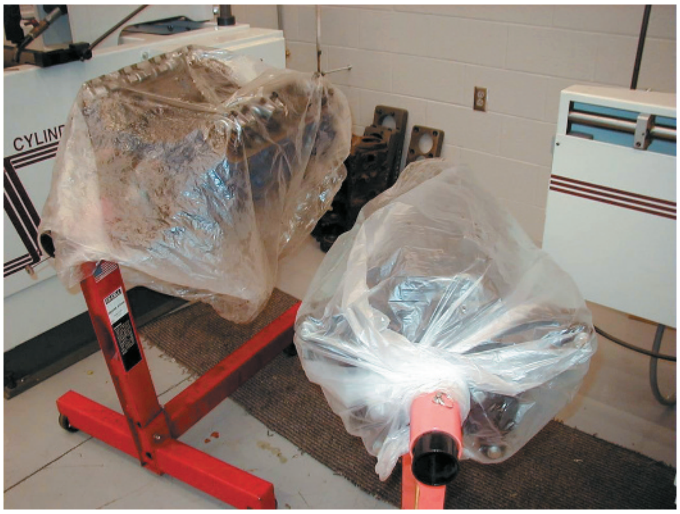


FIGURE 9–59 Two engines on engine stands. The plastic bags over the engines help keep dirt from getting onto these engines and engine parts.

CAUTION: Always keep feet and other body parts out from underneath the engine or unit being lifted. Always work around a portable crane as if the chain or strap could break at any time.

ENGINE STANDS An **engine stand** is designed to safely hold an engine and to allow it to be rotated. This allows the technician to easily remove, install, and perform service work to the engine. ● **SEE FIGURE 9–59**.

Most engine stands are constructed of steel and supported by four casters to allow easy movement. There are two basic places where an engine stand attaches to the engine depending on the size of the engine. For most engines and stands, the retaining bolts attach to the same location as the bell housing at the rear of the engine.

On larger engines, such as the 5.9 Cummins inline 6-cylinder diesel engine, the engine mounts to the stand using the engine mounting holes in the block. ● **SEE FIGURE 9–60**.

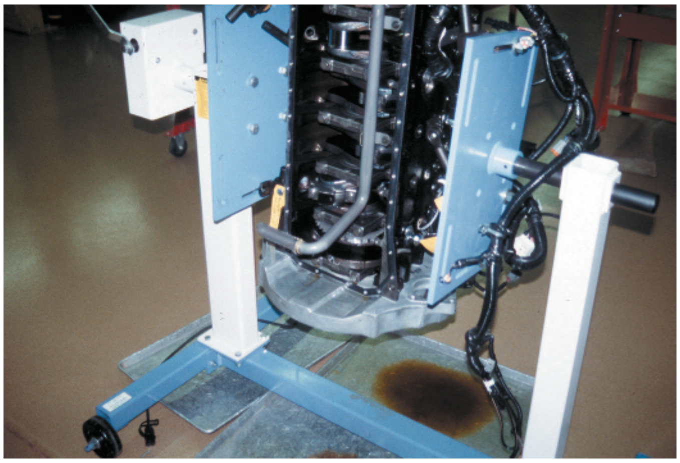


FIGURE 9–60 An engine stand that grasps the engine from the sides rather than the end.

SAFE OPERATION OF AN ENGINE STAND. When mounting an engine to an engine stand, be sure that the engine is being supported by a portable crane. Be sure the attaching bolts are grade 5 or 8 and the same thread size as the threaded holes in the block. Check that there is at least 1/2 inch (13 mm) of bolt thread engaged in the threaded holes in the engine block. Be sure that all attaching bolts are securely tightened before releasing the weight of the engine from the crane. Use caution when loosening the rotation retaining bolts because the engine could rotate rapidly, causing personal injury.

CARE AND MAINTENANCE OF SHOP EQUIPMENT

All shop equipment should be maintained in safe working order. Maintenance of shop equipment usually includes the following operations or procedures.

- **Keep equipment clean.** Dirt and grime can attract and hold moisture, which can lead to rust and corrosion. Oil or grease can attract dirt.
- **Keep equipment lubricated.** While many bearings are sealed and do not require lubrication, always check the instructions for the use of the equipment for suggested lubrication and other service procedures.

CAUTION: Always follow the instructions from the equipment manufacturer regarding proper use and care of the equipment.

REVIEW QUESTIONS

1. Why are wrenches offset 15 degrees?
2. What are the other names for a line wrench?
3. What are the standard automotive drive sizes for sockets?
4. When using a blow gun, what precautions need to be taken?
5. How is the size of a vise determined?

CHAPTER QUIZ

1. When working with hand tools, always ____________.
   a. push the wrench—do not pull toward you
   b. pull a wrench—do not push a wrench
   c. use an open-ended wrench to loosen fasteners
   d. use an adjustable wrench to tighten or loosen any bolt or nut
2. To grip large objects, the ____________ plier is a commonly used tool.
   a. diagonal
   b. multigroove
   c. linesman's
   d. slip-joint

3. What tool should be used to loosen or tighten brake or fuel lines?
   - **a.** Locking pliers
   - **b.** Punch or chisel
   - **c.** Line wrench
   - **d.** Hack saw

4. Two technicians are discussing hand tools. Technician A says that a torque wrench is capable of tightening a fastener with more torque than a conventional breaker bar or ratchet. Technician B says that a screwdriver should fit the head of the fastener. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B

5. What tool does not use compressed air?
   - **a.** Dead-blow hammer
   - **b.** Impact wrench
   - **c.** Air grinder
   - **d.** Blow gun

6. Which tool has a replaceable cutting edge?
   - **a.** Side-cut pliers
   - **b.** Tin snips
   - **c.** Utility knife
   - **d.** Aviation snips

7. What type of socket should be used with an air impact wrench?
   - **a.** Black
   - **b.** Chrome
   - **c.** 12 point
   - **d.** Either a or b

8. What can be used to cover the jaws of a vise to help protect the object being held?
   - **a.** Aluminum
   - **b.** Wood
   - **c.** Copper
   - **d.** Any of the above

9. Which of the following basic hand tools should every technician possess?
   - **a.** Combination wrenches
   - **b.** 3/8 inch drive socket set
   - **c.** Battery operated impact
   - **d.** All of the above

10. Proper care of shop equipment includes _____________.
   - **a.** tuning up every six months
   - **b.** keeping equipment clean
   - **c.** keeping equipment lubricated
   - **d.** Both b and c

Chapter

10

VEHICLE LIFTING AND HOISTING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the purpose of floor jacks.
- Discuss the purpose of creepers.
- Describe vehicle hoists.
- Describe drive-on ramps.
- Discuss the proper methods to follow for safely hoisting a vehicle.

KEY TERMS:

Creeper 88 • Floor jack 88 • Jack stand 88 • Safety stand 88

FLOOR JACK

A **floor jack** is a hand-operated hydraulic device that is used to lift vehicles or components, such as engines, transmissions, and rear axle assemblies. Most floor jacks use casters, which allow the jack to be easily moved around the shop. ● **SEE FIGURE 10–1**.

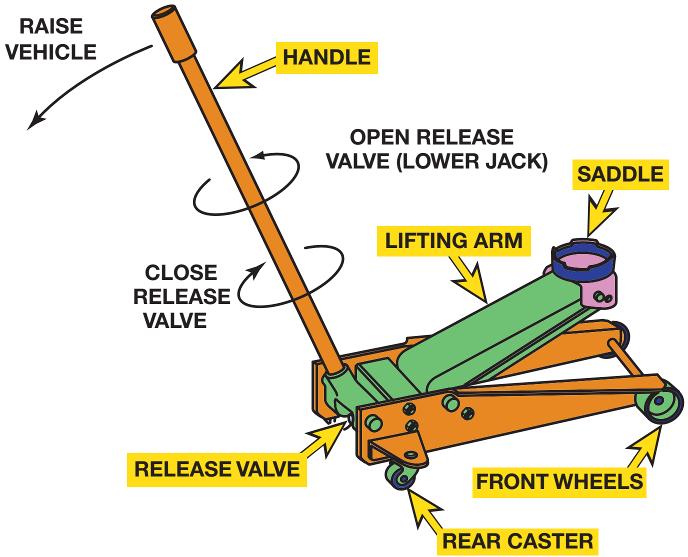


FIGURE 10–1 A hydraulic hand-operated floor jack.

SAFE USE OF FLOOR JACKS Floor jacks are used to lift a vehicle or major vehicle component, but they are not designed to hold a load. Therefore, **safety stands**, also called **jack stands**, should always be used to support the vehicle. After the floor jack has lifted the vehicle, safety stands should be placed under the vehicle, and then, using the floor jack, lowered onto the safety stands. The floor jack can be lifted in position as another safety device, but the load should be removed from the floor jack. If a load is retained on the floor jack, hydraulic fluid can leak past seals in the hydraulic cylinders, which would lower the vehicle, possibly causing personal injury. ● **SEE FIGURE 10–2**.

CREEPERS

When working underneath a vehicle, most service technicians use a **creeper**, which consists of a flat or concaved surface equipped with low-profile casters. A creeper allows the technician to maneuver under the vehicle easily.

SAFE USE OF CREEPERS Creepers can create a fall hazard if left on the floor. When a creeper is not being used, it should be picked up and placed vertically against a wall or tool box to help prevent accidental falls. ● **SEE FIGURE 10–3**.

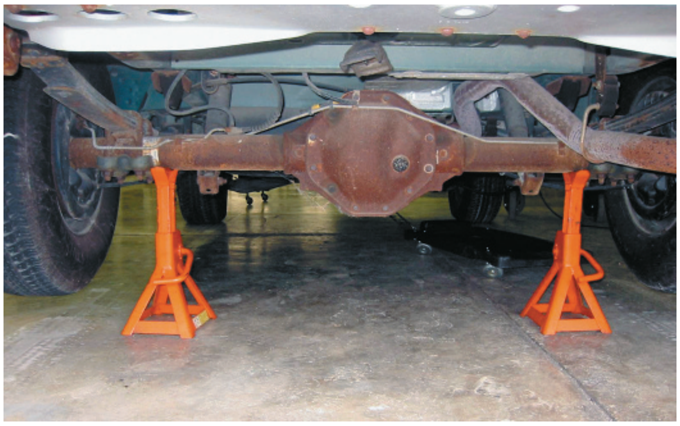


FIGURE 10–2 Safety stands are being used to support the rear of this vehicle.

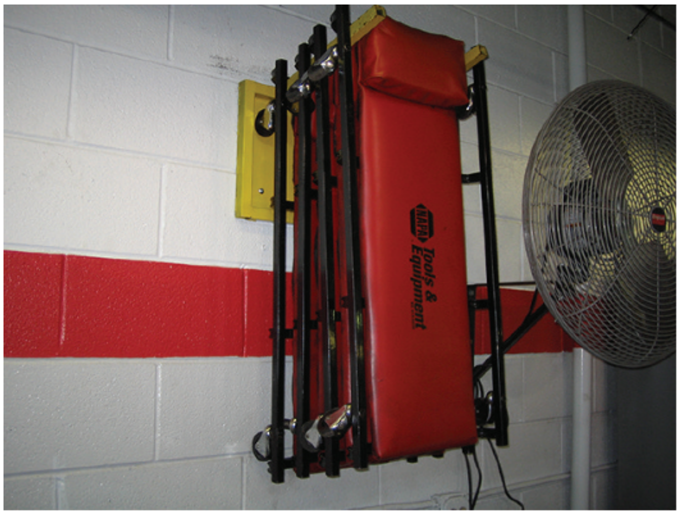


FIGURE 10–3 Creepers should always be stored vertically and not be allowed to be left on the floor where a person could step on it by mistake and fall.

VEHICLE HOISTS

Many chassis and underbody service procedures require that the vehicle be hoisted or lifted off the ground. The simplest methods involve the use of drive-on ramps or a floor jack and safety (jack) stands, whereas in-ground or surface-mounted lifts provide greater access.

Vehicle hoists include older in-ground pneumatic/hydraulic (air pressure over hydraulic) and aboveground units. Most of the vehicle hoists used today use an electric motor to pressurize hydraulic fluid, which lifts the vehicle using hydraulic cylinders. Hoists are rated by the maximum weight that they can safely lift, such as 7,000 to 12,000 pounds or more. Hoists can also have equal length arms, called *symmetrical lifts*, or can be equipped with different length arms, called *asymmetrical lifts*. The asymmetrical lift is designed so that the vehicle doors will not hit the center support column when opened. ● **SEE FIGURE 10–4**.

SETTING THE PADS IS A CRITICAL PART OF THIS PROCEDURE All automobile and light-truck service manuals include recommended locations to be used when hoisting (lifting) a vehicle. Some vehicles have a decal on the driver's door indicating the recommended lift points. The recommended standards for the lift points and lifting procedures are found in SAE Standard JRP-2184. ● **SEE FIGURE 10–5**.

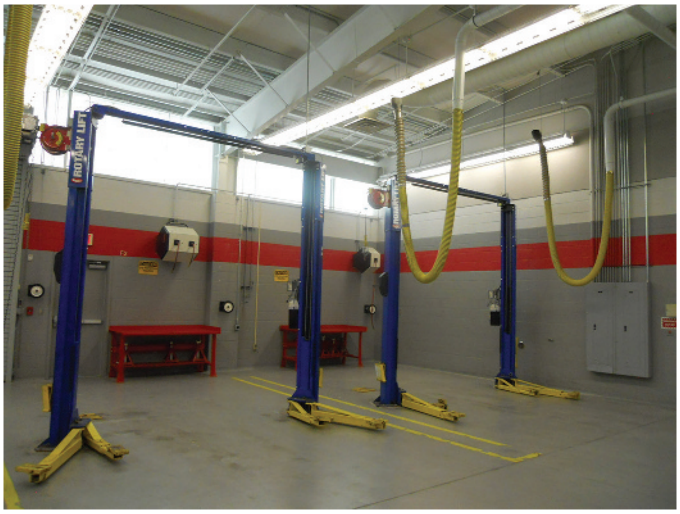


FIGURE 10–4 A typical electric-hydraulic asymmetrical lift where the lift arms on each side include one longer arm and one shorter arm. On an asymmetrical lift, the front arms are slightly shorter than the back arms, so the door is not blocked by the post.

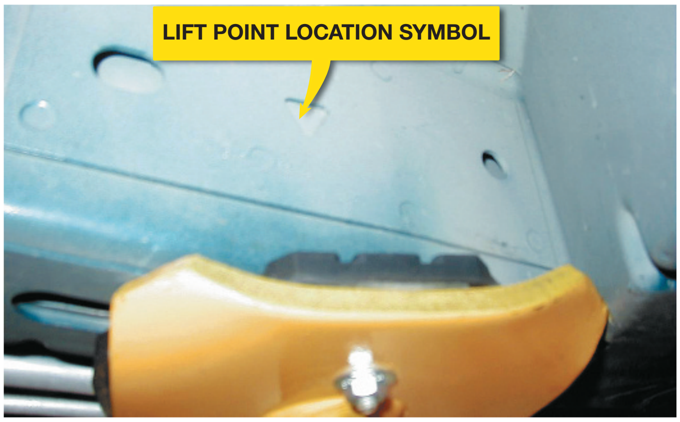


FIGURE 10–5 Most newer vehicles have a triangle symbol indicating the recommended hoisting lift points.

These recommendations typically include the following points.

1. The vehicle should be centered on the lift or hoist so as not to overload one side or put too much force either forward or rearward. Use tall safety stands if a major component is going to be removed from the vehicle, such as the engine, to help support the vehicle. ● **SEE FIGURE 10–6**.
2. The pads of the lift should be spread as far apart as possible to provide a stable platform.
3. Each pad should be placed under a portion of the vehicle that is strong and capable of supporting the weight of the vehicle.
   a. Pinch welds at the bottom edge of the body are generally considered to be strong.

CAUTION: Even though pinch weld seams are the recommended location for hoisting many vehicles with unitized bodies (unit-body), care should be taken not to place the pad(s) too far forward or rearward. Incorrect placement of the vehicle on the lift could cause the vehicle to be imbalanced, and the vehicle could fall. This is exactly what happened to the vehicle in ● FIGURE 10–7.

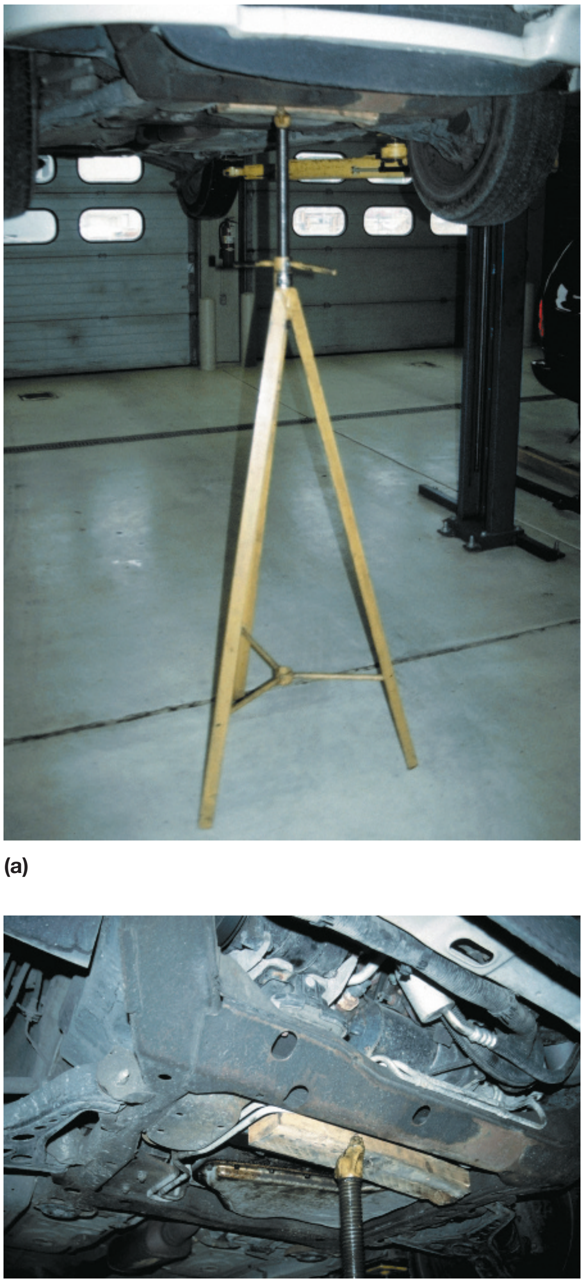


FIGURE 10–6 (a) Tall safety stands can be used to provide additional support for a vehicle while on a hoist. (b) A block of wood should be used to avoid the possibility of doing damage to components supported by the stand.

b. Boxed areas of the body are the best places to position the pads on a vehicle without a frame. Be careful to note whether the arms of the lift might come into contact with other parts of the vehicle before the pad touches the intended location. Commonly damaged areas include the following:

1. Rocker panel moldings
2. Exhaust system (including catalytic converter)
3. Tires or body panels. ● **SEE FIGURE 10–8**.

4. As soon as the pads touch the vehicle, check for proper pad placement. The vehicle should be raised about 1 ft (30 cm) off the floor, then stopped and shaken to check for stability. If the vehicle seems to be stable when checked at a short distance from the floor, continue raising the vehicle and continue to view the vehicle until it has reached the desired height. The hoist should be lowered onto the mechanical locks and then raised off of the locks before lowering.

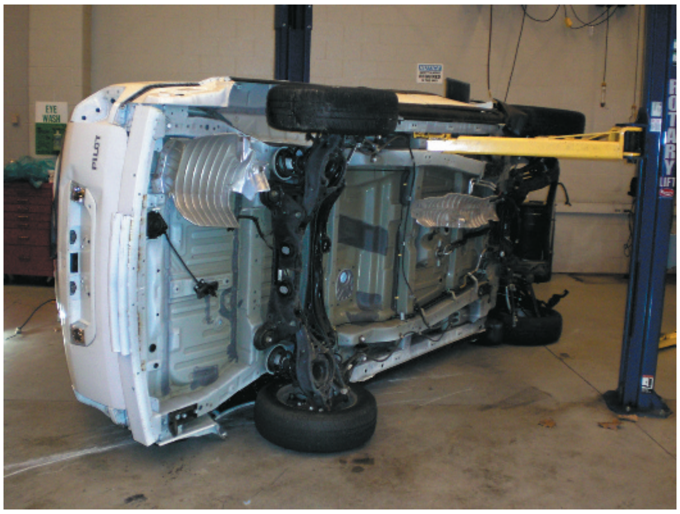


FIGURE 10–7 This training vehicle fell from the hoist when the pads were not set correctly. No one was hurt, but the vehicle was damaged.

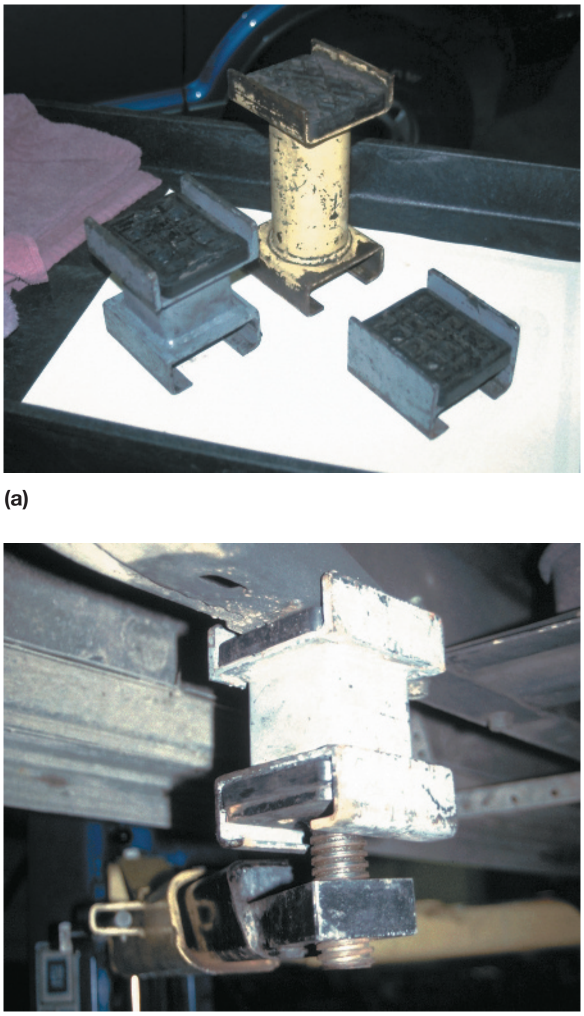


FIGURE 10–8 (a) An assortment of hoist pad adapters that are often necessary to safely hoist many pickup trucks, vans, and sport utility vehicles. (b) A view from underneath a Chevrolet pickup truck showing how the pad extensions are used to attach the hoist lifting pad to contact the frame.

CAUTION: Do not look away from the vehicle while it is being raised (or lowered) on a hoist. Often one side or one end of the hoist can stop or fail, resulting in the vehicle being slanted enough to slip or fall.

NOTE: Most hoists can be safely placed at any desired height as long as it is high enough for the safety latches to engage. For ease while working, the area in which you are working should be at chest level. When working on brakes or suspension components, it is not necessary to work on them down near the floor or over your head. Raise the hoist so that the components are at chest level.

5. Before lowering the hoist, check for open doors, trash cans or other items placed under the vehicle during service and then the safety latch(es) must be released and the direction of the controls reversed. The speed downward is often adjusted to be as slow as possible for additional safety.

DRIVE-ON RAMPS

Ramps are an inexpensive way to raise the front or rear of a vehicle. ● **SEE FIGURE 10–9**. Ramps are easy to store, but they can be dangerous because they can "kick out" when driving the vehicle onto the ramps.

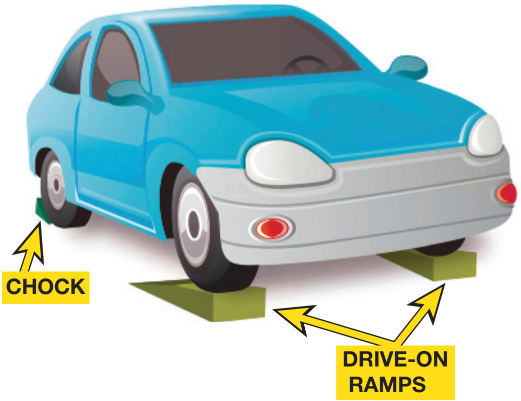
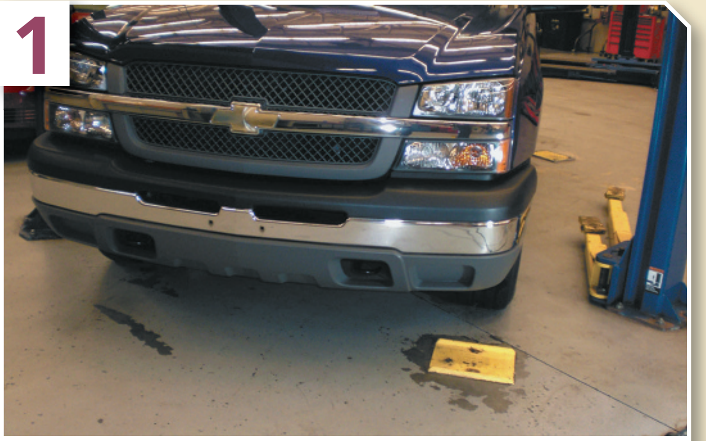


FIGURE 10–9 Drive-on-type ramps. The wheels on the ground level *must* be chocked (blocked) to prevent accidental movement down the ramp.

CAUTION: Professional repair shops do not use ramps because they are dangerous to use. Use only with extreme care.

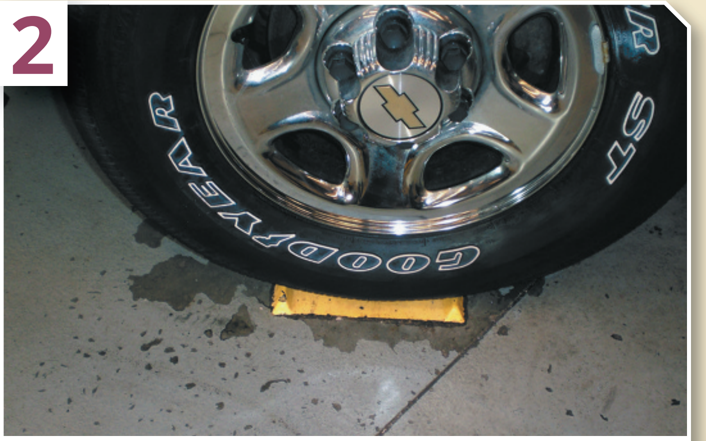
HOISTING THE VEHICLE

1



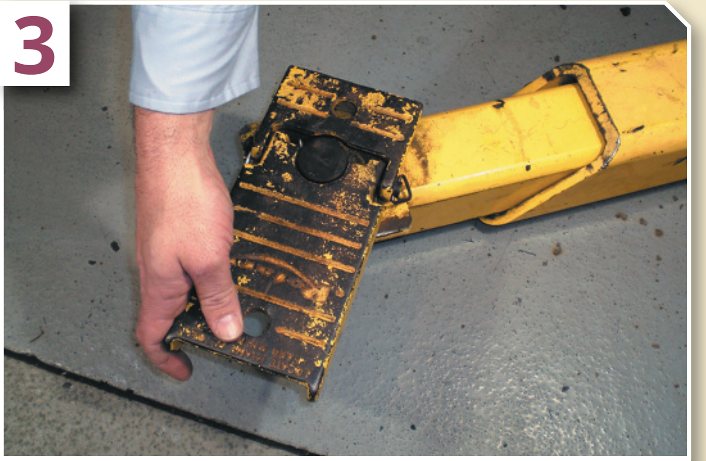
The first step in hoisting a vehicle is to properly align the vehicle in the center of the stall.

2



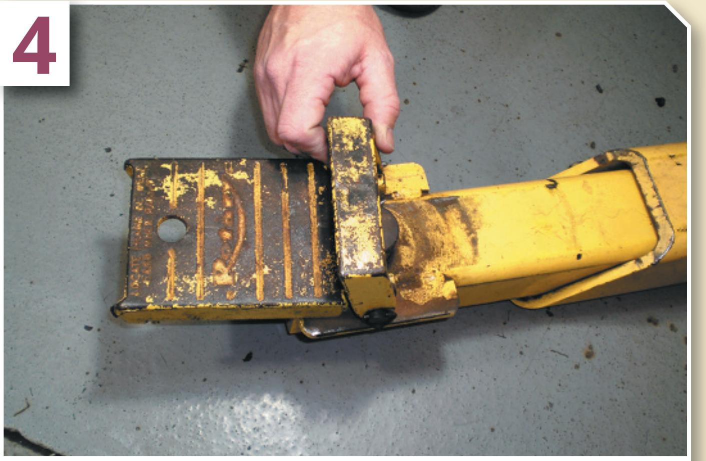
Most vehicles will be correctly positioned when the left front tire is centered on the tire pad.

3



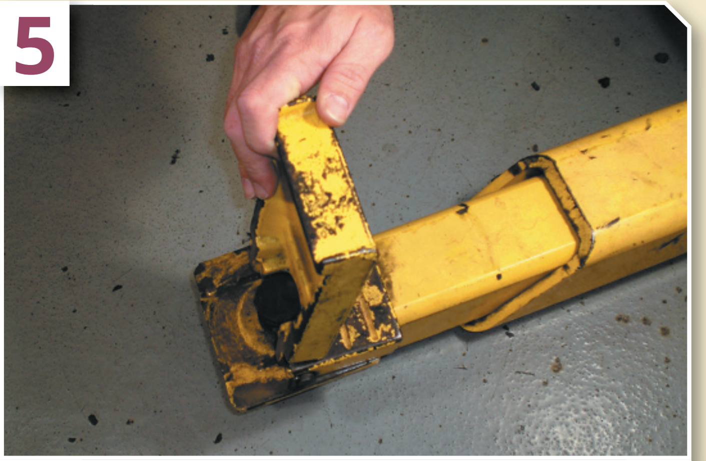
The arms can be moved in and out and most pads can be rotated to allow for many different types of vehicle construction.

4



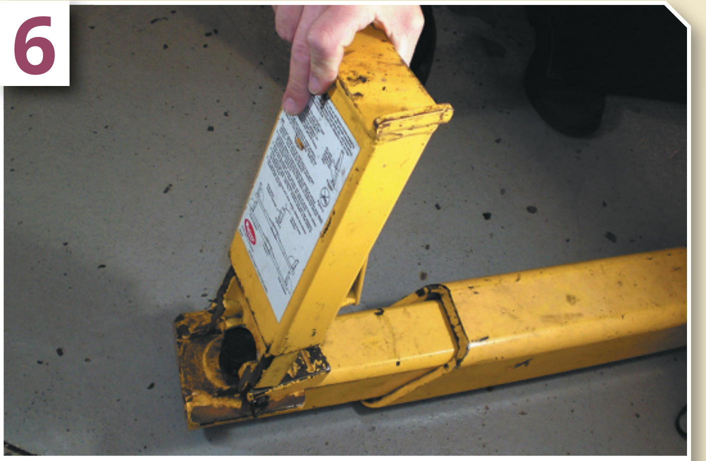
Most lifts are equipped with short pad extensions that are often necessary to use to allow the pad to contact the frame of a vehicle without causing the arm of the lift to hit and damage parts of the body.

5



Tall pad extensions can also be used to gain access to the frame of a vehicle. This position is needed to safely hoist many pickup trucks, vans, and sport utility vehicles.

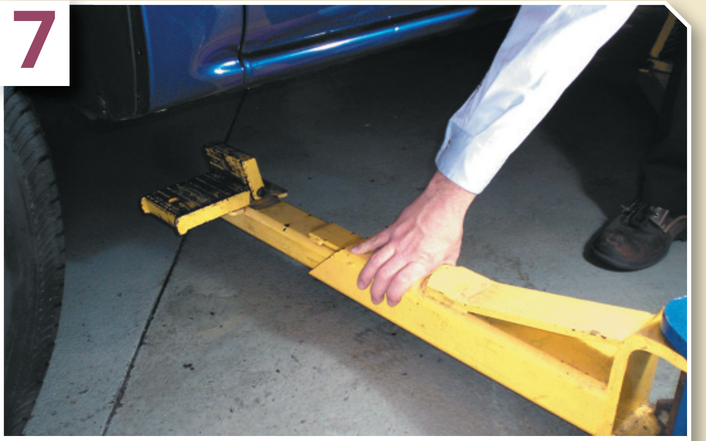
6



An additional extension may be necessary to hoist a truck or van equipped with running boards to give the necessary clearance.

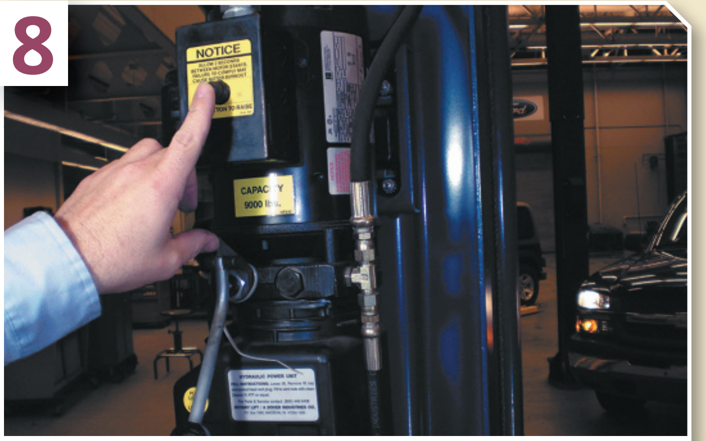
STEP BY STEP

7



Position the pads under the vehicle under the recommended locations.

8



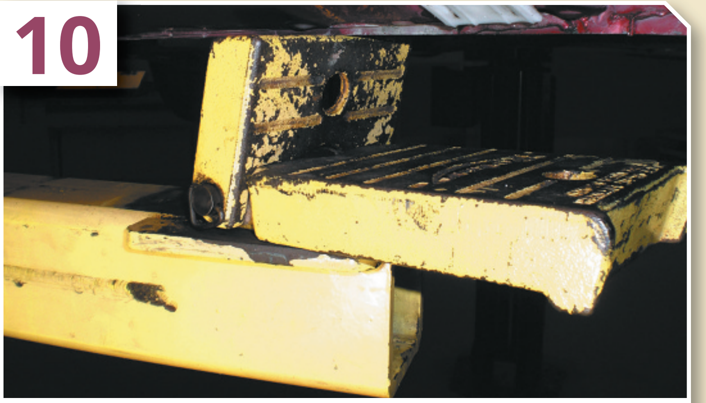
After being sure all pads are correctly positioned, use the electromechanical controls to raise the vehicle.

9

WRANGLER ST
GOODYEAR

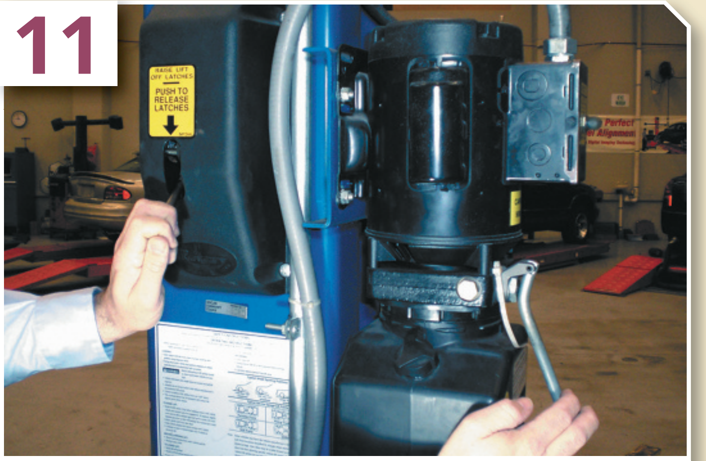
With the vehicle raised one foot (30 cm) off the ground, push down on the vehicle to check to see if it is stable on the pads. If the vehicle rocks, lower the vehicle and reset the pads. The vehicle can be raised to any desired working level. Be sure the safety mechanism is engaged before working on or under the vehicle.

10



If raising a vehicle without a frame, place the flat pads under the pinch weld seam to spread the load. If additional clearance is necessary, the pads can be raised as shown.

11



When the service work is completed, the hoist should be raised slightly and the safety mechanism released before using the hydraulics to lower the vehicle.

12

After lowering the vehicle, be sure all arms of the lift are moved out of the way before driving the vehicle out of the work stall.

REVIEW QUESTIONS

1. Why must safety stands be used after lifting a vehicle with a floor jack?
2. What precautions should be adhered to when storing a creeper?
3. What precautions should be adhered to when hoisting a vehicle?
4. How is a floor jack operated?
5. Where should the hoist pads be located under the vehicle?

CHAPTER QUIZ

1. A safety stand is also called a _________.
   - **a.** jack
   - **b.** jack stand
   - **c.** bottle jack
   - **d.** safety stool
2. A creeper should be stored _________.
   - **a.** vertically
   - **b.** under a vehicle
   - **c.** flat on the floor
   - **d.** upside down on the floor
3. The SAE standard for hoist location is _________.
   - **a.** J-1980
   - **b.** SAE-2009
   - **c.** JRP-2184
   - **d.** J-14302
4. Tall safety stands would be used to _________.
   - **a.** help support the vehicle when a major component is removed from the vehicle
   - **b.** lift a vehicle
   - **c.** lift a component, such as an engine, high off the ground
   - **d.** Both b and c
5. Commonly damaged areas of a vehicle during hoisting include _________.
   - **a.** rocker panels
   - **b.** exhaust systems
   - **c.** tires or body panels
   - **d.** All of the above
6. What method of raising a vehicle is considered too dangerous?
   - **a.** Floor jack and safety stand
   - **b.** Drive-on ramps
   - **c.** Electric-mechanical hoists
   - **d.** Either a or b
7. Technician A says that a hoist can be stopped at any level as long as the safety latch engages. Technician B says that the vehicle should be hoisted to the top of the hoist travel for safety. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Before lowering the vehicle, what should the technician do?
   - **a.** Be sure nothing is underneath the vehicle
   - **b.** Raise the vehicle enough to release the safety latch
   - **c.** Be sure no one will be walking under or near the vehicle
   - **d.** All of the above
9. A hoist with asymmetrical arms means it _________.
   - **a.** has just two lifting arms
   - **b.** uses different length lift arms
   - **c.** uses the same length lift arms
   - **d.** has just one lifting arm
10. When checking for stability, how high should the vehicle be raised?
    - **a.** About 2 inch (5 cm)
    - **b.** About 6 inch (15 cm)
    - **c.** About 1 ft (30 cm)
    - **d.** About 3 ft (91 cm)

SECTION IV

MEASURING, MATH AND SCIENTIFIC PRINCIPLES

CHAPTERS

11 Measuring, Math, and Charts
12 Scientific Principles and Materials

Chapter 11

MEASURING, MATH, AND CHARTS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Compare the English customary measuring system and the metric system.
- Discuss measuring and measuring tools, including rulers, micrometers, gauges, and calipers.
- Discuss mathematic principles relevant to service technicians, including the use of decimals, percentages, fractions, and mathematical formulas.
- Explain how to interpret graphs, charts, and diagrams.

KEY TERMS:

Chart 104 • Decimal point 101 • Diagram 104 • Direct drive 103 • Drive gear 103 • Feeler gauge 99 • Fractions 102 • Gear reduction 103 • Graph 104 • Overdrive 103 • Percentage 101 • Scientific notation 101 • Small-hole gauge 98 • Spindle 96 • Split-ball gauge 98 • Straightedge 100 • Thickness gauge 99 • Thimble 96 • Variable 104

MEASURING SYSTEMS

ENGLISH CUSTOMARY The English customary measuring system was established about 1100 C.E. in England during the reign of Henry I. The foot was determined to be 12 inches and was taken from the length of a typical foot. The yard (36 inches) was determined to be the length from King Henry's nose to the end of his outstretched hand. The mile came from Roman days and was originally defined as the distance traveled by a soldier in 1,000 paces or steps. Other English units, such as the pound (weight) and volume (gallon), evolved over the years from Roman and English measurements.

The Fahrenheit temperature scale was created by Gabriel Fahrenheit (1686–1736); he used 96°F as the temperature of the human body (later adjusted to 98.6°F). On the Fahrenheit scale, water freezes at 32°F and water boils at 212°F.

METRIC SYSTEM Most of the world uses the metric system of measure. The metric system was created in the late 1700s in France and used the physical world for the basis of the measurements. For example, the meter was defined as being 1/40,000,000 of the circumference of the earth (the distance around the earth at the poles). The Celsius temperature scale, developed by Anders Celsius (1701–1744), used the freezing point of water as 0°C (32°F) and the boiling point of water as 100°C (212°F).

Other metric units include a liter of water, which was then used as a standard of weight where 1 liter of water (about 1 quart) weighs 1 kilogram (1,000 grams). Units of measure are then divided or multiplied by 10,100, and 1,000 to arrive at usable measurements. For example, a kilometer is 1,000 meters and is the most commonly used metric measurement for distance for travel.

Other prefixes include:

m = milli = 1/1,000
k = kilo = 1,000
M = mega = 1,000,000

LINEAR METRIC/ENGISH MEASUREMENTS

1 kilometer = 0.62 mile
1 meter = 39.37 inches
1 centimeter (1/100 meter) = 0.39 inch
1 millimeter (1/1,000 meter) = 0.039 inch

VOLUME METRIC/ENGISH MEASUREMENT

1 cc (cubic centimeter) = 0.06 cubic inch
1 liter = 0.26 U.S. gallon (about 1 quart)

WEIGHT METRIC/ENGISH MEASUREMENT

1 gram = 0.035 ounce
1 kilogram (1,000 grams) = 2.2 pounds

PRESSURE METRIC/ENGISH MEASUREMENTS

1 kilopascal (kPa) = 0.14 pound per square inch
(6.9 kPa = 1 PSI)
1 bar = 14.5 pounds per square inch

DERIVED UNITS All units of measure, except for the base units, are a combination of units that are referred to as derived units of measure. Some examples of derived units include:

Torque
Velocity
Density
Energy
Power

MEASUREMENTS

LINEAR MEASUREMENTS A tape measure or ruler divides inches into smaller units. Each smaller unit is drawn with a line shorter than the longer unit. The units of measure starting with the largest include:

1 inch
1/2 inch
1/4 inch
1/8 inch
1/16 inch

Some rules show 1/32 of an inch. ● **SEE FIGURE 11–1**.

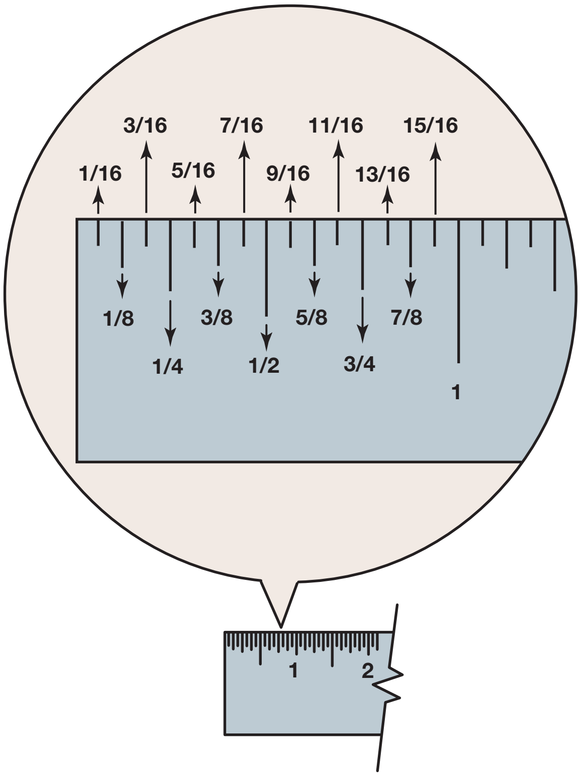


FIGURE 11–1 A rule showing that the larger the division, the longer the line.

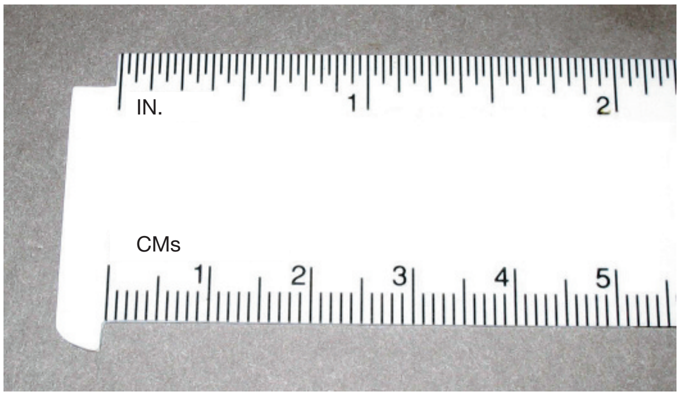


FIGURE 11–2 Plastic rule that has both inches and centimeters. Each line between the numbers on the centimeters represents 1 millimeter because there are 10 millimeters in 1 centimeter.

A metric scale is also included on many tape measures and machinists' rules. ● **SEE FIGURE 11–2**.

MICROMETER A micrometer is the most used measuring instrument used in vehicle service and repair. ● **SEE FIGURE 11–3**.

Every revolution of the **thimble** moves the **spindle** 0.025 inch. The thimble is graduated into 25 equally spaced lines; therefore, each line represents 0.001 inch. Micrometers come in different sizes or ranges, such as 0“ to 1”, 1” to 2”, 2” to 3”.

Every micrometer should be checked for calibration with a gage rod on a regular basis. ● **SEE FIGURES 11–4 THROUGH 11–6**.

CRANKSHAFT MEASUREMENT. Rod journals and the main bearing journals should be measured for out-of-round and taper using the correct size micrometer. ● **SEE FIGURES 11–7 AND 11–8**.

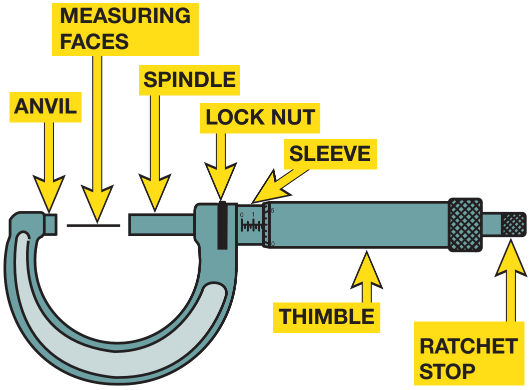


FIGURE 11–3 A typical micrometer showing the names of the parts. The sleeve may also be called the barrel or stock.

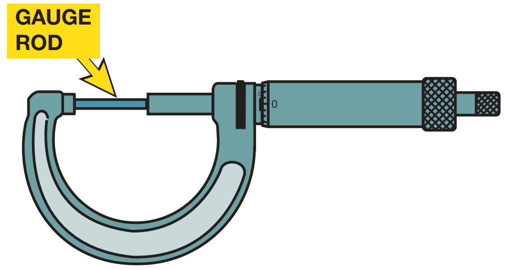
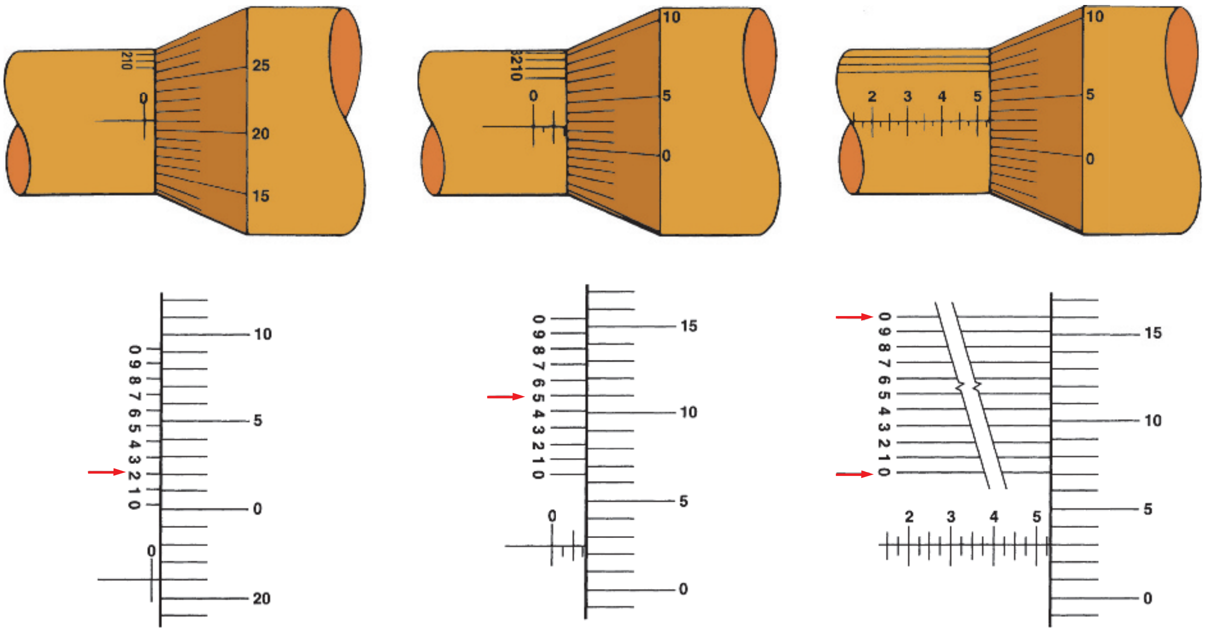


FIGURE 11–4 All micrometers should be checked and calibrated as needed using a gauge rod.

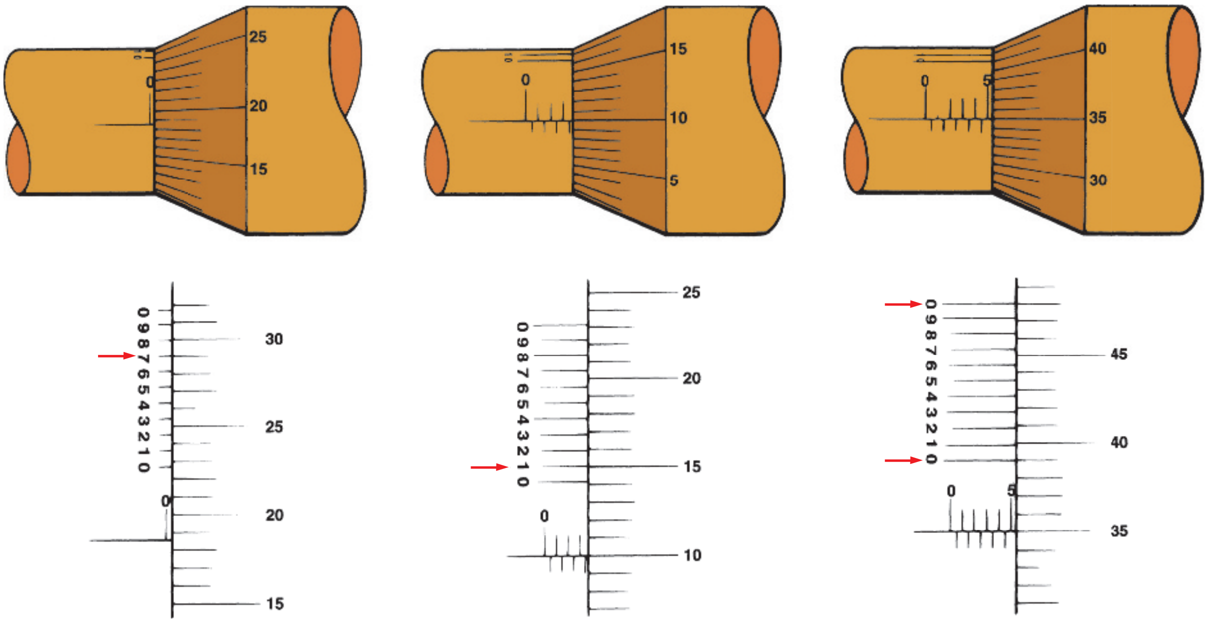


0.0212 in.
(a)

0.0775 in.
(b)

0.5280 in.
(c)

FIGURE 11–5 The three micrometer readings are (a) 0.0212 inch; (b) 0.0775 inch; and (c) 0.5280 inch. These measurements used the vernier scale on the sleeve to arrive at the ten-thousandth measurement. The number that is aligned represents the digit in the ten-thousandth place.



0.187 mm
(a)

3.601 mm
(b)

5.350 mm
(c)

FIGURE 11–6 Metric micrometer readings that use the vernier scale on the sleeve to read to the nearest 0.001 millimeter. The arrows point to the final reading for each of the three examples.

CAMSHAFT MEASUREMENT. The bearing journals of the camshaft(s) can also be measured using a micrometer and compared with factory specifications for taper and out-of-round. ● **SEE FIGURE 11–9**.

The cam lobes can also be measured with a micrometer and compared with factory specifications. ● **SEE FIGURE 11–10**.

DEPTH MICROMETER. A depth micrometer is like a conventional micrometer except that it is designed to measure the depth from a flat surface. ● **SEE FIGURE 11–11**.

TELESCOPING GAUGE

A telescopic gauge is used with a micrometer to measure the inside diameter of a hole or bore.

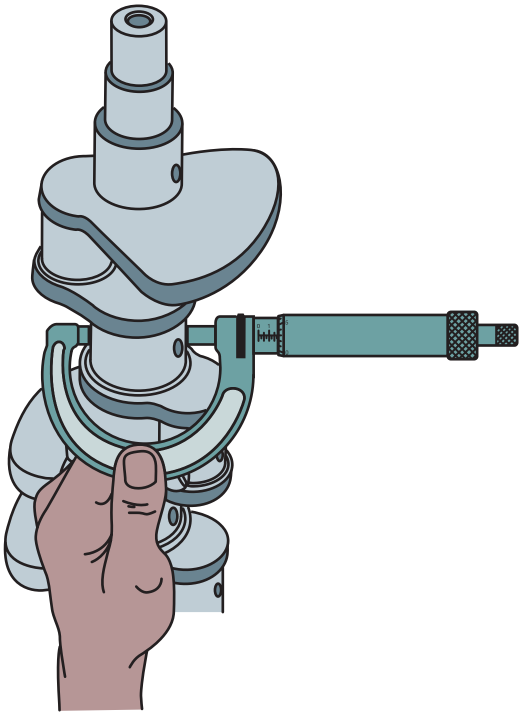


FIGURE 11–7 Using a micrometer to measure the main bearing journal for out-of-round and taper.

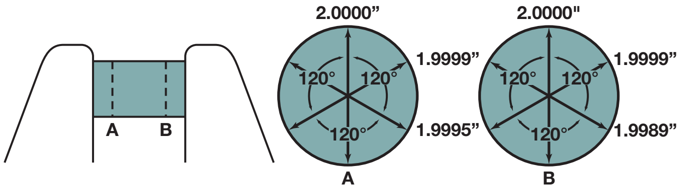


FIGURE 11–8 Crankshaft journal measurements. Each journal should be measured in at least six locations, but also in position A and position B and at 120-degree intervals around the journal.

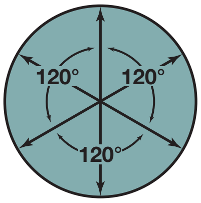


FIGURE 11–9 Camshaft journals should be measured in three locations, 120 degrees apart, to check for out-of-round.

The cylinder bore can be measured by inserting a telescopic gauge into the bore and loosening the handle lock to allow the spring-loaded arms of the gauge to contact the inside bore of the cylinder. Tighten the handle lock and remove the gauge from the cylinder. Use a micrometer to measure the telescopic gauge. ● **SEE FIGURE 11–12**.

A telescopic gauge can also be used to measure the following:

- Camshaft bearing (● **SEE FIGURE 11–13**.)
- Main bearing bore (housing bore)
- Connecting rod bore

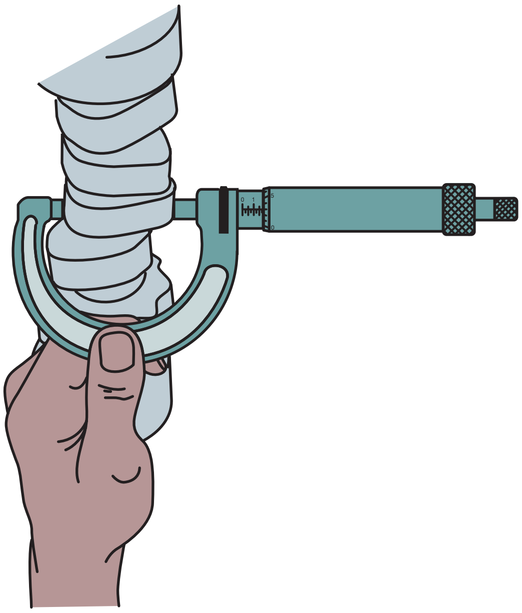


FIGURE 11–10 Checking a camshaft for wear by measuring the lobe height with a micrometer.

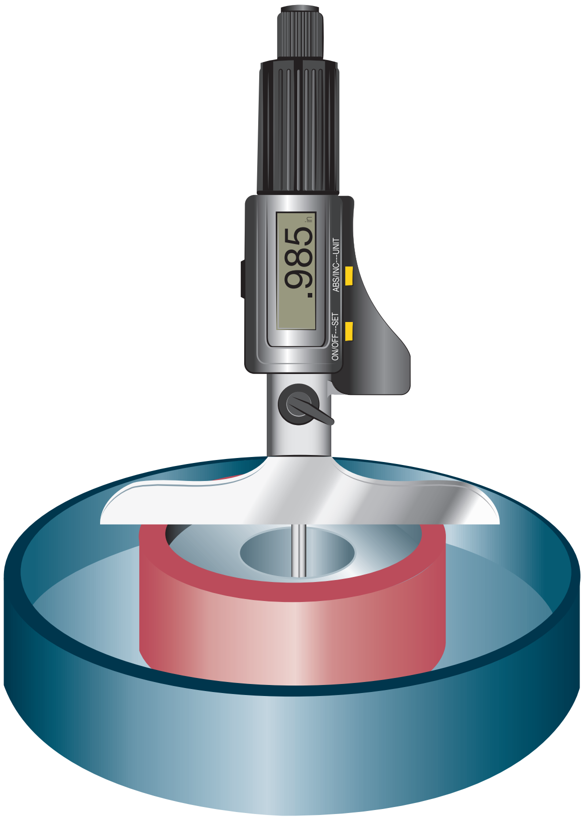


FIGURE 11–11 A digital readout depth micrometer.

SMALL HOLE GAUGE A **small-hole gauge** (also called a **split-ball gauge**) is used with a micrometer to measure the inside diameter of small holes, such as a valve guide in a cylinder head. ● **SEE FIGURES 11–14 AND 11–15**.

DIAL CALIPER A dial caliper is normally used to measure length, inside and outside diameters, and depth. ● **SEE FIGURE 11–16**.

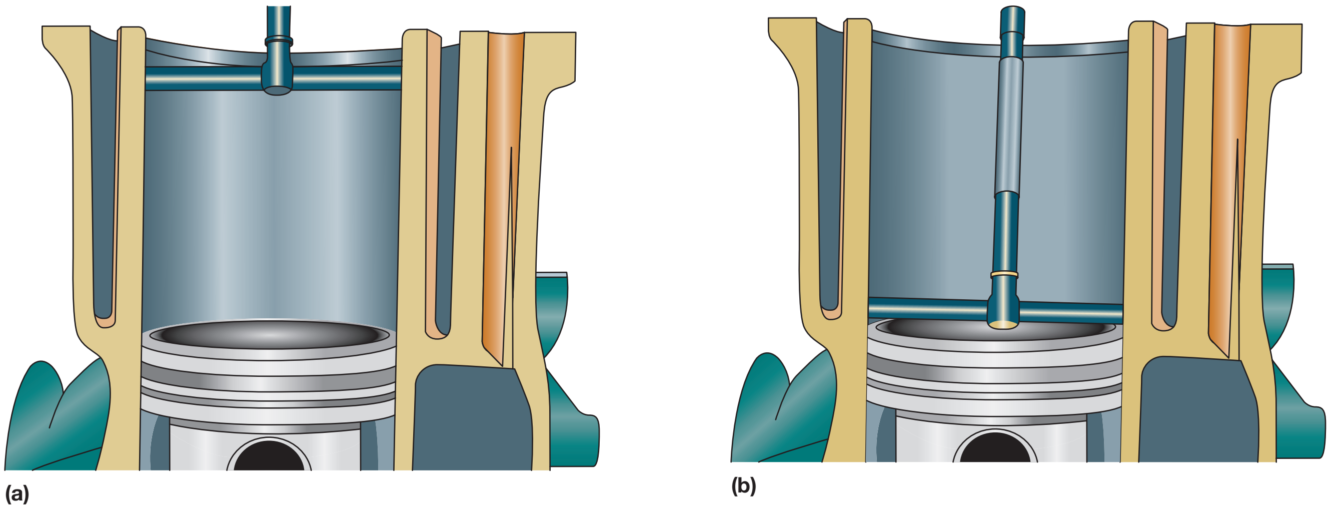


FIGURE 11–12 With the head removed, cylinder taper and out-of-round can be checked below the ridge (a) and above the piston when it is at the bottom of the stroke (b).

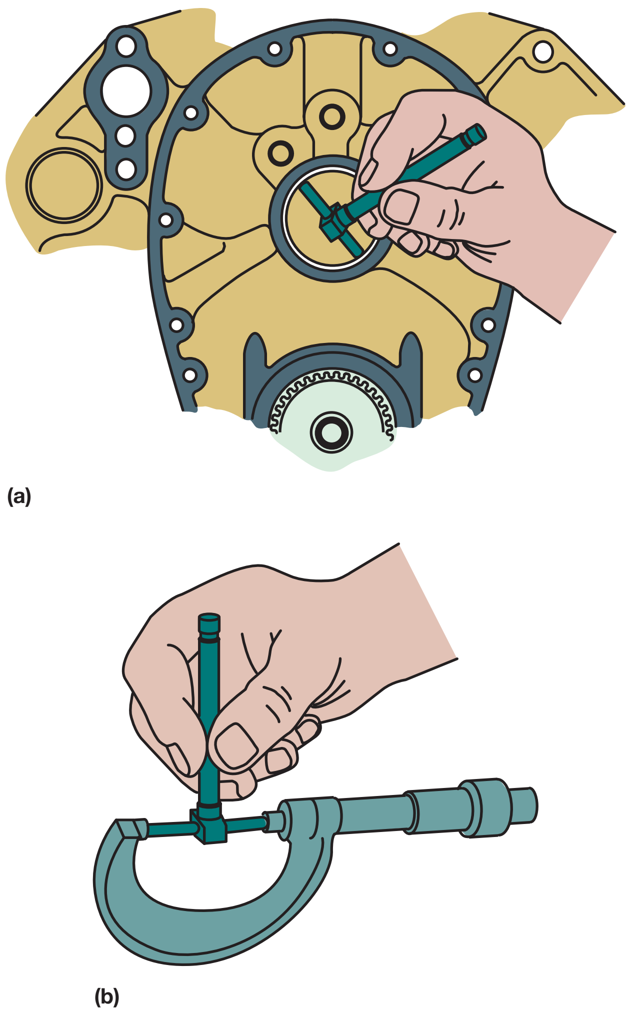


FIGURE 11–13 (a) A telescopic gauge being used to measure the inside diameter (ID) of a camshaft bearing. (b) An outside micrometer used to measure the telescopic gauge.

FEELER GAUGE A **feeler gauge** (also known as a **thickness gauge**) is a strip of metal that is precisely manufactured to a specific thickness. They come in sets that cover 0.0015″ to 0.025″ (0.05 mm to 1 mm) and are used to determine the gap or clearance between two components. ● **SEE FIGURE 11–17**.

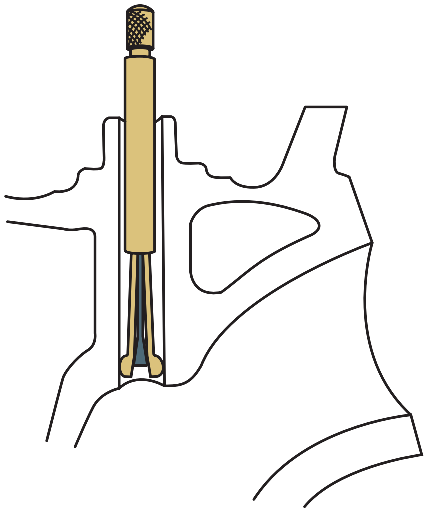


FIGURE 11–14 Cutaway of a valve guide with a small hole gauge adjusted to the hole diameter.

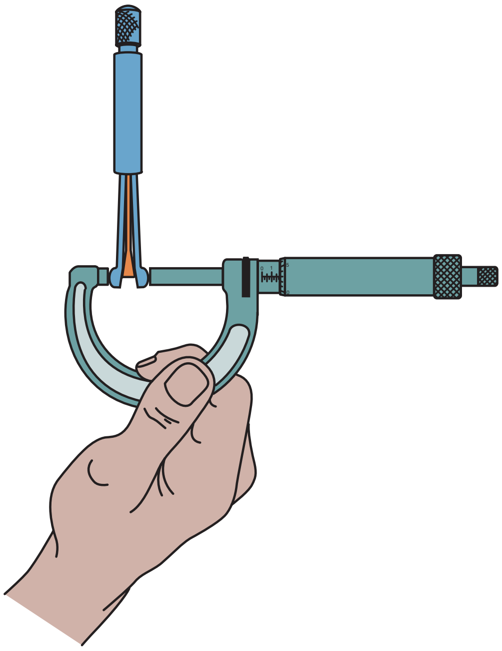


FIGURE 11–15 The outside of a small hole gauge being measured with a micrometer.

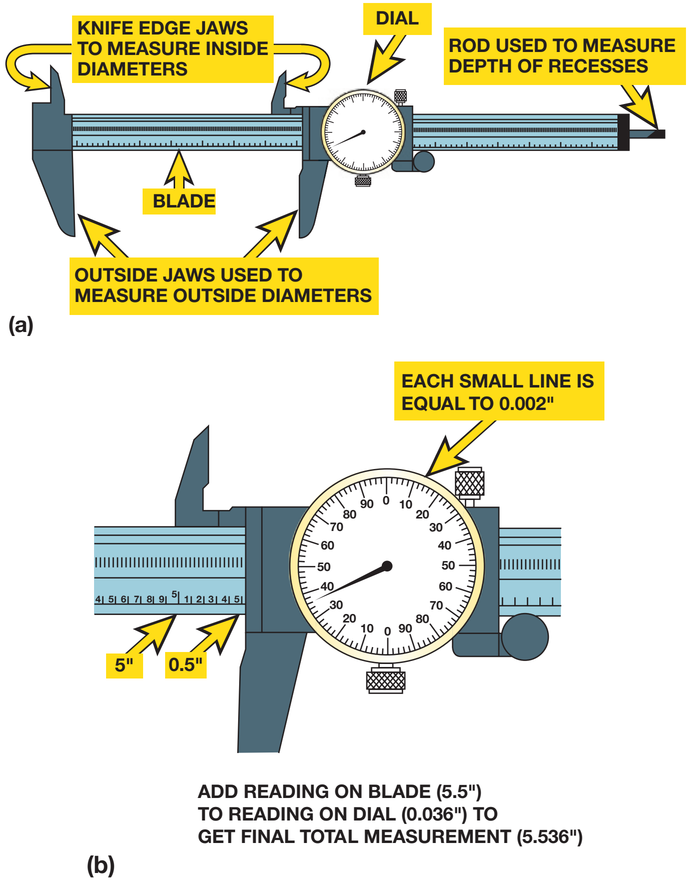

KNIFE EDGE JAWS TO MEASURE INSIDE DIAMETERS
DIAL
ROD USED TO MEASURE DEPTH OF RECESSES
BLADE
OUTSIDE JAWS USED TO MEASURE OUTSIDE DIAMETERS
(a)
EACH SMALL LINE IS EQUAL TO 0.002"
5"
0.5"
ADD READING ON BLADE (5.5") TO READING ON DIAL (0.036") TO GET FINAL TOTAL MEASUREMENT (5.536")
(b)

FIGURE 11–16 (a) A typical dial caliper. This is a very useful measuring tool for automotive engine work because it is capable of measuring inside, outside, and depth measurements. (b) To read a dial caliper, simply add the reading on the blade to the reading on the dial.

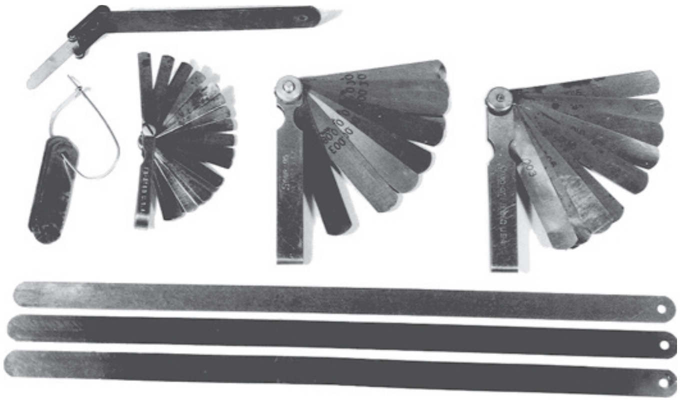


FIGURE 11–17 A group of feeler gauges (also known as thickness gauges) used to measure between two parts. The long gauges on the bottom are used to measure the piston-to-cylinder wall clearance.

A feeler gauge can be used to check the following:

- Piston ring gap (● **SEE FIGURE 11–18.**)
- Piston ring side clearance
- Connecting rod side clearance
- Piston-to-wall clearance
- Valve clearance

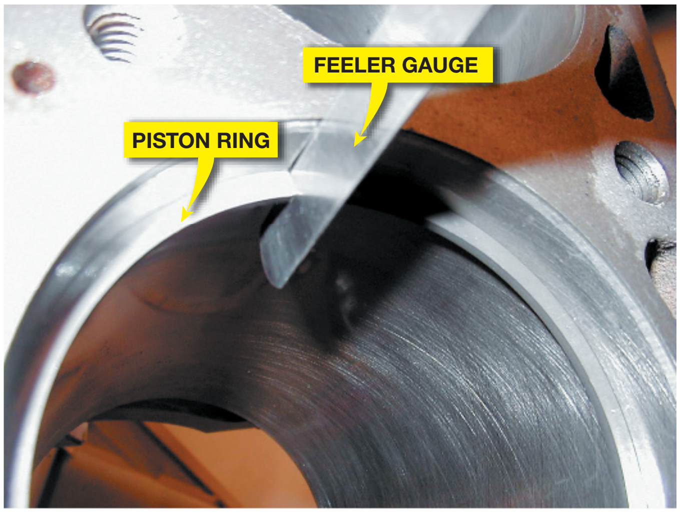

FEELER GAUGE
PISTON RING

FIGURE 11–18 A feeler gauge (also called a thickness gauge) is used to measure the small clearances, such as the end gap of a piston ring.

FREQUENTLY ASKED QUESTION

What Is a Straight Edge Used For?

A **straightedge** is a precision-ground metal measuring gauge that is used to check the flatness of engine components when used with a feeler gauge. A straightedge is used to check the flatness of the following:

- Cylinder heads (● **SEE FIGURE 11–19.**)
- Cylinder block deck
- Straightness of the main bearing bores (saddles)

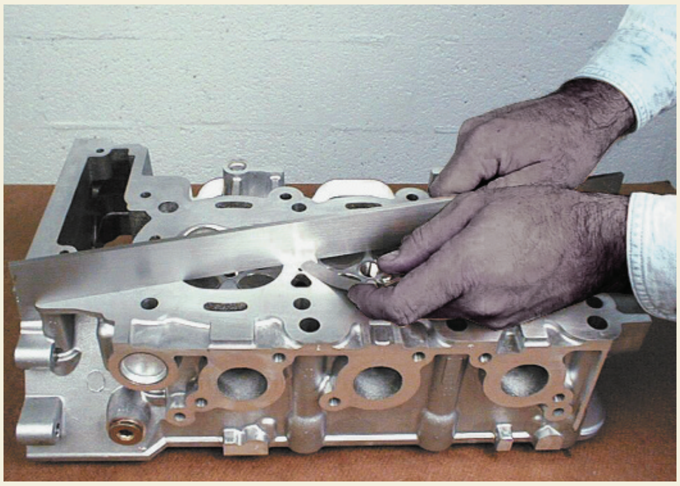


FIGURE 11–19 A straightedge is used with a feeler gauge to determine whether a cylinder head is warped or twisted.

DIAL INDICATOR A dial indicator is a precision measuring instrument used to measure the amount of movement between two components, such as crankshaft end play, crankshaft runout, and brake rotor runout. A dial indicator can be mounted three ways, including:

- Magnetic mount. This is a very useful method because a dial indicator can be attached to any steel or cast-iron part.

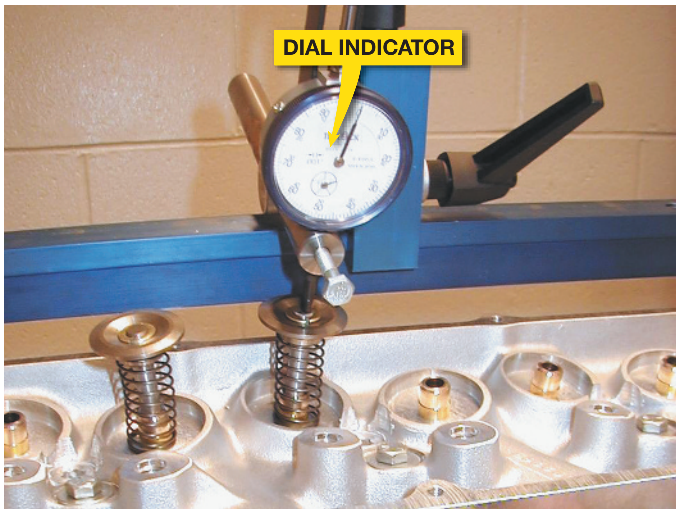


FIGURE 11–20 A dial indicator is used to measure valve lift during flow testing of a high-performance cylinder head.

- Clamp mount. A clamp-mounted dial indicator is used in many places where a mount could be clamped.
- Threaded rod. Using a threaded rod allows the dial indicator to be securely mounted. ● **SEE FIGURE 11–20**.

DIAL BORE GAUGE A dial bore gauge is a gauge used to measure cylinder taper and out-of-round, as well as main bearing (block housing) bore for taper and out-of-round. ● **SEE FIGURE 11–21**.

A dial bore gauge must be adjusted to a specific dimension, such as the factory specifications for a cylinder diameter, using a setting tool. The reading on the dial bore gauge then indicates plus (+) or minus (−) readings from the predetermined dimension. This is why a dial bore is best used to measure taper and out-of-round, because it shows the difference in cylinder or bore, rather than an actual measurement.

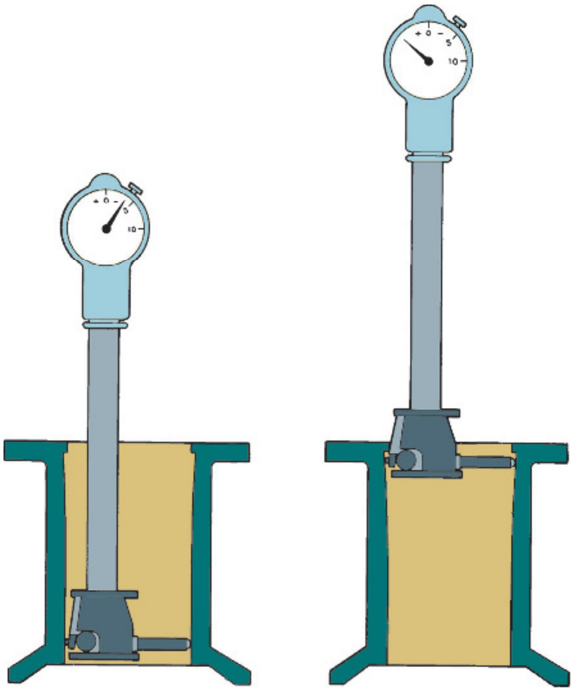


FIGURE 11–21 A dial bore gauge is used to measure cylinders and other engine parts for out-of-round and taper conditions.

MATH

DECIMALS Decimals are commonly used by service technicians. The placement of the decimal point indicates the value of the number. The naming of decimals includes tenths, hundredths, thousandths, and higher. Decimals are used to represent fractions of a unit by using a dot called a **decimal point** to indicate that the number is a decimal.

TENTHS. A decimal with one number to the right of the decimal point indicates an accuracy of 1/10 or 0.1. For example, 0.7 is the same as 7/10 and is pronounced "seven tenths" or "zero point seven." A decimal can also include numbers larger than zero, but has a resolution or accuracy measured in tenths, such as in 14.7.

HUNDREDTH. Decimals with two numbers to the right of the decimal point indicate an accuracy to 1/100 or 0.01. For example, 0.47 is pronounced "forty-seven hundredth" or "zero point four seven."

THOUSANDTH. A decimal with three numbers to the right of the decimal point indicates an accuracy to 1/1,000 or 0.001. For example, 0.867 is pronounced "eight hundred sixty-seven thousandth" or "zero point eight six seven."

ADDING AND SUBTRACTING DECIMALS When adding or subtracting decimals, the decimal points have to be aligned. This ensures that the numbers are placed into the correct position of tenth, hundredth, and thousandth. For example:

$$\begin{array}{r} 0.147 \\ +0.02 \\ \hline 0.167 \end{array}$$

Notice that the top number is expressed in thousandths and the lower number is expressed in hundredths. The final figure is also shown in thousandths.

NOTE: If these numbers were measurements, the first result cannot be more accurate than the least accurate measurement. This means that the result should be expressed in hundredths instead of thousandths. When subtracting or multiplying decimals, keep the decimal points aligned or use a calculator, making certain to include the decimal point.

PERCENTAGE **Percentage** is the relationship of a value or number out of 100. Using money as an example, three quarters (25 cents each) equals 75 cents ($0.75) or 75% of a dollar ($1.00). Many examples are not that easy. For example, 70 is what percentage of 120? To determine the percentage, divide the first number (70) by the second number (120). 70/120 = 0.58

To convert this number to a percentage, multiply the number by 100 or move the decimal point two places to the right (58) and then add a percentage symbol to indicate that the number is a percentage (58%).

SCIENTIFIC NOTATION Very large and very small decimal numbers are frequently expressed using **scientific notation**. Scientific notation is written as a number multiplied by the number of zeros to the right or left of the decimal point. For example, 68,000 could be written as 6.8×10^4, indicating that the number shown has 3 zeros plus the 8 to the right of the decimal point.

Small numbers, such as 0.00068, would use a negative sign beside the number over the 10 to represent that the decimal point needs to be moved toward the left (6.8 x 10^{-4}).

ADDING AND SUBTRACTING

Technicians are often required to add or subtract measurements when working on vehicles. For example, adding and subtracting is needed to select shims (thin pieces of steel) for adjusting valve clearance or differential preload measurements. An example would be on an engine with an overhead cam that uses shims to adjust the valve clearance. ● **SEE FIGURE 11–22**.

- If the valve clearance specification is 0.012 inch and the measured clearance is actually 0.016 inch.
- The shim that is in place between the camshaft lobe and the valve bucket is 0.080 inch thick.
- What size (thickness) of shim needs to be installed to achieve the correct valve clearance?

Solution: The specification requires that the shim needs to be thicker to reduce the valve clearance.

The original clearance is 0.016 inch and the specification is 0.012 inch. The difference is determined by subtracting the actual clearance from the specified clearance:

$$0.016 - 0.012 = 0.004 \text{ in.}$$

The result (0.004 inch) then needs to be added to the thickness of the existing shim to determine the thickness of the replacement shim needed to achieve the correct valve clearance.

Existing shim thickness = 0.080 in.
Additional thickness needed = +0.004 in.
Thickness of new shim = 0.084 in.

FRACTIONS

Fractions, such as 1/2, 1/4, or 5/8 are commonly found in specifications for hose inside-diameter measurements. A tape measure can be used to measure the fitting or the original part. Sometimes, fractions need to be converted to decimal units if the replacement parts are specified in decimal units. When comparing fractions to decimal units, think about the number of cents in a dollar.

1/2 dollar = 50 cents
Quarter = 25 cents
1/10 (dime) = 10 cents
1/20 (nickel) = 5 cents

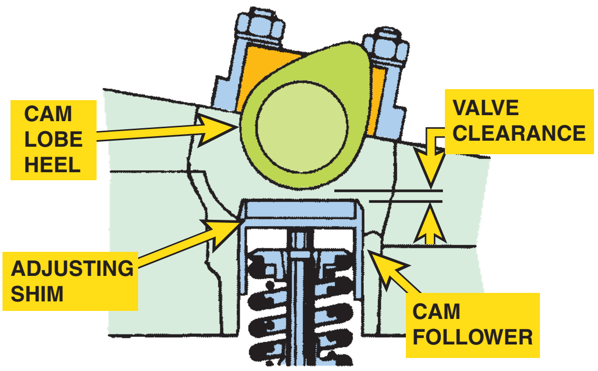


FIGURE 11–22 Valve clearance allows the metal parts to expand and maintain proper operation, both when the engine is cold and at normal operating temperature. Adjustment is achieved by changing the thickness of the adjusting shim.

If a chart is not available, divide the bottom number, called the denominator into the top number, called the numerator.

3/8 = 3 divided by 8 = 0.375
5/8 = 5 divided by 8 = 0.625
5/16 = 5 divided by 16 = 0.3125

MULTIPLYING AND DIVIDING

Multiplying by a service technician is usually done to determine gear ratios and to determine the total of many of the same items. For example, the final overall gear ratio is determined by multiplying the transmission gear ratio by the final drive ratio and is covered later in this chapter.

Dividing is commonly done when calculating the electrical resistance of many resistances connected in parallel. In this situation, the value of the resistance is divided by the number of equal resistances. For example, if four bulbs each with a resistance of 10 ohms were connected in parallel, the total resistance of the four bulbs combined would be 2.5 ohm (10/4 = 2.5).

MATHEMATICAL FORMULAS

A formula uses letters to represent values or measurements and indicates how these numbers are to be multiplied, divided, added, or subtracted. To use a formula, the technician needs to replace the letters with the actual number and perform the indicated math functions. For example, a formula may be used to determine engine speed in revolutions per minute (RPM) and is represented by the following:

$$\text{RPM} = \frac{\text{mph} \times \text{gear ratio} \times 336}{\text{tire diameter (inches)}}$$

This formula is used to determine the speed of the engine compared to the gear ratio and tire size. Sometimes, wheel and tire sizes are changed and knowing this is helpful. To calculate the engine speed, the actual information needs to be placed into the formula.

Mph = 70 mph
Gear ratio = 2:41:1
Tire diameter = 26 inches

Replacing the terms with the actual numbers results in the following:

$$\text{RPM} = \frac{70 \times 2.41 \times 336}{26} = \frac{56{,}683}{26} = 2180 \text{ RPM}$$

CALCULATING FUEL ECONOMY

To calculate fuel economy in miles per gallons, two factors must be known:

1. How far was the vehicle driven.
2. How many gallons of fuel were needed.

This calculation requires that the fuel tank be filled two times; first at the start of the test and then at the end of the test distance.

For example:

STEP 1 Fill the tank until the nozzle clicks off.

NOTE: Try to use the same station and pump, if possible, to achieve the most accurate results.

STEP 2 Drive a reasonable distance. For the example, 220 miles were traveled.

FREQUENTLY ASKED QUESTION

How Is Metric Fuel Economy Measured?

In the United States, fuel economy is expressed in miles per gallon. Outside of the United States, fuel economy is measured in the number of liters of fuel needed to travel 100 kilometers (62 miles), abbreviated L/100 km. This means that as the number increases, the fuel economy decreases. For example:

MPG	L/100 km
5	47.0
10	23.5
15	15.7
20	11.8
25	9.4
30	7.8
35	6.7
40	5.9
45	5.2
50	4.7

In the metric system, the fuel is measured; in the United States, the miles are measured.

STEP 3 Fill the fuel tank and record the number of gallons used. For this example, exactly 10.0 gallons were needed to refill the tank.

STEP 4 Calculate fuel economy: MPG = Miles driven divided by the number of gallons used.

MPG = 220 divided by 10.0 = 22.0 miles per gallon.

CALCULATING GEAR RATIOS When one gear turns another, the speed that the two gears turn in relation to each other is the gear ratio. Gear ratio is expressed as the number of rotations the **drive gear** must make in order to rotate the **driven gear** through one revolution. To obtain a gear ratio, simply divide the number of teeth on the driven gear by the number of teeth on the drive gear. Gear ratios, which are expressed relative to the number one, fall into three categories:

- Direct drive
- Gear reduction
- Overdrive

DIRECT DRIVE. If two meshed gears are the same size and have the same number of teeth, they will turn at the same speed. Since the drive gear turns once for each revolution of the driven gear, the gear ratio is 1:1; this is called a **direct drive**. When a transmission is in direct drive, the engine and transmission output shaft turn at the same speed.

GEAR REDUCTION. If one gear drives a second gear that has three times the number of teeth, the smaller drive gear must travel three complete revolutions in order to drive the larger gear through one rotation. ● **SEE FIGURE 11–23**.

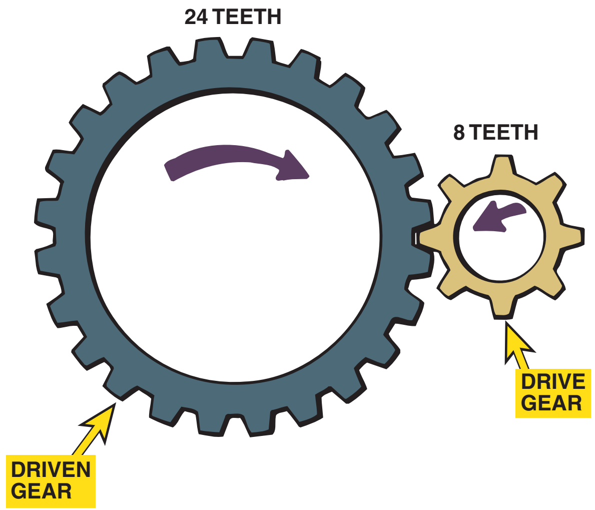


FIGURE 11–23 The drive gear is attached or is closer to the power source and rotates or drives the driven gear.

Divide the number of teeth on the driven gear by the number of teeth on the drive gear and you get a 3:1 gear ratio (pronounced three to one). This type of gear arrangement, where driven gear speed is slower than drive gear speed, provides **gear reduction**. Gear reduction may also be called underdrive as drive speed is less than, or under, driven speed. Both terms mean the same thing and use is a matter of preference. Gear reduction is used for the lower gears in a transmission. First gear in a transmission is called “low” gear because output speed, not gear ratio, is low. Low gears have numerically high gear ratios. That is, a 3:1 gear ratio is a lower gear than those with a 2:1 or 1:1 gear ratio. These three ratios taken in order represent a typical upshift pattern from low gear (3:1), to second gear (2:1), to third gear (1:1).

OVERDRIVE. **Overdrive** is the opposite of a gear reduction condition and occurs when a driven gear turns faster than its drive gear. For the gears shown in **FIGURE 11–24**, the driven gear turns three times for each turn of the drive gear.

The driven gear is said to overdrive the drive gear. For this example, the gear ratio is 0.33:1. Overdrive ratios of 0.65:1 and 0.70:1 are typical of those used in automotive applications.

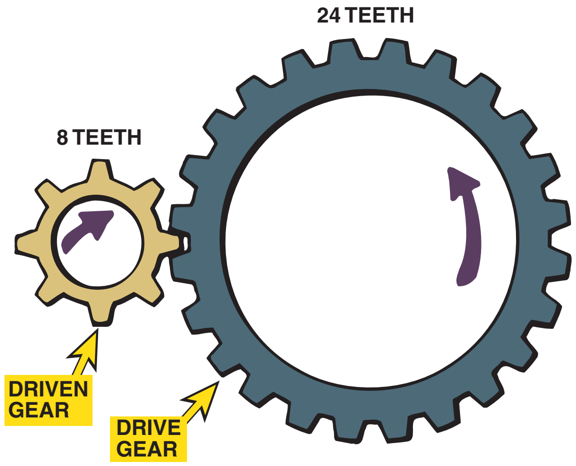


FIGURE 11–24 If the driven gear is rotating faster than the drive gear, it is called an overdrive ratio.

NOTE: Ratios always end in 1 with a colon in between. Therefore, the first number is less than 1 if it is an overdrive ratio and greater than 1 if it is a gear reduction ratio.

GRAPHS, CHARTS, AND DIAGRAMS

GRAPH READING A **graph** is a visual display of information. Graphs are commonly used in the automotive service industry to illustrate trends or specifications along with time or some other variable. A **variable** is a measurement of something that changes, such as engine speed or time. A graph has two variables displayed. One variable change from left to right on the horizontal axis. This is called the X axis. The other variable is displayed on the vertical axis, called the Y axis. A graph is created by making a series of dots at various locations and then connecting the dots with a line. ● **SEE FIGURE 11–25**.

INTERPRETING A GRAPH. To interpret a graph, select a point along the horizontal axis (X axis) and then look directly above the point where the line appears. Mark this spot and then look directly to the left along the vertical axis (Y axis) to see what value is represented by the points on the graph.

CHART READING A **chart** is used to represent data, such as numbers or specifications, along with another variable, such as model or year of vehicle. A chart is very useful for showing many different specifications or other facts in an easy-to-read format.

● **SEE FIGURE 11–26** for an example of a transmission clutch application chart, which shows the transmission components listed across the top and the selected gear of an automatic transmission along the left vertical column.

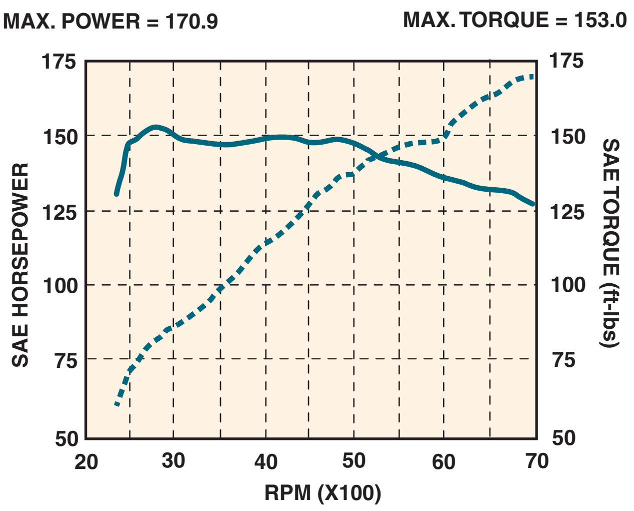


FIGURE 11–25 A graph showing horsepower and torque. Notice that the curves cross at 5252 RPM or a little bit to the right of the 50, which is expressed as the graph number multiplied by 100. The example is 52 multiplied by 100 equals 5200 RPM. The torque and horsepower curves cross at 5252 RPM because torque is measured by a dynamometer. The horsepower is then calculated using a formula that causes both values to be the same at that one engine speed.

INTERPRETING A CHART. A chart can look complicated but if studied, it is easy to interpret. Start by looking along the horizontal or vertical axis for the information, such as the range of the transmission down the left column. Then look to the right to find which device is being used to achieve that transmission drive range.

DIAGRAM READING A **diagram** is a graphic design that explains or shows the arrangement of parts. Diagrams are commonly used in the automotive service industry to show how a component is assembled and in which order the parts are placed together. ● **SEE FIGURE 11–27**.

RANGE	GEAR	2–4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3–4 CLUTCH	LO-ROLLER CLUTCH	LO-REV. CLUTCH
PARK-NEUTRAL									
OVERDRIVE	FIRST GEAR				APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED			APPLIED	HOLDING			
	THIRD GEAR				APPLIED	HOLDING	APPLIED		
	FOURTH GEAR	APPLIED			APPLIED		APPLIED		
DRIVE	FIRST GEAR			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED		APPLIED	APPLIED	HOLDING			
	THIRD GEAR			APPLIED	APPLIED	HOLDING	APPLIED		
MANUAL 2ND	FIRST GEAR			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED		APPLIED	APPLIED	HOLDING			
MANUAL 1ST	FIRST GEAR			APPLIED		HOLDING		HOLDING	APPLIED
REVERSE	REVERSE		APPLIED						APPLIED

FIGURE 11–26 A typical chart showing what is applied in what gear in an automatic transmission.

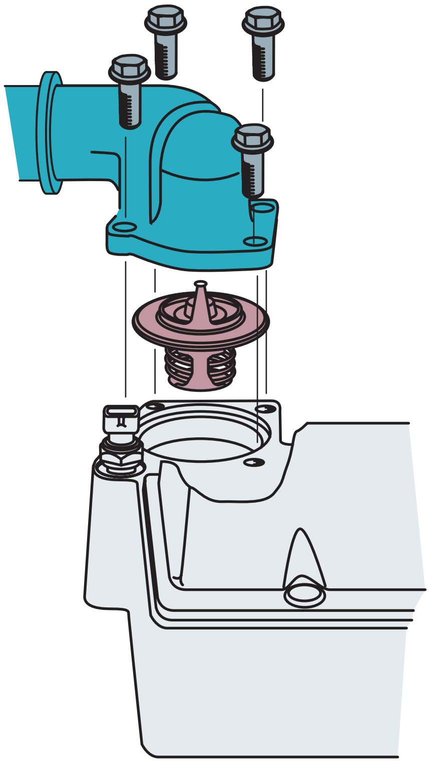


FIGURE 11–27 An exploded view showing how the thermostat is placed in the engine.

INTERPRETING A DIAGRAM. A diagram usually shows the relationship of many parts. Lines are used to show the centerline of the part and the identity of the part is often shown as a number or letter. A separate chart or area of the diagram needs to be looked at to determine the name of the part. Diagrams are most helpful when disassembling or assembling a component, such as a transmission. For best results, use electronic information and print out the diagram so it can be written on and can be thrown away when the repair has been completed. This process also helps prevent getting grease on the pages of a service manual.

REVIEW QUESTIONS

1. How is a micrometer read?
2. What can a feeler gauge measure?
3. What service operation may require the technician to add and subtract?
4. What service operation may require the technician to multiply or divide?
5. What math function is needed to calculate the overall gear ratio if the transmission and differential ratios are both known?

CHAPTER QUIZ

1. The threaded movable part that rotates on a micrometer is called the _________.
   - **a.** sleeve
   - **b.** thimble
   - **c.** spindle
   - **d.** anvil
2. Two kilometers is equal to _________ miles.
   - **a.** 2.0
   - **b.** 0.62
   - **c.** 1.24
   - **d.** 6
3. To check a crankshaft journal for out-of-round, the journal should be measured in at least how many locations?
   - **a.** Two
   - **b.** Four
   - **c.** Six
   - **d.** Eight
4. When looking at a graph, which of these represents the horizontal axis?
   - **a.** Dots in the center
   - **b.** The “Y” axis
   - **c.** The “X” axis
   - **d.** The “C” axis
5. To directly measure the diameter of a valve guide in a cylinder head, use a micrometer and a _________.
   - **a.** telescopic gauge
   - **b.** feeler gauge
   - **c.** small-hole gauge
   - **d.** dial indicator
6. 3/16 is what number in decimal form?
   - **a.** 0.1875
   - **b.** 1.875
   - **c.** 0.5333
   - **d.** 5.333
7. How is 0.183 pronounced?
   - **a.** One hundred eighty-three thousandth
   - **b.** One thousand eighty-three
   - **c.** Zero dot one hundred and eighty-three hundredths
   - **d.** One tenth and 83 hundredths
8. A vehicle traveled 280 miles and used 12.6 gallons of fuel. What is the calculated miles per gallon?
   - **a.** 18 MPG
   - **b.** 22.2 MPG
   - **c.** 28 MPG
   - **d.** 42 MPG
9. Which of these numbers is the smallest?
   - **a.** 1/16
   - **b.** 0.25
   - **c.** 3/8
   - **d.** 0.33
10. Gear ratio is expressed as the number of rotations the _________ must make in order to rotate the _________ one revolution.
    - **a.** drive gear/driven gear
    - **b.** driven gear/drive gear
    - **c.** input gear/output gear
    - **d.** output gear/input gear

Chapter 12

SCIENTIFIC PRINCIPLES AND MATERIALS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the use of scientific methods and energy principles in solving problems.
- Explain the relationship between torque, work, power, and horsepower.
- Explain the importance of Newton's laws of motion in brake design.
- Explain the importance of kinetic energy in brake design.
- Explain the importance of inertia in brake design.
- Explain the importance of mechanical principles in brake design.
- Discuss the concepts of heat and temperature.
- Discuss the concepts of acids and bases.
- Discuss gas laws.
- Discuss sound and acoustics.
- Discuss iron and steel.
- Describe SAE steel designations.
- Describe aluminum and aluminum alloys.

KEY TERMS:

Acid material 113 • Alkaline 112 • Brake 108 • Brake horsepower (bhp) 108 • BTUs 111 • Caustic material 113 • Celsius 111 • Conduction 111 • Conductor 111 • Convection 111 • Dynamometer 108 • Energy 107 • Fahrenheit 112 • First-class lever 110 • Force 107 • Fulcrum 110 • Horsepower 107 • Hypothesis 106 • Inertia 110 • Insulator 111 • Kinetic energy 107 • Leverage 110 • Mass 110 • Mechanical advantage 111 • Newton's laws of motion 109 • Pedal ratio 111 • pH 113 • Potential energy 107 • Power 107 • Propagation 113 • Radiation 111 • Root cause 106 • Scientific method 106 • Second-class lever 110 • Third-class lever 110 • Torque 107 • Weight 110 • Work 107 • Wrought alloys 114

SCIENTIFIC METHOD AND ENERGY PRINCIPLES

The **scientific method** is a series of steps taken to solve a problem. These steps help to eliminate errors and to achieve an accurate result. The scientific method is the foundation of automotive diagnosis. A scientific method involves the following steps:

STEP 1 Observe the conditions or problem and define or describe the problem.

STEP 2 Formulate an explanation that could be the cause of the problem.

STEP 3 Use the explanation (**hypothesis**) to test to see if it matches the existing problem. If not, then return to step 2 to formulate another explanation.

STEP 4 After the explanation has proved to be a possible solution to a problem, additional tests should be performed to verify that the method works all of the time.

USING THE SCIENTIFIC METHOD While a service technician will not perform research, using a scientific approach to problem solving is very important.

This means that every fault should be investigated to determine the root cause rather than solving what at first is thought to be the problem or fault. The **root cause** is the true cause of a failure, which may not be noticed at first. Many service technicians ask themselves "why" when they discover a fault. Often this leads to another possible problem and then the technician should ask another "why." This scientific method of finding the root cause of an automotive problem is often called the "five whys." By the time the technician has asked "why" five times, the root cause is usually discovered.

EXAMPLES OF THE FIVE WHYS As an example of using a scientific method approach to automotive faults, an owner may state that the vehicle does not start and the battery appears to be dead. Therefore, applying the five whys (scientific approach) first ask why:

- First why—What caused the battery to become discharged? To answer this question requires observation and the creating of a hypothesis, such as "is the battery defective" or "did the customer leave the lights on?" This requires questioning the owner and testing the battery.
- Second why—Assume that the battery was in good condition but discharged. Now the technician should ask the second why. "Why did the battery become discharged?" This means that a battery ignition off drain test needs to be performed as well as testing of the charging system. Assume the battery drain test was okay, but that the charging system was not working properly.
- Third why—The charging system was found to be not working correctly. A visual inspection found that the accessory drive belt was not tight enough to properly operate the alternator. The technician needs to ask the third why, "Why is the accessory drive belt still loose?"
- Fourth why—"Why was the accessory drive belt loose?" The cause could be a defective tensioner. If the tensioner itself was not a problem, then another "why" needs to be asked.
- Fifth why—If the accessory belt and belt tensioner were okay, then further investigation would be needed to find the root cause. For example, "Is one of the tensioner retaining bolts loose, maybe from a previous repair?" This could be the root cause.

ENERGY PRINCIPLES **Energy** is the ability or the capacity to do work. There are many forms of energy, but chemical, mechanical, and electrical energy are the most familiar kinds involved in the operation of an automobile. ● **SEE FIGURE 12–1**. Energy in the form of a moving object is called **kinetic energy.** An example of kinetic energy is a moving vehicle. Energy is called **potential energy** if it is capable of being changed to useful energy, such as the potential energy stored in a battery or a vehicle at the top of a hill. In both of these cases, there is no energy being released, but if the battery were connected to an electrical load, such as a light bulb, or the vehicle starts moving down the hill, the energy is being released.

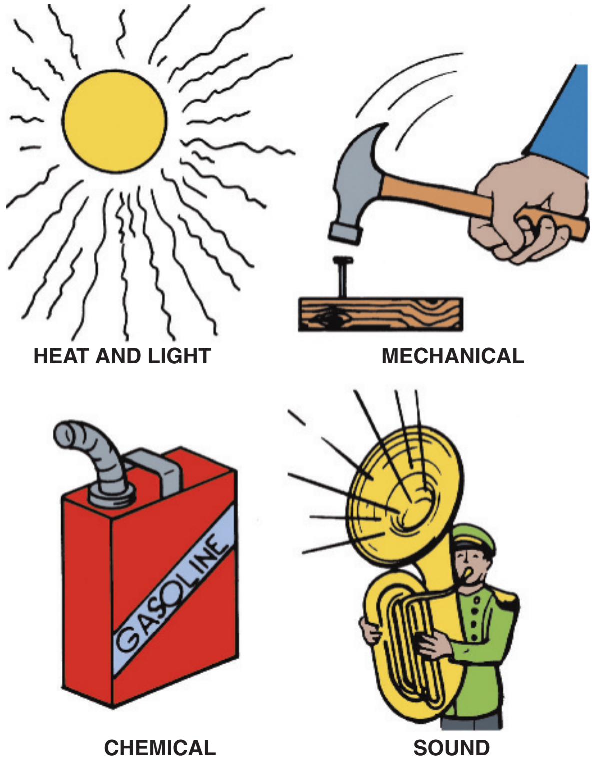


FIGURE 12–1 Energy, which is the ability to perform work, exists in many forms.

TORQUE, WORK, POWER, AND HORSEPOWER

TORQUE **Torque** is the term used to describe a rotating force that may or may not result in motion. Torque is measured as the amount of **force** multiplied by the length of the lever through which it acts. If a one-foot-long wrench is used to apply 10 pounds of force to the end of the wrench to turn a bolt, then 10 pound-feet of torque is being applied. ● **SEE FIGURE 12–2**. The metric unit for torque is Newton-meters because Newton is the metric unit for force and the distance is expressed in meters.

1 pound-foot = 1.3558 Newton-meters

1 Newton-meter = 0.7376 pound-foot

WORK **Work** is defined as actually accomplishing movement when force (torque) is applied to an object. A service technician can apply torque to a bolt in an attempt to loosen it, yet no work is done until the bolt actually moves. Work is calculated by multiplying the applied force (in pounds) by the distance the object moves (in feet). If you applied 100 pounds of force to move an object 10 feet, then you accomplished 1,000 foot-pounds of work (100 pounds × 10 feet = 1,000 foot pounds). ● **SEE FIGURE 12–3**.

POWER The term **power** means the rate of doing work. Power equals work divided by time. Work is achieved when a certain amount of mass (weight) is moved a certain distance by a force. If the object is moved in 10 seconds or 10 minutes does not make a difference in the amount of work accomplished, but it does affect the amount of power needed. Power is expressed in units of foot-pounds per minute.

HORSEPOWER The power an engine produces is called horsepower (hp). One **horsepower** is the power required to move 550 pounds one foot in one second, or 33,000 pounds one foot in one minute (550 lb × 60 sec = 33,000 lb). This is expressed as 500 foot-pounds (ft-lb) per second or 33,000 foot-pounds per minute. ● **SEE FIGURE 12–4**.

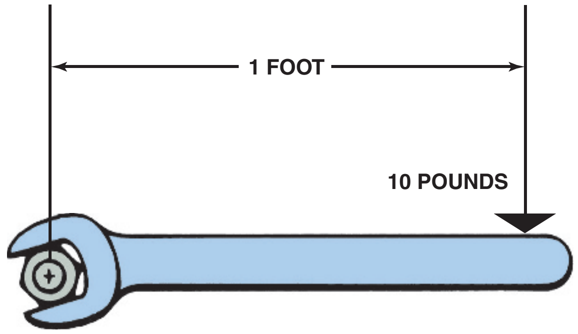


FIGURE 12–2 Torque is a twisting force equal to the distance from the pivot point times the force applied expressed in units called pound-feet (lb-ft) or Newton-meters (N-m).

Newton-Meters to Pound-Feet Conversion Chart
(1 N-m = 0.74 lb-ft)

N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft
1	0.74	26	19.2	51	37.7	76	56.2
2	1.5	27	20.0	52	38.5	77	57.0
3	2.2	28	20.7	53	39.2	78	57.7
4	3.0	29	21.5	54	40.0	79	58.5
5	3.7	30	22.2	55	40.7	80	59.2
6	4.4	31	22.9	56	41.4	81	59.9
7	5.2	32	23.7	57	42.2	82	60.7
8	5.9	33	24.4	58	42.9	83	61.4
9	6.7	34	25.2	59	43.7	84	62.2
10	7.4	35	25.9	60	44.4	85	62.9
11	8.1	36	26.6	61	45.1	86	63.6
12	8.9	37	27.4	62	45.9	87	64.4
13	9.6	38	28.1	63	46.6	88	65.1
14	10.4	39	28.9	64	47.4	89	65.9
15	11.1	40	29.6	65	48.1	90	66.6
16	11.8	41	30.3	66	48.8	91	67.3
17	12.6	42	31.1	67	49.6	92	68.1
18	13.3	43	31.8	68	50.3	93	68.8
19	14.1	44	32.6	69	51.0	94	69.6
20	14.8	45	33.3	70	51.8	95	70.3
21	15.5	46	34.0	71	52.5	96	71.0
22	16.3	47	34.8	72	53.3	97	71.8
23	17.0	48	35.5	73	54.0	98	72.5
24	17.8	49	36.3	74	54.8	99	73.3
25	18.5	50	37.0	75	55.5	100	74.0

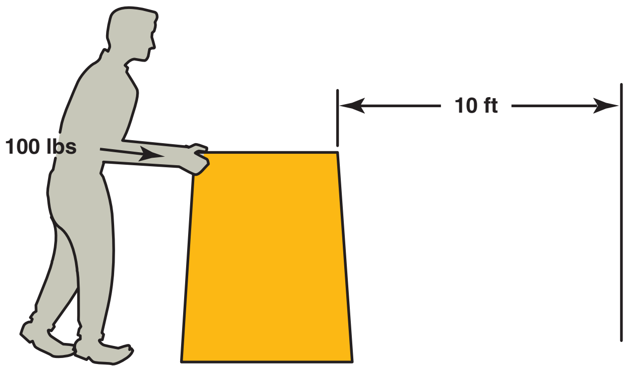


FIGURE 12–3 Work is calculated by multiplying force times distance. If you push 100 pounds 10 feet, you have done 1,000 foot-pounds of work.

The actual horsepower produced by an engine is measured with a **dynamometer**. A dynamometer (often abbreviated as **dyno** or **dyn**) places a load on the engine and measures the amount of twisting force the engine crankshaft places against the load. The load holds the engine speed, so it is called a **brake**. The horsepower derived from a dynamometer is called **brake horsepower (bhp)**. The dynamometer actually measures the torque output of the engine. Torque is a rotating force that may or may not cause movement. The horsepower is calculated from the torque readings at various engine speeds (in revolutions per minute or RPM).

Pound-Feet to Newton-Meters Conversion Chart
(1 lb-ft = 1.4 N-m)

Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m
1	1.4	26	36.4	51	71.4	76	106.4
2	2.8	27	37.8	52	72.8	77	107.8
3	4.2	28	39.2	53	74.2	78	109.2
4	5.6	29	40.6	54	75.6	79	110.6
5	7.0	30	42.0	55	77.0	80	112.0
6	8.4	31	43.4	56	78.4	81	113.4
7	9.8	32	44.8	57	79.8	82	114.8
8	11.2	33	46.2	58	81.2	83	116.2
9	12.6	34	47.6	59	82.6	84	117.6
10	14.0	35	49.0	60	84.0	85	119.0
11	15.4	36	50.4	61	85.4	86	120.4
12	16.8	37	51.8	62	86.8	87	121.8
13	18.2	38	53.2	63	88.2	88	123.2
14	19.6	39	54.6	64	89.6	89	124.6
15	21.0	40	56.0	65	91.0	90	126.0
16	22.4	41	57.4	66	92.4	91	127.4
17	23.8	42	58.8	67	93.8	92	128.8
18	25.2	43	60.2	68	95.2	93	130.2
19	26.6	44	61.6	69	96.6	94	131.6
20	28.0	45	63.0	70	98.0	95	133.0
21	29.4	46	64.4	71	99.4	96	134.4
22	30.8	47	65.8	72	100.8	97	135.8
23	32.2	48	67.2	73	102.2	98	137.2
24	33.6	49	68.6	74	103.6	99	138.6
25	35.0	50	70.0	75	105.0	100	140.0

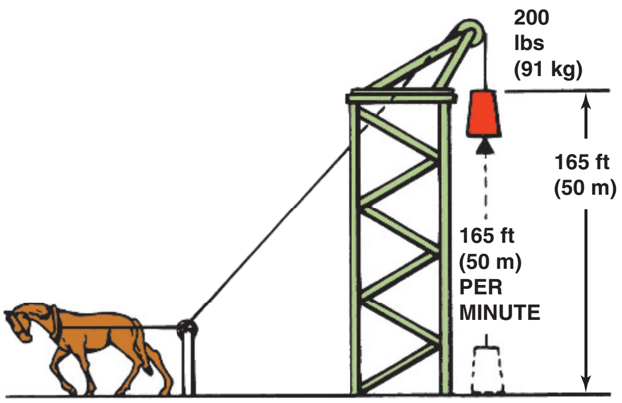


FIGURE 12–4 One horsepower is equal to 33,000 foot-pounds (200 lbs × 165 ft) of work per minute.

Horsepower is torque times RPM divided by 5252.

$$\text{Horsepower} = \frac{\text{Torque} \times \text{RPM}}{5252}$$

Torque is what the driver "feels" as the vehicle is being accelerated. A small engine operating at a high RPM may have the same horsepower as a large engine operating at a low RPM.

NOTE: As can be seen by the formula for horsepower, the higher the engine speed for a given amount of torque, the greater the horsepower.

FREQUENTLY ASKED QUESTION

What Is the Difference between Torque and Work?

The designations for torque and work are often confusing. Torque is expressed in pound-feet because it represents a force exerted a certain distance from the object and acts as a lever. Work, however, is expressed in foot-pounds because work is the movement over a certain distance (feet) multiplied by the force applied (pounds). Engines produce torque and service technicians exert torque represented by the unit pound-feet.

NEWTON'S LAWS OF MOTION

Sir Isaac Newton (1643–1727) was an English physicist and mathematician who developed many theories of science, including three laws of motion.

1. **Newton's first law of motion** states that an object at rest tends to stay at rest and an object in motion tends to stay in motion unless acted on by an outside force. For example, it requires a large force to get a vehicle that is stopped into motion. It also requires that a force be applied to slow and stop a vehicle that is in motion.
2. Newton's second law of motion states that the force needed to move an object is proportional to the mass of the object multiplied by the acceleration rate of the object. This means that it requires a great deal more force to accelerate a heavy sport utility vehicle (SUV) than a small economy vehicle. The rate of acceleration also depends on the amount of force that is applied.
3. Newton's third law of motion states that for every action, there is an opposite and equal reaction. For example, when the air–fuel mixture is ignited in an engine, the force is exerted on the piston, which is forced downward, which causes the crankshaft of the engine to rotate. The opposite action is applied to the cylinder head of the engine and applies the same force although this part is designed not to move.

KINETIC ENERGY

Kinetic energy is a fundamental form of mechanical energy. It is the energy of mass in motion. Every moving object possesses kinetic energy, and the amount of that energy is determined by the object's mass and speed. The greater the mass of an object and the faster it moves, the more kinetic energy it possesses. Even at low speeds, a moving vehicle has enough kinetic energy to cause serious injury and damage. The job of the brake system is to dispose of that energy in a safe and controlled manner.

Engineers calculate kinetic energy using the following formula:

$$\frac{mv^2}{29.9} = E_k$$

where:

m = mass or weight of the vehicle in pounds
v = velocity of the vehicle in miles per hour
E_k = kinetic energy in foot-pounds (ft-lb)

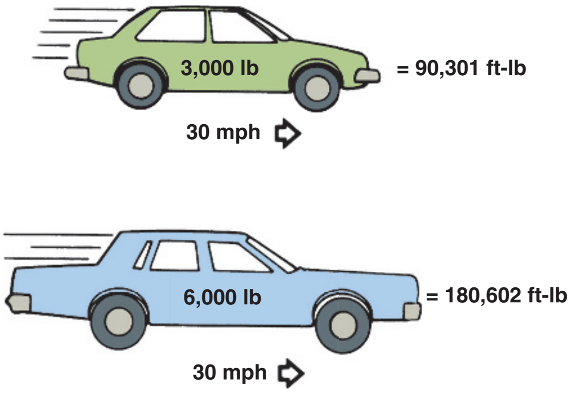


FIGURE 12–5 Kinetic energy increases in direct proportion to the weight of the vehicle.

Another way to express this equation is as follows.

$$\frac{\text{weight} \times \text{speed}^2}{29.9} = \text{kinetic energy}$$

If a 3,000-pound vehicle traveling at 30 mph is compared to a 6,000-pound vehicle also traveling at 30 mph as shown in ● **SEE FIGURE 12–5**, the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{6{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 180{,}602 \text{ ft-lb}$$

The results show that when the weight of a vehicle is doubled from 3,000 to 6,000 pounds, its kinetic energy is also doubled from 90,301 foot-pounds to 180,602 foot-pounds. In mathematical terms, kinetic energy increases *proportionally* as weight increases. In other words, if the weight of a moving object doubles, its kinetic energy also doubles. If the weight quadruples, the kinetic energy becomes four times as great.

If a 3,000-pound vehicle traveling at 30 mph is compared to the same vehicle traveling at 60 mph (● **SEE FIGURE 12–6**), the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{3{,}000 \text{ lb} \times 60^2 \text{ mph}}{29.9} = 361{,}204 \text{ ft-lb}$$

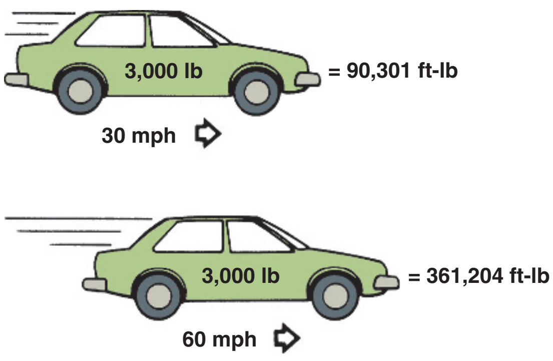


FIGURE 12–6 Kinetic energy increases as the square of any increase in vehicle speed.

FREQUENTLY ASKED QUESTION

What Is the Difference between Mass and Weight?

Mass is the amount of matter in an object. One of the properties of mass is inertia. Inertia is the resistance to being put in motion and the tendency to remain in motion once it is set in motion.

The **weight** of an object is the force of gravity on the object and may be defined as the mass times the acceleration of gravity.

Therefore, mass means the property of an object and weight is a force.

TECH TIP

Brakes Cannot Overcome the Laws of Physics

No vehicle can stop on a dime. The energy required to slow or stop a vehicle must be absorbed by the braking system. All drivers should be aware of this fact and drive at a reasonable speed for the road and traffic conditions.

The results show that the vehicle traveling at 30 mph has over 90,000 foot-pounds of kinetic energy, but at 60 mph the figure increases to over 350,000 foot-pounds. In fact, at twice the speed, the vehicle has exactly four times as much kinetic energy. If the speed were doubled again to 120 mph, the amount of kinetic energy would grow to almost 1,500,000 foot-pounds! In mathematical terms, kinetic energy increases as the *square of its speed.* In other words, if the speed of a moving object doubles (2), the kinetic energy becomes four times as great ($4^2 = 4$). And if the speed quadruples (4), say from 15 to 60 mph, the kinetic energy becomes 16 times as great ($2^2 = 16$). This is the reason speed has such an impact on kinetic energy.

KINETIC ENERGY AND BRAKE DESIGN The relationships between weight, speed, and kinetic energy have significant practical consequences for the brake system engineer. If vehicle A weighs twice as much as vehicle B, it needs a brake system that is twice as powerful. But if vehicle C has twice the speed potential of vehicle D, it needs brakes that are, not twice, but four times more powerful.

INERTIA

Although brake engineers take both weight and speed capability into account when designing a brake system, these are not the only factors involved. Another physical property, inertia, also affects the braking process and the selection of brake components. **Inertia** is defined by Isaac Newton's first law of motion, which states that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line unless acted upon by an outside force.

MECHANICAL PRINCIPLES

The primary mechanical principle used to increase application force in every brake system is **leverage**. In the science of mechanics, a lever is a simple machine that consists of a rigid object, typically a metal bar that pivots about a fixed point called a **fulcrum**. There are three basic types of levers, but the job of all three is to change a quantity of energy into a more useful form.

A **first-class lever** increases the force applied to it and also changes the direction of the force. ● **SEE FIGURE 12–7**.

With a first-class lever, the weight is placed at one end while the lifting force is applied to the other. The fulcrum is positioned at some point in between. If the fulcrum is placed twice as far from the long end of the lever as from the short end, a 10-pound weight on the short end can be lifted by only a 5-pound force at the long end. However, the short end of the lever will travel only half as far as the long end. Moving the fulcrum closer to the weight will further reduce the force required to lift it, but it will also decrease the distance the weight is moved.

A **second-class lever** increases the force applied to it and passes it along in the same direction. ● **SEE FIGURE 12–8**.

With a second-class lever, the fulcrum is located at one end while the lifting force is applied at the other. The weight is positioned at some point in between. If a 10-pound weight is placed at the center of the lever, it can be lifted by only a 5-pound force at the end of the lever. However, the weight will only travel half the distance the end of the lever does. As the weight is moved closer to the fulcrum, the force required to lift it, and the distance it travels, are both reduced.

A **third-class lever** actually reduces the force applied to it, but the resulting force moves farther and faster. ● **SEE FIGURE 12–9**.

With a third-class lever, the fulcrum is located at one end and the weight is placed at the other. The lifting force is applied at some point in between. If a 10-pound weight is placed at the end of the lever, it can be lifted by a 20-pound force applied at

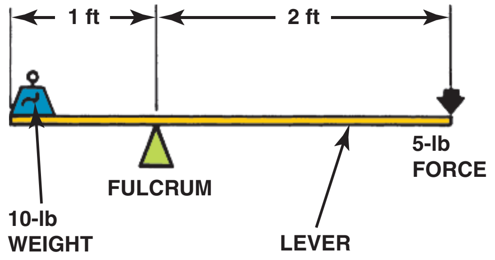


FIGURE 12–7 A first-class lever increases force and changes the direction of the force.

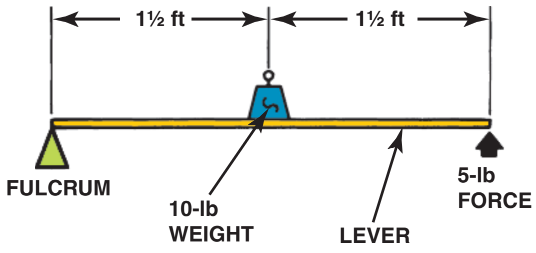


FIGURE 12–8 A second-class lever increases force in the same direction as it is applied.

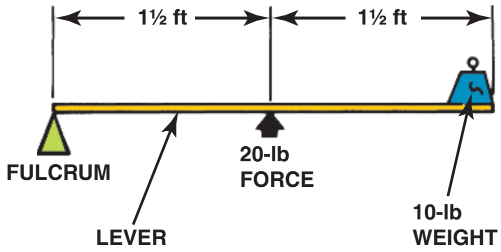


FIGURE 12–9 A third-class lever reduces force but increases the speed and travel of the resulting work.

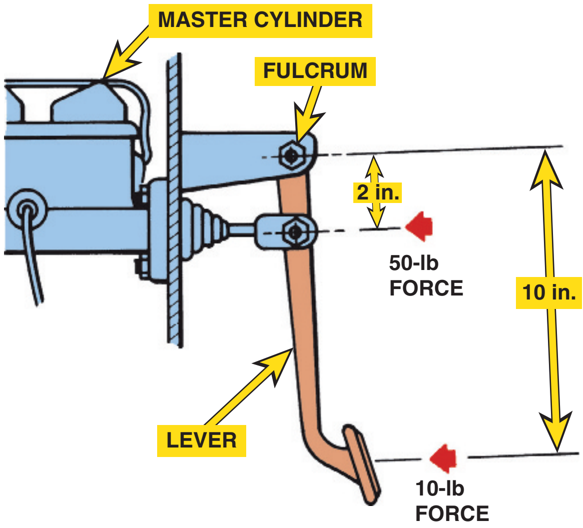


FIGURE 12–10 This brake pedal assembly provides a 5:1 mechanical advantage because a 10-lb force input results in a 50-lb force into the master cylinder.

the middle of the lever. Although the force required to move the weight has doubled, the weight is moved twice as far and twice as fast as the point on the lever where the force was applied. The closer to the fulcrum the lifting force is applied, the greater the force required by the weight and the farther and faster the weight will move.

For example, first- or second-class levers are used on brake systems to increase braking force while making it easier for the driver to control the amount of force applied. Second-class levers are the most common, and the service brake pedal is a good example. In a typical suspended brake pedal, the pedal arm is the lever, the pivot point is the fulcrum, and the force is applied at the foot pedal pad. ● **SEE FIGURE 12–10**. The force applied to the master cylinder by the pedal pushrod attached to the pivot is much greater than the force applied at the pedal pad, but the pushrod does not travel nearly as far.

Leverage creates a **mechanical advantage** that, at the brake pedal, is called the **pedal ratio**. For example, a pedal ratio of 5 to 1 is common for brakes, which means that a force of 10 pounds at the brake pedal will result in a force of 50 pounds at the pedal pushrod. In practice, leverage is used at many points in both the service and parking brake systems.

HEAT AND TEMPERATURE

Heat and temperature are related, but are not the same. Temperature is the intensity of the heat source, whereas heat is the quantity of heat. For example, the heat from a match and a large fire may measure the same temperature, but the amount of heat generated by the fire is far greater than the amount of heat generated by a single match.

HEAT Heat is measured in units called **British Thermal Units,** abbreviated **BTUs**. One BTU is the amount of heat needed to raise the temperature of one pound of water one degree Fahrenheit. For example, room heaters and air conditioners are rated in how many BTUs per hour can be added (heater) or removed (air conditioner) from a space in one hour.

Heat energy can be transferred by three ways, including:

- **Conduction**—Conduction is the process of the heat traveling from a hotter part to a colder part of the same object or by direct contact. For example, if one end of a steel bar is heated, then the heat will travel by conduction toward the colder areas of the bar. Also, if the metal were touched, heat would travel from the steel bar to the finger. Metals are good conductors of heat, whereas plastic, rubber, and ceramics are poor conductors of heat and are called **insulators**.
- **Convection**—Convection is the transfer of heat through a liquid or a gas, which causes it to rise while the cooler liquid or gas falls within a container. A hot air balloon is an example where hot gas in the balloon causes it to rise above the surrounding cooler air.
- **Radiation**—Radiation is a method of energy transfer where heat is transmitted through the air. Heat from the sun is transmitted through the atmosphere where it heats the ground. Heat can be felt above a hot stove.

TEMPERATURE Temperature is the measurement of the ability to give up or absorb heat from another body. Heat always flows from a warmer object to a colder object.

Temperature is measured using two scales:

1. **Celsius** (also called **centigrade**). The Celsius scale was devised by taking the freezing point and the boiling point of water and dividing it into 100 equal parts.

TECH TIP

Conductors and Insulators

If a material is a good conductor of heat, it is also a good conductor of electricity. Most **conductors** are metals, such as steel, copper, aluminum, and brass. Most insulators are nonmetals, such as plastic and rubber. Therefore, if a material does not conduct heat, it usually will not conduct electricity.

FREQUENTLY ASKED QUESTION

How Does a Coat Keep You Warm?

A coat is worn in cold weather to keep warm. Does it keep the cold out or the heat in? Actually, both, but because heat travels from a warm object (human body) to a colder object (outside cold air), the primary purpose of a coat is to keep the body heat from escaping into the cold air.

TECH TIP

Quick and Easy Temperature Conversion

Many service information and scan tool data are expressed in degrees Celsius, which is often confusing to those used to temperature expressed in Fahrenheit degrees. A quick and easy way to get an *approximate* conversion is to take the degrees in Celsius, double it, and add 25.

For example,

Celsius × 2 + 25 = approximate Fahrenheit degrees:

0°C × 2 = 0 + 25 = 25°F (actual = 32°F)
10°C × 2 = 20 + 25 = 45°F (actual = 50°F)
15°C × 2 = 30 + 25 = 55°F (actual = 59°F)
20°C × 2 = 40 + 25 = 65°F (actual = 68°F)
25°C × 2 = 50 + 25 = 75°F (actual = 77°F)
30°C × 2 = 60 + 25 = 85°F (actual = 86°F)
35°C × 2 = 70 + 25 = 95°F (actual = 95°F)
40°C × 2 = 80 + 25 = 105°F (actual = 104°F)
45°C × 2 = 90 + 25 = 115°F (actual = 113°F)
50°C × 2 = 100 + 25 = 125°F (actual = 122°F)

For exact temperature conversion, use a smartphone and perform a temperature conversion.

2. **Fahrenheit.** The Fahrenheit scale was developed by Gabriel Fahrenheit (1686–1736), a German physicist who proposed the scale in 1724. He wanted to avoid using negative numbers, so the scale used had zero degrees representing the coldest outside air temperature he had ever measured and used his own body temperature to represent 100 degrees. Later, more accurate measurements indicate that average human body temperature to be 98.6 degrees so he was off by 1.4 degrees. Also, negative outside air temperatures can occur. ● **SEE FIGURE 12–11** and the comparison chart.

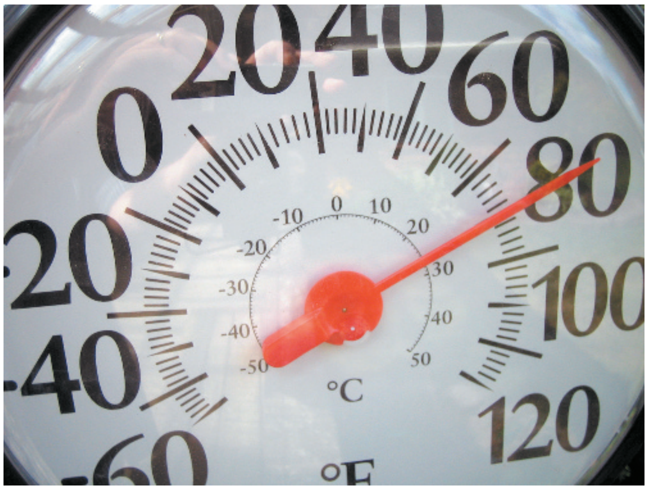


FIGURE 12–11 A typical outdoor thermometer which is used to measure temperature, not heat.

Temperature Symbol	Degree Celsius °C	Degree Fahrenheit °F
Boiling point of water	100.0	212.0
Average human body temperature	37.0	98.6
Average room temperature	20.0—25.0	68.0—77.0
Melting point of ice	0.0	32.0

FREQUENTLY ASKED QUESTION

What Is Thermodynamics?

Thermodynamics is the study of the relationship among temperature, pressure, and volume changes. The laws of thermodynamics help engineers design and develop engines with higher efficiency. Thermodynamics is therefore used in the design of the cooling system, as well as in the engine. The more heat created by the burning of fuel in the engine, the more power the engine can develop using the same or less amount of fuel.

FREQUENTLY ASKED QUESTION

Can Water and Acid Be Mixed Together?

Acids have a very strong affinity for water and as a result, if water is poured into acid, the resulting reaction would be extremely violent and acid would be forced outward in all directions. Always pour acid into water, never water into acid.

Technicians seldom need to work with acids because even battery electrolytes from the water and acid are premixed to help prevent the possibility of a technician creating a harmful reaction.

ACIDS AND BASES

ACIDS Acids are substances that can corrode metals and some can cause severe burns to the skin. Common household acids that are not harmful and taste sour include vinegar and lemon juice (citric acid). Stronger acids include:

- Hydrochloric acid
- Nitric acid
- Battery acid

BASES A base is a substance that can also burn the skin if strong enough and is also referred to as **alkaline**. Common household bases are generally not harmful unless eaten and have a bitter taste, including baking soda, soap, and antacid, such as Milk of Magnesia®. Stronger bases, which can burn the skin, include:

- Lye (sodium hydroxide)
- Bleach
- Drain cleaner

pH SCALE Most chemical cleaners used for cleaning carbon-type deposits are a strong soap, or **caustic material**. A value called **pH**, measured on a scale from 1 to 14, is used to indicate the amount of chemical activity. The term *pH* is from the French word *pouvoir hydrogine,* meaning "hydrogen power." Pure water is neutral. On the pH scale, water is pH 7. Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the caustic action will be. **Acid materials** have pH numbers from 6 through 1. The lower the number, the stronger the acid action will be. Caustic materials and acid materials neutralize each other, such as when baking soda (a caustic) is used to clean the outside of the battery (an acid surface). The caustic baking soda neutralizes any sulfuric acid that has been spilled or splashed on the outside of the battery.

CAUTION: Whenever working with chemicals, eye protection must be used.

GAS LAWS

Gas laws are a set of characteristics that describe how gases act and the relationship between their temperature, pressure, and volume. Gas laws have application in most systems of the vehicle, including tires, air-conditioning systems, and anywhere else gases are present.

BOYLE'S LAW Boyle's law was first written in 1662 by Robert Boyle (1627–1691) and describes the relationship between volume and pressure of a gas in a closed container. Boyle's law states that the volume of a gas varies inversely (opposite) with the pressure exerted against it in a closed container. Therefore, if a closed container is compressed, the volume of the gas inside is reduced, but the pressure is increased.

CHARLES'S LAW Charles's law was first formulated about 1787 by a French scientist, Jacque Charles (1746–1823). According to Charles's law, when the temperature of a gas increases, the volume increases. When the temperature of a gas decreases, the volume decreases.

SOUND AND ACOUSTICS

Sound is the movement of air that the ear interprets as sound. Sound travels through the air, which is called **propagation**. Propagation of sound is normally thought to be only transmitted through air, but liquids can also transmit sound waves. Sound has two properties:

- **Frequency.** This is also called the pitch of the sound and is measured in Hertz or cycles per second. Normal hearing frequency ranges from as low as 20 Hertz to 20,000 Hertz. Very low frequencies, such as the heartbeat, of one or two Hertz cannot be heard. High frequencies over 20,000 Hertz also cannot be detected by humans.
- **Intensity.** The intensity of sound, which is also called loudness, is measured in decibels (dB) named for Alexander Graham Bell (1847–1922), the inventor of the telephone. Relative intensity (loudness), using the decibel scale, includes the following examples:

Whisper	10–20 dB
Normal conversation	60 dB
Thunder	110 dB
Threshold of pain	120 dB

ACOUSTICS Acoustics is the study of sound and how it is generated and transmitted. Acoustic engineers are employed by vehicle manufacturers to help reduce noise and designing methods to reduce or stop the noise from being transmitted into the passenger compartment. For example, according to acoustic engineers, about 80% of the noise created by the movement of the tires on the road is transmitted through the chassis and body of the vehicle. Only about 20% of the sound is transferred to the passenger compartment through the air.

IRON AND STEEL

Iron is a chemical element with a symbol of Fe. It is one of the most commonly available elements on earth and is refined from iron ore. Steel is made from iron after further refining. The main difference between iron and steel is the amount of carbon. The amount of carbon is critical to the strength and characteristics of iron and steel.

CAST IRON Cast iron contains 2% to 4% carbon and this carbon is usually in the form of flakes of graphite 0.001 to 0.004 inches long. Cast iron is used in many automotive applications, including engine blocks, rear axle assemblies, and some suspension components.

DUCTILE CAST IRON In ductile iron, the carbon in the alloy with silicon are small ball-shapes called spheroidols. Ductile iron is also called malleable iron and is used to make crankshafts.

GRAY CAST IRON Gray cast iron is cast iron that has another element, silicon, in the alloy, giving the metal a gray color. Gray cast iron is used for engine blocks.

NOTE: Cast iron contains graphite, which acts as a lubricant when being machined. As a result, cooling oil or water is not needed when machining cast iron brake rotors or brake drums.

SAE STEEL DESIGNATIONS

Steels are designed by a system established by the Society of Automotive Engineers and includes numbers to indicate the main element used in the alloy, plus the "points of carbon." One part of carbon is 0.01%. In other words, 100 points of carbon is equal to 1%. The percentage of carbon in steel has a huge input on the strength and characteristics of the steel. For example,

- **Mild (low carbon) steel** has less than 20 points of carbon (0.02%). Mild steel is soft and easily formed, but is not very strong. Common usage of low carbon steel is in tables and chairs and vehicle body parts where strength is not an issue.

- **Medium carbon steel** usually has between 25 and 50 points of carbon (0.25% and 0.50%). This type of steel can be heat treated to create steel that is ductile (flexible) and yet has good strength. This type of steel is usually used in forgings and machined components.
- **High carbon steel** usually has between 60 and 100 points (0.60% and 1.00%) of carbon and is very strong. It is commonly used in vehicle springs and can be hardened.

CAUTION: Both medium carbon and high carbon steel can be hardened by heating and then cooling, using water or oil to rapidly cool the metal. Therefore, if heating any metal, always allow it to cool slowly to avoid changing the hardness of the steel.

The SAE numbering designation usually includes four numbers:

- The first two numbers indicate the type of alloy which could include several alloy elements.
- The last two numbers designate the points of carbon.

1xxx = plain carbon steels
2xxx = nickel steels
3xxx = nickel-chromium steels
4xxx = molybdenum steels
5xxx = chromium steels
6xxx = chromium-vanadium steels
7xxx = tungsten-chromium steels
9xxx = silicon-manganese steels

A commonly used alloy for forged crankshafts is SAE 4340. The analysis of this designation is: 4340 = An alloy that contains 1.82% nickel, 0.5% to 0.8% chromium, and 0.25% molybdenum with 40 points of carbon.

ALUMINUM AND ALUMINUM ALLOYS

Aluminum is a lightweight metal that is used in many automotive applications, including suspension components, engine blocks, and cylinder heads. Aluminum is almost always combined with small quantities of other metals to form an alloy, using copper, manganese, zinc, or silicon. Aluminum and aluminum alloys that are mechanically shaped are called **wrought alloys** and are labeled according to the International Alloy Designation system. The system uses a four-digit number, which identifies the alloying elements, followed by a dash (-) and then a letter identifying the type of heat treatment. This is followed by a number identifying the specific hardness or temper of the finished alloy. A typical example would be 6061-T6. The 6061 is a 6000 series alloy with magnesium and silicon. The "61" further identifies other elements and their percentages. The numbering system for cast aluminum alloy is similar, but is designed by standards of the Aluminum Association (AA).

REVIEW QUESTIONS

1. What is kinetic energy?
2. How is mechanical advantage used in the braking system?
3. What is the difference between torque and power?
4. How is sound intensity measured?
5. What is the pH of acids and bases?

CHAPTER QUIZ

1. What law is used to describe gas laws?
   a. Ohm's law
   b. Boyle's law
   c. Charles's law
   d. Both b and c
2. Technician A says that work is being performed if a force is being applied, yet the object does not move. Technician B says that torque is a twisting force that may or may not result in motion. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Two technicians are discussing engine horsepower and torque figures. Technician A says that torque is measured on a dynamometer. Technician B says that horsepower is derived from the torque readings as measured on a dynamometer. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. An example of a lever and mechanical advantage used on a vehicle is the ______________.
   a. radio volume control
   b. brake pedal
   c. fuel tank
   d. battery
5. Two technicians are discussing the scientific method. Technician A says that it starts with observation. Technician B says to start with a hypothesis. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Heat can move or travel by ______________.
   a. conduction
   b. convection
   c. radiation
   d. All of the above

7. Technician A says that zero degrees Celsius is the freezing temperature of water. Technician B says that 100 degrees Celsius is the boiling temperature of water. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

8. Technician A says that frequency is measured in dB. Technician B says that the pH of acids is less than 7. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

9. Technician A says that the kinetic energy of a vehicle is proportional to its weight. Technician B says that the kinetic energy of a moving vehicle is directly proportional to its speed. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

10. A 1020 steel is __________________.
a. high carbon steel
b. medium carbon steel
c. low carbon steel
d. an aluminum alloy with molybdenum

SECTION V

SERVICE INFORMATION AND ROUTINE MAINTENANCE

CHAPTERS
13 Service Information, Work Orders, and Vehicle Identification
14 Preventative Maintenance and Service Procedures

Chapter 13

SERVICE INFORMATION, WORK ORDERS, AND VEHICLE IDENTIFICATION

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the importance of vehicle owner's manuals, service records, and service information.
- Explain the different types of service information.
- Describe technical service bulletins.
- Describe vehicle recalls and campaigns.
- Discuss the importance of the work order.
- Explain why service records are important.
- Explain additional information to be obtained from the customer about the vehicle.
- Discuss the parts of a vehicle.
- Differentiate between front-wheel drive and rear-wheel drive.
- Discuss vehicle identification.
- Describe the vehicle safety certification label.
- Describe the VECI label.

KEY TERMS:

Campaign 117 • Country of origin 120 • Flat rate 119 • Gross axle weight rating (GAWR) 121 • Gross vehicle weight rating (GVWR) 121 • Labor guides 119 • Model year (MY) 120 • Owner's manual 116 • Recall 117 • Repair order (RO) 117 • Service information 117 • Technical service bulletin (TSB) 117 • Vehicle emissions control information (VECI) 121 • Vehicle identification number (VIN) 120 • Viscosity 116 • Work order 117

OWNER'S MANUALS

CONTENT The **owner's manual** is the instructional booklet that comes with every new vehicle and includes important information. It has been said by many automotive professional technicians and service advisors that the owner's manual is not read by many vehicle owners. Most owners' manuals contain all or most of the following information:

1. Meaning of dash symbols
2. How to reset the maintenance reminder light
3. Specifications, including **viscosity** of oil needed and number of quarts (liters)
4. Tire pressures and standard, as well as optional, tire sizes
5. Maintenance schedule for all fluids, including coolant, brake fluid, automatic transmission fluid, and differential fluid
6. How to program the remote control, as well as the power windows and door locks
7. How to reset the tire pressure monitoring system (TPMS) after a tire rotation. ● **SEE FIGURE 13–1**.

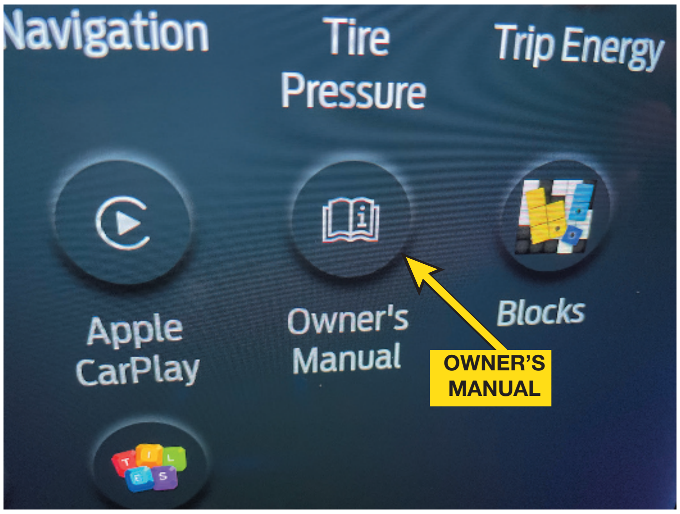


FIGURE 13–1 The owner's manual is usually printed and located in the glove compartment. In many newer vehicles, the owner's manual is accessible on the center control screen..

SERVICE INFORMATION

PURPOSE OF SERVICE INFORMATION **Service information** is needed to correctly service or repair vehicles because it contains all of the specifications, as well as the specified procedures to follow when servicing or repairing a vehicle.

FACTORY SERVICE INFORMATION Until the 1990s, most service information was found in paper manuals called *service manuals* or *shop manuals*. More recently, the manufacturer provides this information in a digital format. The most comprehensive and accurate service information is the service information from the vehicle manufacturer. This information is available for most, if not all, vehicles and can be purchased from their website. For the exact location for purchasing factory service information, visit National Automotive Service Task Force (NASTF) website for the websites for all vehicle manufacturers' service information and cost: www.NASTF.org.

AFTERMARKET SERVICE INFORMATION While factory service manuals cover just one year and one or more models of the same vehicle, most aftermarket service manuals cover multiple years and/or models in one manual. Originally, aftermarket service information was available only in paper manuals. Paper service manuals had the following disadvantages:

1. Required a lot of storage space
2. The pages would become dirty from handling
3. Difficult to use at the vehicle or to make copies from the thick manuals.

Paper service manuals were replaced with electronic service information that came on CDs and DVDs, before becoming available on the Internet. Most electronic service information has technical service bulletins (TSBs), wiring diagrams, and a main menu that includes the major components of the vehicle as a starting point. ALLDATA and Mitchell On-Demand are examples of commonly used subscription services that include service information for many vehicles. ● **SEE FIGURE 13–2**.

TECH TIP

Print It Out

It is often a benefit to have the written instructions or schematics (wiring diagrams) at the vehicle while diagnosing or performing a repair. The advantage of electronic service information is that the material can be printed out and taken to the vehicle for easy access. This also allows the service technician to write or draw on the printed copy, which can be a big help when performing tests, such as electrical system measurements. The schematic can be color-coded to show where there should be voltage and where a ground should be detected. These notes can then be used to document the test results on the work order.

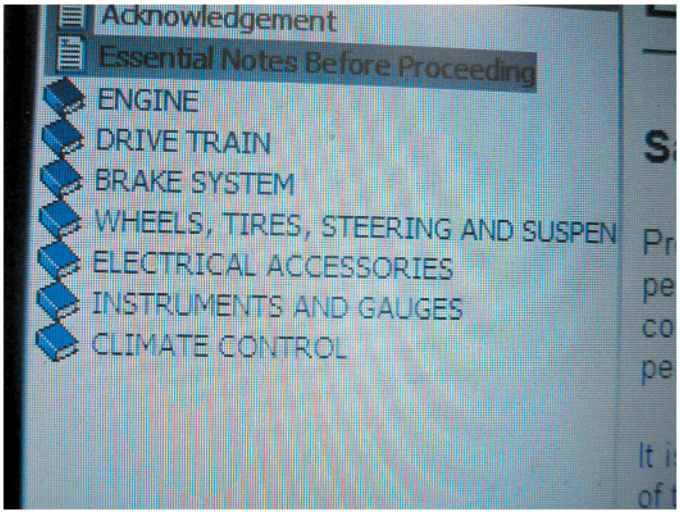


FIGURE 13–2 A main menu showing the major systems of the vehicle. Clicking on one of these major topics opens up another menu showing more detailed information.

TECHNICAL SERVICE BULLETINS

A **technical service bulletin (TSB)** is issued by the vehicle manufacturer to notify service technicians of a potential problem or other critical information. The TSB may include diagnostic procedures and the necessary corrective action. TSBs are not an authorization for repair or a guarantee to correct a concern. TSBs are designed for dealership technicians but are republished by aftermarket companies and made available along with other service information to shops and vehicle repair facilities.

RECALLS AND CAMPAIGNS

A **campaign** is typically issued when a manufacturer wants to improve a product's performance or increase the customer's satisfaction. If the campaign involves a safety or emissions concern, it is considered a recall. A **recall** can occur when either the manufacturer or the National Highway Traffic Safety Administration (NHTSA) determines there is a concern. A recall or campaign is issued by a vehicle manufacturer and a notice is sent to all owners of record. While these faults may be repaired by independent shops, it is generally handled by a local dealer and treated as a warranty repair. Items that have created recalls in the past have included potential fuel system leakage problems, exhaust leakage, or electrical malfunctions that could cause a possible fire or the engine to stall. Unlike TSBs, whose cost is only covered when the vehicle is within the warranty period, a recall or campaign is always done at no cost to the vehicle owner regardless of the age or mileage on the vehicle. To check if a vehicle is subject to a recall, visit www.nhtsa.gov/recalls.

WORK ORDER

SERVICE ADVISOR DOCUMENTATION The **work order**, also called a **repair order (RO)**, is a legal document that is signed by the vehicle owner or his/her representative. Historically, the

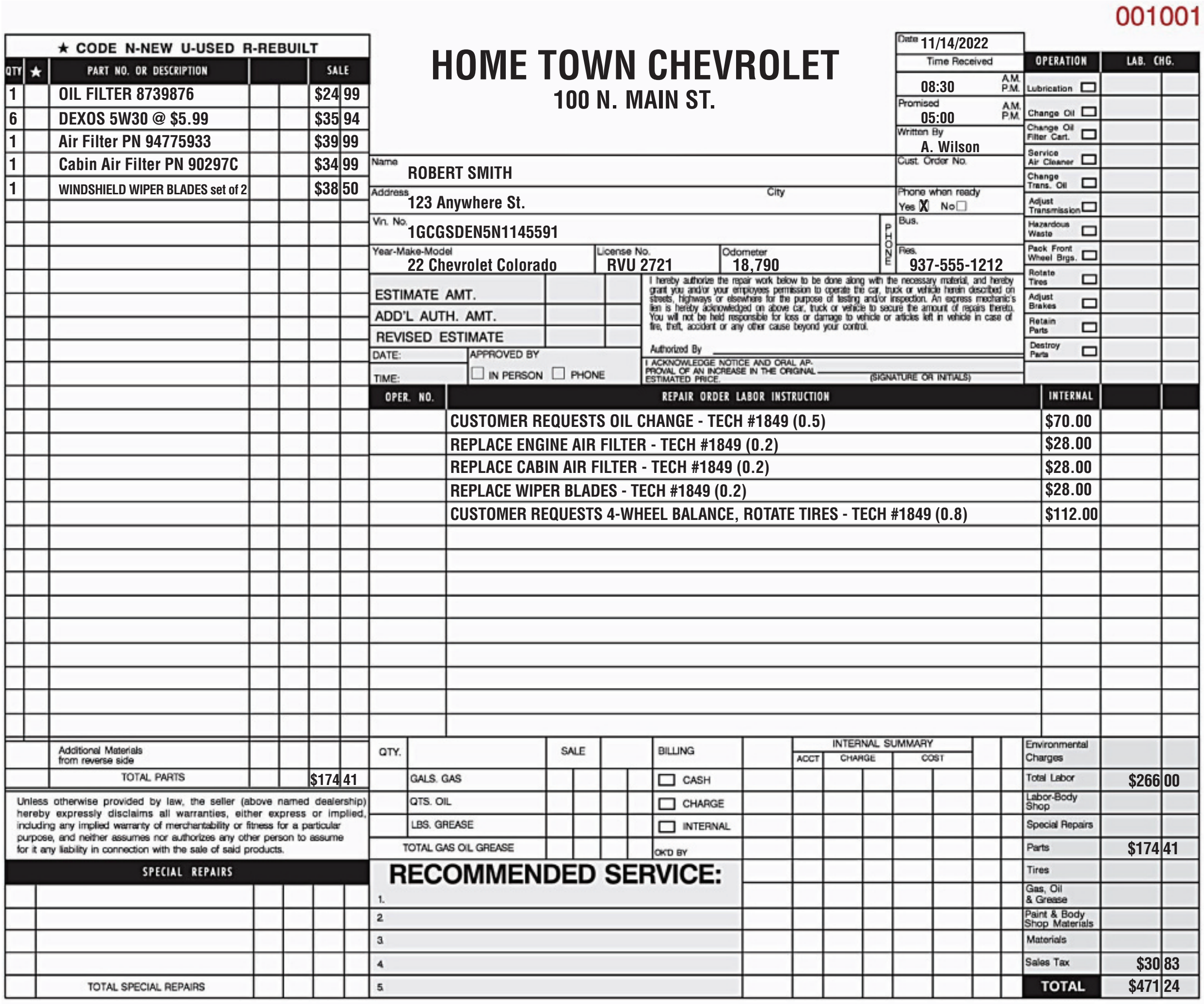
RO has been a paper document. However, more recently, many repair facilities have switched to using an electronic RO. The service advisor or the person designated to complete the work order has to include the following information:

- Make, model, and year and other identifying information, such as color and vehicle identification number (VIN)
- Name and address of the owner with contact information, such as the cell phone number and email address
- Date of service and the name of the person who wrote the service invoice
- The miles shown on the odometer
- Estimate amount and list of requested work

All professional service facilities and shops use a form that is designed for their purposes and include all of the required information, as specified by the local area and state. The work order is a legal document because it is basically a contract between the owner of the vehicle and the shop. If the invoice is not paid, a lien can be placed on the vehicle and it will not be released to the owner until the bill is paid. If the bill is not paid, the ownership of the vehicle can be transferred to the shop. Because this document is so important, all work performed on the vehicle should be clearly stated, including any measured values along with the specified values from service information. Also listed on the service invoice (work or repair order) are the parts used and their costs.

SERVICE TECHNICIAN DOCUMENTATION The role of the service technician is to not only perform the services and repairs as requested by the vehicle owner, but also to document the work order so that an accurate record of what was performed and the parts used on the work order. The service technician is usually identified by a technician number and the number is included under each operation that was performed by the shop. For example, there may be more than one technician assigned to one vehicle and the number of the technician who performed each operation is documented. This is commonly used where the oil change is performed by the lube technician, while the electrical diagnosis and repair was performed by another service technician. The technician should document the work order by stating not only what was done, but what service tools were used such as:

1. Verified the customer concern of a rough running engine and the "check engine light" was on by visual inspection.
2. Looked for stored diagnostic trouble codes using a factory scan tool and noted that a P0300 (random misfire detected) was set.
3. Performed a visual inspection of the secondary ignition system components.
4. Found evidence of a coil boot that arced to the cylinder head on cylinders 2 and 3. Recommended the replacement of the coils and boots for cylinders 2 and 3. The technician also stated on the work order that the coils and the boots on the other cylinder may need to be replaced too, because they are all operating under the same operating conditions. ● **SEE FIGURE 13–3**.



001001

HOME TOWN CHEVROLET
100 N. MAIN ST.

★ CODE N-NEW U-USED R-REBUILT

QTY	★	PART NO. OR DESCRIPTION	SALE
1		OIL FILTER 8739876	$24 99
6		DEXOS 5W30 @ $5.99	$35 94
1		Air Filter PN 94775933	$39 99
1		Cabin Air Filter PN 90297C	$34 99
1		WINDSHIELD WIPER BLADES set of 2	$38 50
		Additional Materials from reverse side	
		TOTAL PARTS	$174 41

Date 11/14/2022
Time Received 08:30 A.M. P.M.
Promised 05:00 A.M. P.M.
Written By A. Wilson
Cust. Order No.
Name ROBERT SMITH
Address 123 Anywhere St. City
Phone when ready Yes ☒ No ☐
Vin. No. 1GCGSDEN5N1145591
PHONE Bus.
Res. 937-555-1212
Year-Make-Model 22 Chevrolet Colorado
License No. RVU 2721
Odometer 18,790

ESTIMATE AMT.
ADD'L AUTH. AMT.
REVISED ESTIMATE
DATE: APPROVED BY
TIME: ☐ IN PERSON ☐ PHONE

I hereby authorize the repair work below to be done along with the necessary material, and hereby grant you and/or your employees permission to operate the car, truck or vehicle herein described on streets, highways or elsewhere for the purpose of testing and/or inspection. An express mechanic's lien is hereby acknowledged on above car, truck or vehicle to secure the amount of repairs thereto. You will not be held responsible for loss or damage to vehicle or articles left in vehicle in case of fire, theft, accident or any other cause beyond your control.

Authorized By

I ACKNOWLEDGE NOTICE AND ORAL APPROVAL OF AN INCREASE IN THE ORIGINAL ESTIMATED PRICE. (SIGNATURE OR INITIALS)

OPERATION		LAB. CHG.
Lubrication	☐	
Change Oil	☐	
Change Oil Filter Cart.	☐	
Service Air Cleaner	☐	
Change Trans. Oil	☐	
Adjust Transmission	☐	
Hazardous Waste	☐	
Pack Front Wheel Brgs.	☐	
Rotate Tires	☐	
Adjust Brakes	☐	
Retain Parts	☐	
Destroy Parts	☐	

OPER. NO.	REPAIR ORDER LABOR INSTRUCTION	INTERNAL
	CUSTOMER REQUESTS OIL CHANGE - TECH #1849 (0.5)	$70.00
	REPLACE ENGINE AIR FILTER - TECH #1849 (0.2)	$28.00
	REPLACE CABIN AIR FILTER - TECH #1849 (0.2)	$28.00
	REPLACE WIPER BLADES - TECH #1849 (0.2)	$28.00
	CUSTOMER REQUESTS 4-WHEEL BALANCE, ROTATE TIRES - TECH #1849 (0.8)	$112.00

Unless otherwise provided by law, the seller (above named dealership) hereby expressly disclaims all warranties, either express or implied, including any implied warranty of merchantability or fitness for a particular purpose, and neither assumes nor authorizes any other person to assume for it any liability in connection with the sale of said products.

QTY.		SALE
	GALS. GAS	
	QTS. OIL	
	LBS. GREASE	
	TOTAL GAS OIL GREASE	

BILLING
☐ CASH
☐ CHARGE
☐ INTERNAL
OK'D BY

INTERNAL SUMMARY

ACCT	CHARGE	COST

SPECIAL REPAIRS

TOTAL SPECIAL REPAIRS

RECOMMENDED SERVICE:
1.
2
3
4
5

Environmental Charges	
Total Labor	$266 00
Labor-Body Shop	
Special Repairs	
Parts	$174 41
Tires	
Gas, Oil & Grease	
Paint & Body Shop Materials	
Materials	
Sales Tax	$30 83
TOTAL	$471 24

FIGURE 13–3 A typical work order showing the customer concern and what was done to correct the issue. Electronic work orders include all of the same required information.

PARTS DOCUMENTATION Parts are those items used to repair a vehicle or to restore it to useful service. The part number(s) and the costs are usually documented on the work order by the parts department personnel in larger shops, or the shop owner or service manager in smaller shops. The service technician orders and installs parts. The service technician should provide all of the necessary information as may be required, including the VIN so that the correct part can be ordered or pulled from stock.

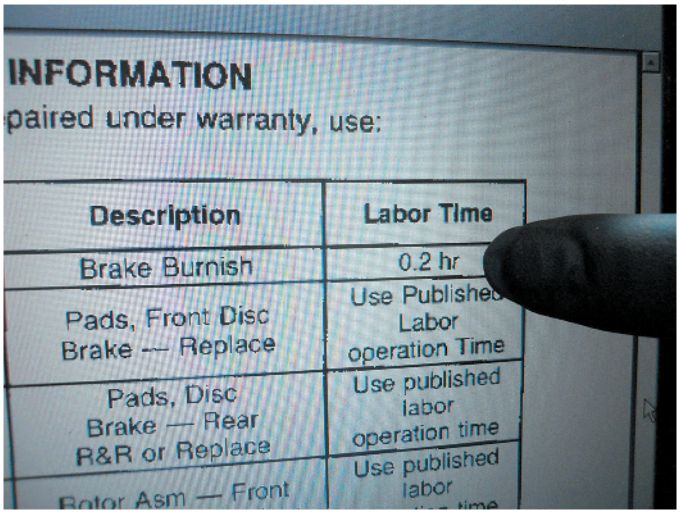
LABOR TIME DOCUMENTATION The labor time, called **flat rate**, is found in **labor guides** and lists vehicle service procedures and the time it should take an average technician to complete the task. This flat-rate time is the basis for estimates and the pay for the technicians. The flat rate is not determined by the technician in most cases, but is determined by the designated warranty person or the shop owner in small shops. All times are expressed in tenths of an hour with each tenth representing six minutes. ● **SEE CHART 13–1**.

Some TSBs include the time needed to accomplish the task. ● **SEE FIGURE 13–4**.

TENTHS OF AN HOUR	NUMBER OF MINUTES
0.1	6 minutes
0.2	12 minutes
0.3	18 minutes
0.4	24 minutes
0.5	30 minutes
0.6	36 minutes
0.7	42 minutes
0.8	48 minutes
0.9	54 minutes
1.0	60 minutes

CHART 13–1

The time that is published for repair and service operations are expressed in tenths of an hour.



INFORMATION

paired under warranty, use:

Description	Labor Time
Brake Burnish	0.2 hr
Pads, Front Disc Brake — Replace	Use Publishe Labor operation Time
Pads, Disc Brake — Rear R&R or Replace	Use published labor operation time
Rotor Asm — Front	Use published labor

FIGURE 13–4 Some technical service bulletins also include the designated flat-rate time when specifying a repair procedure.

SERVICE RECORDS

PURPOSE The purpose of service records is to provide a history of the service work that has been performed on the vehicle in the past. Whenever service work is performed, a record of what was done is usually kept on file or stored electronically on a network or online server for a number of years. The wise service technician will check the vehicle service history if working on a vehicle with an unusual problem. Often, a previous repair may indicate the reason for the current problem or it could be related to the same circuit or components.

- **Example #1**—A collision could have caused hidden damage that can affect the operation of the vehicle. Knowing that a collision had been recently repaired may be helpful to the technician. An accident could cause faults due to hidden damage and some faults could be related to a previous repair.
- **Example #2**—If the current issue is an error code for an engine misfire and the history of the service work on the vehicle does not show an oil change for several years, this might help the technician to find the root cause.

ADDITIONAL INFORMATION

FROM THE CUSTOMER The service advisor or shop owner records the following information from the customer and about the vehicle:

1. Record the vehicle identification number (VIN) of the vehicle on the work order
2. Record the make, model, year, and mileage on the work order
3. Record what the customer's complaint (concern) is so that the service technician can verify the complaint and make the proper repair
4. Review the customer's vehicle history file and identify additional required service.

CHECK THE VEHICLE BEFORE WORK IS STARTED As part of the work order writing process, the service advisor should look over the vehicle and make a written note of any vehicle damage that may already exist. If any damage is noted, it should be mentioned to the customer and noted on the work order. Often the customer is not aware of any damage, especially on the passenger side, and thus would blame the shop for the damage after the service work was performed.

PARTS OF A VEHICLE

The names of the parts of a vehicle are based on the location and purpose of the component.

LEFT SIDE OF THE VEHICLE—RIGHT SIDE OF THE VEHICLE Both of these terms refer to the left and right as if the driver is sitting behind the steering wheel.

FRONT AND REAR The proper term for the back portion of any vehicle is rear (e.g., left rear tire).

FRONT-WHEEL DRIVE VERSUS REAR-WHEEL DRIVE

Front-wheel drive (FWD) means that the front wheels are being driven by the engine, as well as turned by the steering wheel. Rear-wheel drive (RWD) means that the rear wheels are driven by the engine. If the engine is in the front, it can be either front- or rear-wheel drive. In many cases, a front-engine vehicle can also drive all four wheels, called four-wheel drive (4WD) or all-wheel drive (AWD). If the engine is located at the rear of the vehicle, it can be rear-wheel drive or four-wheel drive.

VEHICLE IDENTIFICATION

All service work requires that the vehicle, including the engine and accessories, be properly identified. The most common identification is the make, model, and year of the vehicle.

Make: e.g., Chevrolet
Model: e.g., Traverse
Year: e.g., 2018

The year of the vehicle is often difficult to determine exactly. A model may be introduced as the next year's model as soon as January of the previous year. Typically, a new **model year** (abbreviated **MY**) starts in September or October of the year prior to the actual new year, but not always. This is why the **vehicle identification number**, usually abbreviated **VIN,** is so important. ● **SEE FIGURE 13–5**.

Since 1981, all vehicle manufacturers have used a VIN that is 17 characters long. ● **SEE FIGURE 13–6**. Although every vehicle manufacturer assigns various letters or numbers within these 17 characters, there are some constants, including:

- The first number or letter designates the **country of origin**. ● **SEE CHART 13–2**.
- The model of the vehicle is commonly the fourth and/or fifth character.
- The eighth character is often the engine code. (Some engines cannot be determined by the VIN.)
- The tenth character represents the model year (MY) on all vehicles. ● **SEE CHART 13–3**.

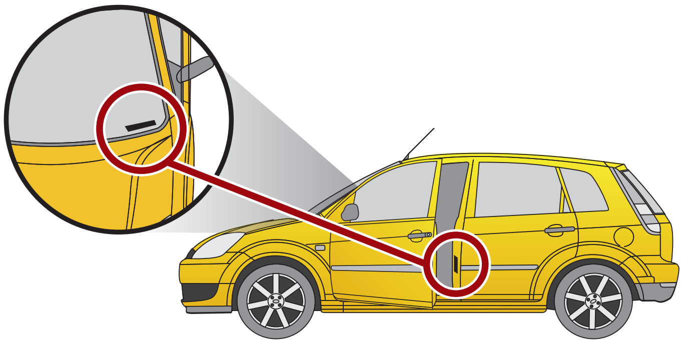


FIGURE 13–5 The vehicle identification number (VIN) is visible through the base of the windshield and on a decal inside the driver's door.

1 = United States
2 = Canada
3 = Mexico
4 = United States
5 = United States
6 = Australia
7 = United States
8 = Argentina
9 = Brazil
J = Japan
K = Korea
L = China
M = India
N = Turkey
P = Philippines
R = Taiwan
S = England
T = Czechoslovakia
U = Romania
V = France
W = Germany
X = Russia
Y = Sweden
Z = Italy

CHART 13–2

The first number or letter designates the country of origin.

TECH TIP

Use a VIN Decoder

Perform a search for "VIN decoder" and many will be found, including the free one posted on the National Highway Traffic Safety Administration website (www.nhtsa.gov). A VIN decoder is useful to find what equipment and accessories the vehicle has.

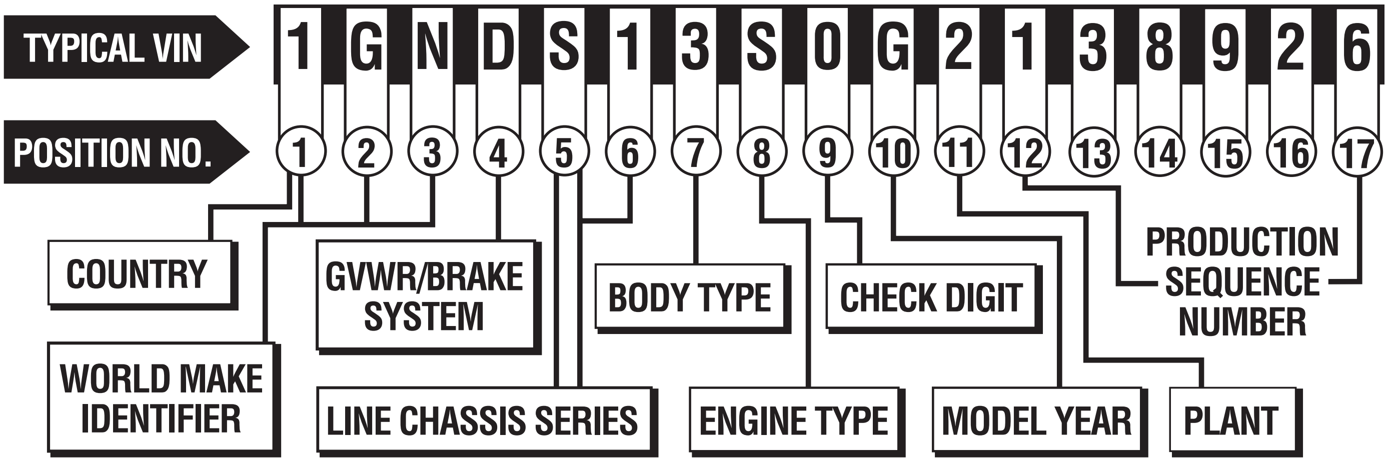


FIGURE 13–6 A typical VIN showing the information that is represented.

A = 1980 / 2010	L = 1990/2020	Y = 2000/2030
B = 1981/2011	M = 1991/2021	1 = 2001/2031
C = 1982/2012	N = 1992/2022	2 = 2002/2032
D = 1983/2013	P = 1993/2023	3 = 2003/2033
E = 1984/2014	R = 1994/2024	4 = 2004/2034
F = 1985/2015	S = 1995/2025	5 = 2005/2035
G = 1986/2016	T = 1996/2026	6 = 2006/2036
H = 1987/2017	V = 1997/2027	7 = 2007/2037
J = 1988/2018	W = 1998/2028	8 = 2008/2038
K = 1989/2019	X = 1999/2029	9 = 2009/2039

CHART 13–3

VIN year chart. (The pattern repeats every 30 years.)

VEHICLE SAFETY CERTIFICATION LABEL

A vehicle safety certification label is attached to the left side pillar post on the rearward-facing section of the left front door. This label indicates the month and year of manufacture, the (VIN), as well as the GVWR and GAWR.

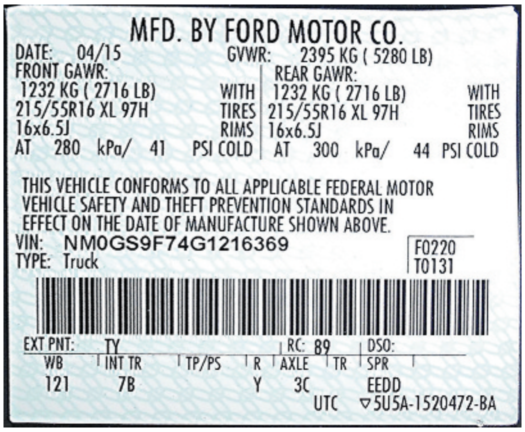
Gross vehicle weight rating (GVWR)—The maximum (upper limit) weight of a vehicle as specified by the vehicle manufacturer. This is important to know if hauling a heavy load, such as in a truck or SUV.

Gross axle weight rating (GAWR)—The maximum weight that an axle can support is usually followed by "FR" for front axle and "RR" for rear axle. ● **SEE FIGURE 13–7**.

VECI LABEL

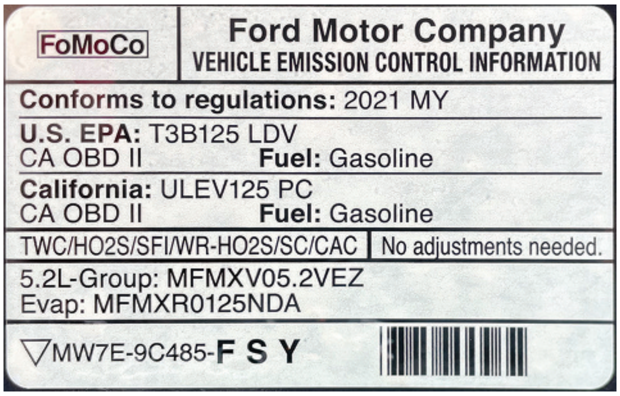
The **vehicle emissions control information (VECI)** label under the hood of the vehicle lists California and federal U.S. EPA emission standard codes and major emission control systems. ● **SEE FIGURE 13–8**.

- The VECI label (sticker) can be located on the bottom side of the hood, the radiator fan shroud, the radiator core support, or the strut towers.



MFD. BY FORD MOTOR CO.
DATE: 04/15 GVWR: 2395 KG (5280 LB)
FRONT GAWR: REAR GAWR:
1232 KG (2716 LB) WITH 1232 KG (2716 LB) WITH
215/55R16 XL 97H TIRES 215/55R16 XL 97H TIRES
16x6.5J RIMS 16x6.5J RIMS
AT 280 kPa/ 41 PSI COLD AT 300 kPa/ 44 PSI COLD
THIS VEHICLE CONFORMS TO ALL APPLICABLE FEDERAL MOTOR VEHICLE SAFETY AND THEFT PREVENTION STANDARDS IN EFFECT ON THE DATE OF MANUFACTURE SHOWN ABOVE.
VIN: NM0GS9F74G1216369 F0220
TYPE: Truck T0131
EXT PNT: TY RC: 89 DSO:
WB INT TR TP/PS R AXLE TR SPR
121 7B Y 3C EEDD
UTC ▽5U5A-1520472-BA

FIGURE 13–7 A typical vehicle safety certification label which shows the gross vehicle weight, gross axles weight rating, as well as the size and inflation pressure of the tires.



FoMoCo
Ford Motor Company
VEHICLE EMISSION CONTROL INFORMATION
Conforms to regulations: 2021 MY
U.S. EPA: T3B125 LDV
CA OBD II **Fuel:** Gasoline
California: ULEV125 PC
CA OBD II **Fuel:** Gasoline
TWC/HO2S/SFI/WR-HO2S/SC/CAC No adjustments needed.
5.2L-Group: MFMXV05.2VEZ
Evap: MFMXR0125NDA
▽MW7E-9C485-**F S Y**

FIGURE 13–8 This vehicle emission control information (VECI) decal indicates this vehicle meets both national EPA Tier3. Bin 125 (T3B125) and California ULEV125 PC (passenger car) standard.

REVIEW QUESTIONS

1. What is included in the vehicle owner's manual that could be helpful for a service technician?
2. Why is factory service information the most detailed of all service information?
3. What customer information needs to be included on a repair order (RO)?
4. What should the service technician include on the work order?
5. What are the major pieces of information that are included in the vehicle identification number (VIN)?

CHAPTER QUIZ

1. What type of information is commonly included in the owner's manual that would be a benefit to service technicians?
   - **a.** Maintenance reminder light reset procedures
   - **b.** Tire pressure monitoring system reset procedures
   - **c.** Maintenance items specifications
   - **d.** All of the above
2. Two technicians are discussing the need for the history of the vehicle. Technician A says that an accident could cause faults due to hidden damage. Technician B says that the customer description of the problem can be helpful. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. A campaign (recall) is mailed to the owner of a vehicle from the _________.
   - **a.** vehicle manufacturer
   - **b.** local dealer
   - **c.** federal government
   - **d.** state or local government
4. Technical service bulletins (TSBs) are issued by the _________.
   - **a.** vehicle manufacturer
   - **b.** local dealer
   - **c.** federal government
   - **d.** state or local government
5. Four-tenths of an hour is how many minutes?
   - **a.** 14
   - **b.** 24
   - **c.** 34
   - **d.** 44
6. What should the service technician document on the work order?
   - **a.** The results of any inspections and tests
   - **b.** What was replaced or serviced
   - **c.** Whether the vehicle is front-wheel drive or rear-wheel drive
   - **d.** Both a and b
7. The proper term for the back portion of any vehicle is _________.
   - **a.** rear
   - **b.** back end
   - **c.** bumper end
   - **d.** tail
8. Which of the following are performed at no cost to the vehicle owner?
   - **a.** TSBs
   - **b.** Campaigns (recalls)
   - **c.** Installing the vehicle safety certification label
   - **d.** Neither a nor b
9. The first character of the vehicle identification number is the country of origin. Where was the vehicle built that has a "5" as the first character?
   - **a.** United States
   - **b.** Canada
   - **c.** Mexico
   - **d.** Japan
10. The VECI label includes all *except* _________.
    - **a.** engine identification
    - **b.** horsepower and torque rating of the engine
    - **c.** California emission standard
    - **d.** Federal (EPA) emission standard

Chapter 14

PREVENTATIVE MAINTENANCE AND SERVICE PROCEDURES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- List the items or systems that require routine maintenance and describe when it should be performed.
- Describe the steps to follow when getting a vehicle ready for service.
- Explain the process to be followed in safety inspection.
- Explain the process to be followed in windshield wiper service.
- Explain the process to be followed in cabin filter replacement.
- Explain the process to be followed in air filter inspection/replacement.
- Describe the brake fluid inspection procedure.
- Describe the engine oil inspection procedure.
- Explain the process of inspecting the cooling system.
- Explain the automatic transmission fluid check.
- Explain how to check power steering fluids.
- Describe how to measure accessory belt tension.
- Describe how to check wheels and tires.
- Describe how to lubricate the chassis.
- Describe how to check the differential fluid.
- Describe how to check the manual transmission fluid.
- Describe how to perform under-vehicle inspection.
- Discuss the purpose and function of diesel exhaust fluid (DEF).

KEY TERMS:

Air filter 126 • Alemite fittings 136 • Algorithm 129 • American Petroleum Institute (API) 137 • American Society for Testing Materials (ASTM) 137 • Automatic transmission fluid (ATF) 131 • Brake fluid 126 • Cabin filter 126 • Dipstick 128 • DOT 3 127 • DOT 4 127 • DOT 5 127 • DOT 5.1 128 • National Lubricating Grease Institute (NLGI) 137 • Penetration test 137 • Polyglycol 127 • Preventative maintenance (PM) 123 • Serpentine (Poly V) 132 • Silicone brake fluid 127 • Synchromesh transmission fluid (STF) 138 • Zerk fittings 136

PREVENTATIVE MAINTENANCE

PURPOSE **Preventative maintenance (PM)** means periodic service work performed on a vehicle that will help keep it functioning correctly for a long time. All vehicle manufacturers publish a list of service work to be performed on a regular basis. Preventative maintenance is also called *routine maintenance* because it is usually performed on a set scheduled routine. The interval specified for preventative maintenance is often expressed in time and miles (km) such as:

- Every six months (could be longer for many vehicles)
- Every 5,000 to 10,000 miles (8,000 to 16,000 km) depending on the vehicle and how it is being operated
- Either of the above, whichever occurs first

ITEMS REQUIRING MAINTENANCE The items or systems that require routine maintenance include

1. Engine oil and oil filter replacement
2. Air and cabin filter replacement
3. Tire inflation pressure check, inspection, and rotation
4. Brake and suspension system inspection
5. Underhood inspection and fluid checks
6. Under-vehicle inspection and fluid checks
7. Air-conditioning system inspection and service
8. Safety inspection, such as all lights and windshield wiper blades
9. Routine cleaning of the vehicle, both inside and out

GETTING READY FOR SERVICE

PRE-SERVICE INSPECTION Prior to any service work, it is wise to check the vehicle for damage and document the work order if any damage is found. In most dealerships and shops, this is the responsibility of the following personnel:

- Service adviser (service writer) or
- Shop supervisor or
- Shop owner

The designated person should check the vehicle for the following:

1. Body damage
2. Missing wheel covers
3. Glass damage, such as a cracked windshield
4. Any faults in the paint or trim
5. Valid license plates

PROTECT THE VEHICLE Before most service work is done, protect the inside of the vehicle by using commercially available plastic or paper protective coverings for the following areas:

- Seats
- Floor
- Steering wheel

● **SEE FIGURE 14–1**.

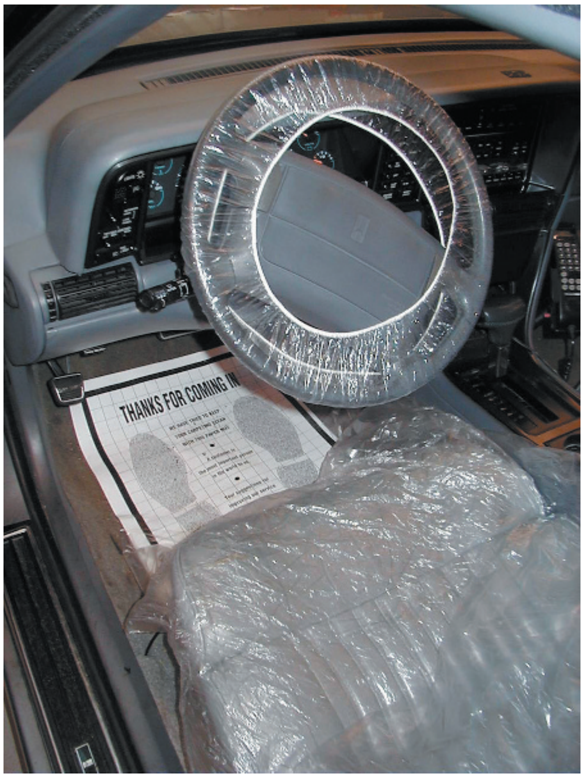


FIGURE 14–1 Before service begins, be sure to cover the seats, floor, and steering wheel with protective coverings.

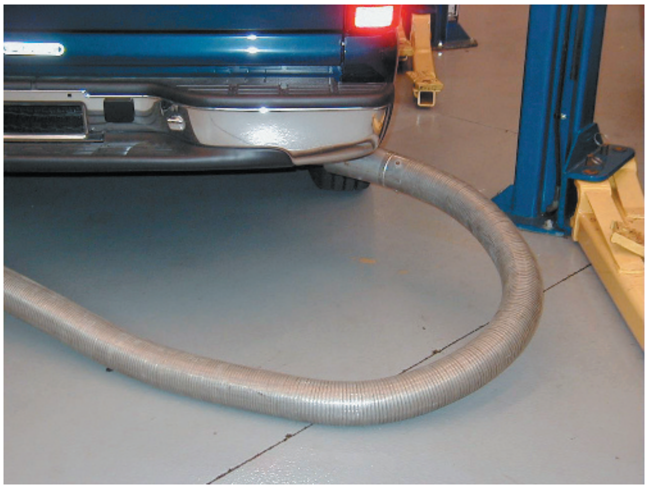


FIGURE 14–2 An exhaust system hose should be connected to the tailpipe(s) whenever the engine is being run indoors.

TECH TIP

Lower the Driver's Side Window

Many shops have a standard operating procedure that the driver's side window be lowered whenever the vehicle is driven into the shop. This is done for two reasons:

1. Helps prevent the keys from being locked in the vehicle.
2. Can prevent damage to the door glass or weather strips. Many vehicles lower the glass slightly when the door is opened to clear the weather seal. If the battery is disconnected, the window cannot be lowered and can cause the glass to shatter or cause damage to the weather strip.

PROTECT THE TECHNICIAN Before starting routine preventative maintenance on a vehicle be sure to perform the following:

1. Open the hood (engine compartment cover). Often the struts that hold a hood open are weak or defective. Therefore, before starting to work under the hood, always make sure that the hood is securely held open.
2. Connect an exhaust system hose to the tailpipe(s) before work is started that will involve operating the engine. ● **SEE FIGURE 14–2**.
3. Wear personal protective equipment (PPE) including
    - Safety glasses
    - Hearing protection, if around air tools or other loud noises
    - Gloves, if handling hot objects or chemicals, such as used engine oil
4. On hybrid vehicles, make sure that the technician has possession of the key transmitter and that the vehicle is *not* in the ready mode before starting any inspection or service procedures.

SAFETY INSPECTION

A safety inspection is recommended to be performed anytime the vehicle is in the shop for service or repair.

These inspections should include all of the following:

1. Exterior lights, including:
   a. Headlights (high and low beam)
   b. Tail lights
   c. Turn signals
   d. License plate light
   e. Parking lights
   f. Brake lights
2. Horn
3. Windshield wiper operation
4. Mirrors
5. Defroster fan operation
6. Steering for excessive looseness or leaks
7. Shock absorbers that allow excessive body sway
8. Tire condition, tread depth, and proper inflation pressure
9. Parking brake operation
10. Exhaust system for excessive noise or leaks

WINDSHIELD WIPER AND WASHER FLUID SERVICE

WINDSHIELD WIPERS Windshield wiper blades are constructed of rubber and tend to become brittle due to age. Wiper blades should be cleaned whenever the vehicle is cleaned, using water and a soft cloth.

TECH TIP

Do No Harm

As stated in the Hippocratic oath, a doctor agrees first to do no harm to the patient during treatment. Service technicians should also try to do no harm to the vehicle while it is being serviced.

Always ask, "Am I going to do any harm if I do this?" before you do it.

TECH TIP

Carefully Check the Windshield

Chips or cracks in the windshield are often caused by stones or debris often kicked up by the vehicle ahead. Extreme temperature changes may cause the glass to shrink and expand, leading to cracks. Generally, a small crack or chip can be repaired and does not require the windshield to be replaced. While there are many do-it-yourself (DIY) fixes are posted on the Internet, most experts recommend that a professional repair for a long-term solution rather than a temporary repair. ● **SEE FIGURE 14–3**.

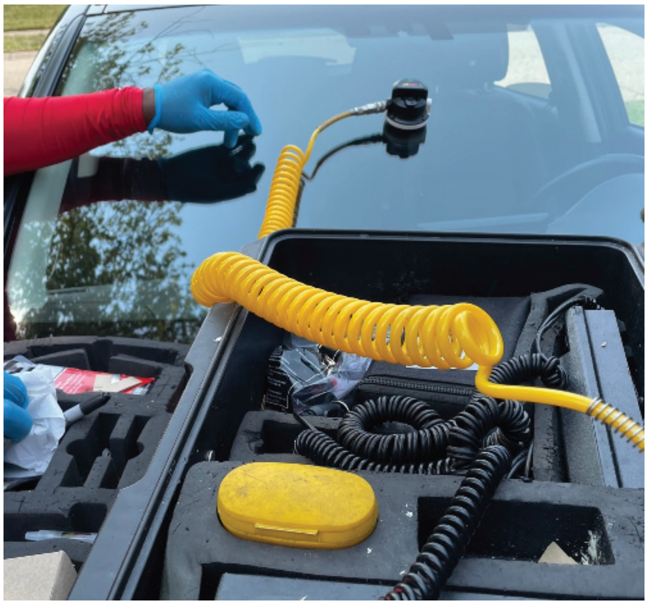


FIGURE 14–3 A professional stone chip repair being performed on a windshield. The unit applies a vacuum to the crack and then inserts a resin to completely seal the chip.

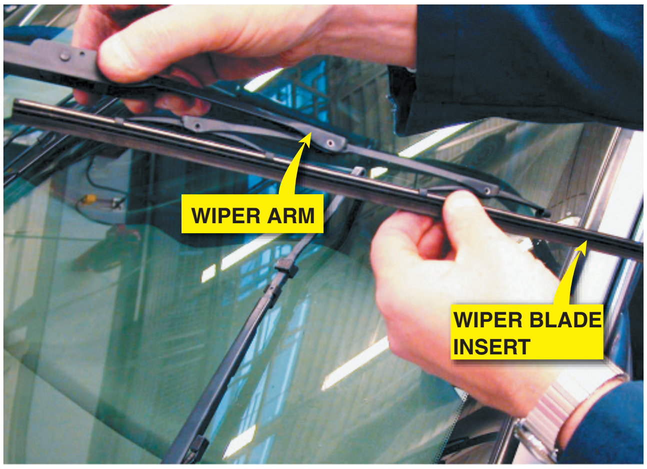


FIGURE 14–4 Installing a wiper blade insert into a wiper arm.

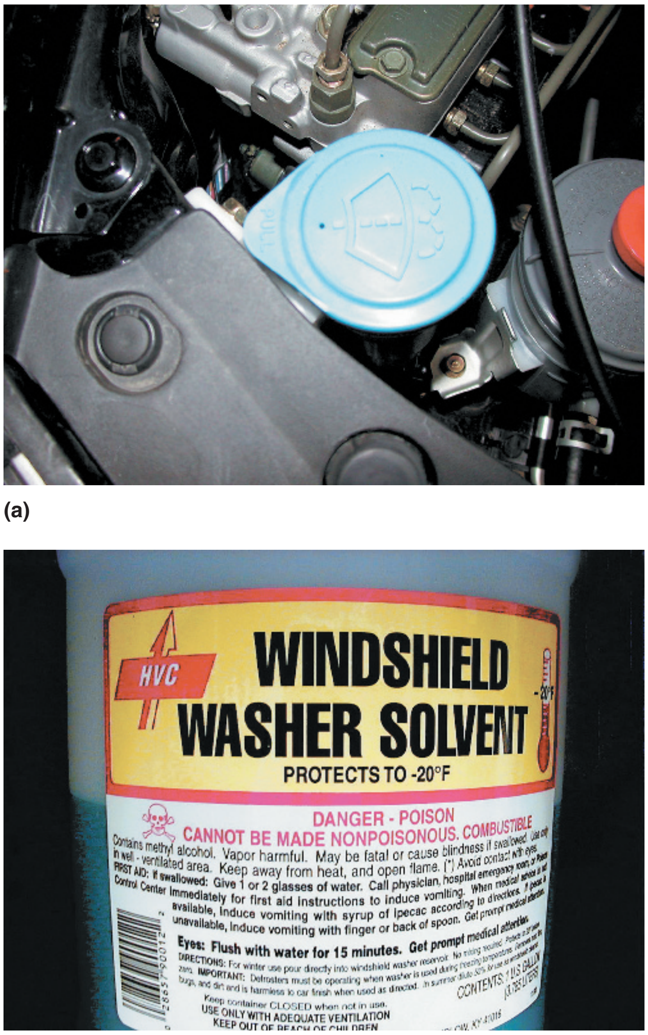
- Remove the insert or the entire blade as per service information and/or the instructions on the replacement windshield wiper blade package.

  ● **SEE FIGURE 14–4**.

WINDSHIELD WASHER FLUID Windshield washer fluid level should be checked regularly and refilled as necessary. Use only the fluid that is recommended for use in vehicle windshield washer systems. ● **SEE FIGURE 14–5**.

Most windshield washer fluid looks like blue water. It is actually water with an alcohol (methanol) additive to prevent freezing and to help clean the windshield by dissolving bugs. Be careful not to spill any washer fluid when filling the reservoir because the corrosiveness can harm wiring and electronic components.

CAUTION: Some mixed fluids are for summer use only and do not contain antifreeze protection. Read the label carefully!


HVC
WINDSHIELD WASHER SOLVENT
PROTECTS TO -20°F
DANGER - POISON
CANNOT BE MADE NONPOISONOUS. COMBUSTIBLE

(a)

(b)

FIGURE 14–5 (a) The windshield wiper fluid reservoir cap is usually labeled with a symbol showing a windshield washer. (b) Use only the recommended washer fluid. Never use antifreeze in the windshield washer reservoir.

⚠ WARNING

Windshield washer fluid usually contains methanol, a poisonous chemical that can cause blindness if ingested.

FREQUENTLY ASKED QUESTION

Why Is Windshield Washer Fluid Regulated?

Automotive windshield washer fluid (AWWF) is a source of pollution because it can contain high levels of methanol, a volatile organic compound (VOC), which is a component of ground-level ozone, one of the main pollutants in smog. The VOC content (methanol) in automotive windshield washer fluid is regulated/limited by federal and, in some cases, by state and local regulation. At the federal level, VOC content is limited to 35% by weight. State and local regulations are more restrictive than the federal regulation, restricting the sale of windshield washer fluid to a VOC weight content that is lower than the 35% federal standard.

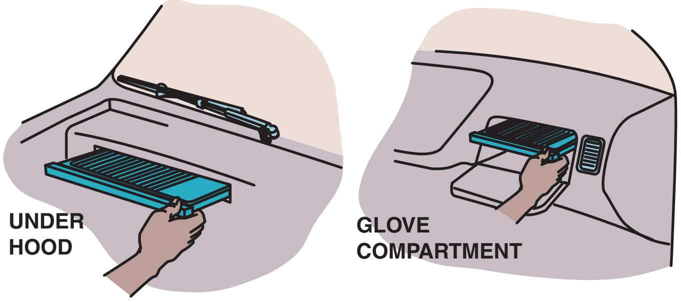


FIGURE 14–6 A cabin filter can be accessed either through the glove compartment or under the hood on most vehicles.

CABIN FILTER REPLACEMENT

A **cabin filter** is used in the heating, ventilation, and air-conditioning (HVAC) system to filter the outside air drawn into the passenger compartment. Some filters contain activated charcoal to help eliminate odors. The cabin air filter should be replaced often—every year or every 12,000 miles (19,000 km). The cabin air filter can be accessed from:

- Under the hood at the cowl (bulkhead) or
- Under the dash, usually behind the glove (instrument panel) compartment (Check service information for the exact location and servicing procedures for the vehicle being serviced.)

● **SEE FIGURE 14–6**.

AIR FILTER INSPECTION/ REPLACEMENT

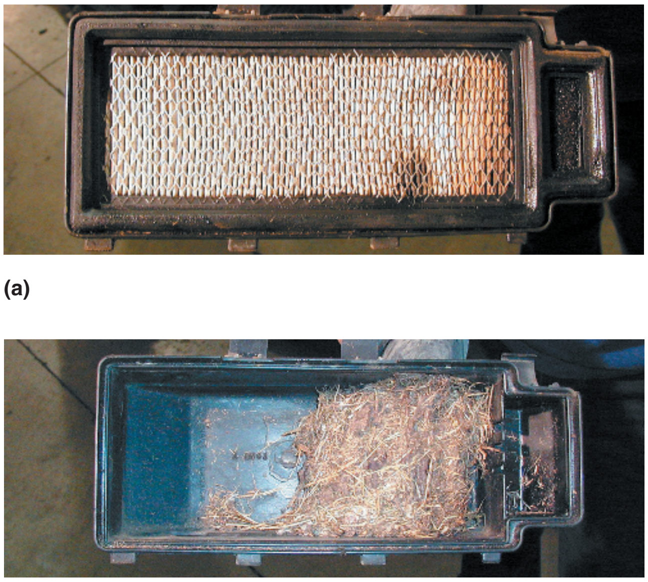
An **air filter** filters dirt from the air before it enters the intake system of the engine. The air filter should be replaced according to vehicle manufacturer's recommendations. Over time, the filter will start to get clogged and decrease the engine's efficiency. Many vehicle manufacturers recommend replacing the air filter every 30,000 miles (50,000 km),or more frequently under dusty conditions. Many service technicians recommend replacing the air filter every year. ● **SEE FIGURE 14–7**.

BRAKE FLUID INSPECTION

BRAKE FLUID LEVEL **Brake fluid** is used to transmit the force of the driver's foot on the brake pedal, called the service brake, to each individual wheel brake. The brake fluid should be checked at the same time the engine oil is changed, or every six months, whichever occurs first. It is normal for the brake fluid level to drop as the disc brake pads wear. Therefore, when the fluid level is low, check for two possible causes.

CAUSE 1 Normal disc brake pad wear (Inspect the brakes if the fluid level is low.)

CAUSE 2 A leak somewhere in the hydraulic brake system (Carefully inspect the entire brake system for leaks if the brakes are not worn and the brake fluid level is low.)



(a)

(b)

FIGURE 14–7 (a) A typical dirty air filter. (b) Always check the inlet passage leading to the air filter for debris that can reduce airflow to the engine.

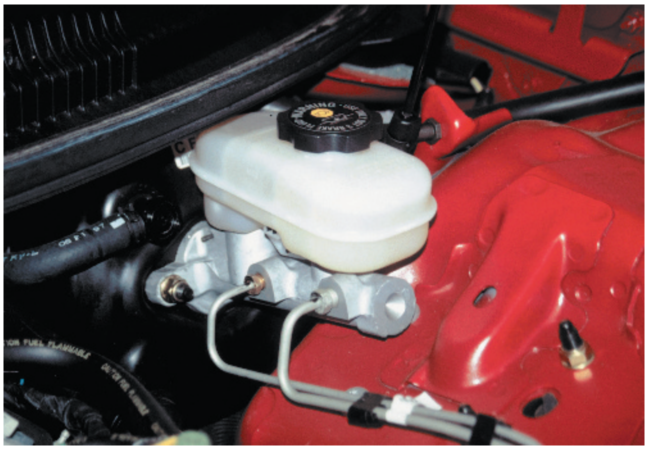


FIGURE 14–8 A master cylinder with a transparent reservoir. The brake fluid level should be between the MAX and the MIN levels as marked on the reservoir.

There are two types of brake master cylinders.

- **Transparent reservoir.** This type allows viewing of the brake fluid (and hydraulic clutch master cylinder, if so equipped) without having to remove the cover of the reservoir. The proper level should be between the MIN (minimum) level indicated and the MAX (maximum) level indicated on the clear plastic reservoir. ● **SEE FIGURE 14–8.**
- **Metal or nontransparent plastic reservoir.** This type of reservoir, used on older vehicles, requires that the cover be removed to check the level of the brake fluid. The proper level of brake fluid should be 0.25 inch (6 mm)from the top.

CAUTION: Do not overfill a brake master cylinder. The brake fluid gets hotter as the brakes are used and there must be room in the master cylinder reservoir for the brake fluid to expand.

BRAKE FLUID TYPES

Brake fluid is made from a combination of various types of glycol, a non-petroleum-based fluid. Brake fluid is a polyalkylene-glycol-ether mixture, called **polyglycol** for short. *All polyglycol brake fluid is clear to amber in color.*

CAUTION: DOT 3 brake fluid is a very strong solvent and can remove paint! Care is required when working with this type of brake fluid to avoid contact with the vehicle's painted surfaces. It also takes the color out of leather shoes or upholstery.

All automotive brake fluid must meet Federal Motor Vehicle Safety Standard 116. The Society of Automotive Engineers (SAE) and the Department of Transportation (DOT) have established brake fluid specification standards.

- **DOT 3.** The **DOT 3** brake fluid is most often used. It absorbs moisture and, according to SAE, can absorb 2% of its volume in water per year. Moisture is absorbed by the brake fluid through microscopic seams in the brake system and around seals. Over time, the water will corrode the system and thicken the brake fluid. Moisture can cause a spongy brake pedal because the increased concentration of water within the fluid boils at lower temperatures and can result in vapor lock. DOT 3 must be used from a sealed (capped) container. If allowed to remain open for any length of time, DOT 3 will absorb moisture from the surrounding air.
- **DOT 4.** The **DOT 4** brake fluid is formulated for use by all vehicles, imported or domestic. It is commonly called low moisture absorption (LMA) because it does not absorb water as fast as DOT 3. It is still affected by moisture, however, and should be used only from a sealed container. The cost of DOT 4 is approximately double the cost of DOT 3. ● **SEE FIGURE 14–9.**
- **DOT 5.** The **DOT 5** type is commonly called **silicone brake fluid**. It is made from polydimethylsiloxanes. Because it does not absorb water, it is called nonhygroscopic. DOT 5 brake fluid does not mix with and should not be used with DOT 3 or DOT 4 brake fluid.

NOTE: Even though DOT 5 does not normally absorb water, it is still tested using standardized SAE procedures in a humidity chamber. After a fixed amount of time, the brake fluid is measured for boiling point. Because it has had a *chance* to absorb moisture, the boiling point after this sequence is called the minimum wet boiling point.

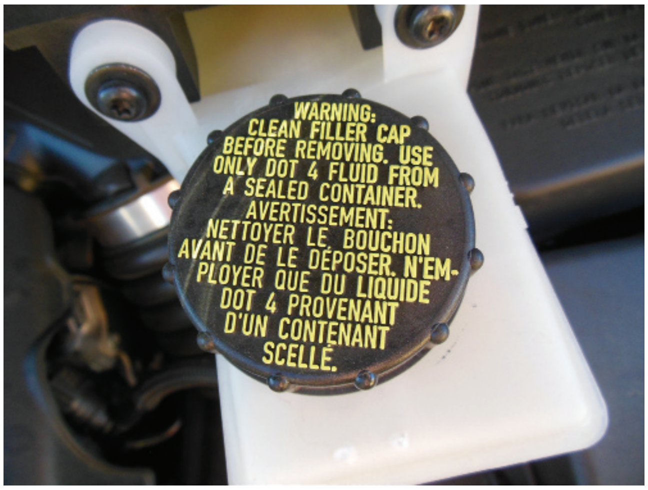


FIGURE 14–9 While most vehicles require DOT 3 brake fluid, many vehicles specify DOT 4. Always check the cap for the specified fluid.

DOT 5 brake fluid is purple (violet), to distinguish it from DOT 3 or DOT 4 brake fluid.

- **DOT 5.1.** The **DOT 5.1** brake fluid is a non-silicone-based polyglycol fluid that is clear to amber in color. This severe-duty fluid has a boiling point of over 500°F (260°C) equal to the boiling point of silicone-based DOT 5 fluid. Unlike DOT 5, the DOT 5.1 fluid can be mixed with either DOT 3 or DOT 4 according to the brake fluid manufacturer's recommendations.

CAUTION: Some vehicle manufacturers, such as Chrysler, do not recommend the use of, or the mixing of, other types of polyglycol brake fluid, and specify the use of DOT 3 brake fluid only. Always follow the vehicle manufacturer's recommendation.

BRAKE FLUID TESTING

- **Visual inspection.** Check the color of the brake fluid. It should be clear or almost clear. If it is dark brown or black, it should be replaced.
- **Test strips.** A quick and easy way to check the condition of the brake fluid is to use test strips. Always follow the instructions that come with the test strips for accurate results. ● **SEE FIGURE 14–10**.
- **Boiling point.** The boiling point of brake fluid can be tested using a handheld tester. Follow the instructions that come with the tester.

FREQUENTLY ASKED QUESTION

What Is Used in the Clutch Master Cylinder?

Vehicles equipped with a manual transmission often use a hydraulically operated clutch. This type of clutch operation uses a master cylinder and an actuator cylinder near the clutch assembly. When the driver depresses the clutch pedal, the hydraulic pressure created in the master cylinder is transferred to the actuator cylinder, which moves and actuates the clutch. Most hydraulic clutches use DOT 3 brake fluid. Check to see that the level is between the maximum and the minimum levels as shown by lines on the reservoir. If low, check for a leak in the system, as it is not normal for brake fluid level to decrease over time.

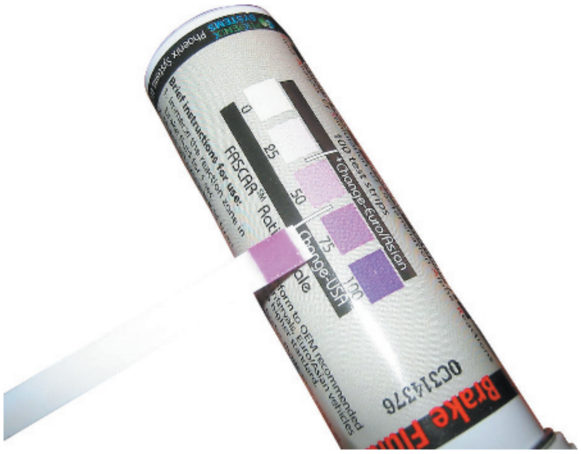


FIGURE 14–10 Brake fluid test strips are a convenient and easy-to-use method to determine if the brake fluid needs to be replaced.

CAUTION: If any mineral oil, such as engine oil, automatic transmission fluid (ATF), or power steering fluid gets into the brake fluid, the rubber seals will swell and cause damage to the entire braking system. Every part that includes a rubber seal will require replacement.

ENGINE OIL INSPECTION

OIL LEVEL The oil level should be checked when the vehicle is parked on level ground and after the engine has been off for at least several minutes. The *oil level indicator*, commonly called a **dipstick**, is clearly marked and in a convenient location. ● **SEE FIGURE 14–11**.

To check the oil, remove the dipstick, wipe off the oil, and reinsert it all the way down. Once again remove the dipstick and check where the oil level touches the indicator. The "low" mark is usually at the 1 quart low point. ● **SEE FIGURE 14–12**.

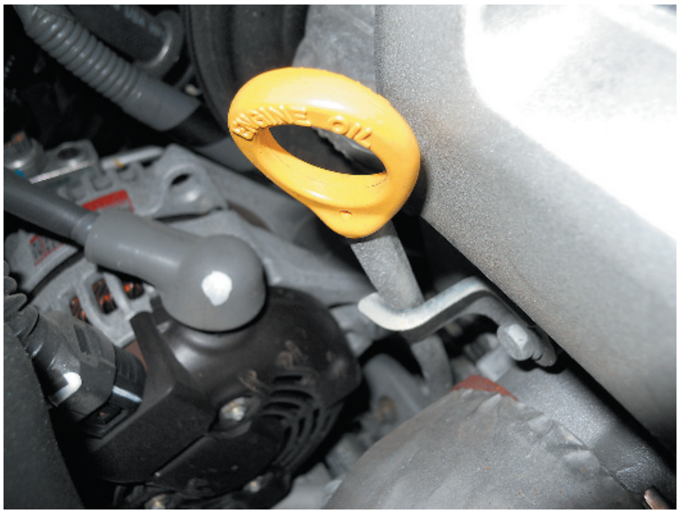


FIGURE 14–11 A typical oil level indicator (dipstick).

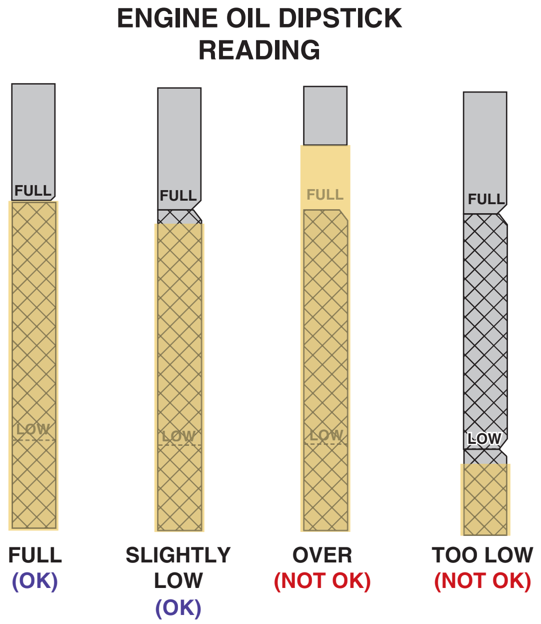


FIGURE 14–12 The oil level should be between the MAX and the MIN marks when the vehicle is on level ground and the oil has had time to drain into the oil pan.

FREQUENTLY ASKED QUESTION

Can I Switch from Synthetic Oil to Regular Oil?

Yes. All oil is *miscible,* meaning that it can be readily mixed. Therefore, synthetic oil can be used one time and then regular mineral oil used the next time. Most important, however, is that the oil be changed at intervals that are never longer than specified by the vehicle manufacturer.

If oil needs to be added, use the specified oil and add to the engine through the oil fill opening (not through the dipstick hole as is done with automatic transmission fluid).

ENGINE OIL CHANGE INTERVALS Most automotive experts recommend that the engine oil be replaced and a new oil filter installed every 5,000 to 7,500 miles (8,000 to 12,000 km) or every six months, whichever occurs first. Most vehicles since the early 2000s have used an oil life monitor system to notify the driver when the engine oil should be changed. The oil life monitor will light a dash lamp when the oil needs to be changed. Most vehicle manufacturers recommend that the oil be changed according to a "normal" or "severe use" schedule. ● **SEE CHART 14–1**.

Most vehicles are driven under severe conditions if all of the factors above are considered. Always follow the vehicle manufacturer's recommended oil change intervals.

See Chapter 23 for details on oils and change procedure.

NORMAL USE	SEVERE USE
Most trips over 10 miles (16 km).	Most trips less than 4 to 10 miles (6 to 16 km).
Operating a vehicle when the outside temperature is above freezing (32°F/0°C).	Operating the vehicle when the outside temperature is below freezing (32°F/0°C).
Most trips do not include slow or stop-and-go driving.	Most trips include slow or stop-and-go driving.
Not towing a trailer or carrying a heavy load.	Towing a trailer or hauling a heavy load.
Driving without dusty conditions.	Driving in dusty conditions.
No police, taxi, or commercial use of the vehicle.	Use by police, taxi, or commercial operation.
The oil change interval recommended by most vehicle manufacturers under normal conditions is 7,500 miles (12,000 km) or six months, whichever occurs first.	The oil change interval recommended by most vehicle manufacturers operating under severe conditions is every 3,000 miles (4,800 km) or every three months, whichever occurs first.

CHART 14–1

The difference between "normal" and "severe" use as specified by many vehicle manufacturers.

FREQUENTLY ASKED QUESTION

How Does an Oil Life Monitor Work?

While some vehicle manufacturers, such as Mercedes, use a sensor to measure oil temperature and acidity, most vehicle oil change monitors function three ways:

1. **Vehicle mileage.** This is the most commonly used vehicle service monitoring system. When a certain number of miles has occurred since it was reset, the control (usually the powertrain control module [PCM]) will turn on a dash light that states maintenance is required.
2. **Oil life computer program.** A computer program called an **algorithm**, or a series of mathematical calculations, is used to determine the life of the engine oil. For example, when the oil change warning light is reset, the oil life is reset to 100%.Then the PCM tracks the number of engine starts, the outside temperature, when the engine was started (based on intake air temperature [IAT] sensor input), and the number of miles traveled. Because long drives are easier on engine oil than short stop-and-go driving, the PCM deducts numbers faster during this condition.
3. **Oil condition sensor.** This sensor measures the dielectric properties of the oil, which changes when exposed to water, soot, ash, and glycol in the oil. A computer program takes the information from the sensor about the changes of the dielectric property of the oil to determine when to light the "change oil" lamp.

FREQUENTLY ASKED QUESTION

What Is the Magnuson-Moss Act?

The Magnuson-Moss Act, passed into law in 1975, allows the use of non–original equipment replacement parts during the service or repair of a vehicle without losing the factory warranty. This means that any oil or air filter, spark plug, or other service part can be used, unless the vehicle manufacturer furnishes these parts for free during the warranty period.

The vehicle manufacturer cannot deny paying a warranty claim for a fault unless the replacement part is proved to be the cause of the condition needed to be covered by the warranty.

Therefore, it is up to the business owner, service manager, or technician to determine if the replacement part is of good quality. While this is very difficult or impossible, unless defects are obviously visible, the best solution is to use the original equipment manufacturer (OEM) parts or service parts from a well-known company.

COOLING SYSTEM INSPECTION

STEPS INVOLVED Normal maintenance involves an occasional check of the following items.

1. Coolant level in the coolant recovery tank or in the surge tank. ● **SEE FIGURE 14–13**.

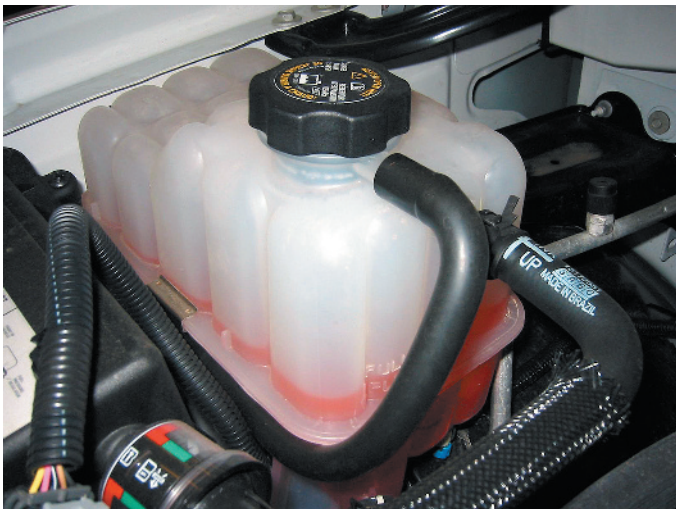


FIGURE 14–13 Visually check the level and color of coolant in the coolant recovery or surge tank.

WARNING

Remove the pressure cap only on a cold engine as the coolant will boil when pressure is released. This occurs because the coolant temperature is above the boiling point, but it does not boil due to the pressure. When the pressure is released, all of the hot coolant immediately boils and expands outward from the opening where the cap was installed. The resulting geyser of boiling hot coolant can cause severe burns or even death.

2. The front of the radiator should be carefully inspected and cleaned of bugs, dirt, or mud that can often restrict airflow.
3. Maintenance should also include a visual inspection for signs of coolant system leaks and for the condition of the coolant hoses and accessory drive belts.

COOLANT TESTING

- **Visual inspection.** Coolant should be clean and close to the color when it was new. If dark or muddy, it should be replaced. Milky colored coolant is an indication of oil in the system that might be caused by a defective engine gasket.
- **Test strips.** Coolant test strips are available to test the condition of the coolant. Check to see that the test strips are being used on the specified type of coolant, as some will work only on the old green inorganic additive technology (IAT) coolant.
- **Boiling/freezing points (refractometer and hydrometer).** A hydrometer can be used to check the freezing and boiling temperatures of the coolant. A refractometer can be used to check the freezing temperature of the coolant.
- **Proper reading.** A proper 50-50 mix of antifreeze and water should result in a freezing temperature of –34°F (–37°C).
    - If the freezing temperature is higher than –34°F (such as –20°F), there is too much water in the coolant.
    - If the freezing temperature is lower than –34°F (such as –46°F), there is too much antifreeze in the coolant. ● **SEE FIGURE 14–14**.

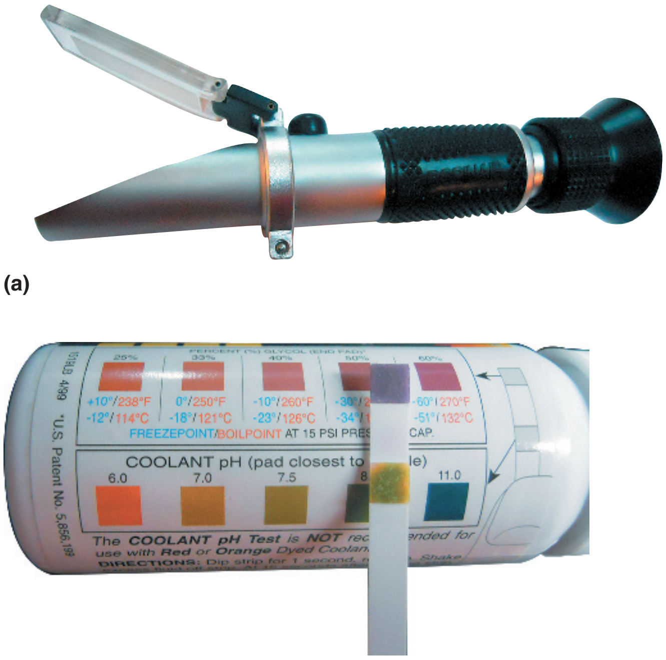

(a)
(b)
FREEZEPOINT/BOILPOINT AT 15 PSI PRES
COOLANT pH (pad closest to
The COOLANT pH Test is NOT rec
use with Red or Orange Dyed Coolan

FIGURE 14–14 (a) A refractometer is used to measure the freezing point of coolant. A drop of coolant is added to a viewing screen, the lid is closed, and then held up to the light to view the display on the tool. (b) The use of tests strips is a convenient and cost-effective method to check coolant condition and freezing temperature.

NOTE: Many hybrid electric vehicles use two separate cooling systems—one for the internal combustion engine (ICE) and the other to cool the electronics. Check service information for the exact procedures to follow.

See Chapter 17 for more details on coolant and coolant testing.

ANTIFREEZE/COOLANT DISPOSAL Used coolant drained from vehicles can usually be disposed of according to federal, state, and local laws. Check with recycling companies authorized by local or state government for the exact method recommended for disposal in your area. ● **SEE FIGURE 14–15**.

RADIATOR AND HEATER HOSES Upper and lower radiator hoses must be pliable, yet not soft. The lower radiator hose will be reinforced or contain an inner spring to prevent the hose from being sucked closed, since the lower hose is attached to the suction side of the water pump. The bypass hose (if equipped) and heater hoses come in the following inside diameter sizes:

- 1/2 inch
- 5/8 inch
- 3/4 inch

The heater hoses connect the engine cooling system to the heater core. A heater core looks like a small radiator and is located inside the vehicle. All automotive hose is constructed of rubber with reinforcing fabric weaving for strength. Sections of

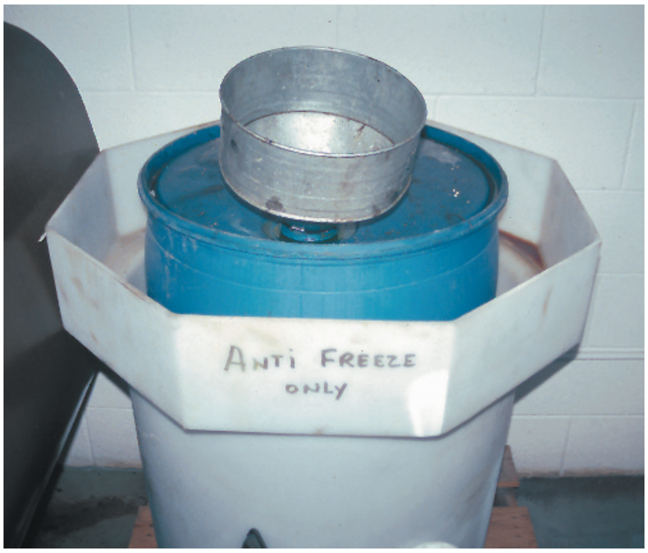


FIGURE 14–15 Used coolant should be stored in a leakproof container until it can be recycled or disposed of according to local, state, or federal laws. Note that the storage barrel is placed inside another container to catch any coolant that may spill out of the inside container.

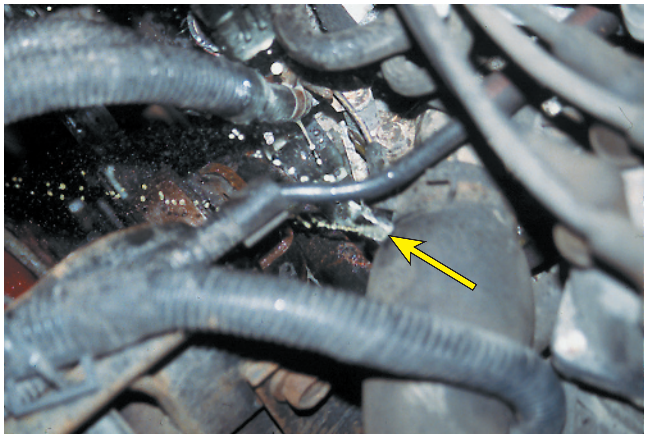


FIGURE 14–16 Using a hand-operated pressure tester. Do not exceed the pressure rating of the radiator cap when pressurizing the system. This vehicle had a leaking upper radiator hose that only leaked when the system was pressurized.

the coolant lines can be made from nylon-reinforced plastic or metal. All hoses should be inspected for leaks (especially near hose clamps), cracks, swollen areas indicating possible broken reinforcing material, and excessively brittle, soft, and swollen sections. Using a hand-operated pressure pump attached to the radiator opening is an excellent way to check for leaks. ● **SEE FIGURE 14–16.**

EMISSION-RELATED HOSES Hoses are also used by some emission control systems, including PCV and EGR systems. These hoses must be of the proper type and size and designed for use in emission control systems.

HOSE CLAMPS There are several types of hose clamps used depending on the make, model, and year of vehicle. The three basic types are as follows:

1. Worm drive (also called a screw band type)
2. Banded-type clamp
3. Wire clamp (spring type) ● **SEE FIGURE 14–17**.

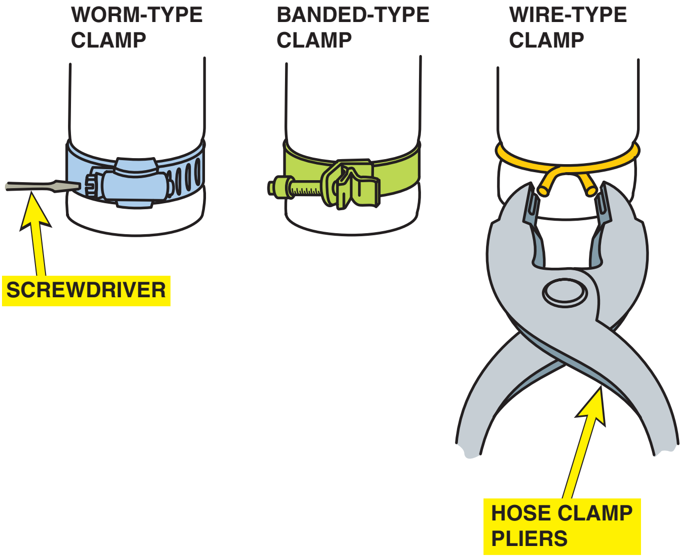


FIGURE 14–17 Hose clamps come in a variety of shapes and designs.

AUTOMATIC TRANSMISSION FLUID CHECK

STEPS INVOLVED The **automatic transmission fluid (ATF)** is another important fluid that should be checked regularly. Most automatic transmission fluid levels should be checked under the following conditions:

- The vehicle should be parked on a level surface.
- The transmission fluid should be at normal operating temperature. This may require the vehicle to be driven several miles before the level is checked.
- The engine should be running with the transmission in neutral or park as specified by the vehicle manufacturer.

NOTE: Honda and Acura manufacturers usually specify that the transmission fluid be checked with the engine off. The recommended procedure is usually stamped on the transmission dipstick or written in the owner's manual and/or service manual.

To check the automatic transmission fluid, perform the following steps:

STEP 1 Start the engine and move the gear selector to all gear positions and return to park or neutral as specified by the vehicle manufacturer.

STEP 2 Remove the transmission/transaxle dipstick (fluid level indicator) and wipe it off using a clean cloth.

STEP 3 Reinsert the dipstick until fully seated. Remove the dipstick again and note the level. ● **SEE FIGURE 14–18**.

NOTE: Some transmissions or transaxles do not use a dipstick. Check service information for the exact procedure to follow to check the fluid level. Some vehicles require the use of a scan tool to check the level of the fluid.

- **Do not overfill any automatic transmission/transaxle.** Even if just 1/2 quart too much were added by mistake (e.g., adding 1 quart when the fluid was at the "add" line instead of the correct amount of 1/2 quart) could cause the

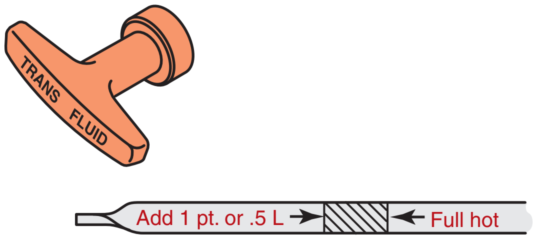


FIGURE 14–18 A typical automatic transmission dipstick.

TECH TIP

The Paper Towel Test

New ATF will penetrate a paper towel better than used oxidized ATF. To compare old fluid with new, place three drops of new fluid on a paper towel and three drops of used ATF on the paper towel about 3 inches from the first sample. Wait for 30 minutes. The new ATF will have expanded (penetrated through the paper towel) much farther than the old, oxidized fluid. This test can be used to convince a customer that the ATF should be changed according to the vehicle manufacturer's recommended interval even though, to the naked eye, the fluid looks okay.

fluid to foam. Foaming of the ATF is caused by the moving parts inside the transmission/transaxle, which stir up the fluid and introduce air into it. This foamy fluid cannot adequately lubricate or operate the hydraulic clutches that make the unit function correctly.

NOTE: The "add" mark on most automatic transmission/transaxle dipsticks means that 1/2 quart (1/2 liter) of automatic transmission fluid needs to be added.

- **Smell the ATF on the dipstick.** If it seems burned or rancid, further service of the automatic transmission/transaxle will be necessary.
- **Look at the color of the fluid.** It should be red or light brown. A dark brown or black color indicates severe oxidation, usually caused by too high an operating temperature. Further service and diagnosis of the automatic transmission/transaxle will be required.

NOTE: Chrysler warns that color and smell should not be used to determine the condition of ATF + 4 used in most Chrysler-built vehicles since the 2000 model year. The dyes and additives can change during normal use and it is not an indication of fluid contamination. This is true for most highly friction-modified ATF. Always follow the vehicle manufacturer's recommendation.

POWER STEERING FLUID

CHECKING POWER STEERING FLUID Check power steering fluid level with the engine off. The cap for the power steering reservoir is marked with an icon of a steering wheel or the words "power steering." Remove the cap by twisting it counterclockwise and use the level indicator as part of the cap to determine the level.

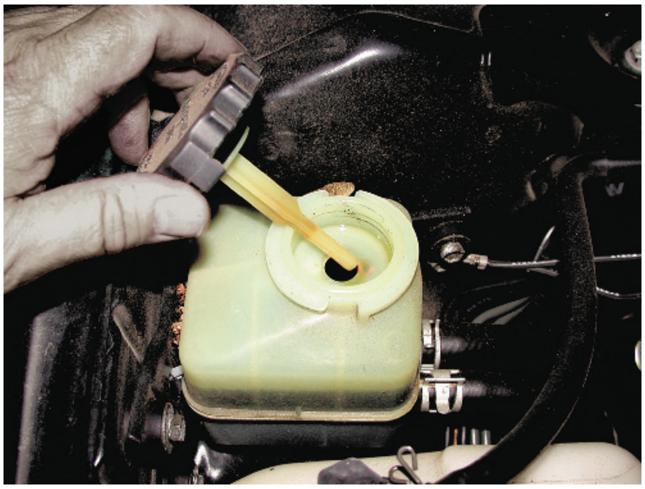


FIGURE 14–19 Most vehicles use a combination filler cap and level indicator (dipstick) that shows the level of power steering fluid in the reservoir.

Often the level marks are for cold and hot fluid.

- *If too low,* check for leaks, especially at the high-pressure lines and fittings. Add the specified fluid to the correct level.
- *If too high,* use a fluid siphon pump or a "turkey baster" and remove the excess fluid until the level is correct.

TYPES OF POWER STEERING FLUID The correct power steering fluid is *critical* to the operation and service life of the power steering system! The *exact* power steering fluid to use varies by vehicle manufacturer, and sometimes between models made by the same vehicle manufacturer, because of differences among various steering component manufacturers. Always check service information for the specified fluid to use. ● **SEE FIGURE 14–19.**

The types of power steering fluid can include:

- Automatic transmission fluid (check for the exact type)
- Power steering fluid
- Unique fluid that is specially designed for the vehicle

CAUTION: Do not use fluid that is labeled for all vehicles as this type may not be compatible with the seals used in the power steering system or provide the specified friction additives needed to provide the proper steering feel to the driver.

ACCESSORY DRIVE BELT INSPECTION

TYPES OF BELTS Older V-belts (so-named because of their shape) are 34 degrees at the V. The pulley they ride through is generally 36 degrees. This 2-degree difference results in a wedging action and makes power transmission possible, but it is also the reason why V-belts must be closely inspected.

It is generally recommended that all belts, including the **serpentine** (or **Poly V**) belts be replaced every four to seven years. When a belt that turns the water pump breaks, the engine could rapidly overheat, causing serious engine damage. Use a wear gauge to check a serpentine belt for wear. ● **SEE FIGURES 14–20, 14–21, AND 14–22.**

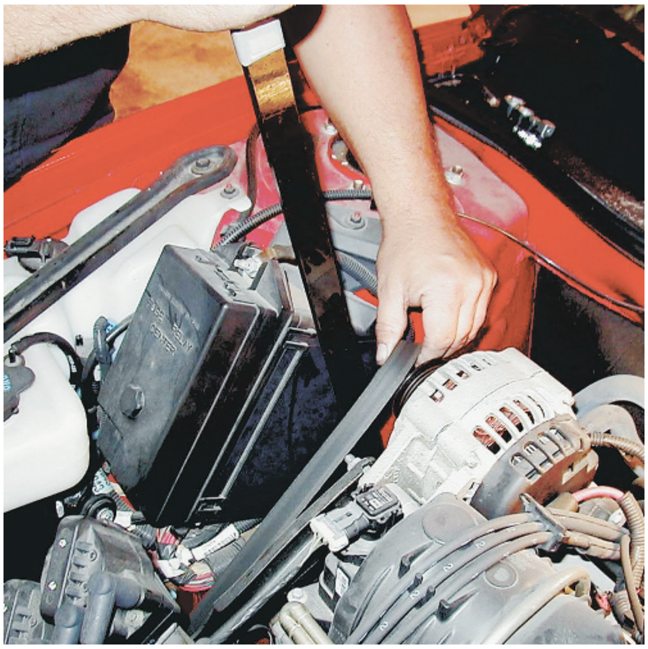


FIGURE 14–20 A special tool is useful when installing a new accessory drive belt. The long-handled wrench fits in a hole of the belt tensioner.

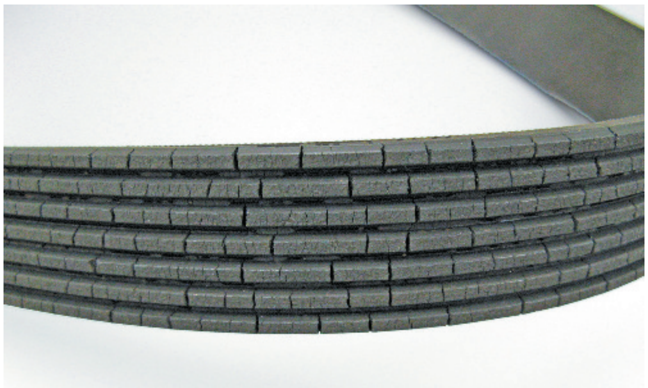


FIGURE 14–21 A typical worn serpentine accessory drive belt. Newer belts made from ethylene propylene diene monomer (EPDM) do not crack like older belts that were made from neoprene rubber.

BELT TENSION MEASUREMENT There are four ways that vehicle manufacturers specify that the belt tension is within factory specifications.

1. **Belt tension gauge.** A belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications or use the table below for an example of the proper tension based on the size of the belt. ● **SEE FIGURE 14–22**.

Serpentine Belts	
Number of Ribs Used	**Tension Range (lb)**
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145

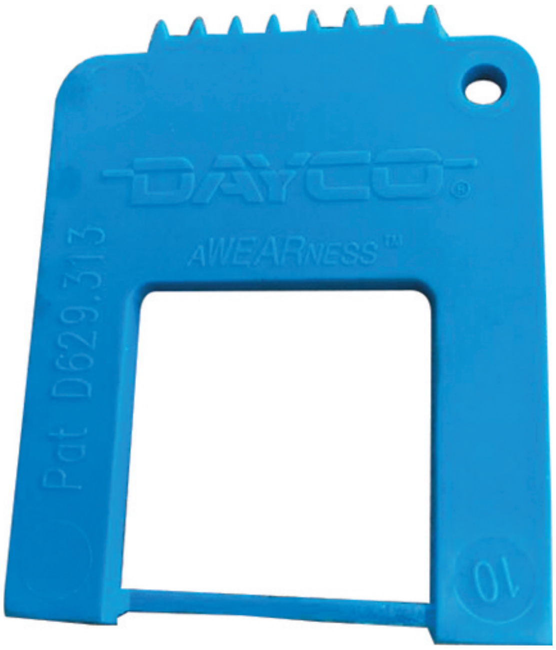


FIGURE 14–22 If the wear gauge can be moved side to side, then the belt is worn and should be replaced. It is almost impossible to check a serpentine belt made from EPDM for wear visually without using a wear gauge.

TECH TIP

The Water Spray Trick

Lower-than-normal alternator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the Vs of the belt and the angle of the Vs on the pulley. Over time, this interference angle is worn off the edges of the V of the belt. As a result, the belt may start to slip and make a squealing sound, even if tensioned properly.

A fast method to determine if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running.

- If the belt noise stops, but returns when the belt dries out, the cause is often called *chirp* and is due to pulley misalignment.
- If the belt noise gets louder when sprayed with water, the cause is often called *squeal* and is caused by low belt tension.

Replace any serpentine belt that has more than three cracks in any one rib that appears in a 3-inch span.

2. **Marks on a tensioner.** Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the preferred location of the tensioner mark.
3. **Torque wrench reading.** Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced. ● **SEE FIGURE 14–23**.
4. **Deflection.** Depress the belt between the two pulleys that are the farthest apart; the flex or deflection should be 0.5 inch.

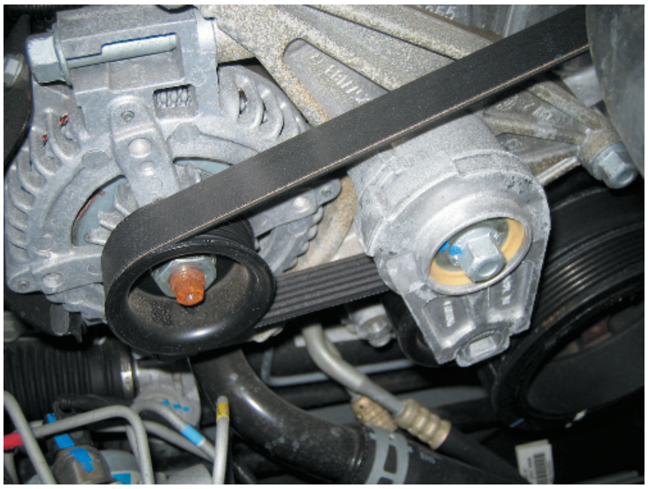


FIGURE 14–23 A spring-loaded accessory drive belt tensioner.

BELT ROUTING GUIDE Always check the belt routing diagram located on the underhood sticker or in service information for the proper routing when replacing an accessory drive belt. The belt routing can vary depending on engine size and accessories.

TIRE AND WHEEL SERVICE

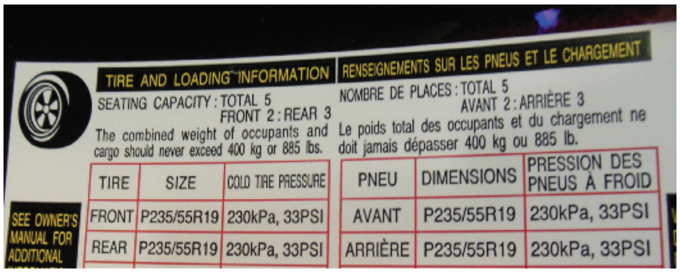
INFLATION PRESSURE Tire pressure should be checked when the tires are cold. As a vehicle is driven, the flexing of the tire and friction between the tire and the road causes an increase in temperature.

- As the tire heats up, the air inside the tire also increases in temperature.
- The increased temperature of the air increases the air pressure inside the tire.
- The air pressure typically increases in pressure 4 to 6 pounds per square inch (PSI) after the vehicle has been driven several miles.
- If air is then removed from the hot tire, the tire would be underinflated. The tire pressure specified is for a tire that has not been driven and is therefore cold, so the air pressure should be checked before the vehicle has been driven more than 2 miles (3 km).

NOTE: Tire pressure changes according to air temperature about 1 PSI per 10°F; therefore, during a change of season, the tire pressure has to be adjusted. For example, when the summer temperature of 80°F; changes to 40°F in the fall, the tire pressure will drop about 4 PSI (80 − 40 = 40).

HOW TO CHECK TIRE PRESSURE Use a good-quality tire pressure gauge and push it against the tire valve stem after removing the cap. Be sure no air escapes when the pressure gauge is used as this will cause an inaccurate reading. Compare the pressure reading with the specified tire pressure. The specified pressure is located on a placard attached to the driver's door or doorpost or in the glove compartment. ● **SEE FIGURE 14–24**.

CAUTION: Do not inflate tires to the maximum rating on the tire sidewall. Even though this pressure represents the maximum tire pressure, inflating the tires to this pressure usually results in a very harsh ride and often unacceptable handling.



TIRE AND LOADING INFORMATION

SEATING CAPACITY : TOTAL 5
FRONT 2 : REAR 3

The combined weight of occupants and cargo should never exceed 400 kg or 885 lbs.

TIRE	SIZE	COLD TIRE PRESSURE
FRONT	P235/55R19	230kPa, 33PSI
REAR	P235/55R19	230kPa, 33PSI

SEE OWNER'S MANUAL FOR ADDITIONAL

RENSEIGNEMENTS SUR LES PNEUS ET LE CHARGEMENT

NOMBRE DE PLACES : TOTAL 5
AVANT 2 : ARRIÈRE 3

Le poids total des occupants et du chargement ne doit jamais dépasser 400 kg ou 885 lb.

PNEU	DIMENSIONS	PRESSION DES PNEUS À FROID
AVANT	P235/55R19	230kPa, 33PSI
ARRIÈRE	P235/55R19	230kPa, 33PSI

FIGURE 14–24 The specified tire inflation pressure is printed on a placard on the driver's door or doorpost. This information may also be located in the glove compartment, the owner's manual, and in service information.

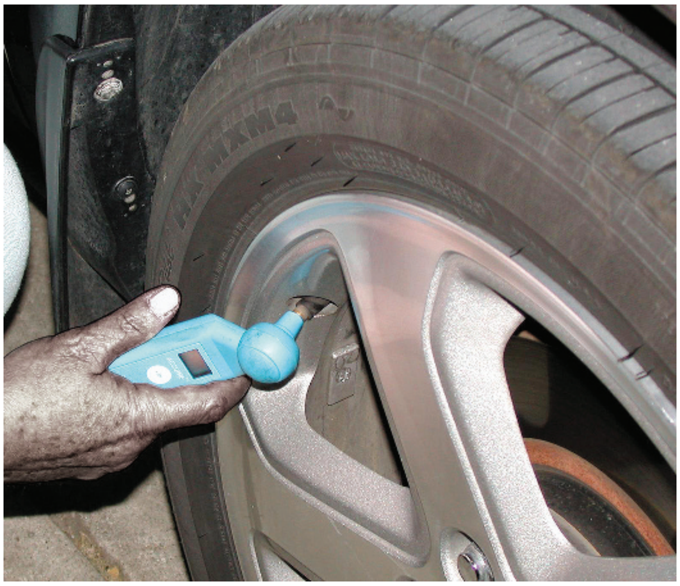


FIGURE 14–25 An electronic tire pressure gauge is usually more accurate than a mechanical "pencil type" gauge and more likely to provide consistent pressure readings. Do not allow air to escape when testing or the reading will not be accurate.

SPECIFIED TIRE PRESSURE The specified tire inflation pressure should always be used when checking or adjusting tire pressure. Tire pressure should be checked and adjusted, if necessary, after a tire rotation has been completed because some vehicles require different inflation pressure for front and rear tires. Therefore, when the tires are rotated, the front and rear tire inflation pressure may need to be adjusted. The spare tire should also be checked at each oil change interval. Check service information for the exact inflation pressure.

The recommendation sometimes includes a statement about tire pressures to use if operating under all highway-driving conditions or operating the vehicle in a fully loaded condition. Specifications for these conditions commonly include increasing the pressure, usually about 4 to 6 PSI (27 to 41 kPa). ● **SEE FIGURE 14–25**.

TIRE INSPECTION All tires should be carefully inspected for faults in the tire itself or for signs that something may be wrong with the steering or suspension systems of the vehicle. The tires should be checked for the following conditions:

- Thread depth (2/32 of an inch is the standard minimum allowable tread depth in most states)
- Unequal wear

TECH TIP

Two Quick Checks

If the vehicle is hoisted on a frame-contact lift, perform two quick checks:

1. Spin each tire to check that the brakes are not dragging. You should be able to turn all four wheels by hand if the parking brake is off and the transmission is in neutral.
2. When spinning the tire, look over the top of the tire to check if it is round. An improperly mounted tire or a tire that is out-of-round due to a fault in the tire can be detected by watching for the outside of the tire to move up and down as it is being rotated.

- Cuts in the tread or sidewall
- Bulges or uneven sidewalls

Check the spare tire for proper inflation pressure as well as condition of the tire and wheel.

TIRE ROTATION To assure long life and even tire wear, it is important to rotate each tire to another location. Some rear-wheel-drive vehicles, for example, may show premature tire wear on the front tires. The wear usually starts on the outer tread row and usually appears as a front-to-back (high and low) wear pattern on individual tread blocks. These *blocks of tread* rubber are deformed during cornering, stopping, and turning, which can cause tire noise and/or tire roughness. While some shoulder wear on front tires is normal, it can be reduced by proper inflation, alignment, and tire rotation. ● **SEE FIGURE 14–26** for suggested methods of rotation.

NOTE: Radial tires can cause a radial pull due to their construction. If the wheel alignment is correct, attempt to correct a pull by rotating the tires front to rear or, if necessary, side to side.

HINT: To help remember when to rotate the tires, just remember that it should be done at every other oil change. Most manufacturers recommend changing the engine oil every 5,000 miles (8,000 km) or every six months and recommend tire rotation every 10,000 miles (16,000 km) or every year.

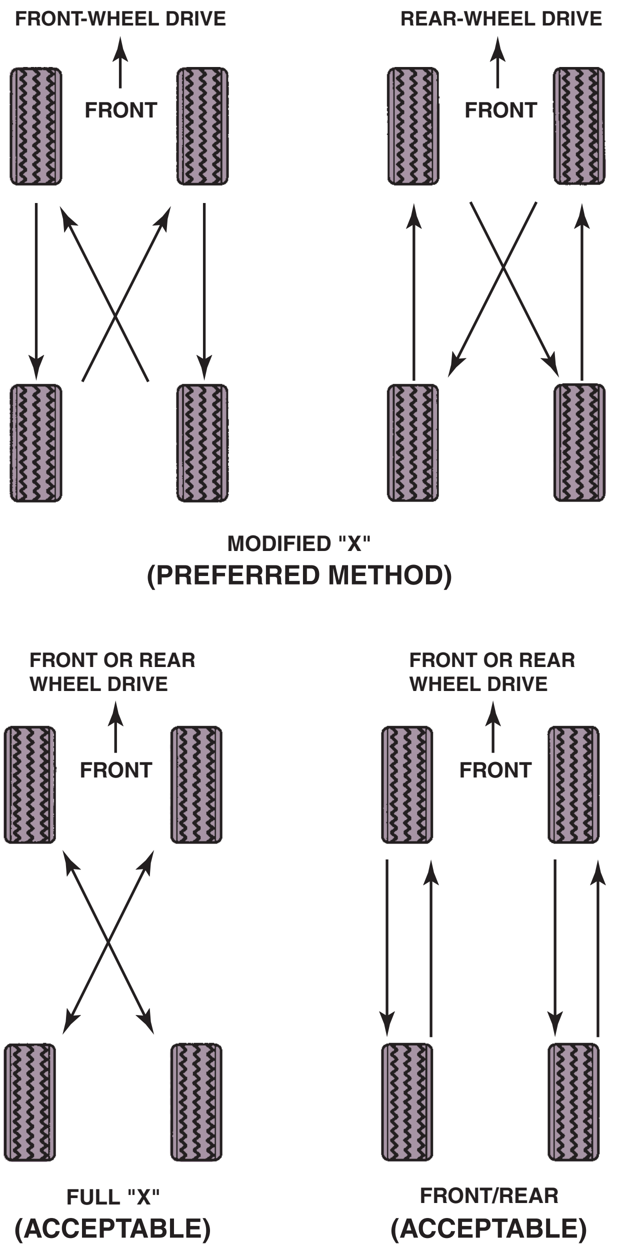


FIGURE 14–26 The method most often recommended is the modified X method. Using this method, each tire eventually is used at each of the four wheel locations. An easy way to remember the sequence, whether front-wheel drive or rear-wheel drive, is "Drive wheels straight, cross the nondrive wheels."

WHEEL MOUNTING TORQUE There are two commonly used methods to ensure proper tire lug nut torque.

- **Torque wrench.** Using a torque wrench is the preferred method to tighten the wheel lug nuts.
- **Torque sticks.** These long sticks are calibrated to transmit a limited amount of torque to the lug nut when used according to factory instructions. Make certain that the wheel studs are clean and dry and torqued to manufacturer's specifications. Most vehicles specify a tightening torque of between 80 and 100 lb-ft (108 and 136 N-m).

TECH TIP

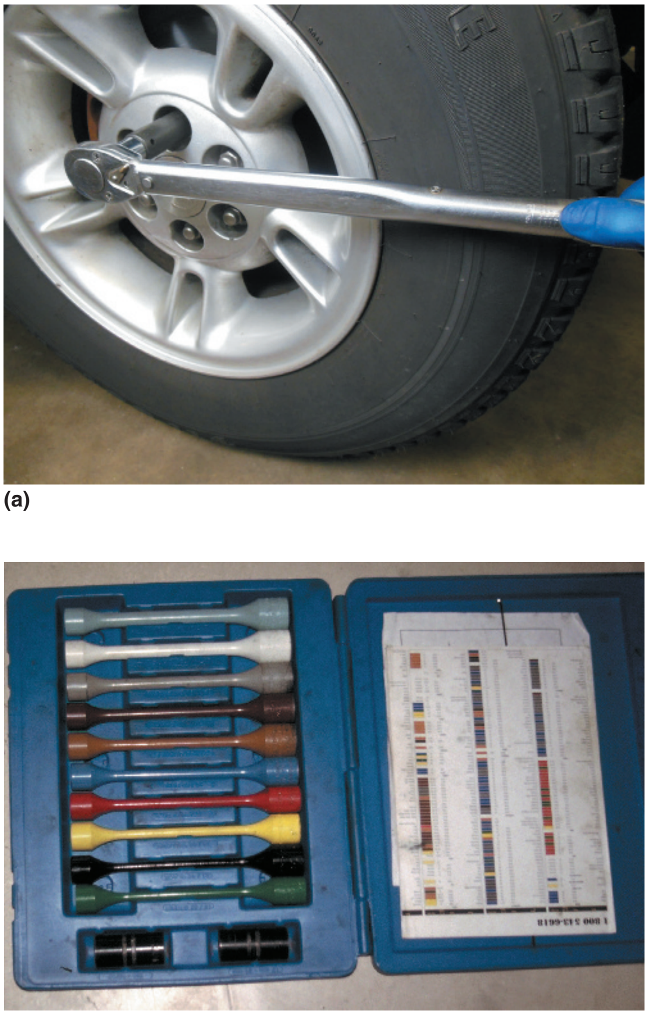
Check for Wheel Lock Key

Many vehicles have wheel locks that require a special key to remove. The wise technician should always ask the customer or service writer about wheel locks before pulling the vehicle into the shop or before the vehicle is hoisted.

CAUTION: Most manufacturers warn that the wheel studs should not be oiled or lubricated with grease because this can cause the wheel lug nuts to loosen while driving.

Always tighten lug nuts gradually, in the proper sequence (tighten one nut, skip one, and tighten the next nut), to prevent warping the brake drums or rotors, or bending a wheel. ● **SEE FIGURE 14–27**.

NOTE: Anytime you install a brand-new set of aluminum wheels, retorque the wheels after the first 25 miles. The soft aluminum often compresses slightly, loosening the torque on the wheels.


(a)

(b)

FIGURE 14–27 (a) Using a torque wrench is the preferred method to use when installing wheels. Check service information for the specified torque. (b) A color-coded assortment of torque sticks.

FREQUENTLY ASKED QUESTION

When Is the "Second Click" Heard?

A student service technician was observed applying a lot of force to a clicker-type torque wrench attached to a wheel lug nut. When the instructor asked what the student was doing, the student replied that they were turning the lug nut tighter until they heard a second click from the torque wrench.

This was confusing to the instructor until the student explained that they had heard a second click of the torque wrench during the demonstration. The instructor at once realized that the student had heard a click when the proper torque was achieved, plus another click when the force on the torque wrench was released.

No harm occurred to the vehicle because all of the lug nuts were reinstalled and properly torqued. The instructor learned that a more complete explanation for the use of click-type torque wrenches was needed.

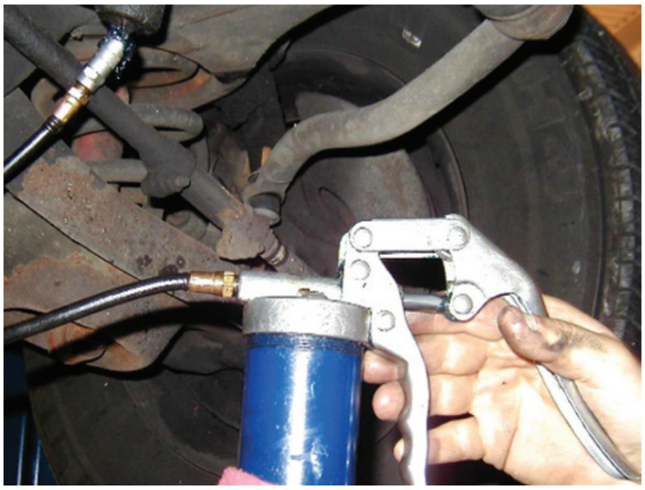


FIGURE 14–28 A hand-operated grease gun is being used to lubricate the steering component through a grease fitting.

CHASSIS LUBRICATION

GREASE FITTINGS Chassis lubrication refers to the greasing of parts that rub against each other or installing grease into a pivot (or ball joints) through a grease fitting. Grease fittings are also called **Zerk fittings** (named for Oscar U. Zerk) or **Alemite fittings** (named for the manufacturer of early grease fittings). These fittings contain a one-way check valve that prevents the grease from escaping. Grease fittings are used on steering components, such as tie-rod ends, and in the suspension ball joints, which require lubrication to prevent wear and noise caused by the action of a ball rotating within a joint during vehicle operation. ● **SEE FIGURE 14–28**.

The procedure for lubricating a grease fitting includes the following steps:

STEP 1 Wipe off the fitting with a shop cloth.

STEP 2 Make sure the grease gun coupler is fully seated on the fitting.

STEP 3 Apply grease only until the dust boot swells.

STEP 4 If the fitting will not accept grease, replace it with a new one and retry.

STEP 5 Remove the grease gun and wipe any spilled grease from the fitting.

CAUTION: If too much grease is forced into a sealed grease boot, the boot itself may rupture, requiring the entire joint to be replaced.

TECH TIP

Watch Out for Vents That Look Like Grease Fittings

Watch for what looks like a grease (Zerk) fitting but is somewhat smaller, as this may be a vent, such as found on a late-model Dodge Caravan on the ball joints. If the grease gun does not fit on it, do not be tempted to remove and replace with a grease fitting.

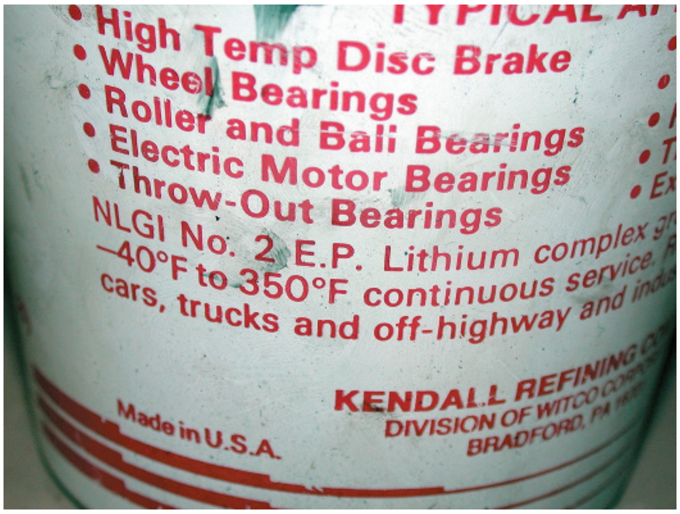


FIGURE 14–29 Most vehicle manufacturers recommend the use of grease meeting the NLGI #2 and "GC" for wheel bearings and "LB" for chassis lubrication. Many greases have both designations, and therefore, can be used for wheel bearings or chassis lubrication.

TYPES OF GREASE

Vehicle manufacturers specify the type and consistency of grease for each application. The technician should know what these specifications mean. Grease is oil with a thickening agent added to allow it to be installed in places where a liquid lubricant would not stay. Greases are named for their thickening agent, such as aluminum, barium, calcium, lithium, or sodium.

CAUTION: Grease types are often not compatible with each other.

The **American Society for Testing Materials (ASTM)** specifies the consistency of grease using a **penetration test**. The **National Lubricating Grease Institute (NLGI)** uses the penetration test as a guide to assign the grease a number. Low numbers are very fluid and higher numbers are more firm or hard. Most vehicle manufacturers specify NLGI #2 for wheel bearing and chassis lubrication. ● **SEE FIGURE 14–29**.

NLGI also specifies grease by its use, as follows:

- The "GC" designation is acceptable for wheel bearings.
- The "LB" designation is acceptable for chassis lubrication.

Many greases are labeled with both GC and LB and are, therefore, acceptable for both wheel bearings and chassis use, such as in lubricating ball joints and tie-rod ends.

DIFFERENTIAL FLUID CHECK

PROCEDURE FOR CHECKING

Rear-wheel-drive vehicles use a differential in the rear of the vehicle to change the direction of power flow from the engine to the rear wheels. The differential also provides a gear reduction to increase engine torque applied to the drive wheels. Four-wheel-drive vehicles also use a differential at the front of the vehicle in addition to the differential in the rear. To check the differential fluid level and condition, perform the following steps:

STEP 1 Hoist the vehicle safely.

STEP 2 Visually check for any signs of leakage. ● **SEE FIGURE 14–30**.

STEP 3 Remove the inspection plug from the side or rear cover of the differential assembly.

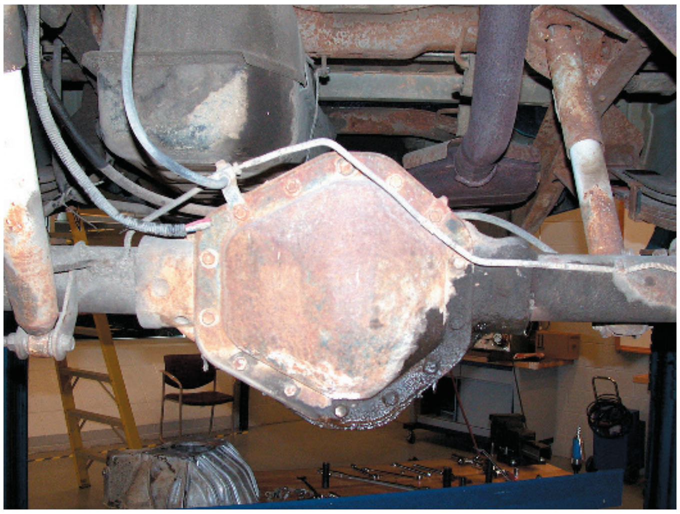


FIGURE 14–30 This differential assembly has been leaking fluid. The root cause should be determined and the unit filled to the proper level using the specified lubricant, to help prevent early failure and an expensive repair later.

STEP 4 Insert your small finger into the hole in the housing and then remove your finger.

- If the differential fluid is on your finger, then the fluid level is okay. Rub the fluid between your fingers. If the fluid is not gritty feeling, reinstall the inspection plug. If the fluid is gritty feeling, further service will be necessary to determine the cause and correct it.
- If the differential fluid is not on your finger, then the fluid level is too low.

NOTE: The reason for the low fluid level should be determined. If repairs are not completed immediately, additional differential fluid should be added by pumping it into the differential through the inspection hole.

DIFFERENTIAL LUBRICANTS

All differentials use hypoid gear sets; and a special lubricant is necessary because the gears both roll and slide between their meshed teeth. Gear lubes are specified by the **American Petroleum Institute (API)**. Most differentials require:

1. SAE 80W-90 GL-5 *or*
2. SAE 75W-90 GL-5 *or*
3. SAE 80W GL-5

TECH TIP

Check the Fill Plug before Draining a Transmission

Experienced technicians have learned that it is wise to check that the fill plug can be removed *before* draining the manual transmission or transfer case through the drain plug. If the fill plug cannot be removed, then the fluid should not be drained until the problem is resolved. Once the fluid has been drained, there is no option but to do whatever it takes to get the fill plug open. This process is often difficult and may result in having to replace the entire assembly. ● **SEE FIGURE 14–31.**

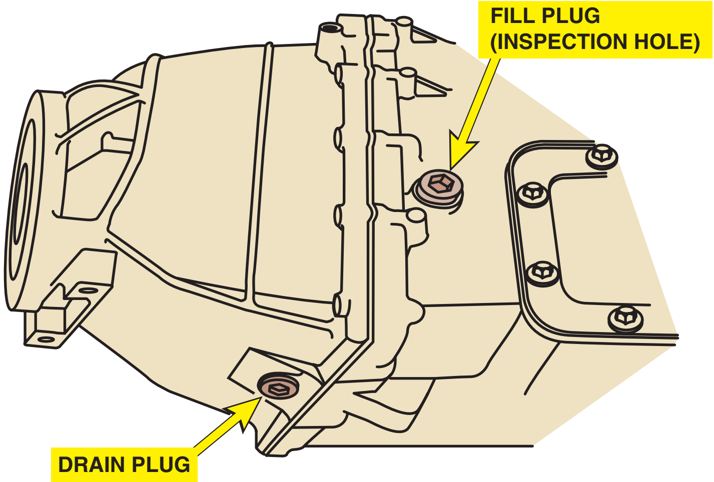


FIGURE 14–31 Always ensure that the fill plug can be accessed and removed *before* draining the fluid from a manual transmission.

Limited slip differentials (often abbreviated LSD) often use an additive that modifies the friction characteristics of the rear axle lubricant to prevent chattering while cornering.

MANUAL TRANSMISSION/ TRANSAXLE LUBRICANT CHECK

TYPES OF MANUAL TRANSMISSION FLUID

Manual transmissions/transaxles may use any one of the following lubricants:

- Gear lube (usually SAE 80W-90)
- Automatic transmission fluid (ATF)
- Engine oil (usually SAE 5W-30)
- Manual transmission fluid (sometimes called **synchromesh transmission fluid**, or **STF**). This type of lubricant is similar to ATF, with special additives to ease shifting, especially when cold.

PROCEDURE FOR CHECKING

To check manual transmissions/transaxles lubricant, perform the following:

- Hoist the vehicle safely.
- Locate the transmission/transaxle inspection (fill) plug. Consult the factory service manual for the proper plug to remove, to check the fluid level.
- If the fluid drips out of the hole, then the level is correct. If the fluid runs out of the hole, the level is too full. Allow it to flow out until it stops. The correct level of fluid is at the bottom of the inspection hole.
- If low, first determine the correct fluid to use and then fill until the fluid level is at the bottom of the inspection hole or until the fluid runs out of the inspection hole.

UNDER-VEHICLE INSPECTION

VISUAL CHECKS

Other items underneath the vehicle that may need checking or lubricating include:

- Shock absorbers and springs. ● **SEE FIGURE 14–32.**
- Transmission/transaxle shift linkage (check the service manual for the correct lubricant to use).
- Exhaust system, including all pipes and hangers. ● **SEE FIGURE 14–33.**

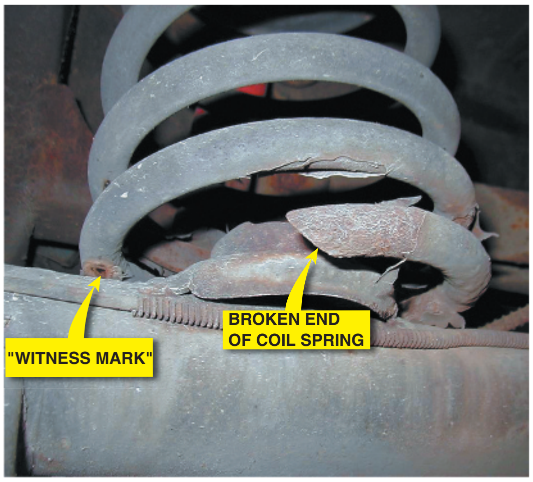


FIGURE 14–32 A broken coil spring was found during an under-vehicle inspection. The owner was not aware of a problem and it did not make any noise, but the vehicle stability was affected.

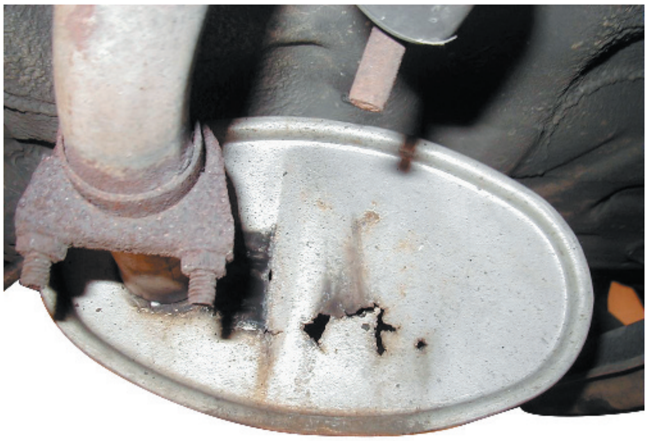


FIGURE 14–33 This corroded muffler was found during a visual inspection, but was not detected by the driver because it was relatively quiet.

- Brake lines for evidence of damage or leakage.
- Shock absorbers for leakage or damaged mounts.
- Steering linkage for obvious looseness, or damaged or missing parts.
- Parking brake cable guides.

CAUTION: Do not lubricate plastic-coated parking brake cables. The lubricant can destroy the plastic coating.

DIESEL EXHAUST FLUID

Most diesel engines built after 2007 require that the diesel exhaust fluid (DEF) be refilled on a regular basis, usually at each oil change. Diesel exhaust fluid (DEF) is a mixture of 32.5% laboratory grade urea and 67.5% deionized water and is used to reduce NOx exhaust emissions. Most diesel vehicles are equipped with a DEF reservoir large enough to last until the next scheduled oil change making this service convenient for the vehicle owner. ● **SEE FIGURE 14–34**.

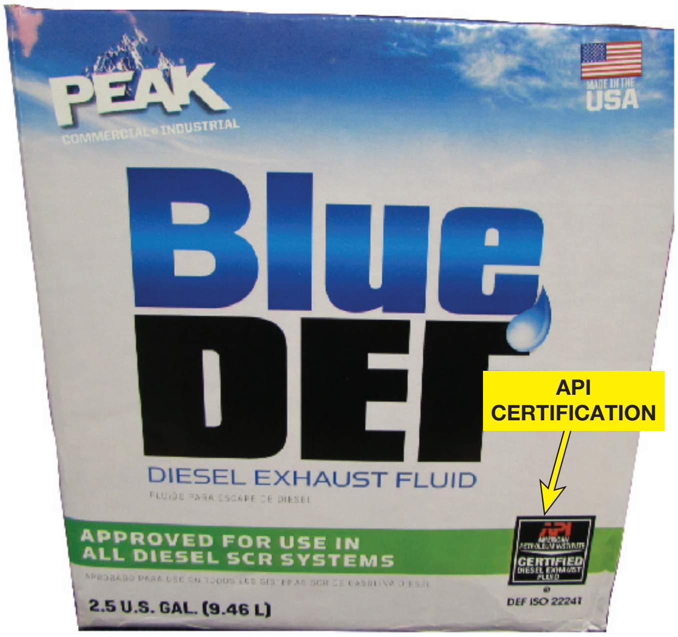


FIGURE 14–34 Diesel exhaust fluid (DEF) is available in consumer-friendly containers or in bulk.

REVIEW QUESTIONS

1. Why should brake fluid not be filled above the full or MAX level as indicated on the master cylinder reservoir?
2. Why should brake fluid be kept in an airtight container?
3. How do you check differential fluid?
4. What are four lubricants that a manual transmission/transaxle *may* require, depending on exact year, make, and model of the vehicle.
5. How often does diesel exhaust fluid (DEF) need to be refilled?

CHAPTER QUIZ

1. Preventative maintenance includes all of these *except* ________________.
   - **a.** tire balancing
   - **b.** oil and filter change
   - **c.** check tire pressure
   - **d.** air filter replacement
2. When should the engine oil be replaced?
   - **a.** According to the vehicle manufacturer's recommended interval based on time and mileage, whichever occurs first
   - **b.** Every three months, regardless of miles
   - **c.** Every 3,000 miles, regardless of time
   - **d.** All of the above
3. Which of these should be checked during routine service?
   - **a.** A safety check and windshield wiper inspection
   - **b.** Cabin and air filter inspection and replacement
   - **c.** Brake fluid and engine oil inspection
   - **d.** All of the above
4. Routine service includes ________________.
   - **a.** inspecting the cooling system
   - **b.** automatic transmission fluid check
   - **c.** checking power steering fluids
   - **d.** All of the above
5. An under the hood and under-vehicle inspection should include ________________.
   - **a.** checking accessory belt tension and condition
   - **b.** checking tires and wheels and lubricate the chassis
   - **c.** checking differential and manual transmission fluid
   - **d.** All the above
6. Coolant can be checked using ________________.
   - **a.** boiling/freezing points using a refractometer and hydrometer
   - **b.** visual inspection
   - **c.** test strips
   - **d.** All of the above
7. Accessory drive belt tension is determined by ________________.
   - **a.** marks on the tensioner
   - **b.** torque required to rotate the tensioner using a beam-type torque wrench
   - **c.** belt tension using a belt tension gauge
   - **d.** Any of the above depending on the specified procedure as found in service information

8. What inflation pressure specifications should be used when checking or correcting tire pressure?
   a. The MAX pressure as imprinted on the tire sidewall
   b. The driver's door placard pressure
   c. 32 PSI in most tires
   d. 35 PSI in all tires

9. The use of diesel exhaust fluid (DEF) in a vehicle equipped with a diesel engine is used to reduce ________________ emissions.
   a. NO_x
   b. HC
   c. CO
   d. All of the above

10. A service technician removed the inspection/fill plug from a manual transmission and gear lube started to flow out. Technician A says to quickly replace the plug to prevent any more loss of gear lube. Technician B says to catch the fluid and allow the fluid to continue to drain. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

SECTION VI

ENGINE REPAIR (A1)

CHAPTERS

15 Gasoline Engine Operation, Parts, and Specifications
16 Diesel Engine Parts, Operation, and Aftertreatment
17 Antifreeze and Coolant
18 Cooling System Operation and Diagnosis
19 Engine Oil and Filters
20 Lubrication System Operation and Diagnosis
21 Intake and Exhaust Systems
22 Turbocharging and Supercharging
23 Engine Condition Diagnosis
24 In-Vehicle Engine Service
25 Engine Removal and Disassembly
26 Engine Cleaning and Crack Detection
27 Cylinder Head Inspection and Service
28 Camshafts and Valve Trains
29 Variable Valve Timing and Displacement Systems
30 Pistons, Rings, and Connecting Rods
31 Engine Blocks
32 Crankshafts, Balance Shafts, and Bearings
33 Gaskets and Sealants
34 Engine Assembly and Testing
35 Engine Installation and Break-In

Chapter 15

GASOLINE ENGINE OPERATION, PARTS, AND SPECIFICATIONS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the engine's purpose and function.
- Explain how engines use energy and power.
- Discuss engine construction.
- Explain engine parts and systems.
- Explain four-stroke cycle operation.
- Discuss engine classification and construction.
- Explain engine measurement.
- Discuss compression ratio.
- Discuss compression, torque, and horsepower.

KEY TERMS:

Block 142 • Bore 148 • Bottom dead center (BDC) 144 • Boxer 145 • Cam-in-block design 146 • Camshaft 146 • Combustion 142 • Combustion chamber 142 • Compression ratio (CR) 150 • Connecting rod 144 • Crankshaft 144 • Cycle 144 • Cylinder 144 • Displacement 148 • Double overhead camshaft (DOHC) 146 • Exhaust valve 145 • External combustion engine 142 • Four-stroke cycle 144 • Intake valve 144 • Internal combustion engine 142 • Mechanical force 142 • Mechanical power 142 • Naturally aspirated 146 • Nonprincipal end 147 • Oil galleries 143 • Overhead valve (OHV) 146 • Pancake 145 • Piston stroke 144 • Principal end 147 • Pushrod engine 146 • Rotary engine 147 • Single overhead camshaft (SOHC) 146 • Stroke 148 • Supercharger 146 • Top dead center (TDC) 144 • Turbocharger 146 • Wankel engine 147

PURPOSE AND FUNCTION

The purpose and function of an engine is to convert the heat energy of burning fuel into mechanical energy. In a typical vehicle, mechanical energy is used to perform the following:

- Propel the vehicle
- Power the air-conditioning system and power steering
- Produce electrical power for use throughout the vehicle

ENERGY AND POWER

Engines use energy to produce power. The chemical energy in fuel is converted to heat energy by the burning of the fuel at a controlled rate. This process is called **combustion**. If engine combustion occurs within the power chamber, the engine is called an **internal combustion engine**.

NOTE: An external combustion engine burns fuel outside of the engine itself, such as a steam engine.

Engines used in automobiles are internal combustion heat engines. They convert the chemical energy of the gasoline into heat within a power chamber that is called a **combustion chamber**. Heat energy released in the combustion chamber raises the temperature of the combustion gases within the chamber. The increase in gas temperature causes the pressure of the gases to increase. The pressure developed within the combustion chamber is applied to the head of a piston to produce a usable **mechanical force**, which is converted into useful **mechanical power**.

ENGINE CONSTRUCTION OVERVIEW

BLOCK All automotive and truck engines are constructed using a solid frame, called a **block**. A block is constructed of cast iron or aluminum and provides the foundation for most of the engine components and systems. The block is cast and then machined to very close tolerances to allow other parts to be installed.

ROTATING ASSEMBLY Pistons are installed in the block and move up and down (reciprocate) during engine operation. Pistons are connected to connecting rods, which connect the pistons to the crankshaft. The crankshaft converts the up-and-down motion of the piston to rotary motion, which is then transmitted to the drive wheels and propels the vehicle. ● **SEE FIGURE 15–1**.

CYLINDER HEADS All engines use a cylinder head to seal the top of the cylinders, which are in the engine block. The cylinder head also contains intake valves that allow air and fuel into the cylinder, and exhaust valves, which allow the hot gases left over to escape from the engine. Cylinder heads are constructed of cast iron or aluminum and are machined for the valves and other valve-related components. ● **SEE FIGURE 15–2**.

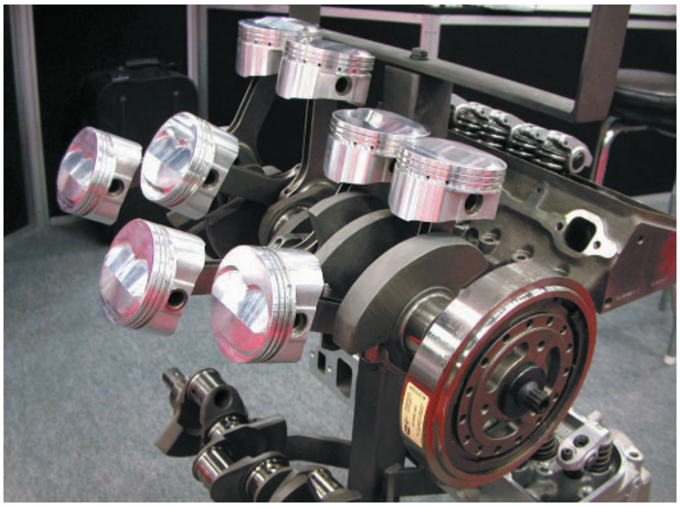


FIGURE 15–1 The rotating assembly for a V-8 engine that has eight pistons and connecting rods and one crankshaft.

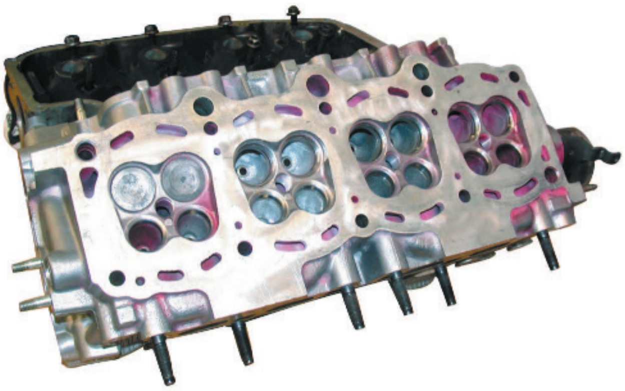


FIGURE 15–2 A cylinder head with four valves per cylinder, two intake valves (larger) and two exhaust valves (smaller).

FREQUENTLY ASKED QUESTION

What Is a Flat-Head Engine?

A flat-head engine is an older type engine design that has the valves in the block. The valves are located next to the cylinders and the air–fuel mixture, and exhaust flows through the block to the intake and exhaust manifolds. Because the valves are in the block, the heads are flat and, therefore, are called flat-head engines. The most commonly known was the Ford flat-head V-8 produced from 1932 until 1953. Typical flat-head engines included

- Inline 4-cylinder engines (many manufacturers)
- Inline 6-cylinder engines (many manufacturers)
- Inline 8-cylinder engines (many manufacturers)
- V-8s (Cadillac and Ford)
- V-12s (Cadillac and Lincoln)

ENGINE PARTS AND SYSTEMS

INTAKE AND EXHAUST MANIFOLDS Air and fuel enter the engine through an intake manifold and exit the engine through the exhaust manifold. Intake manifolds operate cooler than exhaust manifolds and are therefore constructed of nylon-reinforced plastic or aluminum. Exhaust manifolds must be able to withstand hot exhaust gases, so most are constructed from cast iron or steel tubing.

COOLING SYSTEM All engines must have a cooling system to control engine temperatures. While some older engines were air cooled, all current production passenger vehicle engines are cooled by circulating antifreeze coolant through passages in the block and cylinder head. The coolant picks up the heat from the engine. After the thermostat opens, the water pump circulates the coolant through the radiator where the excess heat is released to the outside air, cooling the coolant. The coolant is continuously circulated through the cooling system and the temperature is controlled by the thermostat. ● **SEE FIGURE 15–3.**

LUBRICATION SYSTEM All engines contain moving and sliding parts that must be kept lubricated to reduce wear and friction. The oil pan, bolted to the bottom of the engine block, holds 4 to 7 quarts (4 to 7 liters) of oil. An oil pump, which is driven by the engine, forces the oil through the oil filter and into passages in the crankshaft and block. These passages are called **oil galleries**. The oil is also forced up to the valves and falls down through openings in the cylinder head and block, then back into the oil pan. ● **SEE FIGURE 15–4.**

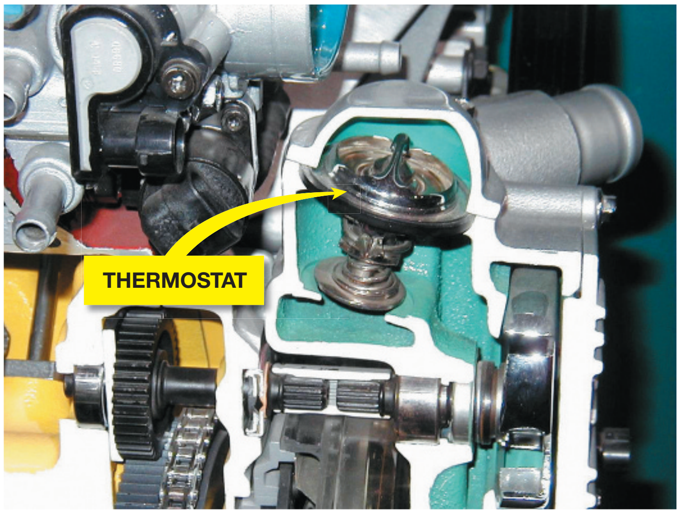


FIGURE 15–3 The coolant temperature is controlled by the thermostat, which opens and allows coolant to flow to the radiator when the temperature reaches the rating temperature of the thermostat.

FUEL SYSTEM AND IGNITION SYSTEM All engines require both a fuel system to supply fuel to the cylinders and an ignition system to ignite the air–fuel mixture in the cylinders. The fuel system includes the following components:

- Fuel tank, where fuel is stored and where most fuel pumps are located
- Fuel filter and lines, which transfer the fuel from the fuel tank to the engine

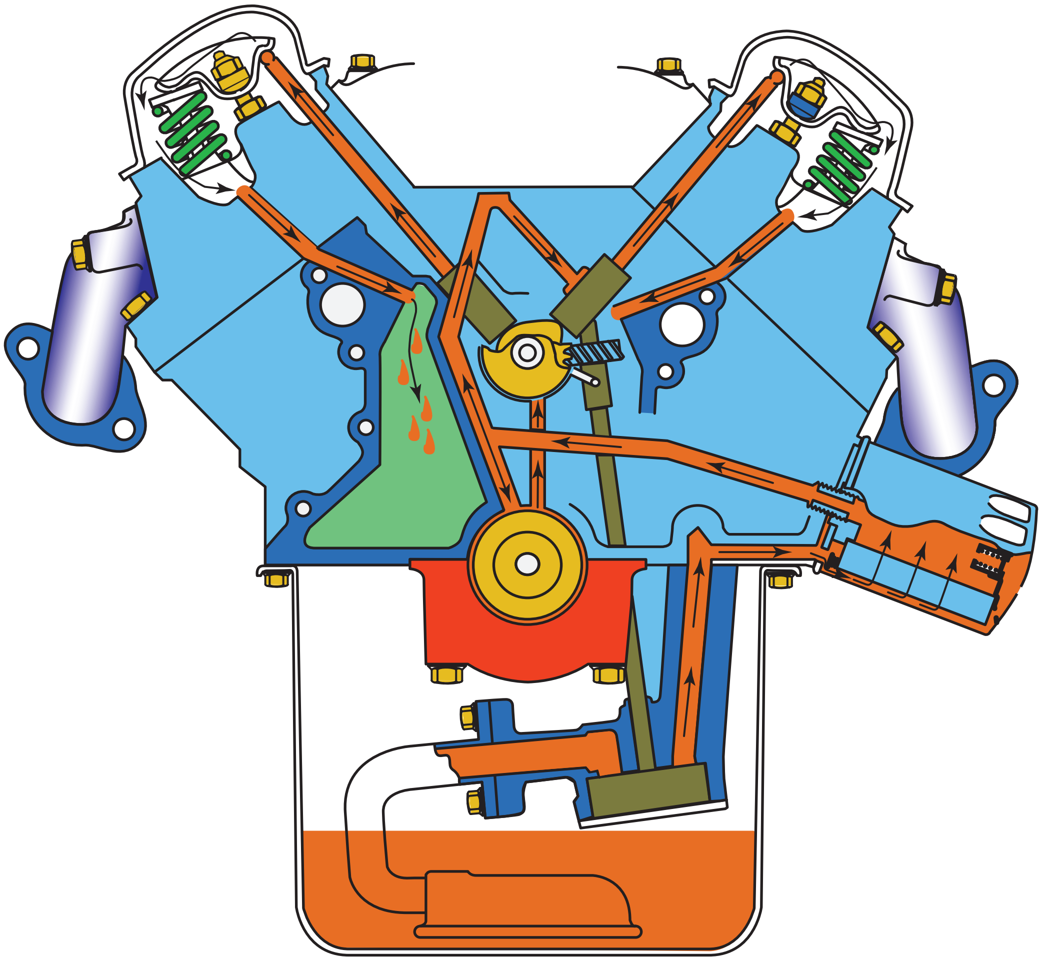


FIGURE 15–4 A typical lubrication system, showing the oil pan, oil pump, oil filter, and oil passages.

- Fuel injectors, which spray fuel into the intake manifold or directly into the cylinder, depending on the type of system used.

The ignition system is designed to take 12 volts from the battery and convert it to 5,000 to 40,000 volts needed to jump the gap of a spark plug. Spark plugs are threaded into the cylinder head of each cylinder, and when the spark occurs, it ignites the air–fuel mixture in the cylinder, creating pressure and forcing the piston down in the cylinder. The following components are part of the ignition system:

- **Spark plugs.** Provide an air gap inside the cylinder where a spark occurs to start combustion
- **Sensor(s).** Includes crankshaft position (CKP) and camshaft position (CMP) sensors, used by the powertrain control module (PCM) to trigger the ignition coil(s) and the fuel injectors
- **Ignition coils.** Increase battery voltage to 5,000 to 40,000 volts
- **Ignition control module (ICM).** Controls when the spark plug fires
- **Associated wiring.** Electrically connects the battery, ICM, coil, and spark plugs

FOUR-STROKE CYCLE OPERATION

PRINCIPLES The first **four-stroke cycle** engine was developed by a German engineer, Nickolaus Otto, in 1876. Most automotive engines use the four-stroke cycle of events. The process begins by the starter motor rotating the engine until combustion takes place. The four-stroke cycle is repeated for each cylinder of the engine. ● **SEE FIGURE 15–5.**

A piston that moves up and down, or reciprocates, in a **cylinder** can be seen in **FIGURE 15–5**. The piston is attached to a **crankshaft** with a **connecting rod**. This arrangement allows the piston to reciprocate (move up and down) in the cylinder as the crankshaft rotates. ● **SEE FIGURE 15–6.**

OPERATION Engine cycles are identified by the number of piston strokes required to complete the cycle. A **piston stroke** is a one-way piston movement either from top to bottom or bottom to top of the cylinder. During one stroke, the crankshaft rotates 180 degrees (1/2 revolution). A **cycle** is a complete series of events that continually repeats. Most automobile engines use a four-stroke cycle.

- **Intake stroke.** The **intake valve** is open and the piston inside the cylinder travels downward, drawing a mixture of air and fuel into the cylinder. The crankshaft rotates 180 degrees from **top dead center (TDC)** to **bottom dead center (BDC)** and the camshaft rotates 90 degrees.
- **Compression stroke.** As the engine continues to rotate, the intake valve closes and the piston moves upward in the

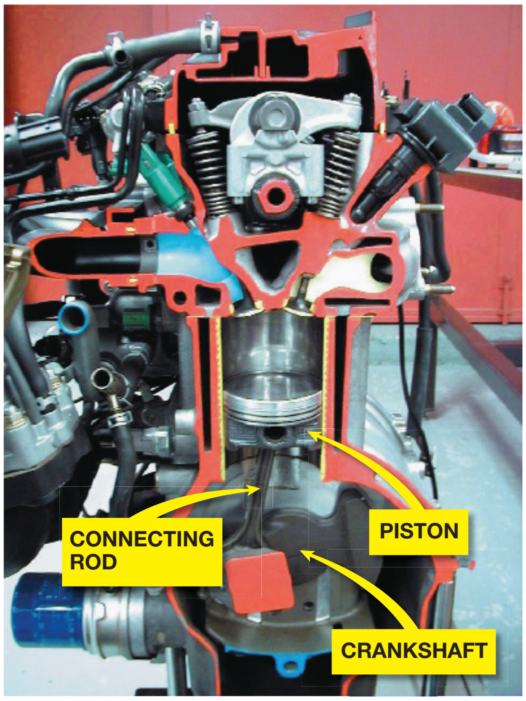


FIGURE 15–6 Cutaway of an engine showing the cylinder, piston, connecting rod, and crankshaft.

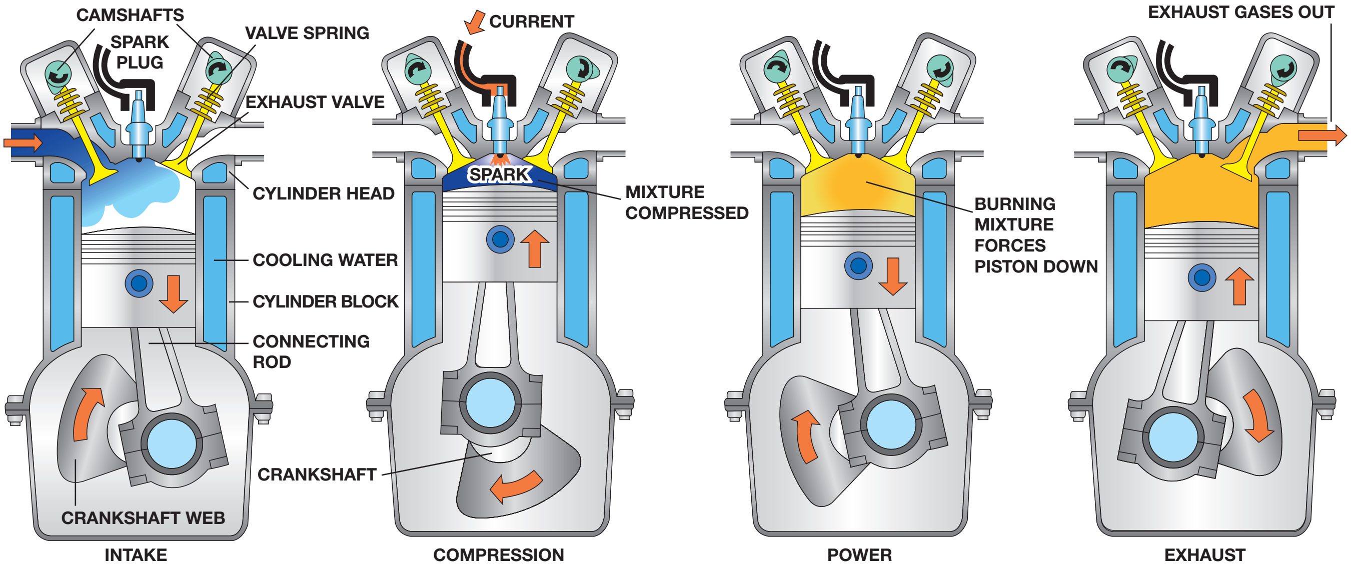


FIGURE 15–5 The downward movement of the piston draws the air–fuel mixture into the cylinder through the intake valve on the intake stroke. On the compression stroke, the mixture is compressed by the upward movement of the piston with both valves closed. Ignition occurs at the beginning of the power stroke, and combustion drives the piston downward to produce power. On the exhaust stroke, the upward-moving piston forces the burned gases out of the open exhaust valve.

cylinder, compressing the air–fuel mixture. The crankshaft rotates 180 degrees from BDC to TDC and the camshaft rotates 90 degrees.

- **Power stroke.** When the piston gets near the top of the cylinder, the spark at the spark plug ignites the air–fuel mixture, which forces the piston downward. The crankshaft rotates 180 degrees from TDC to BDC and the camshaft rotates 90 degrees. The combustion pressure developed in the combustion chamber at the correct time will push the piston downward to rotate the crankshaft.
- **Exhaust stroke.** The engine continues to rotate, and the piston again moves upward in the cylinder. The exhaust valve opens, and the piston forces the residual burned gases out of the **exhaust valve**, and into the exhaust manifold and exhaust system. The crankshaft rotates 180 degrees from BDC to TDC and the camshaft rotates 90 degrees.

This sequence repeats as the engine rotates. To stop the engine, the electricity to the ignition system is shut off by the ignition switch, which stops the spark to the spark plugs.

THE 720-DEGREE CYCLE Each cycle (four strokes) of events requires that the engine crankshaft make two complete revolutions, or 720 degrees (360 degrees × 2 = 720 degrees). Each stroke of the cycle requires that the crankshaft rotate 180 degrees. The greater the number of cylinders, the closer together the power strokes of the individual cylinders will occur. The number of degrees that the crankshaft rotates between power strokes can be expressed as an angle. To find the angle between power strokes of an engine, divide 720 by the number of cylinders.

Angle with 3 cylinders: 720/3 = 240 degrees
Angle with 4 cylinders: 720/4 = 180 degrees
Angle with 5 cylinders: 720/5 = 144 degrees
Angle with 6 cylinders: 720/6 = 120 degrees
Angle with 8 cylinders: 720/8 = 90 degrees
Angle with 10 cylinders: 720/10 = 72 degrees

In a 4-cylinder engine, a power stroke occurs at every 180 degrees of the crankshaft rotation (every 1/2 rotation). A V-8 is a much smoother operating engine because a power stroke occurs twice as often (every 90 degrees of crankshaft rotation).

ENGINE CLASSIFICATION AND CONSTRUCTION

Engines are classified by several characteristics, including:

- **Number of strokes.** Most automotive engines use the four-stroke cycle.
- **Cylinder arrangement.** An engine with more cylinders is smoother operating because the power pulses produced by the power strokes are more closely spaced. An inline engine places all cylinders in a straight line. The 4-, 5-, and 6-cylinder engines are commonly manufactured inline engines. A V-type engine, such as a V-6 or V-8, has the number of cylinders split and built into a V shape. ● **SEE FIGURE 15–7**.

  Horizontally opposed 4- and 6-cylinder engines have two banks of cylinders that are horizontal, resulting in a low engine. This style of engine is used in Porsche and Subaru engines and is often called the **boxer** or **pancake** engine design. ● **SEE FIGURE 15–8**.

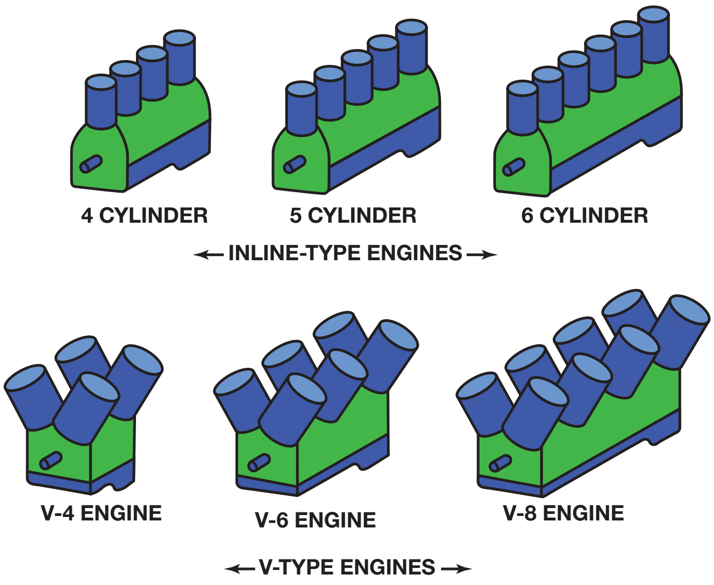

4 CYLINDER
5 CYLINDER
6 CYLINDER
INLINE-TYPE ENGINES
V-4 ENGINE
V-6 ENGINE
V-8 ENGINE
V-TYPE ENGINES

FIGURE 15–7 Automotive engine cylinder arrangements.

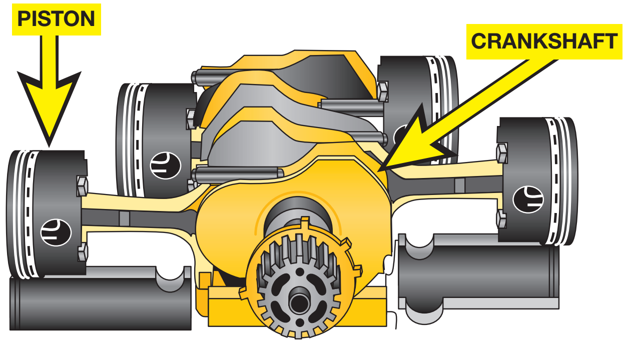

PISTON
CRANKSHAFT

FIGURE 15–8 A horizontally opposed engine design helps to lower the vehicle's center of gravity.

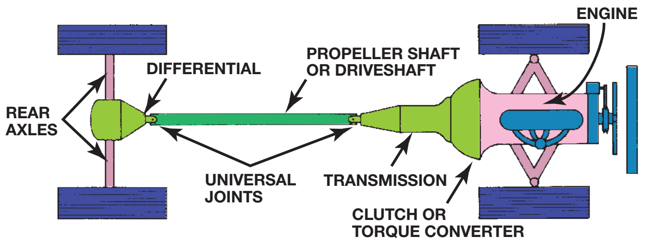

ENGINE
PROPELLER SHAFT OR DRIVESHAFT
DIFFERENTIAL
REAR AXLES
UNIVERSAL JOINTS
TRANSMISSION
CLUTCH OR TORQUE CONVERTER

FIGURE 15–9 A longitudinally mounted engine drives the rear wheels through a transmission, driveshaft, and differential assembly.

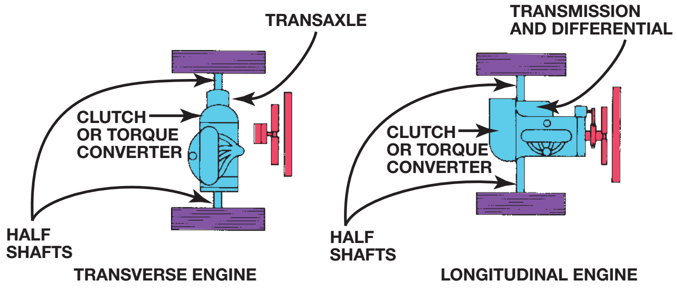

TRANSAXLE
TRANSMISSION AND DIFFERENTIAL
CLUTCH OR TORQUE CONVERTER
CLUTCH OR TORQUE CONVERTER
HALF SHAFTS
HALF SHAFTS
TRANSVERSE ENGINE
LONGITUDINAL ENGINE

FIGURE 15–10 Two types of front-engine, front-wheel drive mountings.

- **Longitudinal and transverse mounting.** Engines may be mounted either parallel with the length of the vehicle (longitudinally) or crosswise (transversely). ● **SEE FIGURES 15–9 AND 15–10**. The same engine may be mounted in various vehicles in either direction.

NOTE: Although it might be possible to mount an engine in different vehicles both longitudinally and transversely, the engine component parts may *not* be interchangeable. Differences can include different engine blocks and crankshafts, as well as different water pumps.

- **Valve and camshaft number and location.** The number of valves per cylinder and the number and location of camshafts are major factors in engine operation. A typical older-model engine uses one intake valve and one exhaust valve per cylinder. Many newer engines use two intake and two exhaust valves per cylinder. The valves are opened by a **camshaft**. Some engines use one camshaft for the intake valves and a separate camshaft for the exhaust valves. When the camshaft is located in the block, the valves are operated by lifters, pushrods, and rocker arms.

  This type of engine is called:
- A **pushrod engine**
- **Cam-in-block design**
- **Overhead valve (OHV)**, because an overhead valve engine has the valves located in the cylinder head (● **SEE FIGURE 15–11**.)

When one overhead camshaft is used, the design is called a **single overhead camshaft (SOHC)** design. When two overhead camshafts are used, the design is called a **double overhead camshaft (DOHC)** design. ● **SEE FIGURES 15–12 AND 15–13**.

NOTE: A V-type engine uses two banks or rows of cylinders. An SOHC design, therefore, uses two camshafts but only one camshaft per bank (row) of cylinders. A DOHC V-6, therefore, has four camshafts, two for each bank.

- **Type of fuel.** Most engines operate on gasoline, whereas some engines are designed to operate on ethanol (E85), methanol (M85), natural gas, propane, or diesel fuel.
- **Cooling method.** Most engines are liquid cooled, but some older models were air cooled. Air-cooled engines, such as the original VW Beatle, could not meet exhaust emission standards.
- **Type of induction pressure.** If atmospheric air pressure is used to force the air–fuel mixture into the cylinders, the engine is called **naturally aspirated**. Some engines use a **turbocharger** or **supercharger** to force the air–fuel mixture into the cylinder for even greater power.

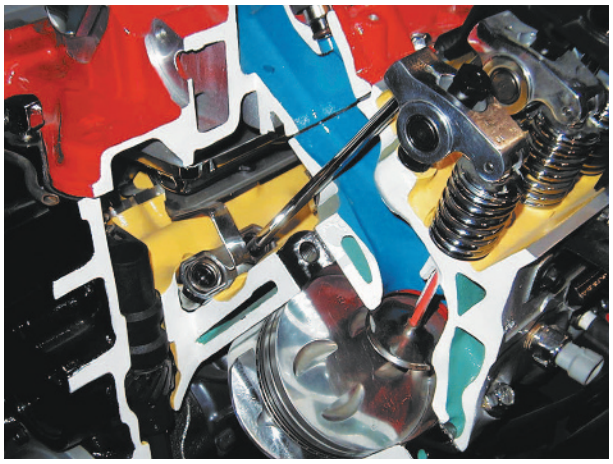


FIGURE 15–11 Cutaway of an overhead valve (OHV) V-8 engine showing the lifters, pushrods, roller rocker arms, and valves.

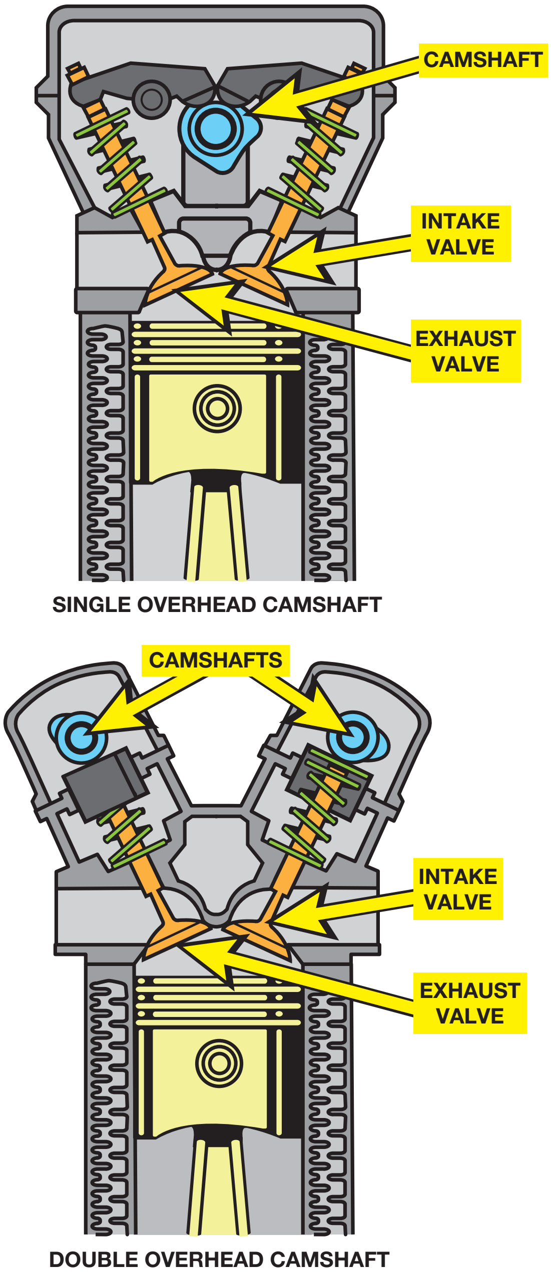


FIGURE 15–12 SOHC engines usually require additional components, such as a rocker arm, to operate all of the valves. DOHC engines often operate the valves directly.

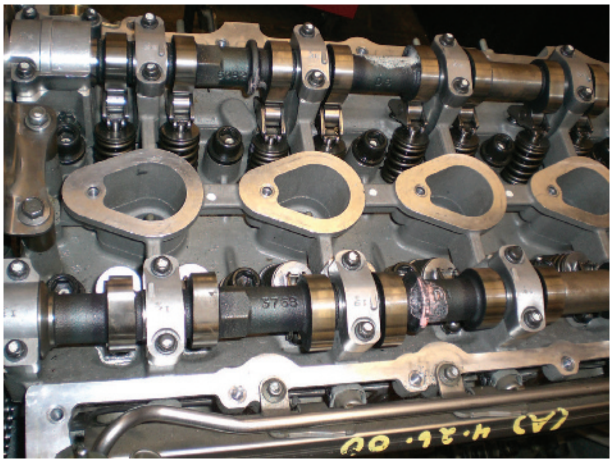


FIGURE 15–13 A DOHC engine uses a camshaft for the intake valves and a separate camshaft for the exhaust valves in each cylinder head.

FREQUENTLY ASKED QUESTION

What Is a Rotary Engine?

A successful alternative engine design is the **rotary engine**, also called the **Wankel engine** after its inventor, Felix Heinrich Wankel (1902–1988), a German inventor. The Mazda RX-7 and RX-8 represent the only long-term use of the rotary engine. The rotating combustion chamber engine runs very smoothly, and produces high power for its size and weight.

The basic rotating combustion chamber engine has a triangular-shaped rotor turning in a housing. The housing is in the shape of a geometric figure called a two-lobed epitrochoid. A seal on each corner, or apex, of the rotor is in constant contact with the housing, so the rotor must turn with an eccentric motion. This means that the center of the rotor moves around the center of the engine. The eccentric motion can be seen in ● **FIGURE 15–14**.

ENGINE ROTATION DIRECTION The SAE standard for automotive engine rotation is counterclockwise (CCW) as viewed from the flywheel end (clockwise as viewed from the front of the engine). The flywheel end of the engine is the end to which the power is applied to drive the vehicle. This is called the **principal end** of the engine. The **nonprincipal end** of the engine is opposite the principal end and is generally referred to as the *front* of the engine, where the accessory belts are used. ● **SEE FIGURE 15–15**.

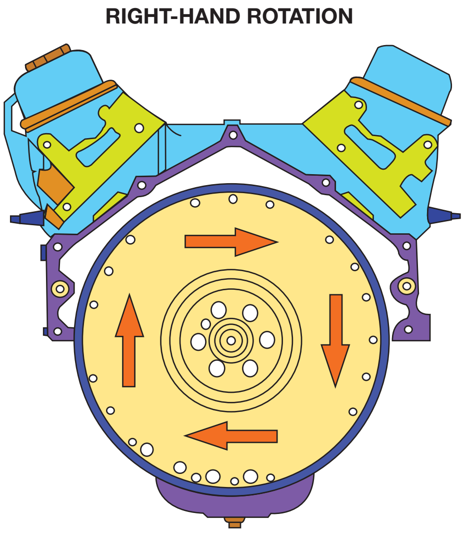


FIGURE 15–15 Normal direction of rotation is counterclockwise (CCW) as viewed from the flywheel (principle) end.

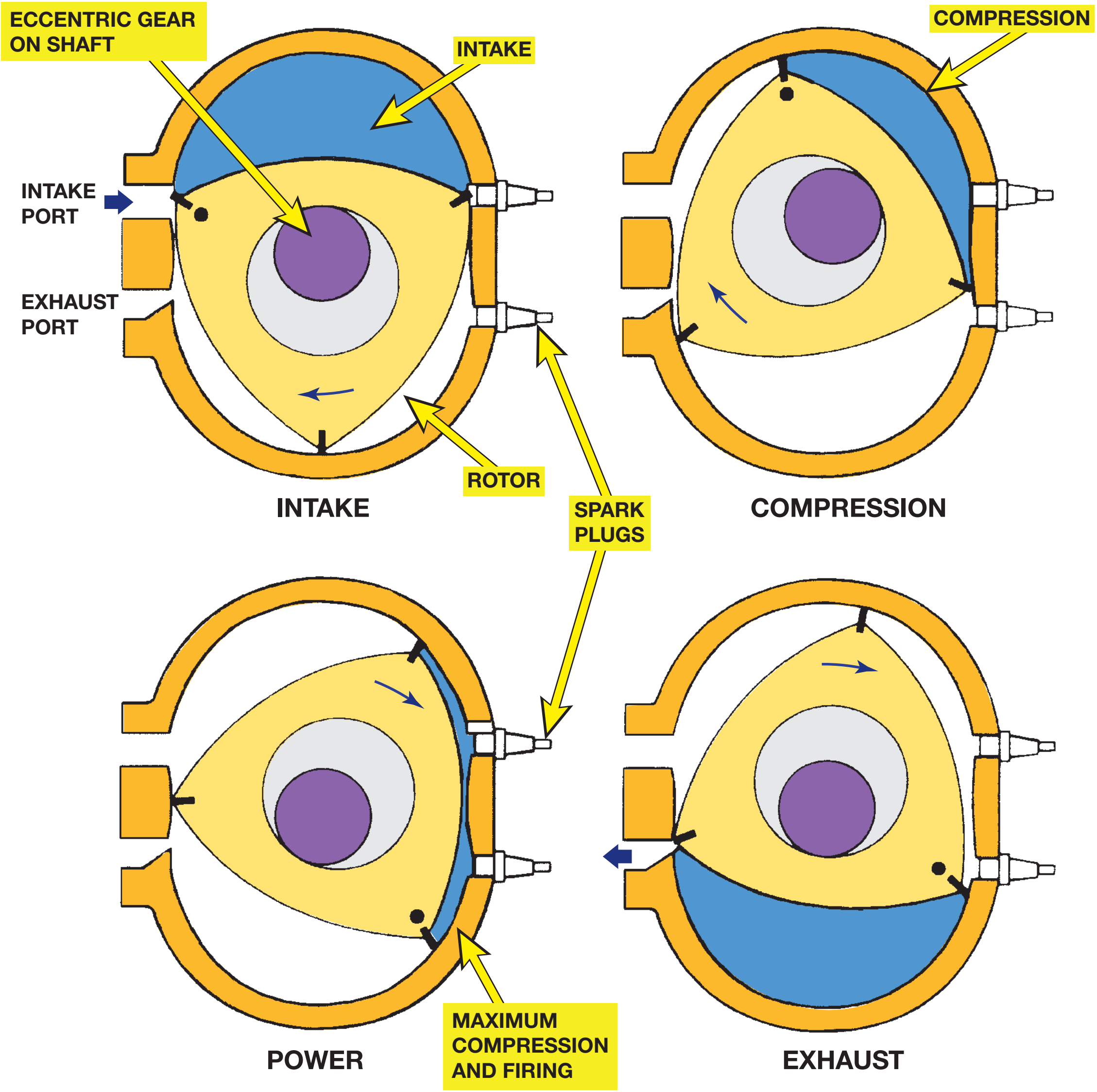


FIGURE 15–14 A rotary engine operates on the four-stroke cycle but uses a rotor instead of a piston and crankshaft to achieve intake, compression, power, and exhaust stroke.

Therefore, in most rear-wheel-drive vehicles, the engine is mounted longitudinally with the principal end at the rear of the engine. Most transversely mounted engines also adhere to the same standard for direction of rotation. Many Honda engines, and some marine applications, may differ from this standard.

ENGINE MEASUREMENT

BORE The diameter of a cylinder is called the **bore**. The larger the bore, the greater the area on which the gases have to work. Pressure is measured in units, such as pounds per square inch (PSI). The greater the area (in square inches), the higher the force exerted by the pistons to rotate the crankshaft. ● **SEE FIGURE 15–16**.

STROKE The **stroke** of an engine is the distance the piston travels from top dead center (TDC) to bottom dead center (BDC). This distance is determined by the throw of the crankshaft. The throw is the distance from the centerline of the crankshaft to the centerline of the crankshaft rod journal. The throw is one-half of the stroke. ● **SEE FIGURE 15–17**.

The longer the distance, the greater the amount of air- fuel mixture that can be drawn into the cylinder. The more air–fuel mixture inside the cylinder, the more force will result when the mixture is ignited.

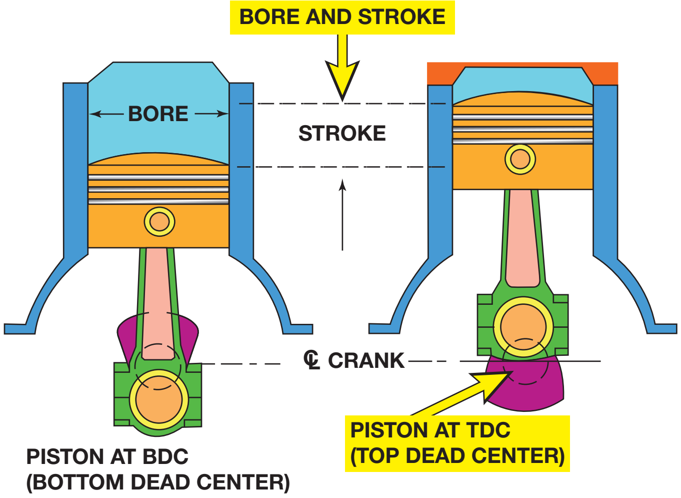


FIGURE 15–16 The bore and stroke of pistons are used to calculate an engine's displacement.

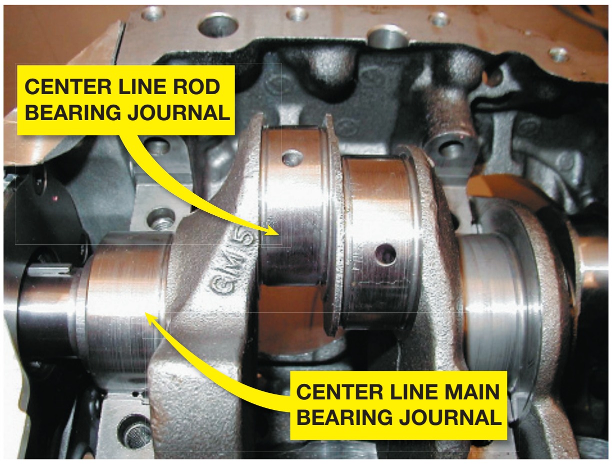


FIGURE 15–17 The distance between the centerline of the main bearing journal and the centerline of the connecting rod journal determines the stroke of the engine.

FREQUENTLY ASKED QUESTION

What Is the Atkinson Cycle?

In 1882, James Atkinson, a British engineer, invented an engine that achieved a higher efficiency than the Otto cycle, but produced lower power at low engine speeds. The Atkinson cycle engine was produced in limited numbers until 1890, when sales dropped, and the company that manufactured the engines finally went out of business in 1893.

However, the one key feature of the Atkinson cycle that remains in use today is that the intake valve is held open longer than normal to allow a reverse flow into the intake manifold. This reduces the effective compression ratio and engine displacement and allows the expansion to exceed the compression ratio, while retaining a normal compression pressure. This is desirable for good fuel economy because the compression ratio in a spark ignition engine is limited by the octane rating of the fuel used. A high expansion delivers a longer power stroke and reduces the heat wasted in the exhaust. This increases the efficiency of the engine because more work is being achieved. The Atkinson cycle engine design is commonly used in hybrid electric vehicles.

NOTE: Changing the connecting rod length does *not* change the stroke of an engine. Changing the connecting rod only changes the position of the piston in the cylinder. Only the crankshaft determines the stroke of an engine.

DISPLACEMENT Engine size is described as displacement. **Displacement** is the cubic inch (cu. in.) or cubic centimeter (cc) volume displaced, or how much air is moved by all of the pistons. A liter (L) is equal to 1,000 cubic centimeters; therefore, most engines today are identified by their displacement in liters.

1 L = 1,000 cc
1 L = 61 cu. in.
1 cu. in. = 16.4 cc

CONVERSION

- To convert cubic inches to liters, divide cubic inches by 61.02.

$$\textbf{Liters} = \frac{\textbf{Cubic inches}}{\textbf{61.02}}$$

- To convert liters into cubic inches, multiply by 61.02.

$$\textbf{Cubic inches} = \textbf{Liters} \times \textbf{61.02}$$

CALCULATING CUBIC INCH DISPLACEMENT The formula to calculate the displacement of an engine is basically the formula for determining the volume of a cylinder multiplied by the number of cylinders.

The formula is:

$$\textbf{Cubic inch displacement} = \pi\textbf{(pi)} \times \textbf{R}^2 \times \textbf{Stroke} \times \textbf{Number of cylinders}$$

R = Radius of the cylinder or one-half of the bore.

The πR^2 part is the formula for the area of a circle.

Applying the formula to a 6-cylinder engine:

- Bore = 4.000 inch
- Stroke = 3.000 inch
- p = 3.14
- R = 2 inch
- R^2 = 4 (2^2 or 2 × 2)

Cubic inches = 3.14 × 4 (R^2) × 3 (stroke) × 6 (number of cylinders)

Cubic inches = 226 cubic inches

Because 1 cubic inch equals 16.4 cubic centimeters, this engine displacement equals 3,706 cubic centimeters or, rounded to 3,700 cubic centimeters, 3.7 liters. ● **SEE CHART 15–1** for an example of engine sizes for a variety of bore and stroke measurements.

ENGINE SIZE CONVERSION Many vehicle manufacturers will round the displacement so the calculated cubic inch displacement may not agree with the published displacement value. ● **SEE CHART 15–2**.

V-8 ENGINE

Stroke	3.50	3.75	3.875	4.00	4.125
Bore	cu. in.	cu. in.	cu. in.	cu. in.	cu. in.
3.00	199	212	219	226	233
3.125	214	229	237	244	252
3.250	232	249	257	265	274
3.375	251	269	277	286	295
3.500	269	288	298	308	317
3.625	288	309	319	330	339
3.750	309	332	343	354	365
3.875	331	354	366	378	390
4.00	352	377	389	402	414
4.125	373	399	413	426	439

6-CYLINDER ENGINE

Stroke	3.50	3.75	3.875	4.00	4.125
Bore	cu. in.	cu. in.	cu. in.	cu. in.	cu. in.
3.00	148	159	164	169	175
3.125	161	172	178	184	190
3.250	174	186	193	199	205
3.375	188	201	208	215	222
3.500	202	216	223	228	238
3.625	216	232	239	247	255
3.750	232	249	257	265	273
3.875	248	266	275	283	292
4.00	264	283	292	301	311
4.125	280	299	309	319	329

4-CYLINDER ENGINE

Stroke	3.50	3.75	3.875	4.00	4.125
Bore	cu. in.	cu. in.	cu. in.	cu. in.	cu. in.
3.00	99	106	110	113	117
3.125	107	115	119	123	126
3.250	116	124	129	133	137
3.375	125	134	139	143	148
3.500	135	144	149	152	159
3.625	144	158	160	165	170
3.750	155	166	171	177	182
3.875	165	177	183	189	195
4.00	176	188	195	201	207
4.125	186	200	206	213	220

CHART 15–1

To find the cubic inch displacement, find the bore that is closest to the actual value, then go across to the closest stroke value.

LITERS TO CUBIC INCHES					
LITERS	CUBIC INCHES	LITERS	CUBIC INCHES	LITERS	CUBIC INCHES
1.0	61	3.2	196	5.4	330
1.3	79	3.3	200/201	5.7	350
1.4	85	3.4	204	5.8	351
1.5	91	3.5	215	6.0	366/368
1.6	97/98	3.7	225	6.1	370
1.7	105	3.8	229/231/232	6.2	381
1.8	107/110/112	3.9	239/240	6.4	389/390/391
1.9	116	4.0	241/244	6.5	396
2.0	121/122	4.1	250/252	6.6	400
2.1	128	4.2	255/258	6.9	420
2.2	132/133/134/135	4.3	260/262/265	7.0	425/427/428/429
2.3	138/140	4.4	267	7.2	440
2.4	149	4.5	273	7.3	445
2.5	150/153	4.6	280/281	7.4	454
2.6	156/159	4.8	292	7.5	460
2.8	171/173	4.9	300/301	7.8	475/477
2.9	177	5.0	302/304/305/307	8.0	488
3.0	181/182/183	5.2	318	8.8	534
3.1	191	5.3	327		

CHART 15–2

Liters to cubic inches is often not exact and can result in representing several different engine sizes based on their advertised size in liters.

TECH TIP

How Fast Can an Engine Rotate?

Most passenger vehicle engines are designed to rotate at low speed for the following reasons:

- Maximum efficiency is achieved at low engine speed. A diesel engine used in a large ship, for example, will rotate at about 100 RPM for maximum efficiency.
- Piston ring friction is the highest point of friction in the engine. The slower the engine speed, the less loss to friction from the piston rings.

However, horsepower is what is needed to get a vehicle down the road quickly. Horsepower is torque times engine speed divided by 5,252. Therefore, a high engine speed usually indicates a high horsepower. For example, a Formula 1 race car is limited to 1.6 liter V-6 but uses a 1.6 inch (40 mm) stroke. This extremely short stroke means that the engine can easily achieve the upper limit allowed by the rules of 18,000 RPM while producing over 700 horsepower.

The larger the engine, the more power the engine is capable of producing. Several sayings are often quoted about engine size:

"There is no substitute for cubic inches."

"There is no replacement for displacement."

Although a large engine generally uses more fuel, making an engine larger is often the easiest way to increase power.

COMPRESSION RATIO

DEFINITION **Compression ratio (CR)** is the ratio of the difference in the cylinder volume when the piston is at the bottom of the stroke to the volume in the cylinder above the piston when the piston is at the top of the stroke. The compression ratio of an engine is an important consideration when rebuilding or repairing an engine. ● **SEE FIGURE 15–18**.

If Compression Is Lower	If Compression Is Higher
Lower power	Higher power possible
Poorer fuel economy	Better fuel economy possible
Easier engine cranking	Harder to crank engine, especially when hot
More advanced ignition timing possible without spark knock (detonation)	Less ignition timing required to prevent spark knock (detonation)

CALCULATING COMPRESSION RATIO The compression ratio (CR) calculation uses the formula:

$$\text{CR} = \frac{\textbf{Volume in cylinder with piston at bottom of cylinder}}{\textbf{Volume in cylinder with piston at top center}}$$

● **SEE FIGURE 15–19**.

For example: What is the compression ratio of an engine with 50.3 cu. in. displacement in one cylinder and a combustion chamber volume of 6.7 cu. in.?

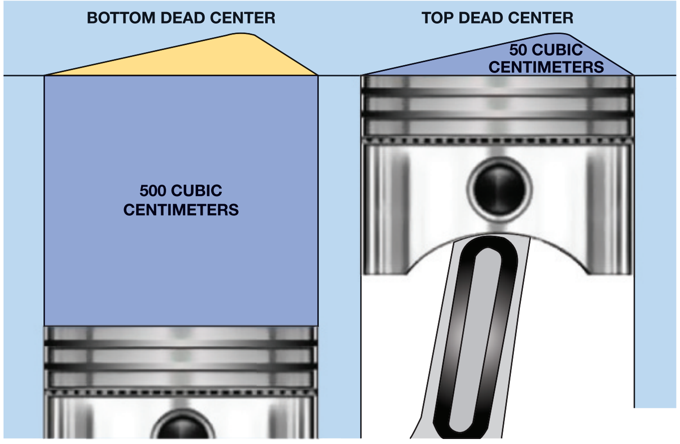


FIGURE 15–18 Compression ratio is the ratio of the total cylinder volume (when the piston is at the bottom of its stroke) to the clearance volume (when the piston is at the top of its stroke).

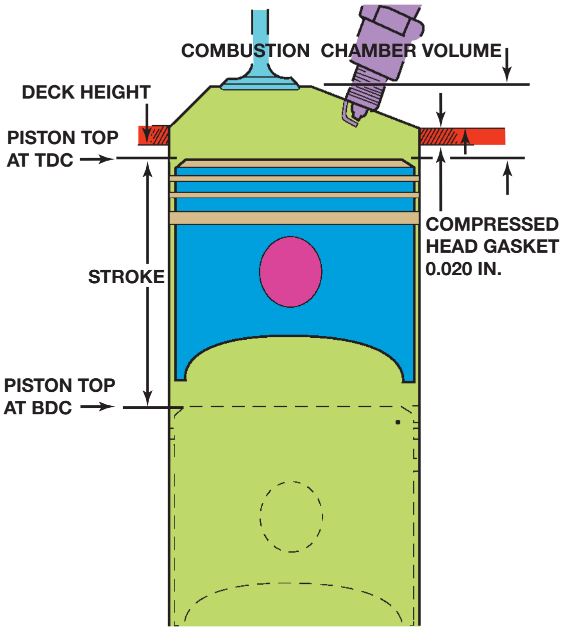


FIGURE 15–19 Combustion chamber volume is the volume above the piston with the piston is at top dead center.

$$CR = \frac{50.3 + 6.7 \text{ cu. in.}}{6.7 \text{ cu. in.}} = \frac{57.0}{6.7} = 8.5$$

CHANGING COMPRESSION RATIO Any time an engine is modified, the compression ratio should be checked to make sure it is either the same as it was originally or has been changed to match the diesel compression ratio. Factors that can affect compression ratio include:

- **Head gasket thickness.** A thicker than stock gasket will decrease the compression ratio and a thinner than stock gasket will increase the compression ratio.
- **Increasing the cylinder size.** If the bore or stroke is increased, a greater amount of air will be compressed into the combustion chamber, which will increase the compression ratio.

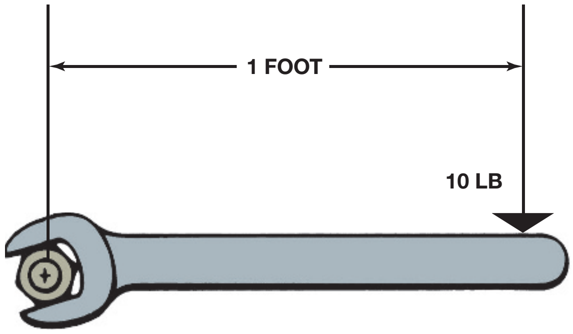


FIGURE 15–20 Torque is a twisting force equal to the distance from the pivot point times the force applied expressed in units called pound-feet (lb-ft) or newton-meters (N-m).

TORQUE AND HORSEPOWER

DEFINITION OF TORQUE Torque is the term used to describe a rotating force that may or may not result in motion. Torque is measured as the amount of force multiplied by the length of the lever through which it acts. If a one-foot-long wrench is used to apply 10 pounds (LB) of force to a bolt at the end of the wrench, this results in an application of 10 pound-feet (lb-ft) of torque. ● **SEE FIGURE 15–20**.

Torque is the twisting force measured at the end of the crankshaft and measured on a dynamometer. Engine torque is always expressed at a specific engine speed (RPM) or range of engine speeds where the torque is at the maximum. For example, an engine may be listed as producing 275 pound-feet @ 2,400 RPM.

The metric unit for torque is newton-meters, because the newton is the metric unit for force and the distance is expressed in meters.

1 pound-foot = 1.3558 newton-meters

1 newton-meter = 0.7376 pound-foot

DEFINITION OF POWER The term *power* means the rate of doing work. Power equals work divided by time. Work is achieved when a certain amount of mass (weight) is moved a certain distance by a force. If the object is moved in 10 seconds or 10 minutes does not make a difference in the amount of work accomplished, but it does affect the amount of power needed. Power is expressed in units of foot-pounds per minute and power also includes the engine speed (RPM) where the maximum power is achieved. For example, an engine may be listed as producing 280 hp @ 4,400 RPM.

DEFINITION OF HORSEPOWER The power of one horse was determined by James Watt (1736–1819) a Scottish inventor who first calculated the power of a horse while working on a steam engine to remove water from a coal mines.

One horsepower was determined to be the power required to move 550 pounds one foot in one second or 33,000 pounds one foot in one minute (550 × 60 seconds = 33,000 pounds per minute). Engine output is measured using a dynamometer. A dynamometer measures the torque of the engine and calculates the horsepower by the formula:

Horsepower = Torque × RPM/5252

FREQUENTLY ASKED QUESTION

What's with These Kilowatts?

A watt is the electrical unit for *power*, the capacity to do work. It is named after a Scottish inventor, James Watt (1736–1819). The symbol for power is *P*. Electrical power is calculated as amperes times volts:

$$P\,(\text{power}) = I\,(\text{amperes}) \cdot E\,(\text{volts})$$

Engine power is commonly rated in watts or kilowatts (1,000 watts equal 1 kilowatt), because 1 horsepower is equal to 746 watts. For example, a 200 horsepower engine can be rated in the metric system, as having the power equal to 149,200 watts or 149.2 kilowatts (kW).

Horsepower is always expressed with the rating and the engine speed where the maximum power was achieved. For example, an engine may be listed as producing 280 hp @ 4,400 RPM.

HORSEPOWER AND ALTITUDE Because the density of the air is lower at high altitude, the power that a normal engine can develop is greatly reduced at high altitude. According to SAE conversion factors, a nonsupercharged or nonturbocharged engine loses about 3% of its power for every 1,000 feet (300 m) of altitude.

Therefore, an engine that develops 200 brake horsepower at sea level will only produce about 116 brake horsepower at the top of Pike's Peak in Colorado at 14,110 feet (4,300 m) ($3\% \times 14 = 42\%$). Supercharged and turbocharged engines are not as greatly affected by altitude as normally aspirated engines, which are those engines that breathe air at normal atmospheric pressure.

REVIEW QUESTIONS

1. How is the angle between power strokes determined?
2. What brands of vehicles use horizontally opposed 4- and 6-cylinder engines?
3. What are the strokes of a four-stroke cycle?
4. If an engine at sea level produces 100 hp, how many horsepower would it develop at 6,000 feet of altitude?
5. What is the difference between torque and power?

CHAPTER QUIZ

1. The chemical energy in fuel is converted to heat by the burning of the fuel at a controlled rate. This process is called ________________.
   - **a.** combustion
   - **b.** consumption
   - **c.** power
   - **d.** torque
2. An SOHC V-8 engine has how many camshafts?
   - **a.** One
   - **b.** Two
   - **c.** Three
   - **d.** Four
3. The coolant flow through the radiator is controlled by the ________________.
   - **a.** size of the passages in the block
   - **b.** thermostat
   - **c.** cooling fan(s)
   - **d.** water pump
4. Torque is expressed in units of ________________.
   - **a.** pound-feet
   - **b.** foot-pounds
   - **c.** foot-pounds per minute
   - **d.** pound-feet per second
5. Horsepower is expressed in units of ________________.
   - **a.** pound-feet
   - **b.** foot-pounds
   - **c.** foot-pounds per minute
   - **d.** pound-feet per second
6. A normally aspirated automobile engine loses about ________________ power per 1,000 feet of altitude.
   - **a.** 1%
   - **b.** 3%
   - **c.** 5%
   - **d.** 6%
7. One cylinder of an automotive four-stroke cycle engine completes a cycle every ________________.
   - **a.** 90 degrees
   - **b.** 180 degrees
   - **c.** 360 degrees
   - **d.** 720 degrees
8. How many rotations of the crankshaft are required to complete each stroke of a four-stroke cycle engine?
   - **a.** One-fourth
   - **b.** One-half
   - **c.** One
   - **d.** Two
9. A rotating force is called ________________.
   - **a.** horsepower
   - **b.** torque
   - **c.** combustion pressure
   - **d.** eccentric movement
10. Technician A says that a crankshaft determines the stroke of an engine. Technician B says that the length of the connecting rod determines the stroke of an engine. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter

16

DIESEL ENGINE PARTS, OPERATION, AND AFTERTREATMENT

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- State the characteristics of diesel engines.
- Describe the fuel tank and lift pump.
- Describe the injection pump.
- Describe the engine-driven vacuum pump.
- Explain the HEUI system.
- Discuss the purpose of diesel injector nozzles.
- Discuss the purpose of glow plugs.
- Discuss the purpose of diesel fuel heaters.
- Explain the purpose of diesel engine turbochargers.
- Discuss the purpose of the exhaust gas recirculation system.
- Explain diesel particulate matter.
- Discuss the function of diesel oxidation catalysts.
- Discuss the function of diesel exhaust particulate filters.
- Discuss selective catalytic reduction.

KEY TERMS:

Diesel exhaust fluid (DEF) 165 • Diesel exhaust particulate filter (DPF) 163 • Diesel oxidation catalyst (DOCs) 163 • Differential pressure sensor (DPS) 164 • Direct injection (DI) 155 • Glow plug 159 • Heat of compression 153 • High-pressure common rail (HPCR) 157 • Hydraulic electronic unit injection (HEUI) 158 • Indirect injection (IDI) 154 • Injection pump 156 • Lift pump 156 • Particulate matter (PM) 162 • Regeneration 163 • Selective catalytic reduction (SCR) 165 • Soot 162 • Urea 165 • Water–fuel separator 156

DIESEL ENGINES

FUNDAMENTALS In 1892, a German engineer named Rudolf Diesel perfected the compression ignition engine that bears his name. The diesel engine uses heat created by compression to ignite the fuel, so it requires no spark ignition system.

The diesel engine requires compression ratios of 16:1 and higher. Incoming air is compressed until its temperature reaches about 1,000°F (540°C). This is called **heat of compression**. As the piston reaches the top of its compression stroke, fuel is injected into the cylinder, where it is ignited by the hot air. ● **SEE FIGURE 16–1**.

As the fuel burns, it expands and produces power. Because of the very high compression and torque output of a diesel engine, it is made heavier and stronger than the same size gasoline-powered engine.

Older diesel engines use a fuel system with a mechanical injection pump and individual fuel injectors. The pump delivers fuel to the injectors at a high pressure and at timed intervals.

Current models use a high-pressure common rail system and electrically actuated injectors. The injectors spray fuel into the combustion chamber at the precise moment required for efficient combustion. ● **SEE FIGURE 16–2**.

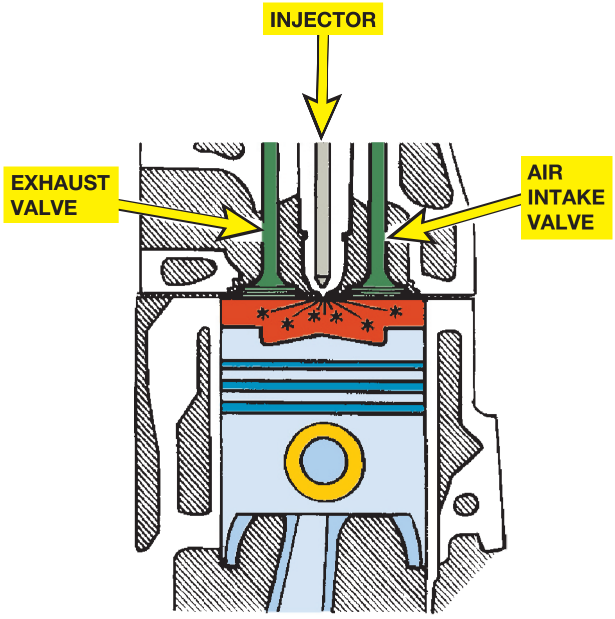


FIGURE 16–1 Diesel combustion occurs when fuel is injected into the hot, highly compressed air in the cylinder.

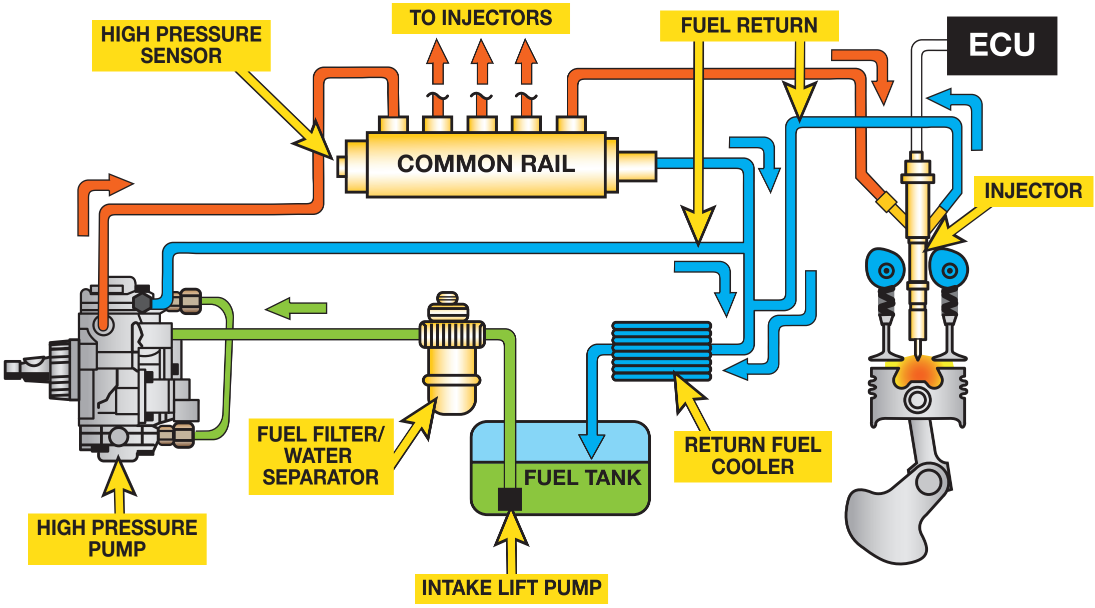


FIGURE 16–2 A typical high-pressure common rail (HPCR)-type diesel fuel system.

ADVANTAGES AND DISADVANTAGES

A diesel engine has several advantages compared to a similar size gasoline-powered engine, including:

1. More torque output
2. Greater fuel economy
3. Long service life

A diesel engine has several disadvantages compared to a similar size gasoline-powered engine, including:

1. Engine noise, especially when cold and/or at idle speed
2. Exhaust smell
3. Cold weather startability
4. Vacuum pump that is needed to supply the vacuum needs of the heat, ventilation, and air-conditioning system
5. Heavier than a gasoline engine
6. Fuel availability
7. Extra cost compared to a gasoline engine

CONSTRUCTION

Diesel engines must be constructed heavier than gasoline engines because of the tremendous pressures that are created in the cylinders during operation. ● **SEE CHART 16–1.** The torque output of a diesel engine is often double or more than the same size gasoline-powered engines.

AIR–FUEL RATIOS

In a diesel engine, air is not controlled by a throttle, as in a gasoline engine. Instead, the amount of fuel injected is varied to control power and speed. The air–fuel mixture of a diesel engine can vary from as lean as 85:1 at idle to as rich as 20:1 at full load. This higher air–fuel ratio and the increased compression pressures make the diesel more fuel efficient than a gasoline engine, in part because diesel engines do not suffer from throttling losses. Throttling losses involve the power needed in a gasoline engine to draw air past a closed or partially closed throttle.

In a gasoline engine, the speed and power are controlled by the throttle valve, which controls the amount of air entering the engine. Adding more fuel to the cylinders of a gasoline engine without adding more air (oxygen) will not increase the speed or power of the engine. In a diesel engine, speed and power are not controlled by the amount of air entering the cylinders because the engine air intake is always wide open. Therefore, the engine always has enough oxygen to burn the fuel in the cylinder and will increase speed (and power) when additional fuel is supplied.

SYSTEM OR COMPONENT	DIESEL ENGINE	GASOLINE ENGINE
Block	Cast iron and heavy (● **SEE FIGURE 16–3.**)	Cast iron or aluminum and as light as possible
Cylinder head	Cast iron or aluminum	Cast iron or aluminum
Compression ratio	17:1–25:1	8:1–12:1
Peak engine speed	2000–2500 RPM	5000–8000 RPM
Pistons	Aluminum with combustion pockets and heavy-duty connecting rods (● **SEE FIGURE 16–4.**)	Aluminum, usually flat top or with valve relief, but no combustion pockets

CHART 16–1

Comparison between a typical gasoline and a diesel engine.

NOTE: Many newer diesel engines are equipped with a throttle valve. This valve is used by the emission control system and is not designed to control the speed of the engine.

INDIRECT AND DIRECT INJECTION

In an **indirect injection** (abbreviated **IDI**) diesel engine, fuel is injected into a small prechamber, which is connected to the cylinder by a narrow opening. The initial combustion takes place in this prechamber. This has the effect of slowing the rate of combustion, which tends to reduce noise. ● **SEE FIGURE 16–5.**

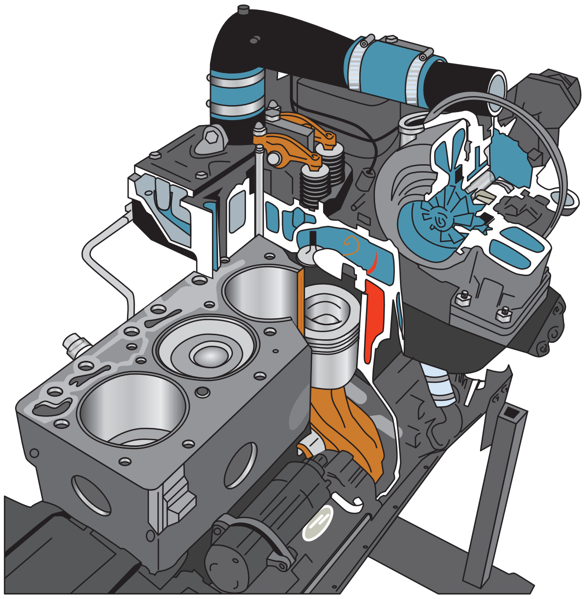


FIGURE 16–3 A Cummins diesel engine as found in a Dodge (Ram) pickup truck. A high-pressure pump (up to 30,000 PSI) is used to supply diesel fuel to the common rail, which has tubes running to each injector. Note the thick cylinder walls and heavy-duty construction.

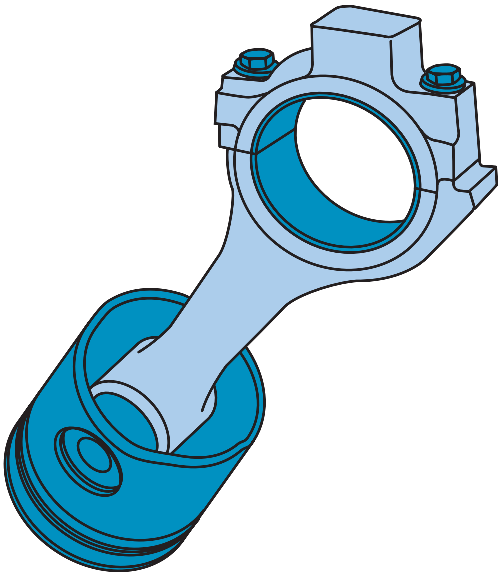


FIGURE 16–4 A rod/piston assembly from a 5.9 liter Cummins diesel engine used in a Ram pickup truck.

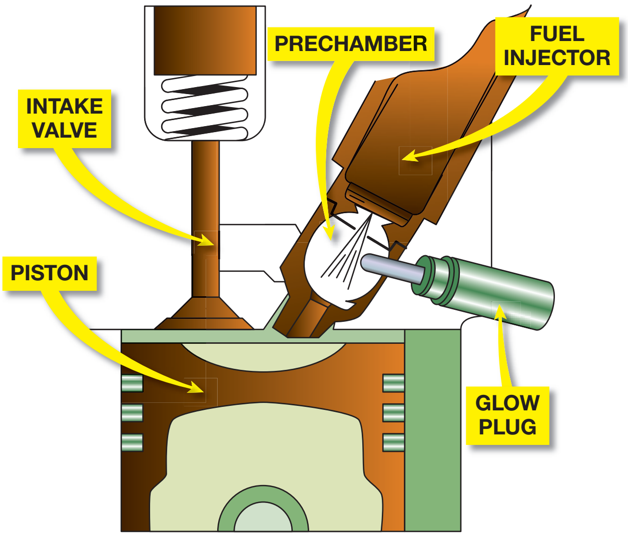


FIGURE 16–5 An indirect injection diesel engine uses a prechamber and a glow plug.

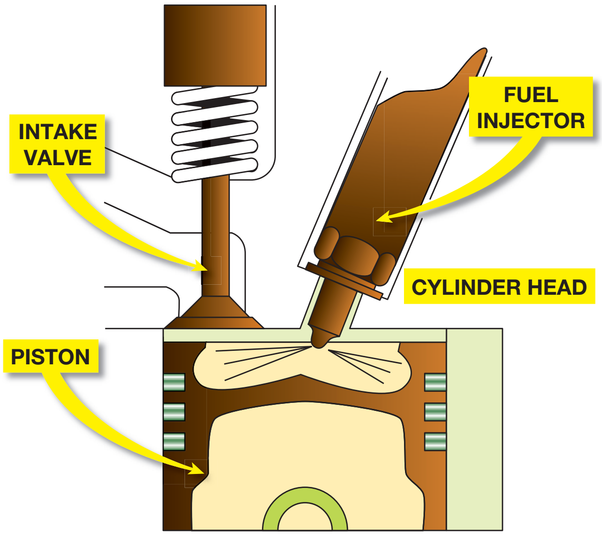


FIGURE 16–6 A direct injection diesel engine injects the fuel directly into the combustion chamber. Many designs do not use a glow plug.

All indirect injection diesel engines require the use of a glow plug, which is an electrical heater that helps start the combustion process.

In a **direct injection** (abbreviated **DI**) diesel engine, fuel is injected directly into the cylinder. The piston incorporates a depression where initial combustion takes place. Direct injection diesel engines are generally more efficient than indirect injection engines but have a tendency to produce greater amounts of noise. ● **SEE FIGURE 16–6**.

While some direct injection diesel engines use glow plugs to help cold starting and to reduce emissions, many direct injection diesel engines do not use glow plugs.

DIESEL FUEL IGNITION

Ignition occurs in a diesel engine by injecting fuel into the air charge, which has been heated by compression to a temperature greater than the ignition point of the fuel or about 1,000°F (538°C). The chemical reaction of burning the fuel creates heat, which causes the gases to expand, forcing the piston to rotate the crankshaft. A four-stroke diesel engine requires two rotations of the crankshaft to complete one cycle.

- On the intake stroke, the piston passes top dead center (TDC), the intake valve(s) opens, and filtered air enters the cylinder, while the exhaust valve(s) remains open for a few degrees to allow all of the exhaust gases to escape from the previous combustion event.
- On the compression stroke, after the piston passes BDC, the intake valve(s) closes and the piston travels up to TDC (completion of the first crankshaft rotation).
- On the power stroke, the piston nears TDC on the compression stroke and diesel fuel is injected into the cylinder by the injectors. The ignition of the fuel does not start immediately, but the heat of compression starts the combustion phases in the cylinder. During this power

stroke, the piston passes TDC and the expanding gases force the piston down, rotating the crankshaft.

- On the exhaust stroke, as the piston passes BDC, the exhaust valve(s) opens and the exhaust gases start to flow out of the cylinder. This continues as the piston travels up to TDC, pumping the spent gases out of the cylinder. At TDC, the second crankshaft rotation is complete.

FUEL TANK AND LIFT PUMP

PARTS INVOLVED

A fuel tank used on a vehicle equipped with a diesel engine differs from the one used with a gasoline engine in the following ways:

- The filler neck is larger for diesel fuel. The nozzle size is 15/16 inch (24 mm) instead of 13/16 inch (21 mm) for gasoline filler necks. Truckstop diesel nozzles for large over-the-road trucks are usually larger, 1.25 inch or 1.5 inch (32 mm or 38 mm) to allow for faster fueling of large-capacity fuel tanks.
- There are no evaporative emission control devices or a charcoal (carbon) canister. Diesel fuel is not as volatile as gasoline and, therefore, diesel vehicles do not have evaporative emission control devices.

The diesel fuel is usually drawn from the fuel tank by a separate pump, called a **lift pump**, and delivers the fuel to the injection pump. Between the fuel tank and the lift pump is a **water–fuel separator**. Water is heavier than diesel fuel and sinks to the bottom of the separator. Part of normal routine maintenance on a vehicle equipped with a diesel engine is to drain the water from the water-fuel separator. A float is often used inside the separator, which is connected to a warning light on the dash that lights if the water reaches a level where it needs to be drained. The water separator is often part of the fuel filter assembly. Both the fuel filter and the water separator are common maintenance items.

NOTE: Water can cause corrosive damage and wear to diesel engine parts because it is not a good lubricant. Water cannot be atomized by a diesel fuel injector nozzle and will often "blow out" the nozzle tip.

Many diesel engines also use a *fuel temperature sensor.* The computer uses this information to adjust fuel delivery based on the density of the fuel. ● **SEE FIGURE 16–7**.

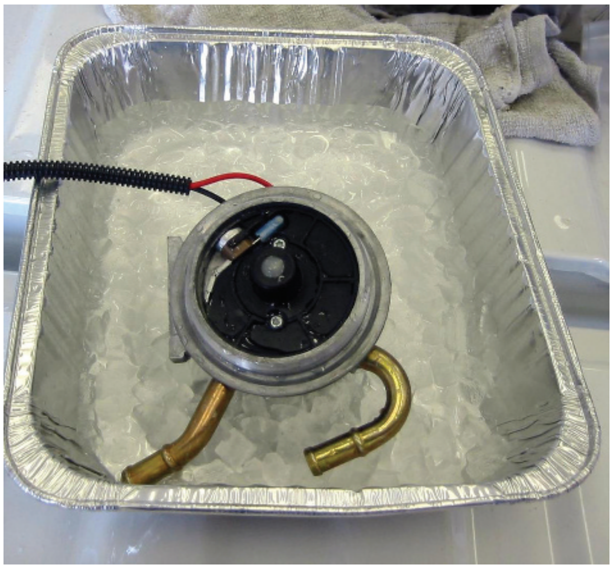


FIGURE 16–7 A fuel temperature sensor is being tested using an ice bath.

INJECTION PUMP

MECHANICAL INJECTION PUMP

A diesel engine **injection pump** is used to increase the pressure of the diesel fuel from very low values from the lift pump to the extremely high pressures needed for injection.

- The lift pump is a *low-pressure, high-volume pump.*
- The high-pressure injection pump is a *high-pressure, low-volume pump.*

Mechanical injection pumps are usually driven by a gear off the camshaft at the front of the engine. As the injection pump shaft rotates, the diesel fuel is fed from a fill port to a high-pressure chamber. If a distributor-type injection pump is used, the fuel is forced out of the injection port to the correct injector nozzle through the high-pressure line. ● **SEE FIGURE 16–8**.

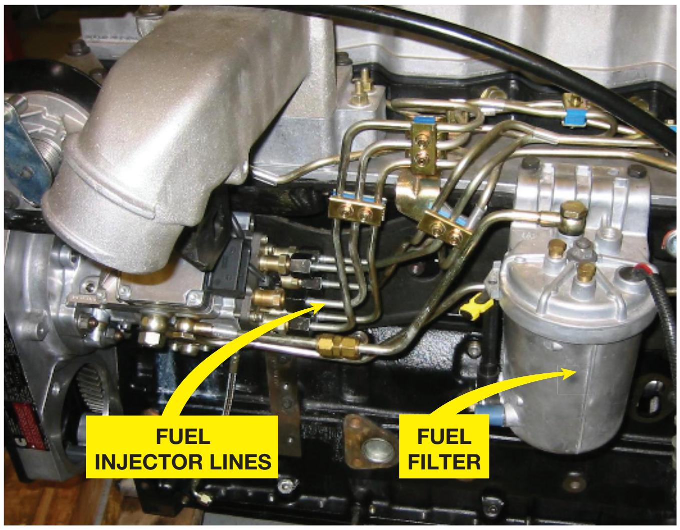


FIGURE 16–8 A typical distributor-type diesel injection pump showing the pump, lines, and fuel filter.

NOTE: Because of the very tight tolerances in a diesel engine, the smallest amount of dirt can cause excessive damage to the engine and to the fuel-injection system.

DISTRIBUTOR INJECTION PUMP

A distributor diesel injection pump is a high-pressure pump assembly with lines leading to each individual injector. The high-pressure lines between the distributor and the injectors must be the exact same length to ensure proper injection timing. The high-pressure fuel causes the injectors to open. Due to the internal friction of the lines, there is a slight delay before fuel pressure opens the injector nozzle. The injection pump itself creates the injection advance needed for engine speeds above idle, often by using a stepper motor attached to the advance piston, and the fuel is then discharged into the lines. ● **SEE FIGURE 16–9**.

NOTE: The lines expand during an injection event. This is how timing checks are performed. The pulsing of the injector line is picked up by a probe used to detect the injection event similar to a timing light used to detect a spark on a gasoline engine.

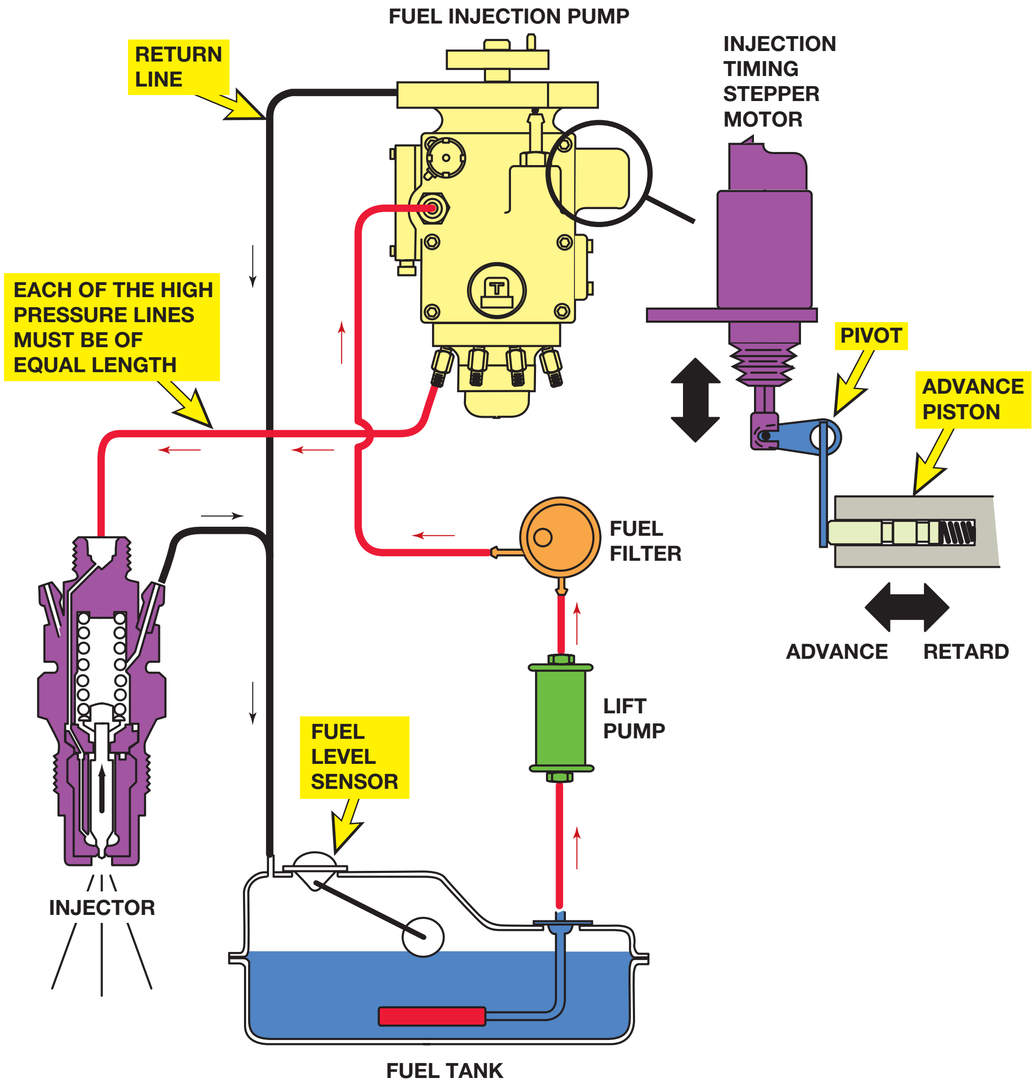


FIGURE 16–9 A schematic of a Stanadyne distributor diesel injection pump assembly showing all of the related components.

HIGH-PRESSURE COMMON RAIL Newer diesel engines use a fuel delivery system referred to as a **high-pressure common rail (HPCR)** design. Diesel fuel under high pressure, over 20,000 PSI (138,000 kPa), is applied to the injectors, which are opened by a solenoid controlled by the computer. Because the injectors are computer controlled, the combustion process can be precisely controlled to provide maximum engine efficiency with the lowest possible noise and exhaust emissions. ● **SEE FIGURE 16–10**.

ENGINE-DRIVEN VACUUM PUMP

Because a diesel engine is unthrottled, it creates very little vacuum in the intake manifold. Several engine and vehicle components operate using vacuum, such as the exhaust gas recirculation (EGR) valve, and the heating and ventilation blend and air doors. Most diesels used in cars and light trucks are equipped with an engine-driven vacuum pump to supply the vacuum for these components.

FREQUENTLY ASKED QUESTION

How Can You Tell If Gasoline Has Been Added to the Diesel Fuel by Mistake?

If gasoline has been accidentally added to diesel fuel and is burned in a diesel engine, the result can be very damaging to the engine. The gasoline can ignite faster than diesel fuel, which would tend to increase the temperature of combustion. This high temperature can harm injectors and glow plugs, as well as pistons, head gaskets, and other major diesel engine components. If contaminated fuel is suspected, first smell the fuel at the filler neck. If the fuel smells like gasoline, the tank should be drained and refilled with diesel fuel. If the smell test does not indicate a gasoline or any rancid smell, test a sample for proper specific gravity.

NOTE: Diesel fuel designed for on-road use should be green and the price includes a road use tax. Red diesel fuel should only be found in off-road or farm equipment and is not taxed.

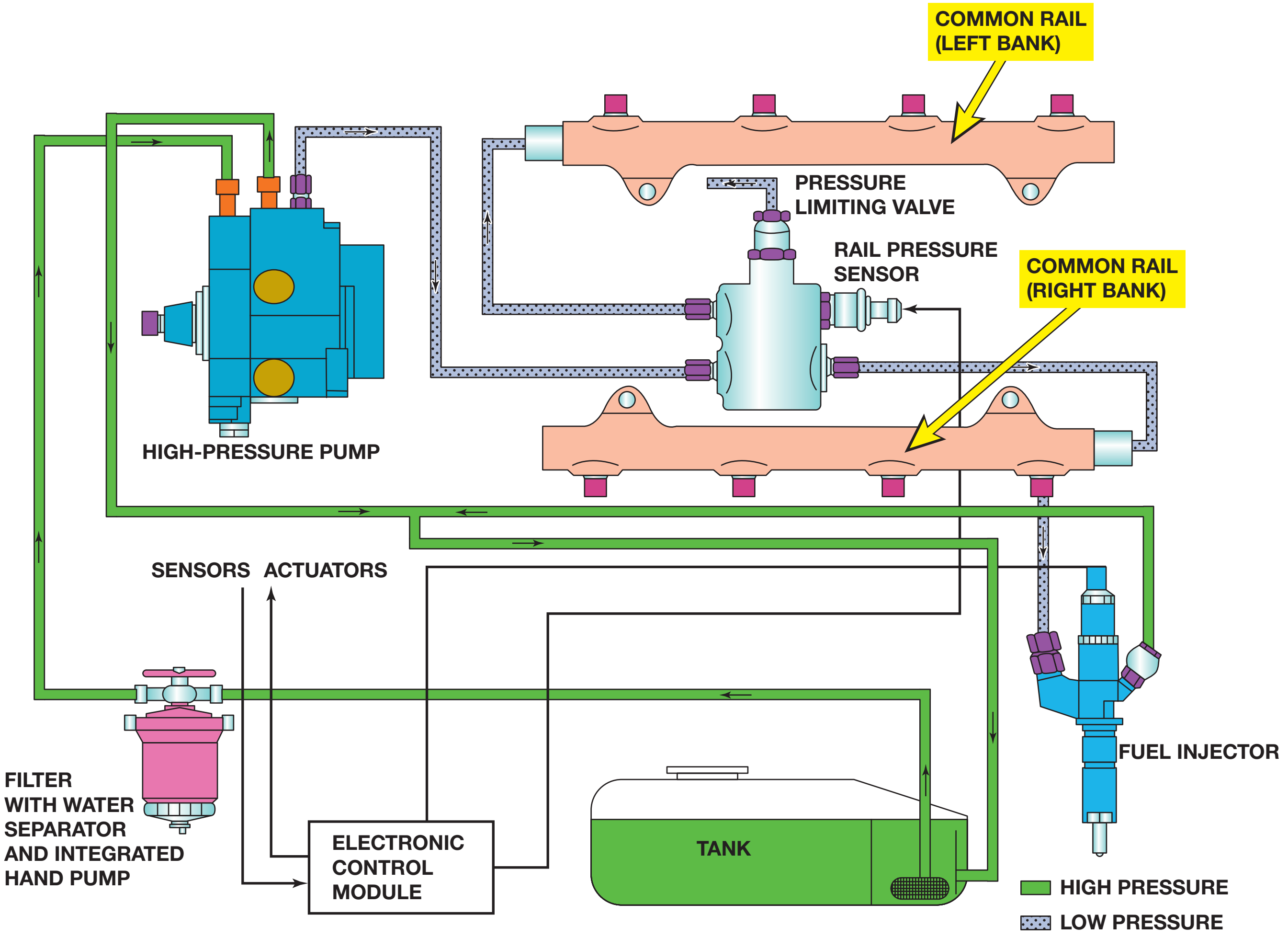

COMMON RAIL (LEFT BANK)
PRESSURE LIMITING VALVE
RAIL PRESSURE SENSOR
COMMON RAIL (RIGHT BANK)
HIGH-PRESSURE PUMP
SENSORS
ACTUATORS
FUEL INJECTOR
FILTER WITH WATER SEPARATOR AND INTEGRATED HAND PUMP
ELECTRONIC CONTROL MODULE
TANK
HIGH PRESSURE
LOW PRESSURE

FIGURE 16–10 Overview of a computer-controlled high-pressure common rail V-8 diesel fuel system.

HEUI SYSTEM

PRINCIPLES OF OPERATION Ford 7.3, 6.0, and 6.4 liter (and Navistar) diesels use a system called a **hydraulic electronic unit injection** system, or **HEUI** system. The components used include:

- High-pressure engine oil pump and reservoir
- Pressure regulator for the engine oil
- Passages in the cylinder head for flow of fuel to the injectors

OPERATION The engine oil is pressurized to provide an opening pressure strong enough to overcome the fuel pressure when the solenoid is commanded to open by the PCM. The system functions as follows:

- Fuel is drawn from the tank by the tandem fuel pump, which circulates fuel at low pressure through the fuel filter/water separator/fuel heater bowl. Fuel is then directed back to the fuel pump where fuel is pumped at high pressure into the cylinder head fuel galleries.
- The injectors, which are hydraulically actuated by engine oil pressure from the high-pressure oil pump, are then fired by the powertrain control module (PCM). The control system for the fuel injectors is the PCM, and the injectors are fired based on sensor inputs received by the PCM. ● **SEE FIGURE 16–11**.

HEUI injectors rely on O-rings to keep fuel and oil from mixing or escaping, causing performance problems or engine damage.

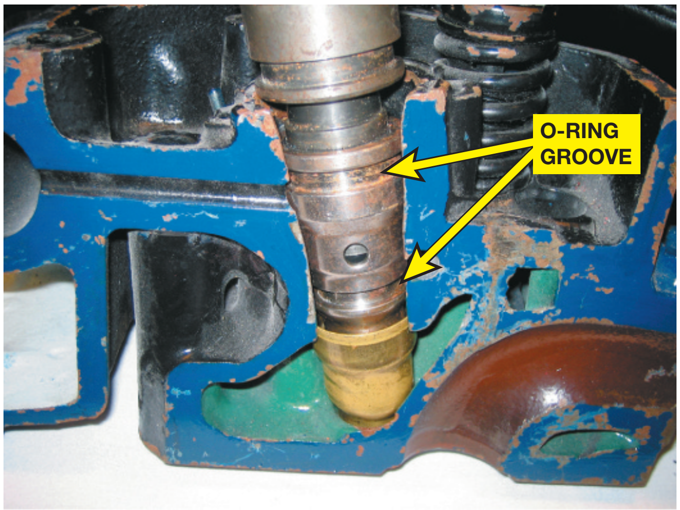

O-RING GROOVE

FIGURE 16–11 A HEUI injector from a Ford Power Stroke diesel engine. The O-ring grooves indicate the location of the O-rings that seal the fuel section of the injector from coolant and from the engine oil.

HEUI injectors use five O-rings. The three external O-rings should be replaced with updated O-rings, if they fail. The two internal O-rings are not replaceable and, if these fail, the injector(s) must be replaced. The most common symptoms of injector O-ring trouble include:

- Oil getting in the fuel
- The fuel filter element turning black

- Long cranking times before starting
- Sluggish performance
- Reduction in power
- Increased oil consumption (This often accompanies O-ring problems or any fault that lets fuel in the oil.)

DIESEL INJECTOR NOZZLES

PARTS INVOLVED Diesel injector nozzles are spring-loaded closed valves that spray fuel directly into the combustion chamber or precombustion chamber when the injector is opened. Injector nozzles are threaded or clamped into the cylinder head, one for each cylinder, and are replaceable as an assembly.

The tip of the injector nozzle has many holes to deliver an atomized spray of diesel fuel into the cylinder. Parts of a diesel injector nozzle include:

- **Heat shield.** This is the outer shell of the injector nozzle and may have external threads where it seals in the cylinder head.
- **Injector body.** This is the inner part of the nozzle and contains the injector needle valve and spring, and threads into the outer heat shield.
- **Diesel injector needle valve.** This precision machined valve and the tip of the needle seal against the injector body when it is closed. When the valve is open, diesel fuel is sprayed into the combustion chamber. This passage is controlled by a computer-controlled solenoid on diesel engines equipped with computer-controlled injection.
- **Injector pressure chamber.** The pressure chamber is a machined cavity in the injector body around the tip of the injector needle. Injection pump pressure forces fuel into this chamber, forcing the needle valve open.

DIESEL INJECTOR NOZZLE OPERATION The electric solenoid attached to the injector nozzle is computer controlled and opens to allow fuel to flow into the injector pressure chamber. ● **SEE FIGURE 16–12**.

The fuel flows down through a fuel passage in the injector body and into the pressure chamber. The high fuel pressure in the pressure chamber forces the needle valve upward, compressing the needle valve return spring and forcing the needle valve open. When the needle valve opens, diesel fuel is discharged into the combustion chamber in a hollow cone spray pattern.

Any fuel that leaks past the needle valve returns to the fuel tank through a return passage and line. ● **SEE FIGURE 16–13**.

TECH TIP

Change Oil Regularly in a Ford Diesel Engine

Ford 7.3, 6.0, and 6.4 liter diesel engines pump unfiltered oil from the sump to the high-pressure oil pump and then to the injectors. This means not changing oil regularly can contribute to accumulation of dirt in the engine and will subject the fuel injectors to wear, and potential damage, as particles suspended in the oil get forced into the injectors.

FIGURE 16–12 Typical computer-controlled diesel engine fuel injectors.

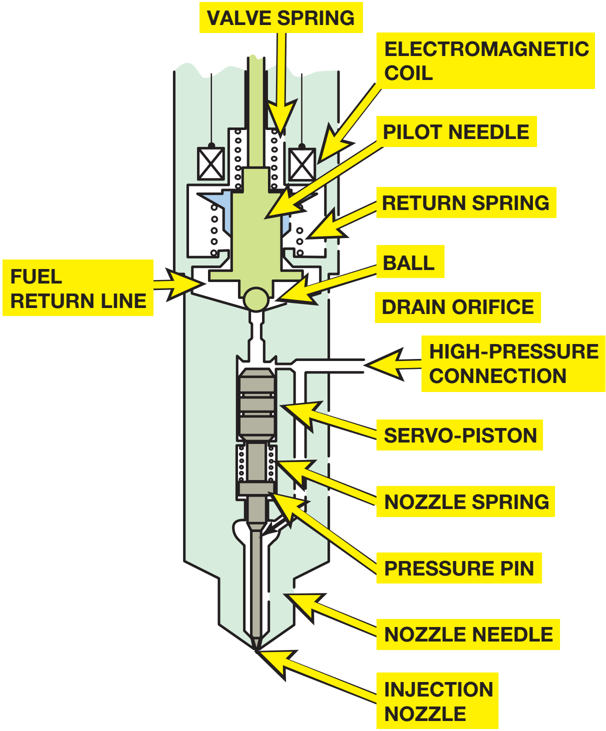


FIGURE 16–13 A Duramax injector showing all the internal parts.

GLOW PLUGS

PURPOSE AND FUNCTION Glow plugs are always used in diesel engines equipped with a precombustion chamber and may be used in direct injection diesel engines to aid starting. A **glow plug** is a heating element that uses 12 volts from the battery and aids in the starting of a cold engine by providing heat to help the fuel to ignite. ● **SEE FIGURE 16–14**.

As the temperature of the glow plug increases, the resistance of the heating element inside increases, thereby reducing the current in amperes needed by the glow plugs.

OPERATION Most glow plugs used in newer vehicles are controlled by the PCM, which monitors coolant temperature and intake air temperature. The glow plugs are turned

TECH TIP

Never Allow a Diesel Engine to Run Out of Fuel

If a gasoline-powered vehicle runs out of gasoline, it is an inconvenience and a possible additional expense to get some gasoline. However, if a vehicle equipped with a diesel engine runs out of fuel, it can be a major concern.

Besides adding diesel fuel to the tank, the other problem is getting all of the air out of the pump, lines, and injectors so the engine will operate correctly.

The procedure usually involves cranking the engine long enough to get liquid diesel fuel back into the system, but at the same time keeping cranking time short enough to avoid overheating the starter. Consult service information for the exact service procedure if the diesel engine runs out of fuel.

NOTE: Some diesel engines, such as the General Motors Duramax V-8, are equipped with a priming pump located under the hood on top of the fuel filter. Pushing down and releasing the priming pump with a vent valve open will purge any trapped air from the system. Always follow the vehicle manufacturer's instructions.

FIGURE 16–14 A glow plug assortment showing the various types and sizes of glow plugs used. Always use the specified glow plugs.

on or pulsed on or off, depending on the temperature of the engine. The PCM will also keep the glow plug turned on after the engine starts, to reduce white exhaust smoke (unburned fuel) and to improve idle quality after starting. ● **SEE FIGURE 16–15**.

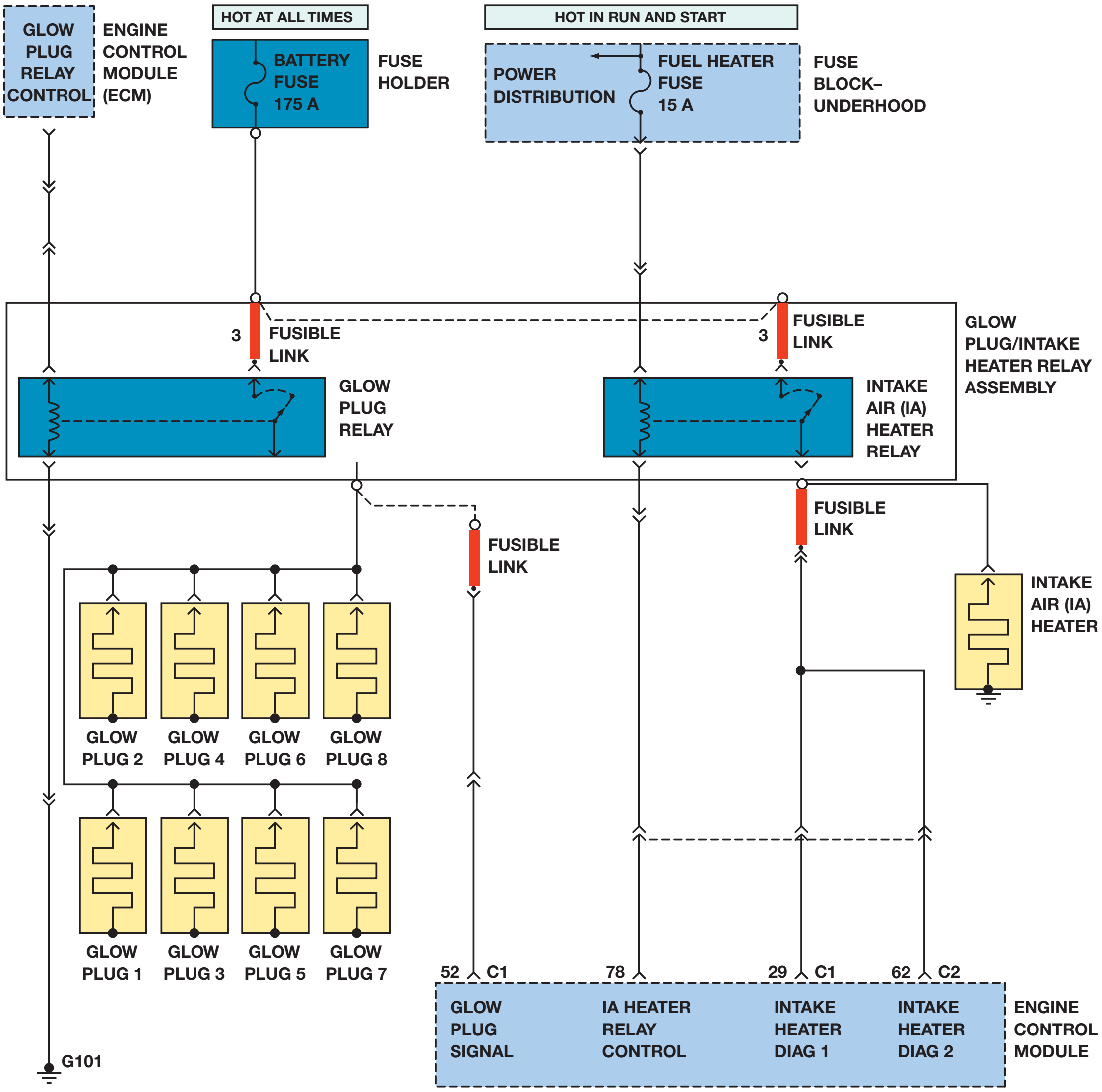

GLOW PLUG RELAY CONTROL
ENGINE CONTROL MODULE (ECM)
HOT AT ALL TIMES
BATTERY FUSE 175 A
FUSE HOLDER
HOT IN RUN AND START
POWER DISTRIBUTION
FUEL HEATER FUSE 15 A
FUSE BLOCK– UNDERHOOD
3
FUSIBLE LINK
3
FUSIBLE LINK
GLOW PLUG/INTAKE HEATER RELAY ASSEMBLY
GLOW PLUG RELAY
INTAKE AIR (IA) HEATER RELAY
FUSIBLE LINK
FUSIBLE LINK
INTAKE AIR (IA) HEATER
GLOW PLUG 2
GLOW PLUG 4
GLOW PLUG 6
GLOW PLUG 8
GLOW PLUG 1
GLOW PLUG 3
GLOW PLUG 5
GLOW PLUG 7
G101
52 C1
78
29 C1
62 C2
GLOW PLUG SIGNAL
IA HEATER RELAY CONTROL
INTAKE HEATER DIAG 1
INTAKE HEATER DIAG 2
ENGINE CONTROL MODULE

FIGURE 16–15 A schematic of a typical glow plug circuit. Notice that the glow plug relay and intake air heater relay are both computer controlled.

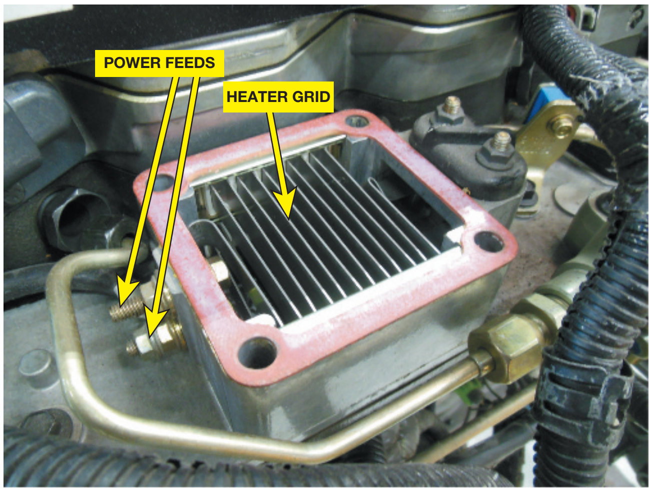


FIGURE 16–16 The intake heater grid is used to warm the intake air and increase pre-ignition temperatures. The heater may continue to be cycled to decrease the amount of time needed to warm the engine.

The "wait to start" lamp (if equipped) will light when the engine and the outside temperatures are low to allow time for the glow plugs to get hot.

HEATED INLET AIR Some diesel engines, such as the Ram Cummins, use an electrical heater wire to warm the intake air to help in cold weather starting and running. ● **SEE FIGURE 16–16**.

DIESEL FUEL HEATERS

Diesel fuel heaters help prevent power loss and stalling in cold weather. The heater is placed in the fuel line between the tank and the primary filter. Some fuel heaters are thermostatically controlled, which allows fuel to bypass the heater once it has reached operating temperature.

DIESEL ENGINE TURBOCHARGERS

TURBOCHARGED DIESELS A turbocharger greatly increases engine power by pumping additional compressed air into the combustion chambers. This allows a greater quantity of fuel to be burned in the cylinders, resulting in greater power output. In a turbocharger, the turbine wheel spins as exhaust gas flows out of the engine and drives the turbine blades. The turbine spins the compressor wheel at the opposite end of the turbine shaft, pumping air into the intake system. ● **SEE FIGURE 16–17**.

AIR CHARGE COOLER The air charge cooler is installed in the air flow between the turbocharger discharge and the inlet air of the engine, and is also called an *intercooler*. It is needed because the air is heated when compressed by the turbocharger. Cooler air entering the engine means more power can be produced by the engine. ● **SEE FIGURE 16–18**.

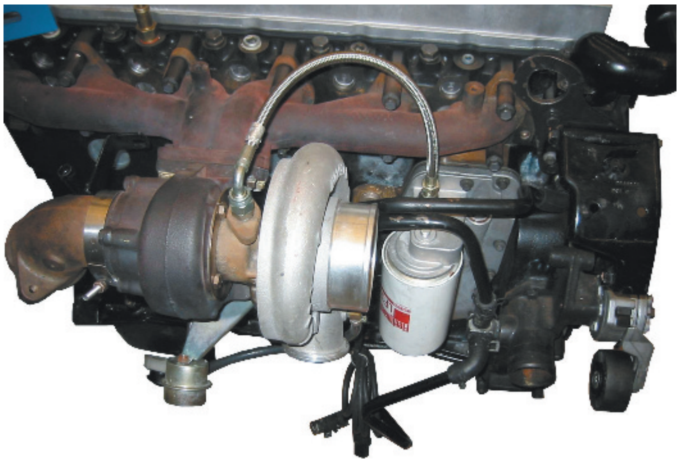


FIGURE 16–17 A Cummins diesel turbocharger is used to increase the power and torque of the engine.

VARIABLE TURBOCHARGER A variable turbocharger is used on many diesel engines for boost control. Boost pressure is controlled independent of engine speed and a wastegate is not needed. The adjustable vanes mount to a unison ring that allows the vanes to move. As the position of the unison ring rotates, the vanes change angle. The vanes are opened to minimize flow at the turbine and exhaust back pressure at low engine speeds. To increase turbine speed, the vanes are closed. The velocity of the exhaust gases increases, as does the speed of the turbine. The unison ring is connected to a cam that is positioned by a rack-and-pinion gear. The turbocharger's vane position actuator solenoid connects to a hydraulic piston, which moves the rack to rotate the pinion gear and cam. ● **SEE FIGURE 16–19**.

The turbocharger vane position control solenoid valve is used to advance the unison ring's relationship to the turbine and thereby articulate the vanes. This solenoid actuates a spool valve that applies oil pressure to either side of a piston. Oil flow has three modes: apply, hold, and release.

- *Apply* moves the vanes toward a closed position.
- *Hold* maintains the vanes in a fixed position.
- *Release* moves the vanes toward the open position.

The turbocharger vane position actuation is controlled by the ECM, which can change turbine boost efficiency independent of engine speed. The ECM provides a control signal to the valve solenoid along with a low-side reference. A pulse-width-modulated signal from the ECM moves the valve to the desired position.

EXHAUST GAS RECIRCULATION

The EGR system recycles some exhaust gas back into the intake stream to cool combustion, which reduces oxides of nitrogen (NO_x) emissions. The EGR system includes:

- Plumbing that carries some exhaust gas from the turbocharger exhaust inlet to the intake ports
- EGR control valve
- Stainless steel cooling element used to cool the exhaust gases (● **SEE FIGURE 16–20**.)

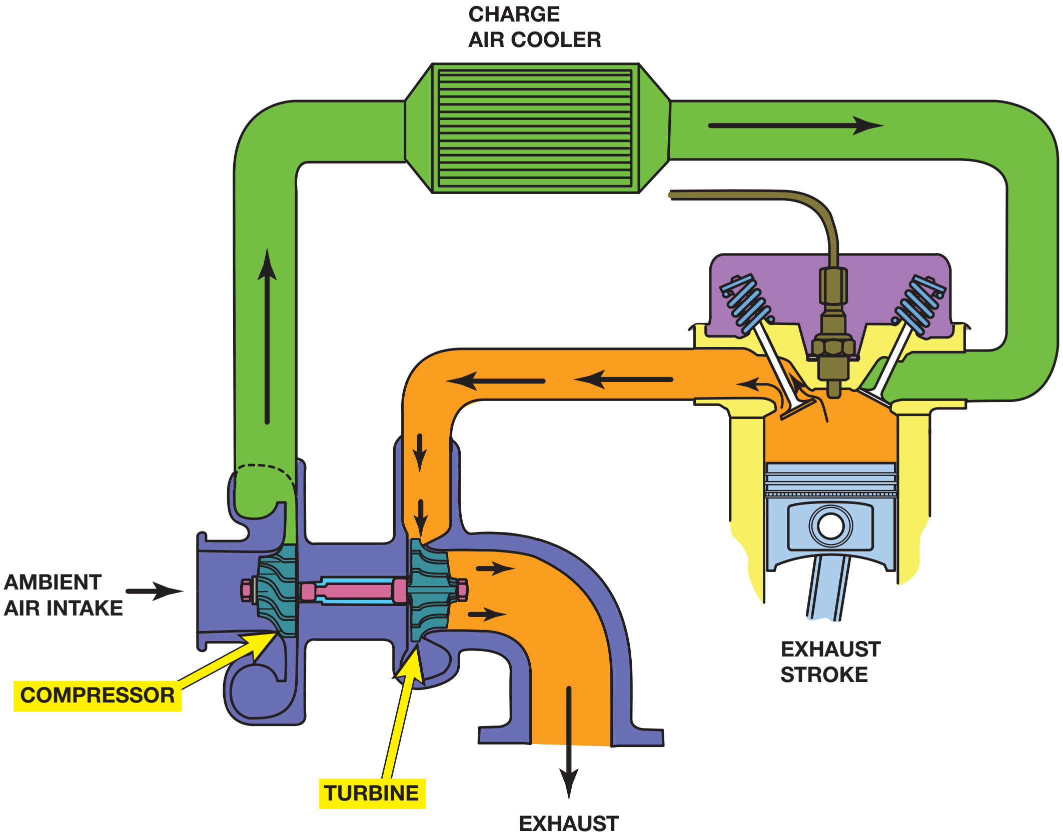


FIGURE 16–18 An air charge cooler is used to cool the compressed air.

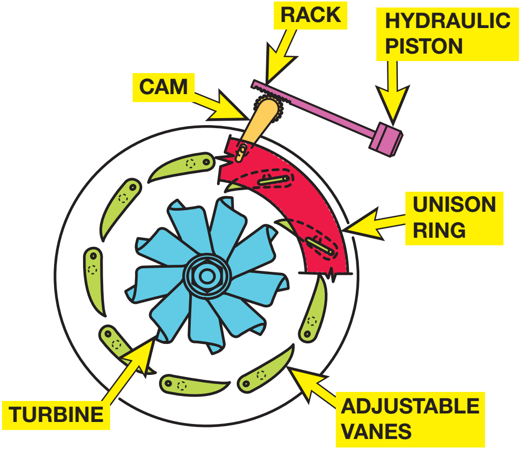


FIGURE 16–19 A variable vane turbocharger allows the boost to be controlled without the need of a wastegate.

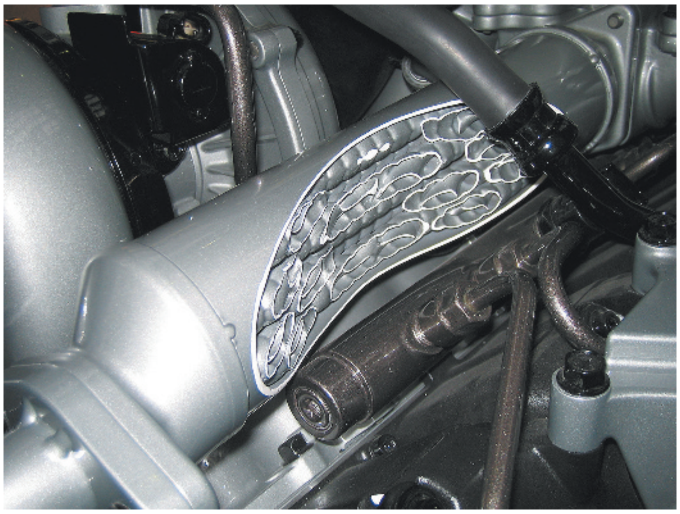


FIGURE 16–20 A cutaway showing the exhaust cooler. The cooler the exhaust is, the more effective it is in controlling NO_x emissions.

The EGR valve is PCM controlled and often uses a DC stepper motor and worm gear to move the valve stem open. The gear is not attached to the valve and can only force it open. Return spring force closes the valve. The EGR valve and sensor assembly is a five-wire design. The PCM uses the position sensor to verify that valve action is as commanded.

DIESEL PARTICULATE MATTER

PARTICULATE MATTER STANDARDS **Particulate matter (PM)**, also called **soot**, refers to tiny particles of solid or semisolid material suspended in the atmosphere. This includes particles between 0.1 and 50 microns in diameter. The heavier particles, larger than 50 microns, typically tend to settle out quickly due to gravity. Particulates are generally categorized as follows:

- **Total suspended particulate (TSP).** Refers to all particles between 0.1 and 50 microns. Up until 1987, the Environmental Protection Agency (EPA) standard for particulates was based on levels of TSP.
- **PM10.** Refers to particulate matter of 10 microns or less (approximately 1/6 the diameter of a human hair). EPA has a standard for particles based on levels of PM10.
- **PM2.5.** Refers to particulate matter of 2.5 microns or less (approximately 1/20 the diameter of a human hair), also called "fine" particles. In July 1997, the EPA approved a standard for PM2.5. ● **SEE FIGURE 16–21**.

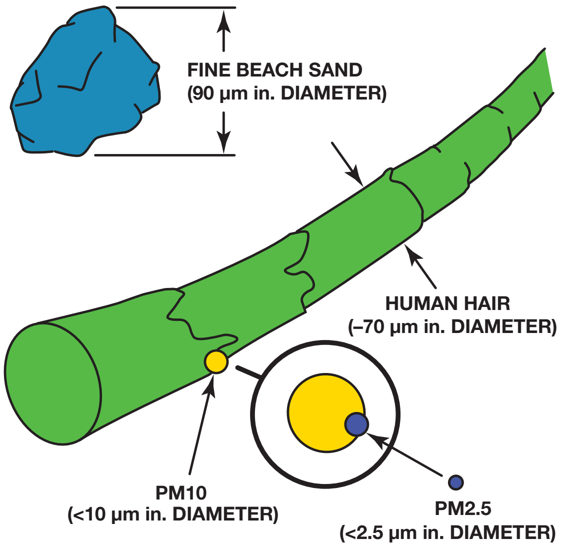


FIGURE 16–21 Relative size of particulate matter to a human hair.

FREQUENTLY ASKED QUESTION

What Is the Big Deal for the Need to Control Very Small Soot Particles?

For many years, soot or particulate matter (PM) was thought to be less of a health concern than exhaust emissions from gasoline engines. It was felt that the soot could simply fall to the ground without causing any noticeable harm to people or the environment. However, it was discovered that the small soot particulates, when breathed in, are not expelled from the lungs like larger particles, but instead get trapped in the deep areas of the lungs, where they accumulate.

SOOT CATEGORIES In general, soot particles produced by diesel combustion fall into the following categories:

- **Fine.** Less than 2.5 microns
- **Ultrafine.** Less than 0.1 micron, and make up 80% to 95% of soot

DIESEL OXIDATION CATALYST

PURPOSE AND FUNCTION **Diesel oxidation catalysts (DOCs)** are used in all light-duty diesel engines, since 2007. They consist of a flow-through honeycomb-style substrate structure that is wash coated with a layer of catalyst materials, similar to those used in a gasoline engine catalytic converter. These materials include the precious metals platinum and palladium, as well as other base metal catalysts.

Catalysts chemically react with exhaust gas to convert harmful nitrogen oxide into nitrogen dioxide, and to oxidize absorbed hydrocarbons. The chemical reaction acts as a combustor for the unburned fuel that is characteristic of diesel compression ignition. The main function of the DOC is to start a regeneration event by converting the fuel-rich exhaust gases to heat.

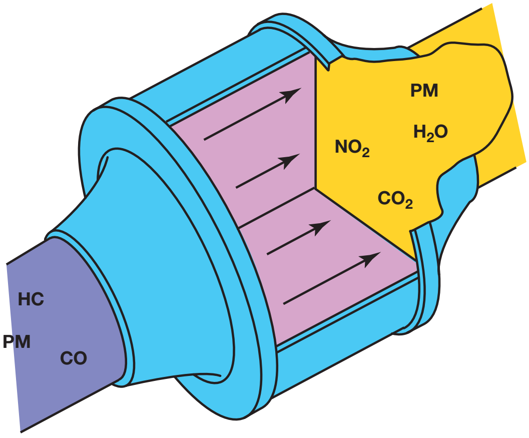


FIGURE 16–22 Chemical reaction within the DOC.

The DOC also reduces:

- Carbon monoxide (CO)
- Hydrocarbons (HC)
- Odor-causing compounds, such as aldehydes and sulfur

● **SEE FIGURE 16–22**.

DIESEL EXHAUST PARTICULATE FILTER

FUNCTION **Diesel exhaust particulate filters (DPFs)** are used in all light-duty diesel vehicles, since 2007, to meet the exhaust emissions standards. The heated exhaust gas from the DOC flows into the DPF, which captures diesel exhaust gas particulates (soot) to prevent them from being released into the atmosphere. ● **SEE FIGURE 16–23**. This is done by forcing the exhaust through a porous cell that has a silicon carbide substrate with honeycomb-cell-type channels that trap the soot. The main difference between the DPF and a typical catalyst filter is that the entrance to every other cell channel in the DPF substrate is blocked at one end. So instead of flowing directly through the channels, the exhaust gas is forced through the porous walls of the blocked channels and exits through the adjacent open-ended channels. This type of filter is also referred to as a "wall-flow" filter.

OPERATION Soot particulates in the gas remain trapped on the DPF channel walls where, over time, the trapped particulate matter will begin to clog the filter. The filter must therefore be purged periodically to remove accumulated soot particles. The process of purging soot from the DPF is described as **regeneration**. When the temperature of the exhaust gas is increased, the heat incinerates the soot particles trapped in the filter and is effectively renewed. ● **SEE FIGURE 16–24**.

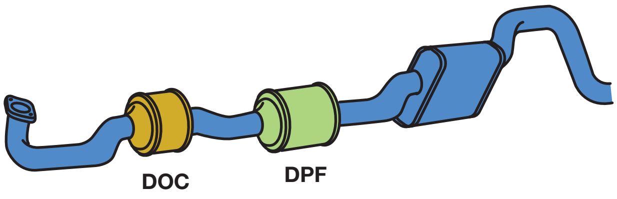


FIGURE 16–23 After-treatment of diesel exhaust is handled by the DOC and DPF.

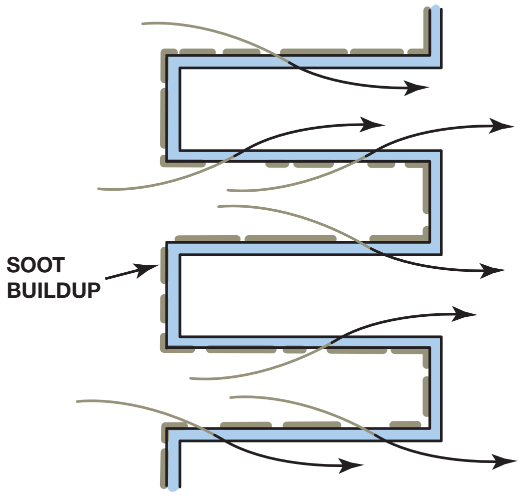


FIGURE 16–24 The soot is trapped in the passages of the DPF. The exhaust has to flow through the sides of the trap and exit.

EXHAUST GAS TEMPERATURE SENSORS

The following two exhaust gas temperature sensors are used to help the PCM control the DPF:

- EGT sensor 1 is positioned between the DOC and the DPF where it can measure the temperature of the exhaust gas entering the DPF.
- EGT sensor 2 measures the temperature of the exhaust gas stream immediately after it exits the DPF.

The PCM monitors the signals from the EGT sensors as part of its calibrations to control DPF regeneration. Proper exhaust gas temperatures at the inlet of the DPF are crucial for proper operation and for starting the regeneration process. Too high a temperature at the DPF will cause the DPF substrate to melt or crack. Regeneration will be terminated at temperatures above 1,470°F (800°C). With too low a temperature, self-regeneration will not fully complete the soot-burning process. ● **SEE FIGURE 16–25**.

DPF DIFFERENTIAL PRESSURE SENSOR

The DPF **differential pressure sensor (DPS)** has two pressure sample lines.

- One line is attached before the DPF.
- The other is located after the DPF.

The exact location of the DPS varies by vehicle model type, such as medium duty, pickup, or van. By measuring the exhaust supply (upstream) pressure from the DOC, and the post DPF (downstream) pressure, the PCM can determine differential pressure, also called “delta” pressure, across the DPF. Data from the DPF differential pressure sensor is used by the PCM to calibrate the DPF exhaust system operation.

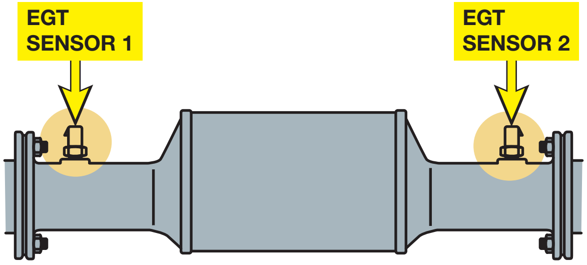


FIGURE 16–25 EGT 1 and EGT 2 are used by the PCM to help control after-treatment system operation.

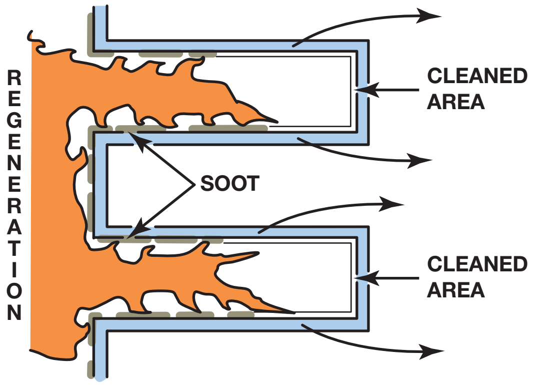


FIGURE 16–26 Regeneration burns the soot and renews the DPF.

DIESEL PARTICULATE FILTER REGENERATION

The primary reason for soot removal is to prevent the buildup of exhaust back pressure. Excessive back pressure increases fuel consumption, reduces power output, and can potentially cause engine damage. Several factors can trigger the diesel PCM to perform regeneration, including:

- Distance since last DPF regeneration
- Fuel used since last DPF regeneration
- Engine run time since last DPF regeneration
- Exhaust differential pressure across the DPF

DPF REGENERATION PROCESS

A number of engine components are required to function together for the regeneration process to be performed:

1. PCM controls that impact DPF regeneration include late post-injections, engine speed, and adjusting fuel pressure.
2. Adding late post-injection pulses provides the engine with additional fuel to be oxidized in the DOC, which increases exhaust temperatures entering the DPF to 900°F (500°C) or higher. ● **SEE FIGURE 16–26**.
3. The intake air valve acts as a restrictor that reduces air entry to the engine, which increases engine operating temperature.
4. The intake air heater may also be activated to warm intake air during regeneration.

TYPES OF DPF REGENERATION

DPF regeneration can be initiated in a number of ways, depending on the vehicle application and operating circumstances. The two main regeneration types are as follows:

- **Passive regeneration.** During normal vehicle operation when driving conditions produce sufficient load and exhaust temperatures, passive DPF regeneration may

FREQUENTLY ASKED QUESTION

Will the Post-Injection Pulses Reduce Fuel Economy?

Maybe. Due to the added fuel-injection pulses and late fuel-injection timing, an increase in fuel consumption may be noticed on the driver information center (DIC) during the regeneration time period. A drop in overall fuel economy should not be noticeable. ● **SEE FIGURE 16–27**.

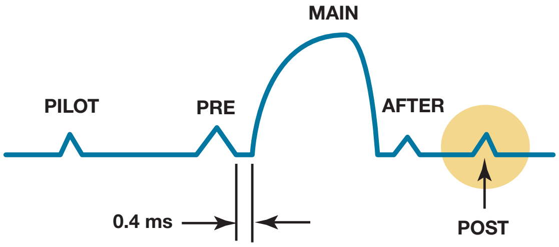


FIGURE 16–27 The post-injection pulse occurs to create the heat needed for regeneration.

occur. This passive regeneration occurs without input from the PCM or the driver. A passive regeneration may typically occur while the vehicle is being driven at highway speed or towing a trailer.

- **Active regeneration.** Active regeneration is commanded by the PCM when it determines that the DPF requires it to remove excess soot buildup and conditions for filter regeneration have been met. The vehicle needs to be driven at speeds above 30 mph for approximately 20 to 30 minutes to complete a full regeneration. During regeneration, the exhaust gases reach temperatures above 1,000°F (550°C).

FREQUENTLY ASKED QUESTION

What Is an Exhaust Air Cooler?

An exhaust air cooler is simply a section of tailpipe that has slits for air to enter. As hot exhaust rushes past the gap, outside air is drawn into the area which reduces the exhaust discharge temperature. The cooler significantly lowers exhaust temperature at the tailpipe from about 800°F (430°C) to approximately 500°F (270°C). ● **SEE FIGURE 16–28**.

WARNING

Tailpipe outlet exhaust temperature will be greater than 572°F (300°C) during service regeneration. To help prevent personal injury or property damage from fire or burns, keep vehicle exhaust away from any object and people.

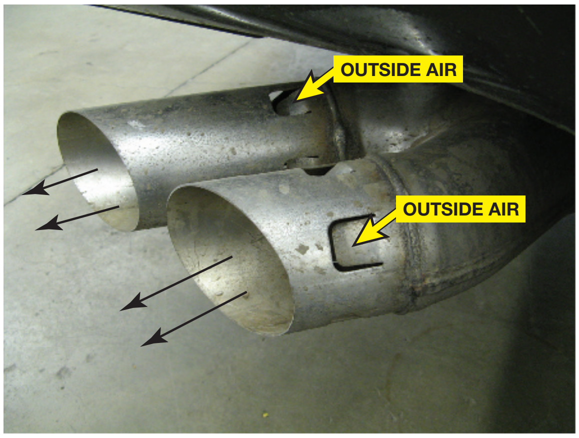


FIGURE 16–28 The exhaust is split into two outlets and has slits to help draw outside air in as the exhaust leaves the tailpipe. The end result is cooler exhaust gases exiting the tailpipe.

ASH LOADING Regeneration will not burn off ash. Only the particulate matter (PM) is burned off during regeneration. Ash is a noncombustible by-product from normal oil consumption. Ash accumulation in the DPF will eventually cause a restriction in the particulate filter. To service an ash-loaded DPF, the DPF will need to be removed from the vehicle and cleaned or replaced. Low ash content engine oil (API CJ-4) is required for vehicles with the DPF system. The CJ-4 rated oil is limited to 1% ash content.

SELECTIVE CATALYTIC REDUCTION

PURPOSE AND FUNCTION **Selective catalytic reduction (SCR)** is a method used to reduce NO_x emissions by injecting urea into the exhaust stream. Instead of using large amounts of exhaust gas recirculation (EGR), the SCR system uses a urea. **Urea** is used as a nitrogen fertilizer. It is colorless, odorless, and nontoxic. Urea is called **diesel exhaust fluid (DEF)** in North America and AdBlue in Europe: ● **SEE FIGURE 16–29**.

The urea is injected into the catalyst where it sets off a chemical reaction, which converts nitrogen oxides (NO_x) into nitrogen (N_2) and water (H_2O). Vehicle manufacturers size the onboard urea storage tank so that it needs to be refilled at about each scheduled oil change or every 7,500 miles (12,000 km). A warning light alerts the driver when the urea level needs to be refilled. If the warning light is ignored and the diesel exhaust fluid is not refilled, current EPA regulations require that the operation of the engine be restricted and may not start unless the fluid is refilled. This regulation is designed to prevent the engine from being operated without the fluid, which, if not, would greatly increase exhaust emissions. ● **SEE FIGURE 16–30**.

ADVANTAGES OF SCR Using urea injection instead of large amounts of EGR results in the following advantages:

- Potential higher engine power output for the same size engine
- Reduced NO_x emissions up to 90%
- Reduced HC and CO emissions up to 50%
- Reduced particulate matter (PM) by 50%

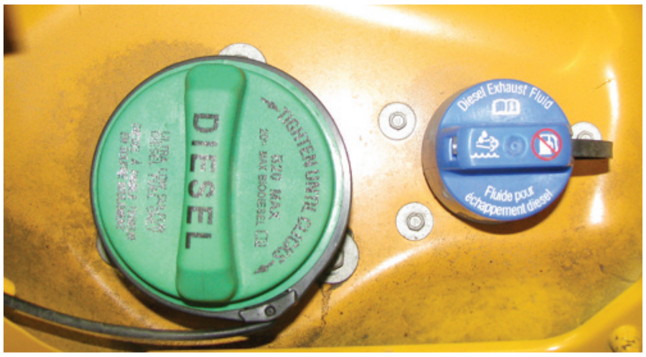


FIGURE 16–29 Diesel exhaust fluid is housed in a separate container that holds from 5 to 10 gallons, or enough to last until the next scheduled oil change, in most diesel vehicles that use SCR.

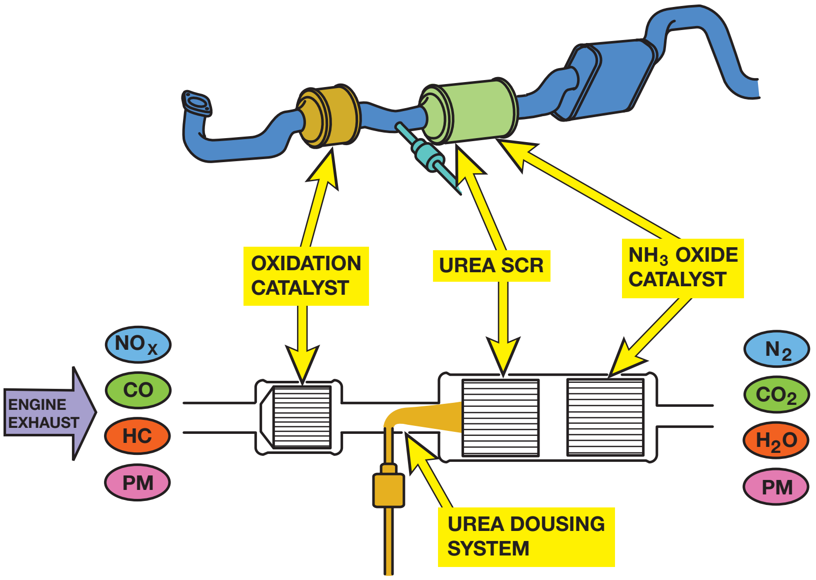


FIGURE 16–30 Urea (diesel exhaust fluid) injection is used to reduce NO_x exhaust emissions. It is injected after the diesel oxidation catalyst (DOC) and before the diesel particulate filter (DPF) on this 6.7 liter Ford diesel engine.

DISADVANTAGES OF SCR Using urea injection instead of large amounts of EGR results in the following disadvantages:

- Onboard storage tank required for the urea
- If the DEF level becomes low, engine power is reduced
- Increased costs to the vehicle owner due to refilling the urea storage tank

TECH TIP

Do Not Switch Injectors

In the past, it was common practice to switch diesel fuel injectors from one cylinder to another when diagnosing a dead cylinder problem. However, most high-pressure common rail systems used in new diesel engines utilize precisely calibrated injectors that should not be mixed up during service. Each injector has its own calibration number. ● **SEE FIGURE 16–31**.

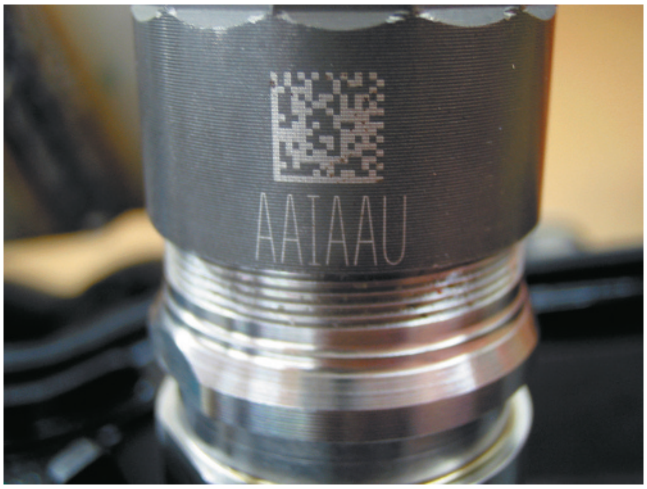


FIGURE 16–31 The letters on the side of this injector on a Cummins 6.7 liter diesel indicate the calibration number for the injector.

REVIEW QUESTIONS

1. What is the difference between direct injection and indirect injection?
2. What is the difference between distributor-type injection and common rail injection?
3. Why are glow plugs kept working after the engine starts?
4. What exhaust after-treatment is needed to achieve exhaust emission standards for vehicles 2007 and newer?
5. What are the advantages and disadvantages of SCR?

CHAPTER QUIZ

1. How is diesel fuel ignited in a warm diesel engine?
   - **a.** Glow plugs
   - **b.** Heat of compression
   - **c.** Spark plugs
   - **d.** Distributorless ignition system
2. Which diesel system supplies high-pressure diesel fuel to all of the injectors all of the time?
   - **a.** Distributor
   - **b.** Inline
   - **c.** High-pressure common rail
   - **d.** Rotary
3. What is different about a diesel fuel system compared to a gasoline engine fuel system?
   - **a.** Uses a larger fuel fill opening
   - **b.** Uses a water separator
   - **c.** May use a lift pump
   - **d.** All of the above
4. Which of the following may be a symptom of injector O-ring trouble in a HEUI system?
   - **a.** Water getting in the fuel
   - **b.** The fuel filter element turning black
   - **c.** Fuel pressure over 20,000 PSI
   - **d.** Tailpipe exhaust temperature over 572°F (300°C)
5. Technician A says that glow plugs are used to help start a diesel engine and are shut off as soon as the engine starts. Technician B says that the glow plugs are turned off as soon as a flame is detected in the combustion chamber. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. The use of a variable vane turbocharger allows the elimination of the ____________________.
   - **a.** turbocharger wastegate
   - **b.** diesel oxygen sensor
   - **c.** intake air cooler
   - **d.** exhaust cooler
7. Selective catalytic reduction (SCR) uses urea injection to reduce ____________________ emissions.
   - **a.** NO_x
   - **b.** CO_2
   - **c.** H_2O
   - **d.** CO
8. Which of these takes place during regeneration in a diesel particulate filter (DPF)?
   - **a.** The oxygen sensor is being cleaned
   - **b.** Soot is being burned
   - **c.** The EGR system is being actively tested
   - **d.** The catalytic converter is being purged
9. A diesel engine-powered vehicle usually uses all these exhaust emission control devices *except* ________________.
   - **a.** diesel oxidation catalysts
   - **b.** diesel exhaust particulate filter
   - **c.** evaporative emission control system (EVAP)
   - **d.** exhaust gas recirculation (EGR)
10. What component is used on some diesel engines that is seldom used on gasoline-powered engines?
    - **a.** Engine-driven vacuum pump
    - **b.** Diesel injector nozzles
    - **c.** Fuel heater
    - **d.** All of the above

Chapter 17

ANTIFREEZE AND COOLANT

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss coolant fundamentals.
- Compare the different types of coolant.
- Discuss water as coolant.
- Discuss coolant freezing/boiling temperatures.
- Discuss coolant testing.
- Discuss coolant replacement issues.

KEY TERMS:

DEX-COOL 169 • Electrolysis 173 • Embittered coolant 170 • Ethylene glycol–based coolant 169 • Galvanic activity 172 • Hybrid organic acid technology (HOAT) 169 • Inorganic additive technology (IAT) 169 • Organic acid technology (OAT) 169 • Passivation 173 • Phosphate hybrid organic acid technology (PHOAT) 170 • Refractometer 172

COOLANT FUNDAMENTALS

DEFINITION Antifreeze is a concentrated, glycol-based liquid that must be diluted with water before using. When mixed with water, it is referred to as coolant. Engine coolant is usually a mixture of 50% antifreeze and 50% water.

PURPOSE OF COOLANT Coolant is used in the cooling system because it:

1. Transfers heat from the engine to the radiator
2. Protects the engine and the cooling system from rust and corrosion
3. Prevents freezing in cold climates

Coolant is a mixture of antifreeze and water. Water is able to absorb more heat per gallon than any other liquid coolant. Under standard conditions, the following occurs.

- Water boils at 212°F (100°C) at sea level.
- Water freezes at 32°F (0°C).
- When water freezes, it increases in volume by about 9%. The expansion of the freezing water can easily crack engine blocks, cylinder heads, and radiators.

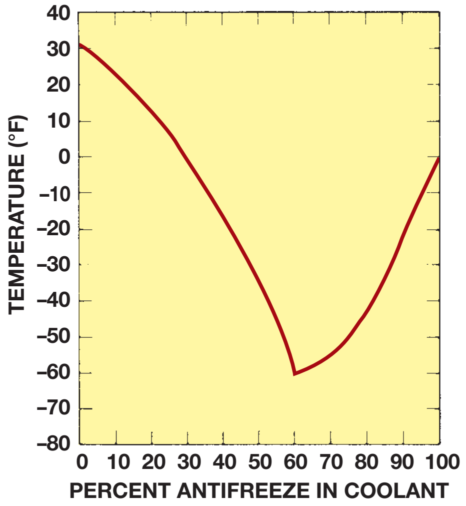


FIGURE 17–1 Graph showing the relationship of the freezing point of the coolant to the percentage of antifreeze used in the coolant.

A curve depicting freezing point as compared with the percentage of antifreeze mixture is shown in ● **FIGURE 17–1**.

FREEZING/BOILING TEMPERATURES It should be noted that the freezing point increases as the antifreeze concentration is

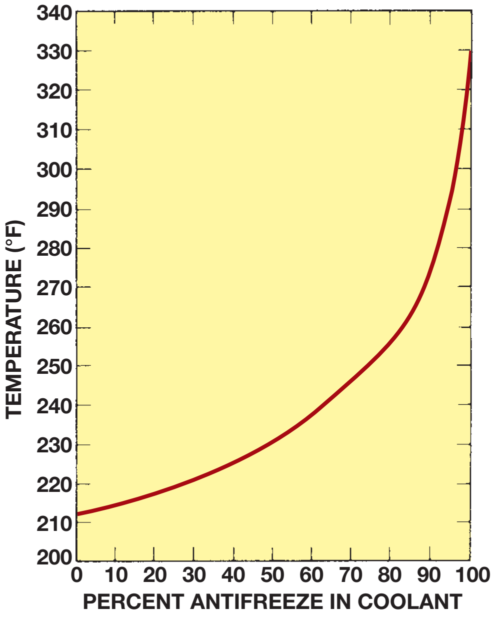


FIGURE 17–2 Graph showing how the boiling point of the coolant increases as the percentage of antifreeze in the coolant increases.

increased above 60%. The normal mixture is 50% antifreeze and 50% water. Ethylene glycol antifreeze contains:

- Anticorrosion additives
- Rust inhibitors
- Water pump lubricants

At the maximum level of protection, an ethylene glycol concentration of 60% will absorb about 85% as much heat as will water. Ethylene glycol–based antifreeze also has a higher boiling point than water. A curve depicting boiling point as compared with the percentage of antifreeze mixture is shown in ● **FIGURE 17–2**.

If the coolant boils, it vaporizes and does not act as a cooling agent because it is not in liquid form or in contact with the cooling surfaces.

All coolants have rust and corrosion inhibitors to help protect the metals in the engine and cooling systems.

COOLANT COMPOSITION All manufacturers recommend the use of **ethylene glycol–based coolant**, which contains:

- Ethylene glycol (EG): 47%
- Water: 50%
- Additives: 3%

Regardless of the type of coolant and its color, the only difference among all original equipment coolants is in the additives. This means that about 97% of all coolants are the same. The only difference is in the additive package and color used to help identify the coolant.

TYPES OF COOLANT

INORGANIC ACID TECHNOLOGY **Inorganic additive technology (IAT)** is conventional coolant that has been used for over 50 years. Most conventional green antifreeze contains inorganic salts such as:

- Sodium silicate (silicates)
- Phosphates
- Borates

Silicates have been found to be the cause of erosive wear to water pump impellers. The color of IAT coolant is green. Phosphates in these coolants can cause deposits to form if used with water that is hard (contains minerals). IAT coolants used in new vehicles were phased out in the mid-1990s.

ORGANIC ACID TECHNOLOGY **Organic acid technology (OAT)** coolant contains ethylene glycol but does not contain silicates or phosphates. The color of this type of coolant is usually orange.

DEX-COOL, developed by Havoline, is just one brand of OAT coolant, which has been used in General Motors vehicles since 1996. ● **SEE FIGURE 17–3**.

DEX-COOL uses ethylhexanoic acid (2-EH) as a corrosive inhibitor. 2-EH is prone to damage plastics, such as Nylon 6.6 used in intake manifold gaskets and radiators. Other brands of OAT coolant that are also orange but do not contain 2-EH include:

- Zerex G30 or G05 OAT
- Peak Global OAT

These coolants are usually available in premix (with water) and pure coolant containers.

HYBRID ORGANIC ACID TECHNOLOGY A newer variation of this technology is called **hybrid organic acid technology (HOAT)**. It is similar to the OAT-type antifreeze as it uses organic acid salts (carboxylates) that are not abrasive to water pumps, yet provide the correct pH. The pH of the coolant is usually above 11. A pH of 7 is neutral, with lower numbers indicating an acidic solution and higher numbers indicating an alkaline solution. If the pH is too high, the coolant can cause scaling and reduce the heat transferability of the coolant. If the pH is too low, the resulting acidic solution could cause corrosion of the engine components exposed to the coolant.

HOAT coolants can be green, orange, yellow, gold, pink, red, or blue.

Samples of HOAT coolants include:

- **VW/Audi pink.** Contains some silicates and an organic acid and is phosphate free
- **Mercedes/Ford yellow.** Contains low amounts of silicate and no phosphate

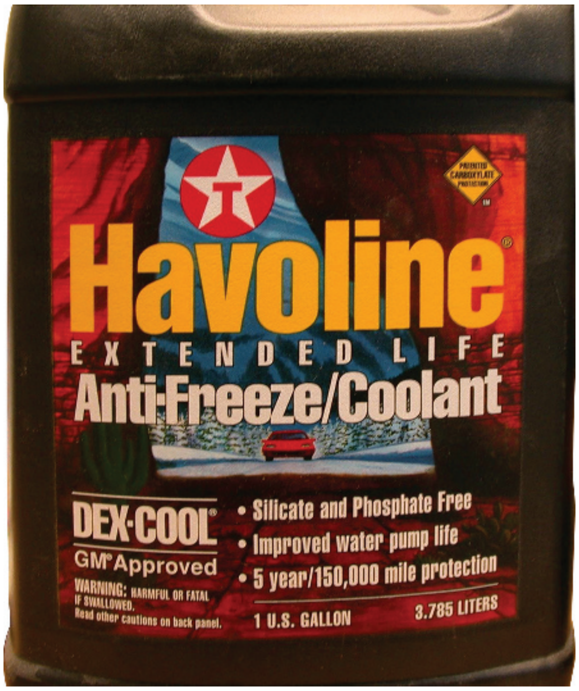

Havoline
EXTENDED LIFE
Anti-Freeze/Coolant
DEX-COOL
GM Approved
• Silicate and Phosphate Free
• Improved water pump life
• 5 year/150,000 mile protection
1 U.S. GALLON
3.785 LITERS

FIGURE 17–3 Havoline was the first company to make and market OAT coolant. General Motors uses the term DEX-COOL.

FREQUENTLY ASKED QUESTION

What Is a "G" Coolant?

The "G" coolants come from the trade name *Glysantin* of BASF in Europe and Valvoline (Zerex) in the United States. The following is a summary of the types listed by G number.

- G05: different from DEX-COOL in certain amounts of additives
- G30 and G34: nonsilicate and phosphate free
- G11: blue VW used before 1997
- G12: pink/red VW 1997+ (purple VW 2003+)
  - HOAT formulation
  - Phosphate free
- G48: low silicate and phosphate free
  - Blue
  - Nitrates, amines, phosphate (NAP) free

- **Ford yellow.** Contains low silicate, no phosphate, and is dyed yellow for identification
- **Honda blue.** Contains a special coolant with just one organic acid
- **European/Korean blue.** Contains low silicates and no phosphates
- **Asian red.** Contains no silicates but has some phosphate

PHOSPHATE HYBRID ORGANIC ACID TECHNOLOGY **Phosphate hybrid organic acid technology (PHOAT)** is used in Mazda-based Fords (2008+), same as Mazda FL-22, and is ethylene glycol based. This coolant is available in a 55% coolant/45% water premix. ● **SEE FIGURE 17–4**.

- Concentration: 55%
- Boiling point (with 15 PSI pressure cap): 270°F (132°C)
- Freezing point: −47°F (−44°C)
- Color: Dark green
- Embittered (made to taste bitter so animals will not drink it)

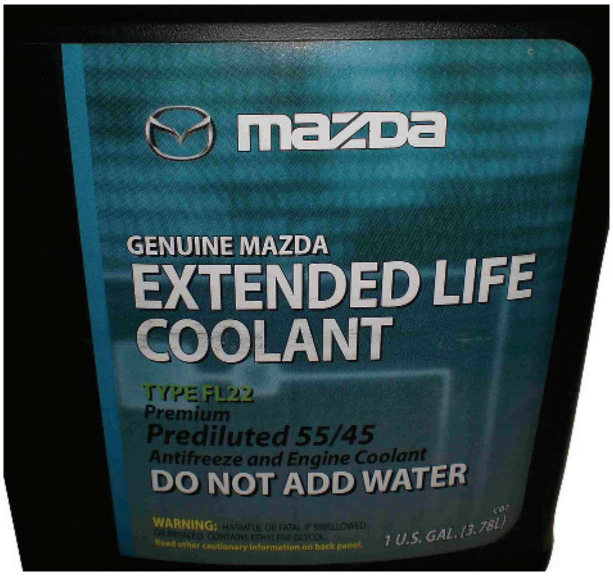


FIGURE 17–4 Coolant used in Fords that use Mazda engines and in Mazda vehicles. It requires the use of a PHOAT coolant which is dark green.

FREQUENTLY ASKED QUESTION

What Is "Pet Friendly" Antifreeze?

Conventional ethylene glycol antifreeze used by all vehicle manufacturers is attractive to pets and animals because it has a sweet taste. Ethylene glycol is fatal to any animal if swallowed, so any spill should be cleaned up quickly. There are two types of coolant that are safer for use around pets than the conventional type.

- **Propylene glycol (PG).** This type of antifreeze is *less* attractive to pets and animals because it is not as sweet, but it is still harmful if swallowed. This type of coolant, including the Sierra brand, should not be mixed with any other ethylene glycol–based coolant.

CAUTION: Some vehicle manufacturers do not recommend the use of propylene glycol coolant. Check the recommendation in the owner manual or service information before using it in a vehicle.

- **Embittered coolant**. This coolant has a small amount of a substance that makes it taste bitter and therefore not appealing to animals. The embittering agent used in ethylene glycol (EG) antifreeze is usually denatonium benzoate, added at the rate of 30 PPM. Oregon and California require all coolant sold in these states since 2004 to be embittered. ● **SEE FIGURE 17–5**.

The use of PHOAT coolant in these engines is required to be assured of proper protection of the material used in the engine. It is also only available in premix containers to ensure that the water used meets specifications.

UNIVERSAL COOLANT Universal coolant is usually a hybrid organic acid technology (HOAT), with extended life, and a low-silicate, phosphate-free antifreeze/coolant. It can be used in many vehicles, but cannot meet the needs for engines requiring a silicate-free formulation.

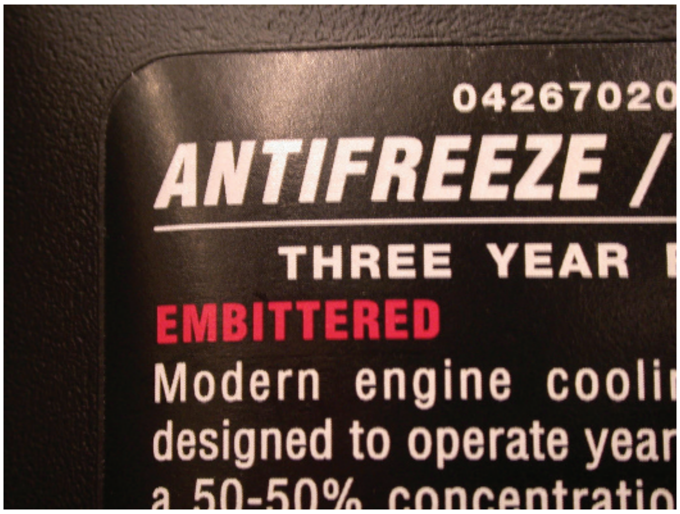


FIGURE 17–5 Not all embittered coolant is labeled embittered.

CASE STUDY

If 50% Is Good, 100% Must Be Better

A vehicle owner said that the cooling system of their vehicle would never freeze or rust. They said that they used 100% antifreeze (ethylene glycol) instead of a 50/50 mixture with water.

However, after the temperature dropped to −20°F (−29°C), the radiator froze and cracked. (Pure antifreeze freezes at about 0°F [−18°C].) After thawing, the radiator had to be replaced. The owner was lucky that the engine block did not also crack.

For best freeze protection with good heat transfer, use a 50/50 mixture of antifreeze and water. As the percentage of antifreeze increases, the boiling temperature increases, and freezing protection increases (up to 70% antifreeze), but the heat transfer performance of the mixture decreases.

Summary:

Complaint—The coolant froze and cracked the radiator.
Cause—Vehicle owner used 100% antifreeze instead of the recommended 50/50 mixture of antifreeze and water.
Correction—The radiator was replaced and the proper mixture of antifreeze/water was used as the coolant.

FREQUENTLY ASKED QUESTION

What Makes Some Water Bad for Coolant?

City water is treated with chloride, which, if the levels are high enough, can cause corrosion problems when used in coolants. Well water may contain iron or other minerals that can affect the coolant and may increase the corrosion or cause electrolysis. Due to the fact that the water quality is often unknown and could affect the engine, many vehicle manufacturers are specifying the use of premixed coolant. In premix coolant, the water is usually demineralized and meets the standards for use in coolant.

WATER

INTRODUCTION Water is half of the coolant and can have an effect on the corrosion protection of coolant due to variations in its quality, which is often unknown. As a result, many vehicle manufacturers, such as Honda and Toyota, are specifying the use of premix coolants only. The main reason is that not only can the water/coolant ratio be maintained, but also the quality of the water can be controlled.

PROPERTIES Water is about half of the coolant and is used because of the following qualities.

1. It is inexpensive.
2. It is an efficient heat-exchange fluid because of its excellent thermal conductivity (the ability of a material to conduct heat).
3. It has good specific heat capacity, meaning it takes more heat energy to increase the temperature, versus one with low specific heat capacity.
4. The boiling point is 212°F (100°C) (at sea level).
5. The freezing point is 32°F (0°C).

COOLANT FREEZING/ BOILING TEMPERATURES

FREEZING POINT An antifreeze and water mixture is an example wherein the freezing point differs from the freezing point of either pure antifreeze or pure water.

	Freezing Point
Pure water	32°F (0°C)
Pure antifreeze*	0°F (−18°C)
50/50 mixture	−34°F (−37°C)
70% antifreeze/30% water	−84°F (−64°C)

*Pure antifreeze is usually 95% ethylene glycol, 2% to 3% water, and 2% to 3% additives.

Depending on the exact percentage of water used, antifreeze (not premixed), as sold in containers, freezes at about 0°F (−18°C). Premixed coolant will freeze at about −34°F (−37°C).

BOILING POINT The boiling point of antifreeze and water is also a factor of mixture concentrations.

	Boiling Point at Sea Level	Boiling Point with 15 PSI Pressure Cap
Pure water	212°F (100°C)	257°F (125°C)
50/50 mixture	218°F (103°C)	265°F (130°C)
70/30 mixture	225°F (107°C)	276°F (136°C)

COOLANT TESTING

Normal coolant tests include:

- **Visual inspection.** Coolant should be clean and bright.
- **Freeze/boiling point.** A high freezing point or low boiling point indicates dilution (too much water).

FREQUENTLY ASKED QUESTION

Why Is Most Coolant 50/50 with Water?

According to the freezing point, it appears that the lowest freezing point of coolant is achieved when 70% antifreeze is used with 30% water. While the freezing temperature is lower, the high concentrate of antifreeze reduces the heat transferability of the coolant. Therefore, most vehicle manufacturers specify a 50/50 mixture of antifreeze and water to achieve the best balance between freeze protection and heat conductivity.

TECH TIP

Ignore the Wind Chill Factor

The wind chill factor is a temperature that combines the actual temperature and the wind speed to determine the overall heat loss effect on open skin. Because it is the heat loss factor for open skin, the wind chill temperature is *not* to be considered when determining antifreeze protection levels.

Although moving air makes it feel colder, the actual temperature is not changed by the wind, and the engine coolant will not be affected by the wind chill. If you are not convinced, try placing a thermometer in a room and wait until a stable reading is obtained. Now turn on a fan and have the air blow across the thermometer. The temperature will not change.

- **pH.** The wrong pH indicates buffer loss, which is used to help maintain the pH level.
- **Coolant voltage.** A high voltage indicates the wrong pH or a stray current flow.

Various methods are used to test coolant.

HYDROMETER TESTING Coolant can be checked using a coolant hydrometer. The hydrometer measures the density of the coolant. The higher the density, the more concentration of antifreeze in the water. Most coolant hydrometers read the freezing and boiling points of the coolant. ● **SEE FIGURE 17–6.**

If the engine is overheating and the hydrometer reading is near −50°F (−60°C), suspect that pure 100% antifreeze is present. For best results, the coolant should have a freezing point lower than −20°F (−29°C) and a boiling point above 234°F (112°C).

REFRACTOMETER A **refractometer** is a tester used to test the freezing point of coolant by placing a few drops of coolant on the prism surface. The technician then holds the unit up to the light and looks through the eyepiece for the location of the shadow on the display.

A refractometer measures the extent to which light is bent (refracted) to determine the index of refraction of a liquid sample.

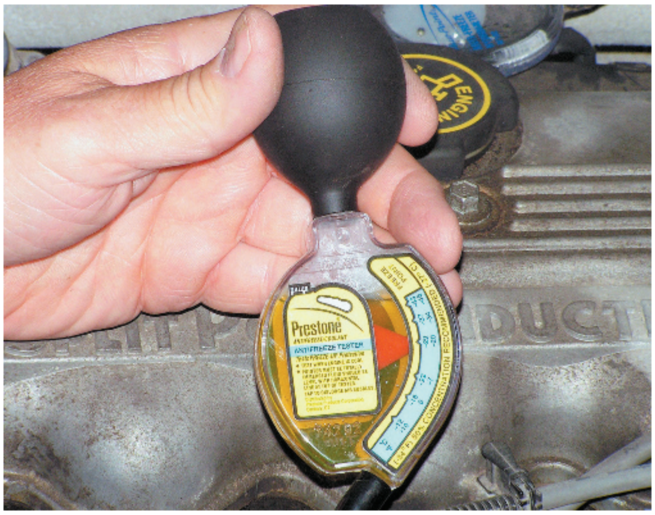


FIGURE 17–6 Checking the freezing temperature of the coolant using a hydrometer.

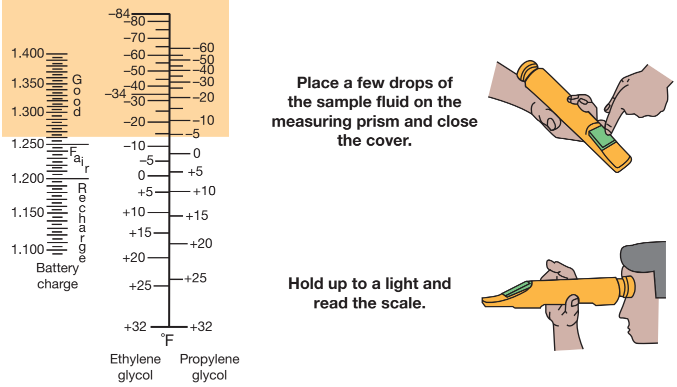


FIGURE 17–7 Using a refractometer is an accurate method to check the freezing point of coolant.

The refractive index is commonly used for the following:

- To identify or confirm the identity of a sample coolant
- To determine the purity of a coolant by comparing its refractive index to the value for the pure substance
- To determine the concentration of a solute in a solution by comparing the solution's refractive index to a standard curve ● **SEE FIGURE 17–7.**

pH The term *pH* comes from a French word, meaning "power of hydrogen" and is a measure of acidity or alkalinity of a solution.

- Less than 7 pH is considered acidic.
- Greater than 7 pH is considered alkaline.

The pH of new coolant varies according to the type of coolant used. Typical pH values for new coolant include:

IAT: 9 to 10.5 new
OAT: 7.5 to 8.5 new (G30 and G34 designations)
HOAT: 7.5 to 8.5 new (G05, G48, G11, or G12 designation)
PHOAT: 7.5 to 8.5 new

When testing for pH, use either a test strip or a pH meter. If using a test strip, be sure that it is calibrated to test the type of coolant being used in the vehicle.

Used coolant pH readings are usually lower than when the coolant is new and range between 7.5 and 10 for IAT and lower for used OAT, HOAT, and PHOAT coolants. For best results, use a pH tester that measures the actual pH of the coolant. ● **SEE FIGURE 17–8.**

GALVANIC ACTIVITY **Galvanic activity** is the flow of an electrical current as a result of two different metals in a liquid, which acts like a battery. Galvanic activity does *not* require an outside source of voltage. The two different metals, usually iron and aluminum, become the plates of the battery and the coolant is the electrolyte. The higher the electrical conductivity of the coolant, the greater is the amount of corrosion. ● **SEE FIGURE 17–9.**

FIGURE 17–8 A meter that measures the actual pH of the coolant can be used for all coolants, unlike many test strips that cannot be used to test the pH of red or orange coolants.

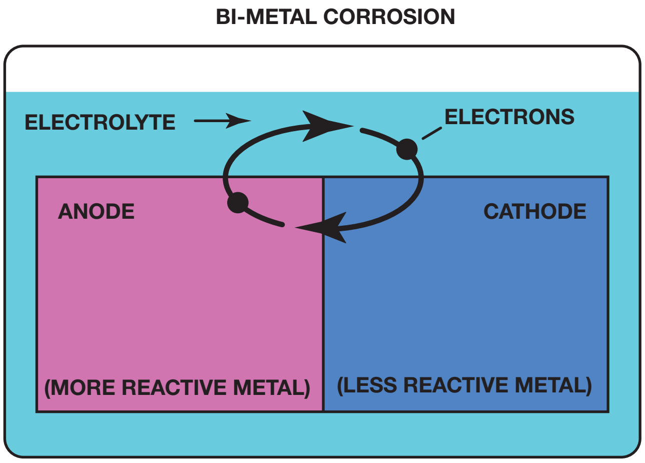


FIGURE 17–9 Galvanic activity is created by two dissimilar metals in contact with a liquid, in this case coolant.

ELECTROLYSIS **Electrolysis** requires the use of an outside voltage source. The source is usually due to a poor electrical ground connection.

- Electrical flow through the cooling system may cause metal to flow into the coolant.
- This metal transfer can eat holes in a heater core or radiator.
- Electrolysis holes will usually start from the inside and have a dark coloration.

TESTING FOR GALVANIC ACTIVITY AND ELECTROLYSIS A voltmeter set to read DC volts is used to test for galvanic activity and electrolysis. To check for excessive voltage caused by galvanic activity or electrolysis, perform the following steps.

STEP 1 Allow the engine to cool and carefully remove the pressure cap from the radiator.

STEP 2 Set the voltmeter to DC volts and connect the black meter lead to a good engine ground.

STEP 3 Place the red meter lead into the coolant.

STEP 4 Read the meter. If the voltage is above 0.5 volt, this indicates excessive galvanic activity. Normal readings should be less than 0.2 volt (200 mV). Flush and refill the cooling system.

STEP 5 To test for excessive electrolysis, start the engine and turn on all electrical accessories, including the headlights on high beam.

STEP 6 Read the voltmeter. If the reading is higher than 0.5 volt, check for improper body ground wires or connections. Normal readings should be less than 0.3 volt (300 mV).

TEST STRIP TESTING Test strips can be used to check one or more of the following:

- Freeze point
- Boiling point
- Level of pH

Test strips will change color when they are dipped into the coolant, and the color change is compared to the container. Test strips are fairly accurate, easy to use, and inexpensive.

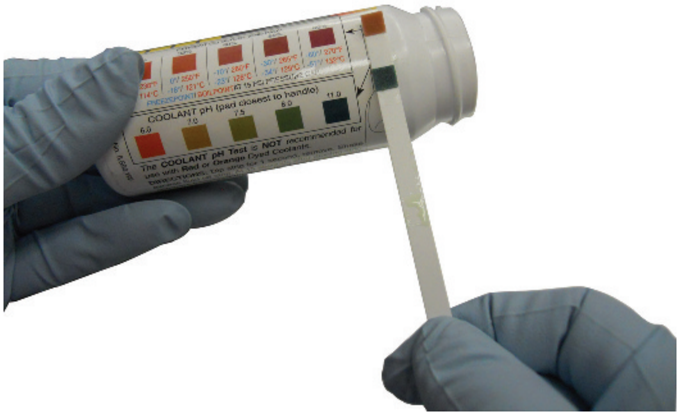


FIGURE 17–10 A test strip can be used to determine the pH and percentage of glycol of the coolant. The percentage of glycol determines the freezing and boiling temperatures, as shown on the bottle that contains the test strips.

For best results, use test strips that are new and have been stored in a sealed bottle. Using older test strips may affect the accuracy. ● **SEE FIGURE 17–10**.

COOLANT REPLACEMENT ISSUES

INTERVALS Coolant should be replaced according to the vehicle manufacturer's recommended interval.

- For most new vehicles using OAT or HOAT type coolant, this interval may be every five years or 150,000 miles (241,000 km), whichever occurs first.
- Japanese brand vehicles usually have a replacement interval of three years or 36,000 miles (58,000 km), whichever occurs first.
- If the coolant is changed from a long life to a conventional IAT coolant, the replacement interval needs to be changed to every two years or 24,000 miles (39,000 km), whichever occurs first.

PASSIVATION **Passivation** is a chemical reaction that takes place between coolant additives and the metal that it protects. This means that a chemical barrier is created between the coolant and the metals of the engine. When changing coolants, passivation can take from a few days to a few weeks.

- Each chemical package does its own passivation.
- If you change chemical packages, passivation has to start over.

Therefore, because of passivation concerns, most experts agree that for best results do not change types of coolants. Always use what the vehicle manufacturer recommends. Always check service information for the exact recommended replacement interval for the vehicle being serviced.

RECYCLING COOLANT Coolant (antifreeze and water) should be recycled. Used coolant may contain heavy metals, such as lead, aluminum, and iron, which are absorbed by the coolant during its use in the engine.

Recycle machines filter out these metals and dirt and reinstall the depleted acids. The recycled coolant, restored to be like new, can be reinstalled into the vehicle.

CAUTION: Most vehicle manufacturers warn that coolant should not be reused unless it is recycled and the acids restored. However, Mercedes lifetime coolant is very expensive, and according to Mercedes can be drained, filtered, and reused.

REVIEW QUESTIONS

1. What types of coolant are used in vehicles?
2. Why is a 50/50 mixture of antifreeze and water commonly used as a coolant?
3. What are the differences among IAT, OAT, HOAT, and PHOAT coolants?
4. What are some of the heavy metals that can be present in used coolant?
5. What is the difference between galvanic activity and electrolysis?

CHAPTER QUIZ

1. Coolant is water and _________.
   - **a.** methanol
   - **b.** glycerin
   - **c.** kerosene
   - **d.** ethylene glycol
2. As the percentage of antifreeze in the coolant increases, _________.
   - **a.** the freezing point decreases (up to a point)
   - **b.** the boiling point decreases
   - **c.** the heat transfer increases
   - **d.** All of the above
3. Adding a chemical to make ethylene glycol coolant bitter to the taste is called _________.
   - **a.** passivation
   - **b.** embittered
   - **c.** refractometer
   - **d.** electrolysis
4. Asian red coolant is what type?
   - **a.** IAT
   - **b.** OAT
   - **c.** HOAT
   - **d.** PHOAT
5. DEX-COOL is what type of coolant?
   - **a.** IAT
   - **b.** OAT
   - **c.** HOAT
   - **d.** PHOAT
6. PHOAT coolant is what color?
   - **a.** Dark green
   - **b.** Red
   - **c.** Orange
   - **d.** Blue
7. DEX-COOL is _________.
   - **a.** propylene glycol
   - **b.** ethylene glycol
   - **c.** silicate and phosphate free
   - **d.** Both b and c
8. Two technicians are discussing testing coolant for proper pH. Technician A says that coolant has a pH above 7 when new and becomes lower with use in an engine. Technician B says that OAT and HOAT coolants have a lower pH when new compared to the old green IAT coolant. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. Reusing old coolant is generally not approved by vehicle manufacturers *except* _________.
   - **a.** General Motors
   - **b.** Ford
   - **c.** Chrysler
   - **d.** Mercedes
10. A voltmeter was used to check the coolant and a reading of 0.2 volt with the engine off was measured. A reading of 0.8 volt was measured with the engine running and all electrical accessories turned on. Technician A says that the coolant should be flushed to solve the galvanic activity. Technician B says that the ground wires and connections should be inspected and repaired to solve the electrolysis problem. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter

18

COOLING SYSTEM OPERATION AND DIAGNOSIS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and function of the cooling system.
- Explain cooling system operation.
- Explain the purpose of thermostats.
- Explain the purpose of radiators.
- Explain the purpose of pressure caps.
- Explain coolant recovery systems.
- Explain the purpose of water pumps.
- Explain auxiliary water pumps.
- Explain coolant flow in the engine.
- Explain the purpose of cooling fans.
- Explain the purpose of heater cores.
- Describe cooling system testing.
- Explain the purpose of a coolant temperature warning light.
- Explain cooling system inspection.
- Explain cooling system service.

KEY TERMS:

Active grille shutters (AGS) 180 • Bar 181 • Bleed holes 185 • Bypass 176 • Centrifugal pump 182 • Coolant recovery system 182 • Cooling fins 179 • Core tubes 179 • Impeller 182 • Parallel flow system 184 • Reverse cooling 182 • Scroll 183 • Series flow system 184 • Series-parallel flow system 184 • Silicone coupling 186 • Steam slits 185 • Surge tank 182 • Thermostatic spring 186

COOLING SYSTEM

PURPOSE AND FUNCTION Satisfactory cooling system operation depends on the design and operating conditions of the system. The design is based on heat output of the engine, radiator size, type of coolant, size of water pump (coolant pump), type of fan, thermostat, and system pressure. The cooling system must allow the engine to warm up to the required operating temperature as rapidly as possible, and then maintain that temperature.

Peak combustion temperatures in the engine run from 4,000°F to 6,000°F (2,200°C to 3,300°C). The combustion temperatures will *average* between 1,200°F and 1,700°F (650°C and 925°C). Continued temperatures as high as this would weaken engine parts, so heat must be removed from the engine. The cooling system keeps the head and cylinder walls at a temperature that is within the range for maximum efficiency. The cooling system removes about one-third of the heat created in the engine. Another third escapes to the exhaust system. ● **SEE FIGURE 18–1**.

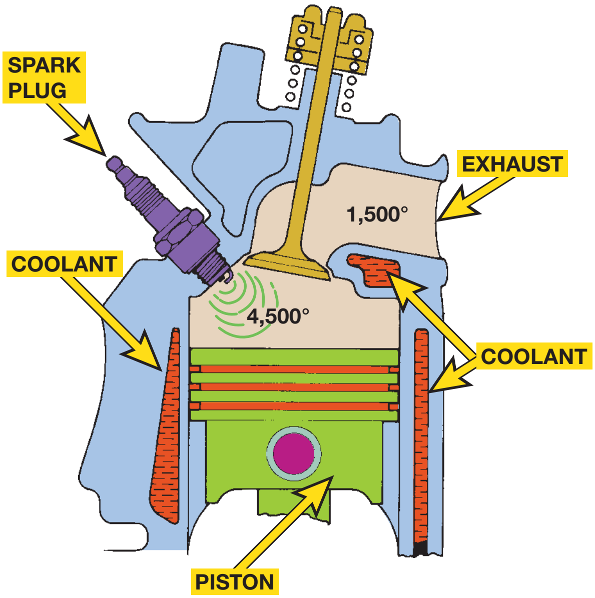


FIGURE 18–1 Typical combustion and exhaust temperatures.

LOW-TEMPERATURE ENGINE PROBLEMS Engine operating temperatures must be above a minimum temperature for proper engine operation. If the coolant temperature does not reach the specified temperature, as determined by the thermostat, the following engine-related faults can occur:

- A P0128 diagnostic trouble code (DTC) can be set. This code indicates "coolant temperature below thermostat regulating temperature," which is usually caused by a defective thermostat staying open or partially open.

TECH TIP

Overheating Can Be Expensive

A faulty cooling system seems to be a major cause of engine failure. Engine rebuilders often have nightmares about seeing their rebuilt engine placed back in service in a vehicle with a clogged radiator. Most engine technicians routinely replace the water pump and all hoses after an engine overhaul or repair. The radiator should also be checked for leaks and proper flow whenever the engine is repaired or replaced. Overheating is one of the most common causes of engine failure.

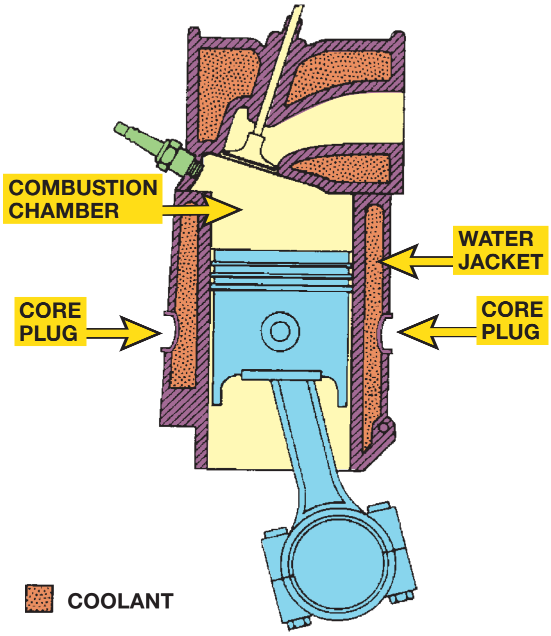


FIGURE 18–2 Coolant circulates through the water jackets in the engine block and cylinder head.

- Moisture created during the combustion process can condense and flow into the oil. *For each gallon of fuel used, moisture equal to a gallon of water is produced.* The condensed moisture combines with unburned hydrocarbons and additives to form carbonic acid, sulfuric acid, nitric acid, hydrobromic acid, and hydrochloric acid.

To reduce cold engine problems and to help start engines in cold climates, most manufacturers offer block heaters as an option. These block heaters are plugged into household current (110 volts AC) and the heating element warms the coolant.

HIGH-TEMPERATURE ENGINE PROBLEMS Maximum temperature limits are required to protect the engine. Higher than normal temperatures can cause the following engine-related issues:

- High temperatures oxidize the engine oil, producing hard carbon and varnish. The varnish causes the hydraulic valve lifter plungers to stick. Higher than normal temperatures also cause the oil to become thinner (lower viscosity than normal). Thinned oil gets into the combustion chamber by going past the piston rings and through valve guides to cause excessive oil consumption.
- The combustion process is very sensitive to temperature. High coolant temperatures raise the combustion temperatures to a point that may cause detonation (also called spark knock or ping) to occur.

COOLING SYSTEM OPERATION

COOLANT FLOW Coolant flows through the engine, where it picks up heat. It then flows to the radiator, where the heat is given up to the outside air. The coolant continually recirculates through the cooling system, as illustrated in ● **FIGURES 18–2 AND 18–3**.

COOLING SYSTEM OPERATION The temperature of the coolant rises as much as 15°F (8°C) as it goes through the engine and cools as it goes through the radiator. *The coolant flow rate may be as high as 1 gallon (4 liters) per minute for each horsepower the engine produces.*

Hot coolant comes out of the thermostat housing on the top of the engine on most engines. The engine coolant outlet is connected to the radiator by the upper radiator hose and clamps. The coolant in the radiator is cooled by air flowing through the radiator. As the coolant moves through the radiator, it cools. The cooler coolant leaves the radiator through an outlet and the lower radiator hose, and then flows to the inlet side of the water pump, where it is recirculated through the engine.

Radiators are designed for the maximum rate of heat transfer using minimum space. Cooling airflow through the radiator is aided by a belt- or electric motor–driven cooling fan.

THERMOSTATS

PURPOSE There is a normal operating temperature range between low-temperature and high-temperature extremes. The thermostat controls the minimum normal temperature. The thermostat is a temperature-controlled valve placed at the engine coolant outlet on most engines.

THERMOSTAT OPERATION An encapsulated wax-based plastic pellet heat sensor is located on the engine side of the thermostatic valve. As the engine warms, heat swells the heat sensor. ● **SEE FIGURE 18–4**.

A mechanical link, connected to the heat sensor, opens the thermostat valve. As the thermostat begins to open, it allows some coolant to flow to the radiator, where it is cooled. The remaining part of the coolant continues to flow through the **bypass,** thereby bypassing the thermostat and flowing back through the engine. ● **SEE FIGURE 18–5**.

The bypass aids in uniform engine warm-up. Its operation eliminates hot spots and prevents the building of excessive coolant pressure in the engine when the thermostat is closed.

The rated temperature of the thermostat indicates the temperature at which the thermostat starts to open. The thermostat is fully open at about 20°F (11°C) higher than opening temperature of 210°F (99°C). ● **SEE CHART 18–1**.

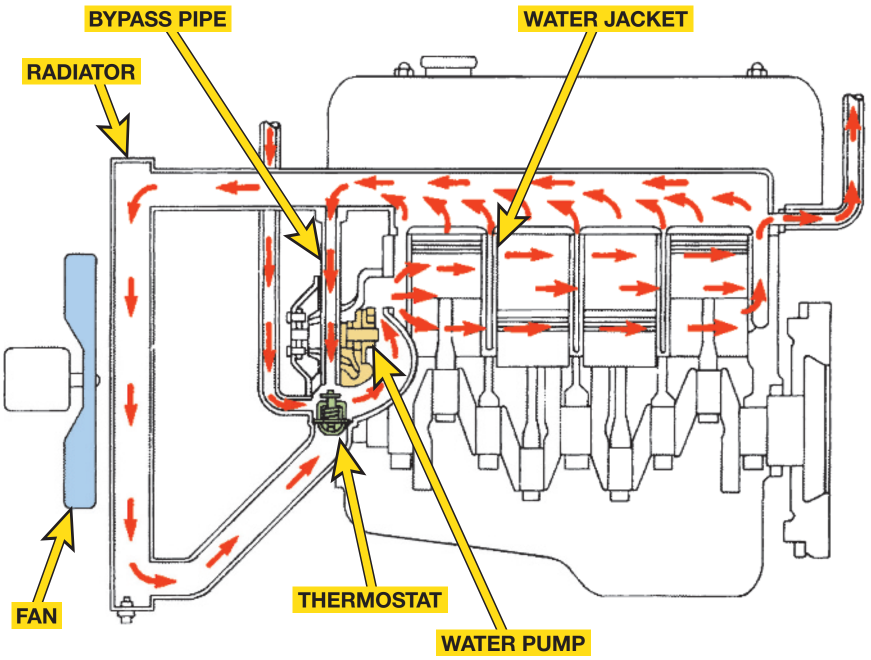

BYPASS PIPE
WATER JACKET
RADIATOR
FAN
THERMOSTAT
WATER PUMP

FIGURE 18–3 Coolant flow through a typical engine cooling system.

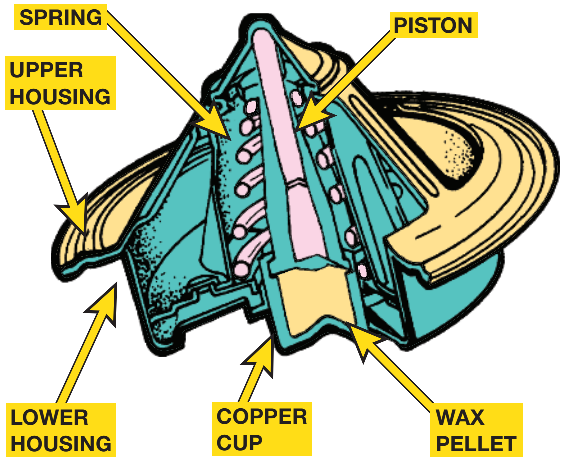

SPRING
PISTON
UPPER HOUSING
LOWER HOUSING
COPPER CUP
WAX PELLET

FIGURE 18–4 A cross section of a typical wax-actuated thermostat showing the position of the wax pellet and spring.

If the radiator, water pump, and coolant passages are functioning correctly, the engine should always be operating within the opening and fully open temperature range of the thermostat. ● **SEE FIGURE 18–6**.

The bypass aids in uniform engine warm-up. Its operation eliminates hot spots and prevents the building of excessive coolant pressure in the engine when the thermostat is closed. ● **SEE FIGURE 18–7**.

THERMOSTAT TESTING There are three basic methods used to check the operation of the thermostat.

1. **Hot water method.** If the thermostat is removed from the vehicle and is closed, insert a 0.015 inch (0.4 mm) feeler gauge in the opening so that the thermostat will hang on the feeler gauge. The thermostat should be suspended by

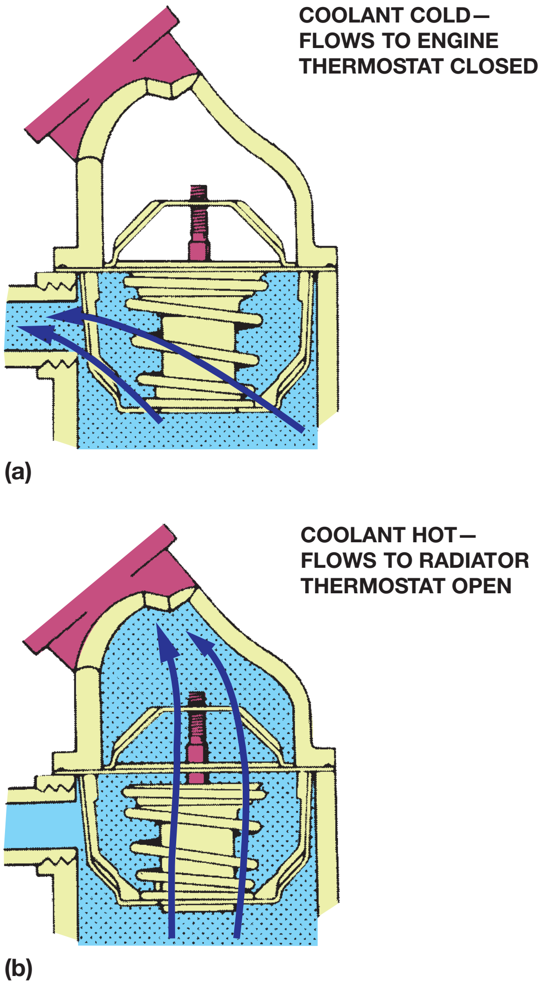

COOLANT COLD—
FLOWS TO ENGINE
THERMOSTAT CLOSED
(a)
COOLANT HOT—
FLOWS TO RADIATOR
THERMOSTAT OPEN
(b)

FIGURE 18–5 (a) When the engine is cold, the coolant flows through the bypass. (b) When the thermostat opens, the coolant can flow to the radiator.

THERMOSTAT TEMPERATURE RATING	STARTS TO OPEN	FULLY OPEN
180°F	180°F	200°F
195°F	195°F	215°F

CHART 18–1

The temperature of the coolant depends on the rating of the thermostat.

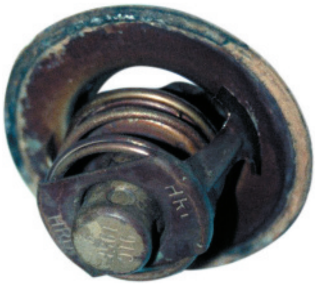


FIGURE 18–6 A thermostat stuck in the open position caused the engine to operate too cold. If a thermostat is stuck closed, this can cause the engine to overheat.

TECH TIP

Do Not Take Out the Thermostat!

Some vehicle owners and technicians remove the thermostat in the cooling system to "cure" an overheating problem. In some cases, removing the thermostat can *cause* overheating rather than stop it. This is true for two reasons.

1. Without a thermostat, the coolant can flow more quickly through the radiator. The thermostat adds some restriction to the coolant flow, and therefore keeps the coolant in the radiator longer. This also allows additional time for the heat transfer between the hot engine parts and the coolant.
2. For the heat to move from the coolant to the radiator and finally to the atmosphere requires that the coolant remain in contact with the surfaces inside the radiator. Moving the coolant too fast through the passages can result in laminar flow. Laminar flow is where the fluid forms layers with the layer closest to the surface and moves slower than the the layers further away from the surface. As a result, the layers act like insulators and the ability to transfer heat is reduced.

FREQUENTLY ASKED QUESTION

Why Is an Electronic Thermostat Used in Some Engines?

An electronic thermostat allows the engine temperature to be more closely controlled during cruise, city driving, or heavy load conditions to optimize fuel economy, and reduce exhaust emissions.
● **SEE FIGURE 18–8**.

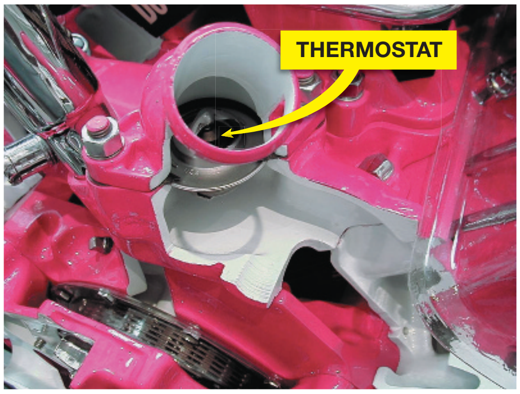


FIGURE 18–7 A cutaway of a small block Chevrolet V-8 showing the passage from the cylinder head through the front of the intake manifold to the thermostat.

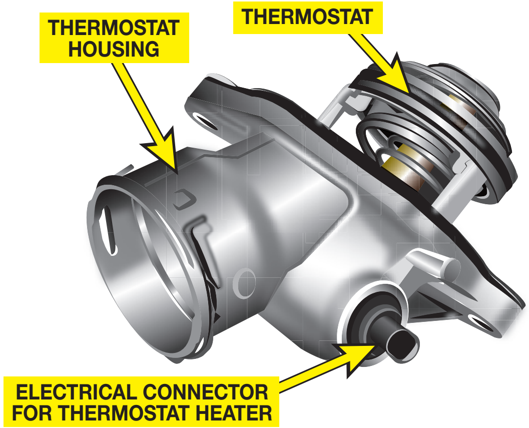
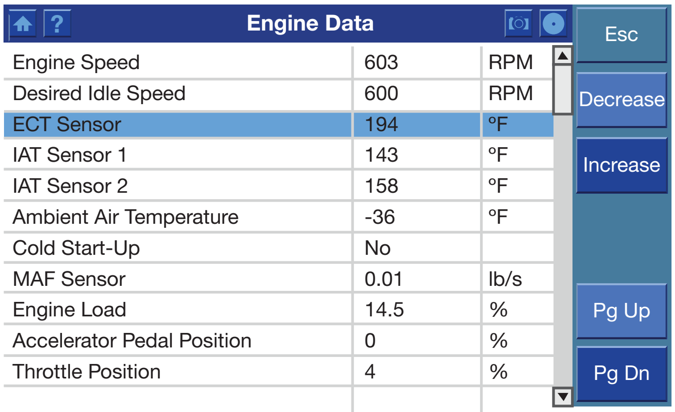


FIGURE 18–8 An electronic thermostat uses a wax pellet to open and a spring to close it, but it also uses an electric heater controlled by the powertrain control module (PCM) to accurately control engine coolant temperature.

the feeler gauge in a container of water or coolant along with a thermometer. The container should be heated until the thermostat opens enough to release and fall from the feeler gauge. The temperature at which the thermostat falls is the opening temperature of the thermostat. If it is within 5°F (1.5°C) of the temperature stamped on the thermostat, the thermostat is satisfactory for use.

2. **Infrared thermometer method.** An infrared thermometer (also called a pyrometer) can be used to measure the temperature of the coolant near the thermostat. The area on the engine side of the thermostat should be at the highest temperature that exists in the engine. A properly operating cooling system should cause the pyrometer to read as follows:
   - As the engine warms, the temperature reaches near thermostat opening temperature.
   - As the thermostat opens, the temperature drops just as the thermostat opens, sending coolant to the radiator.
   - As the thermostat cycles, the temperature should range between the opening temperature of the thermostat and 20°F (11°C) above the opening temperature.

NOTE: If the temperature rises higher than 20°F (11°C) above the opening temperature of the thermostat, inspect the cooling system for a restriction or low coolant flow. A clogged radiator could also cause the excessive temperature rise.



Engine Speed	603	RPM
Desired Idle Speed	600	RPM
ECT Sensor	194	°F
IAT Sensor 1	143	°F
IAT Sensor 2	158	°F
Ambient Air Temperature	-36	°F
Cold Start-Up	No	
MAF Sensor	0.01	lb/s
Engine Load	14.5	%
Accelerator Pedal Position	0	%
Throttle Position	4	%

FIGURE 18–9 A scan tool can be used to monitor the engine coolant temperature (ECT).

3. **Scan tool method.** A scan tool can be used on many vehicles to read the actual temperature of the coolant as detected by the engine coolant temperature (ECT) sensor. Although the sensor or the wiring to and from the sensor may be defective, at least the scan tool can indicate what the computer "thinks" is the engine coolant temperature. ● **SEE FIGURE 18–9**.

THERMOSTAT REPLACEMENT Two important indicators about a thermostat include

1. An overheating engine *may* result from a faulty thermostat.
2. An engine that does not get warm enough *always* indicates a faulty thermostat.

To replace the thermostat, coolant will have to be drained from the radiator drain petcock to lower the coolant level below the thermostat. It is not necessary to completely drain the system. The hose should be removed from the thermostat housing neck, and then the housing removed to expose the thermostat. ● **SEE FIGURE 18–10**.

The gasket flanges of the engine and thermostat housing should be cleaned, and the gasket surface of the housing must be flat. The thermostat should be placed in the engine with the sensing pellet *toward* the engine. Make sure that the thermostat position is correct and install the thermostat housing with a new gasket or O-ring.

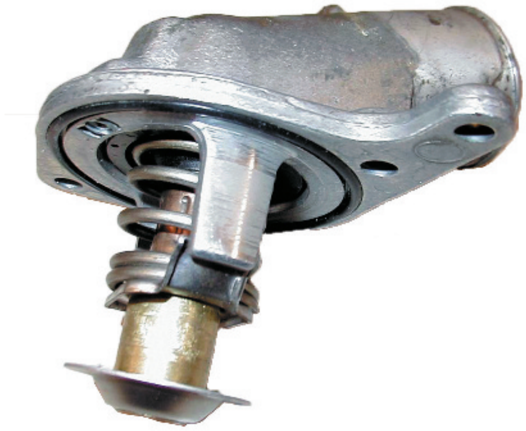


FIGURE 18–10 Some thermostats are an integral part of the housing. This thermostat and radiator hose housing is serviced as an assembly. Some thermostats snap into the engine radiator fill tube underneath the pressure cap.

CAUTION: Failure to set the thermostat into the recessed groove will cause the housing to become tilted when tightened. If this happens and the housing bolts are tightened, the housing will usually crack, creating a leak.

The upper hose should be installed and the system refilled. Install the correct size of radiator hose clamp.

RADIATORS

TYPES The two types of radiator cores in common use in most vehicles are

- Serpentine fin core
- Plate fin core

In each of these types, the coolant flows through oval-shaped **core tubes**. Heat is transferred through the tube wall and soldered joint to **cooling fins**. The fins are exposed to the air that flows through the radiator, which removes heat from the radiator and carries it away. ● **SEE FIGURES 18–11 AND 18–12**.

Older automobile radiators were made from yellow brass. Since the 1980s, most radiators have been made from aluminum with nylon-reinforced plastic side tanks. These materials are corrosion resistant, have good heat transferability, and are easily formed.

Core tubes are made from 0.0045 to 0.012 inch (0.1 to 0.3 mm) sheet brass or aluminum, using the thinnest possible materials for each application. The metal is rolled into round tubes and the joints are sealed with a locking seam.

The two basic designs of radiators include

1. **Down-flow radiators.** This design was used mostly in older vehicles, where the coolant entered the radiator at the top and flowed downward, exiting the radiator at the bottom.
2. **Cross-flow radiators.** Most radiators use a cross-flow design, where the coolant flows from one side of the radiator to the opposite side.

HOW RADIATORS WORK The main limitation of heat transfer in a cooling system is in the transfer from the radiator to the air. Heat transfers from the water to the fins as much as seven times faster than heat transfers from the fins to the air, assuming equal surface exposure. The radiator must be capable of removing an amount of heat energy approximately equal to the heat energy of

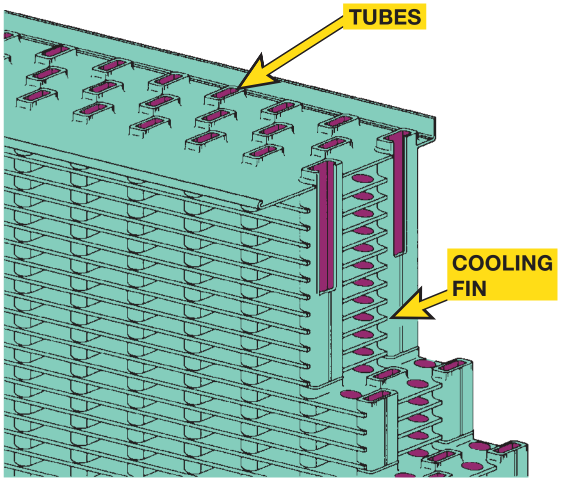


FIGURE 18–11 The tubes and fins of the radiator core.

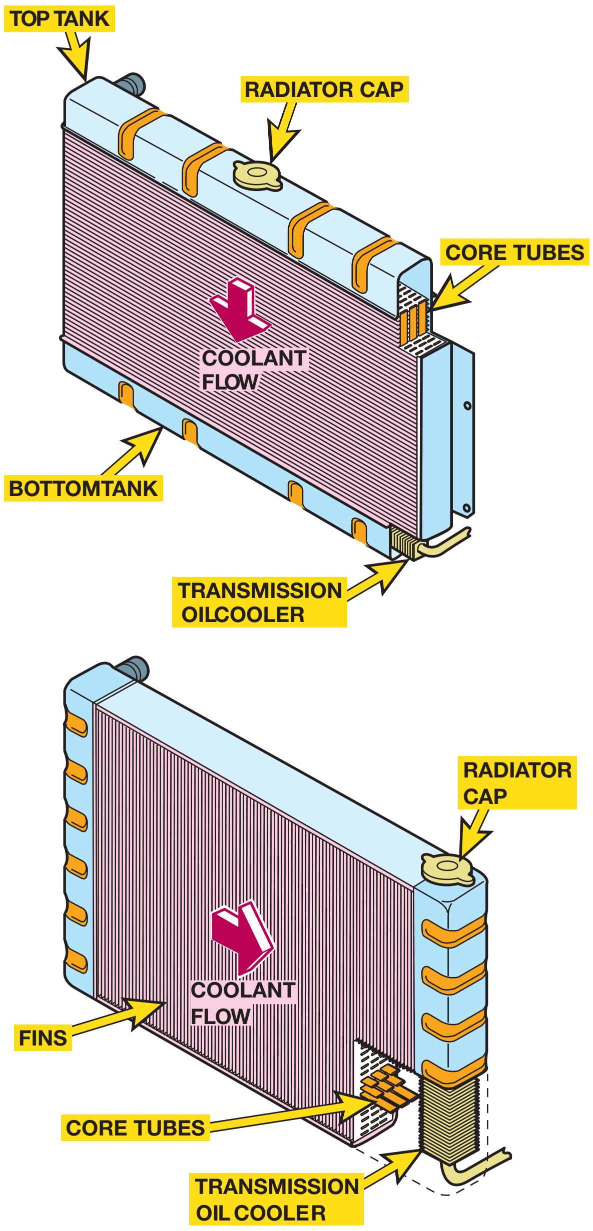


FIGURE 18–12 A radiator may be either a down-flow or a cross-flow type.

the power produced by the engine. *Each horsepower is equivalent to 42 BTUs (10,800 calories) per minute.* As the engine power is increased, the heat-removing requirement of the cooling system is also increased.

With a given frontal area, radiator capacity may be increased by increasing the core thickness, packing more material into the same volume, or both. The radiator capacity may also be increased by placing a shroud around the fan so that more air will be pulled through the radiator.

NOTE: The lower air dam in the front of the vehicle is used to help direct the air through the radiator. If this air dam is broken or missing, the engine may overheat, especially during highway driving due to the reduced airflow through the radiator.

When a transmission oil cooler is used in the radiator, it is placed in the outlet tank, where the coolant has the lowest temperature. ● **SEE FIGURE 18–13**.

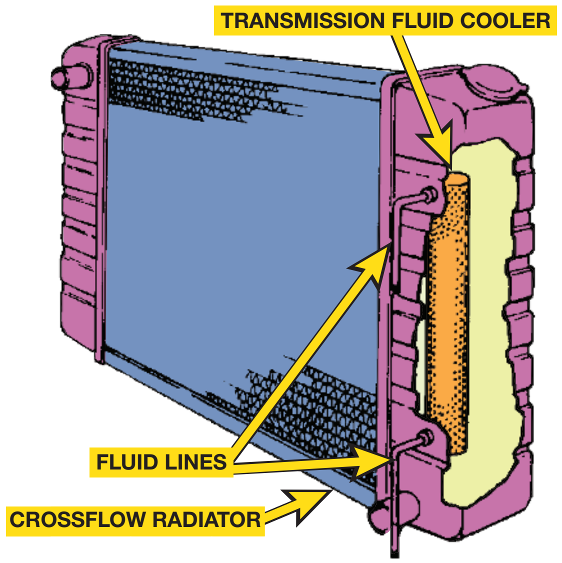


FIGURE 18–13 Many vehicles equipped with an automatic transmission use a transmission fluid cooler installed in one of the radiator tanks.

FREQUENTLY ASKED QUESTION

What Are Active Grille Shutters?

Located between the front grille and the condenser, the **active grille shutters (AGS)**, also called a *radiator shutter assembly*, are located between the front grille and the condenser. The plastic shutters open or close to control the airflow going under the hood. The primary function of the active grille shutters is to reduce the aerodynamic drag of the vehicle when closed. In a conventional vehicle, air is drawn through the grille and into the engine bay and passes through the radiator. Unless that engine is under a heavy load, or operating under extremely hot conditions, there is often more air entering the engine bay than is needed to keep the engine cool. However, the unnecessary air entering the engine bay can create aerodynamic drag, decreasing fuel economy. The higher the speed, the higher the aerodynamic drag. A typical active grille shutters operation includes the following:

- When open to increase cooling, about 60% of the air flows through the grille.
- When closed to increase fuel economy, only about 20% of the air flows through the grille.

Other benefits include improving the warm-up time of the engine and retaining engine heat when the vehicle is parked. ● **SEE FIGURE 18–14**.

PRESSURE CAPS

OPERATION All automotive cooling systems are equipped with a pressure cap somewhere in the cooling system. The cap has a spring-loaded valve that closes the cooling system vent. This causes cooling pressure to build up to the pressure setting of the cap. At this point, the valve will release the excess pressure to

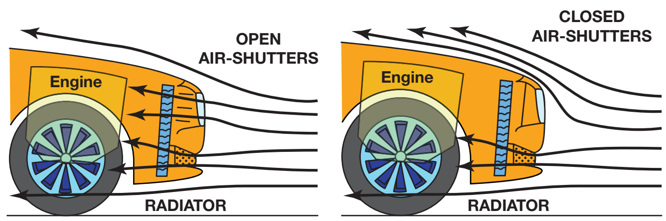


FIGURE 18–14 When the active grille shutters are closed, more air is diverted from entering the engine compartment reducing drag and improving fuel economy.

TECH TIP

Working Better under Pressure

A problem that sometimes occurs with a high-pressure cooling system involves the water pump. For the pump to function, the inlet side of the pump must have a lower pressure than its outlet side. If inlet pressure is lowered too much, the coolant at the pump inlet can boil, producing vapor. The pump will spin the coolant vapors and not pump coolant. This condition is called *pump cavitation.* Therefore, a radiator cap could be the cause of an overheating problem. A pump will not pump enough coolant if not kept under the proper pressure for preventing vaporization of the coolant.

prevent system damage. Engine cooling systems are pressurized to raise the boiling temperature of the coolant.

- *The boiling temperature will increase by approximately 3°F (1.6°C) for each pound of increase in pressure.*
- At sea level, water will boil at 212°F (100°C). With a 15 PSI (100 kPa) pressure cap, water will boil at 257°F (125°C), which is a maximum operating temperature for an engine.

FUNCTIONS The specified coolant system temperature serves two functions.

1. It allows the engine to run at an efficient temperature, close to 200°F (93°C), with no danger of boiling the coolant.
2. The higher the coolant temperature, the more heat the cooling system can transfer. The heat transferred by the cooling system is proportional to the temperature difference between the coolant and the outside air. This characteristic has led to the design of small, high-pressure radiators that are capable of handling large quantities of heat. For proper cooling, the system must have the right pressure cap correctly installed.

A vacuum valve is part of the pressure cap and is used to allow coolant to flow back into the radiator when the coolant cools down and contracts. ● **SEE FIGURE 18–15.**

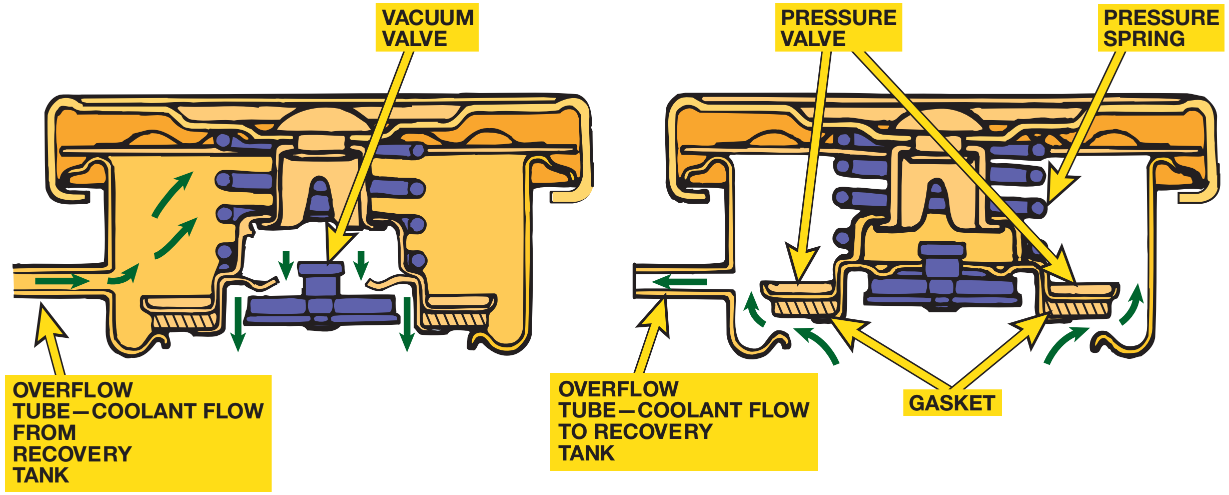
NOTE: The proper operation of the pressure cap is especially important at high altitudes. The boiling point of water is lowered by about 1°F for every 550 ft increase in altitude. Therefore, in Denver, Colorado (altitude 5,280 ft), the boiling point of water is about 202°F (94°C), and at the top of Pike's Peak in Colorado (14,110 ft) water boils at 186°F (86°C).

PRESSURE RATING According to the SAE Handbook, all radiator caps must indicate their nominal (normal) pressure rating. Most original equipment radiator caps are rated at about 14 to 16 PSI (97 to 110 kPa). Many vehicles manufactured in Japan or Europe use radiator pressure indicated in a unit called a **bar**. One bar is the pressure of the atmosphere at sea level, or about *14.7 PSI.* The conversions in ● **CHART 18–2** can be used when replacing a radiator cap, to make certain it matches the pressure rating of the original.

BAR OR ATMOSPHERES	POUNDS PER SQUARE INCH (PSI)
1.1	16
1.0	15
0.9	13
0.8	12
0.7	10
0.6	9
0.5	7

CHART 18–2

Comparison showing the metric pressure as shown on the top of the cap to pounds per square inch (PSI).



VACUUM VALVE OPERATION

PRESSURE VALVE OPERATION

FIGURE 18–15 The pressure valve maintains the system pressure and allows excess pressure to vent. The vacuum valve allows coolant to return to the system from the recovery tank.

COOLANT RECOVERY SYSTEMS

PURPOSE AND FUNCTION Excess pressure usually forces some coolant from the system through an overflow. Most cooling systems connect the overflow to a plastic reservoir to hold excess coolant while the system is hot. ● **SEE FIGURE 18–16**.

When the system cools, the pressure in the cooling system is reduced and a partial vacuum forms. This vacuum pulls the coolant from the plastic container back into the cooling system, keeping the system full. Because of this action, the system is called a **coolant recovery system**. A vacuum valve allows coolant to reenter the system as the system cools so that the radiator parts will not collapse under the partial vacuum.

CASE STUDY

The Collapsed Radiator Hose Story

An automotive student asked the automotive instructor what brand of radiator hose is the best. Not knowing exactly what to say, the instructor asked if there was a problem with the brand hose used. The student had tried three brands, and all of them collapsed when the engine cooled. The instructor then explained that the vehicle needed a new pressure cap and not a new upper radiator hose. The student thought that because the lower hose did not collapse that the problem *had* to be a fault with the hose. The instructor then explained that the lower radiator hose has a spring inside to keep the lower hose from collapsing due to the lower pressure created at the inlet to the water pump. The radiator cap was replaced, and the upper radiator hose did not collapse when the engine cooled.

Summary:

Complaint—An automotive student stated the upper radiator hose would collapse when the engine cools.
Cause—The upper radiator collapsed due to a fault with the radiator pressure cap.
Correction—A new radiator cap solved the problem of the upper radiator hose collapsing.

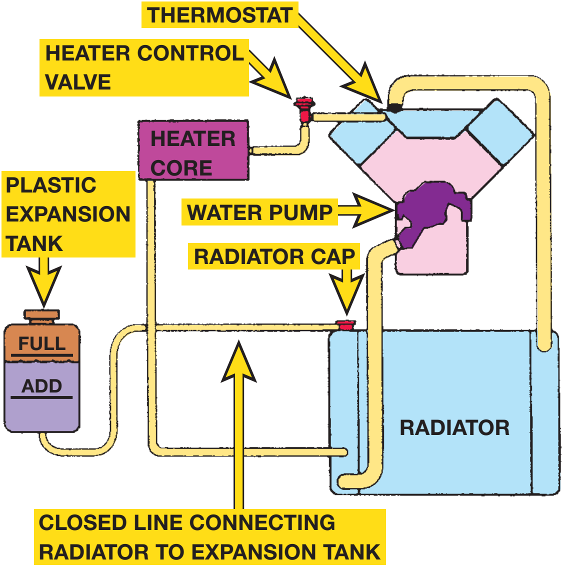


FIGURE 18–16 The level in the coolant recovery system raises and lowers with engine temperature.

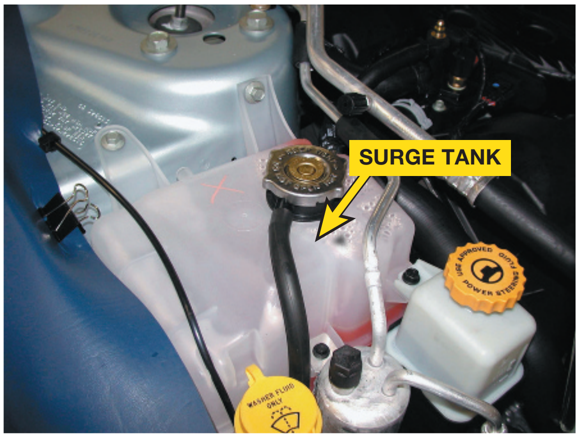


FIGURE 18–17 Some vehicles use a surge tank, which is located at the highest level of the cooling system, with a radiator cap.

SURGE TANK Some vehicles use a **surge tank**, which is located at the highest level of the cooling system and holds about 1 quart (1 liter) of coolant. A hose attaches to the bottom of the surge tank to the inlet side of the water pump. A smaller bleed hose attaches to the side of the surge tank to the highest point of the radiator. The bleed line allows some coolant circulation through the surge tank. Air in the system will rise below the radiator cap and be forced from the system if the pressure in the system exceeds the rating of the radiator cap. ● **SEE FIGURE 18–17**.

WATER PUMPS

OPERATION The water pump (also called a coolant pump) is driven by one of three methods:

- Crankshaft belt
- Camshaft
- Electric motor

Coolant recirculates from the radiator to the engine and back to the radiator. Low-temperature coolant leaves the radiator by the bottom outlet. It is pumped into the warm engine block, where it picks up some heat. From the block, the warm coolant flows to the hot cylinder head, where it picks up more heat.

NOTE: Some engines use reverse cooling. This means that the coolant flows from the radiator to the cylinder head(s) before flowing to the engine block.

Water pumps are not positive displacement pumps. The water pump is a **centrifugal pump** that can move a large volume of coolant without increasing the pressure of the coolant. The pump pulls coolant in at the center of the **impeller**. Centrifugal force throws the coolant outward so that it is discharged at the impeller tips. ● **SEE FIGURE 18–18**.

As engine speeds increase, more heat is produced by the engine and more cooling capacity is required. The pump impeller speed increases as the engine speed increases to provide extra coolant flow at the very time it is needed.

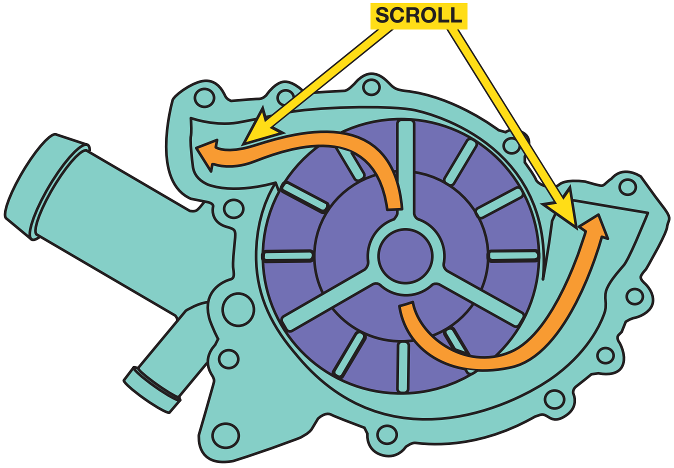


FIGURE 18–18 Coolant flow through the impeller and scroll of a coolant pump for a V-type engine.

Coolant leaving the pump impeller is fed through a **scroll**. The scroll is a smoothly curved passage that changes the fluid flow direction with minimum loss in velocity. The scroll is connected to the front of the engine so as to direct the coolant into the engine block. On V-type engines, two outlets are often used, one for each cylinder bank. Occasionally, diverters are necessary in the water pump scroll to equalize coolant flow between the cylinder banks of a V-type engine in order to equalize the cooling.

FREQUENTLY ASKED QUESTION

How Much Coolant Can a Water Pump Move?

A typical water pump can move a maximum of about 7,500 gallons (28,000 liters) of coolant per hour, or recirculate the coolant in the engine over 20 times per minute. This means that a water pump could be used to empty a typical private swimming pool in an hour! The slower the engine speed, the less power is consumed by the water pump. However, even at 35 mph (56 km/h), the typical water pump still moves about 2,000 gallons (7,500 liters) per hour or 0.5 gallon (2 liters) per second! ● **SEE FIGURE 18–19**.

FIGURE 18–19 A demonstration engine running on a stand, showing the amount of coolant flow that actually occurs through the cooling system.

ELECTRIC WATER PUMP An electric water pump uses a DC motor to power the impeller and is used on most hybrid electric vehicles and some internal combustion engines. The electric water pump usually is attached to the engine and is controlled by the powertrain control module (PCM). Being controlled by the PCM means that it can be operated only when needed to move coolant through the system instead of being powered by the engine at all times. Also, not circulating the coolant until needed allows the engine to reach operating temperature sooner than when using an engine-driven water pump. This results in increased efficiency for improved fuel economy and reduced exhaust emissions.

WATER PUMP SERVICE A worn impeller on a water pump can reduce the amount of coolant flow through the engine. ● **SEE FIGURE 18–20**.

If the seal of the water pump fails, coolant will leak out of the weep hole. The hole allows coolant to escape without getting trapped and forced into the water pump bearing assembly. ● **SEE FIGURE 18–21**.

If the bearing is defective, the pump will usually be noisy and will have to be replaced. Before replacing a water pump

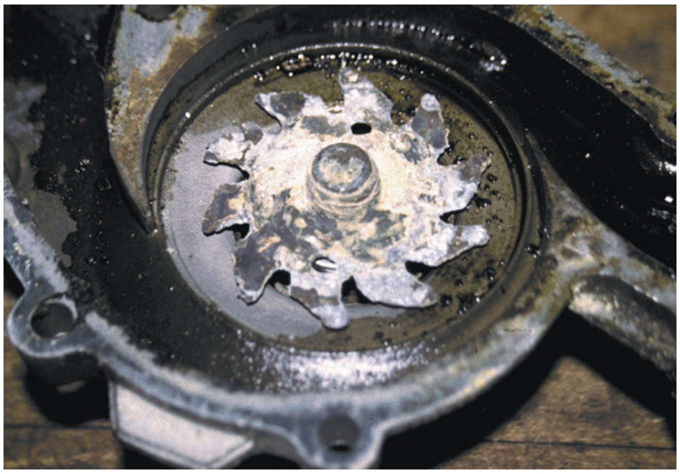


FIGURE 18–20 This severely corroded water pump could not circulate enough coolant to keep the engine cool. As a result, the engine overheated and blew a head gasket.

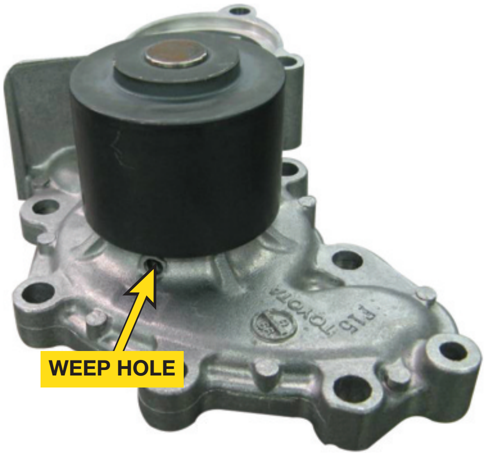


FIGURE 18–21 The bleed weep hole in the water pump allows coolant to leak out of the pump and not be forced into the bearing. If the bearing failed, more serious damage could result.

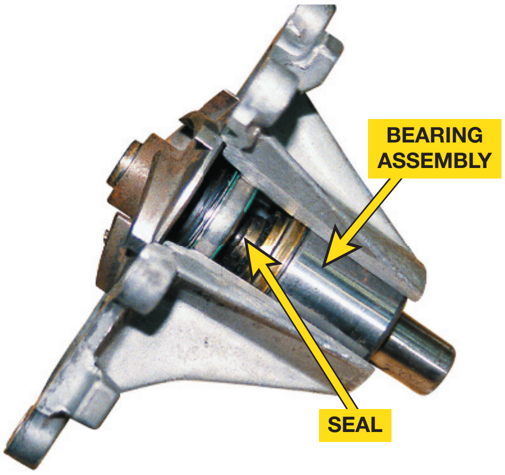


FIGURE 18–22 A cutaway of a typical water pump showing the long bearing assembly and the seal. The weep hole is located between the seal and the bearing. If the seal fails, coolant flows out of the weep hole to prevent the coolant from damaging the bearing.

TECH TIP

Release the Belt Tension before Checking a Water Pump

The technician should release water pump belt tension before checking for water pump bearing looseness. To test a water pump bearing, it is normal to check the fan for movement; however, if the drive belt is tight, any looseness in the bearing will not be felt.

that has failed because of a loose or noisy bearing, check all of the following:

1. Drive belt tension
2. Bent fan
3. Fan for balance

If the water pump drive belt is too tight, excessive force may be exerted against the pump bearing. If the cooling fan is bent or out of balance, the resulting vibration can damage the water pump bearing. ● **SEE FIGURE 18–22**.

AUXILIARY WATER PUMPS

PURPOSE An auxiliary water pump is a DC motor-operated water pump that is used to circulate coolant to the heater core. These pumps are used on many newer vehicles equipped with stop/start systems to improve driver comfort. Hybrid electric vehicles have an electric water pump to cool the battery packs and inverters, and some hybrids will have a second pump for the heater core in the cabin. Most vehicles with stop/start systems also use electric pumps for the oil and transmission fluid.

MODES OF OPERATION The auxiliary water pump does not operate all the time. The coolant may travel through the transmission cooler and windshield washer fluid bottle on some models. The BCM or controlling module will control and regulate the pump based on the following:

- Battery voltage
- Exterior temperature
- Interior temperature
- Vehicle speed
- Engine RPM
- Temperature selected by the driver
- Blend door position

The technician should check to see if the vehicle is equipped with an auxiliary water pump before replacing the thermostat. If the auxiliary water pump fails on some hybrids, the system will disable the hybrid drive system or put the vehicle into a limp mode.

DIAGNOSIS The diagnostic process includes the following steps:

STEP 1 Verify the customer's concern. Operate the vehicle under the same conditions as the customer to verify a lack of cabin heating.

STEP 2 Perform a thorough visual inspection of the engine cooling system looking for leaks, coolant level, condition, and other possible reasons for a lack of cabin heat.

STEP 3 Check for codes with a scan tool. For example, a P2600 on a Mercedes indicates a fault with the auxiliary water pump or water pump circuit. Some codes may appear to be unrelated such as door module operation and loss of communications, but they can cause the auxiliary pump to stop operating. A scan tool can be used to command the pump on and off so its operation can be tested.

STEP 4 Check service information for the exact diagnostic procedure to follow for the vehicle being diagnosed. The electric auxiliary water pump may be called an auxiliary cooling circuit in the service information.

COOLANT FLOW IN THE ENGINE

TYPES OF SYSTEMS Coolant flows through the engine in one of the following ways:

- **Parallel flow system.** In the **parallel flow system**, coolant flows into the block under pressure and then crosses the head gasket to the head through main coolant passages beside each cylinder.
- **Series flow system.** In the **series flow system**, the coolant flows around all the cylinders on each bank. The coolant then enters the rear of the heads. In the heads, the coolant flows forward to a crossover passage on the intake manifold outlet at the *highest point* in the engine cooling passage. This is usually located at the front of the engine. The outlet is either on the heads or in the intake manifold. ● **SEE FIGURE 18–23**.
- **Series-parallel flow system.** Some engines use a combination of these two coolant flow systems and call it a **series-parallel flow system**. Any steam that develops will go directly to the top of the radiator. In series flow systems,

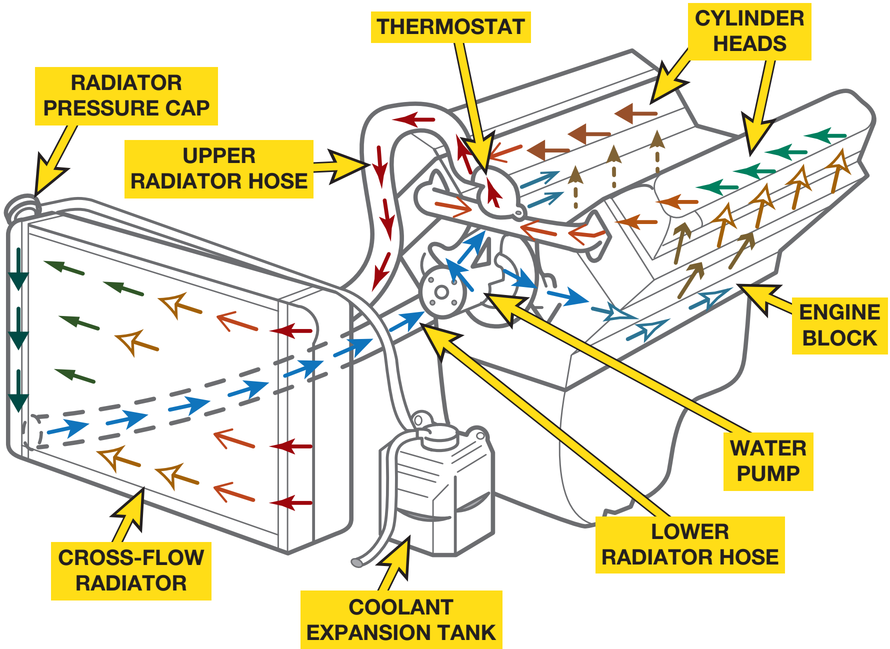

THERMOSTAT
CYLINDER HEADS
RADIATOR PRESSURE CAP
UPPER RADIATOR HOSE
ENGINE BLOCK
WATER PUMP
LOWER RADIATOR HOSE
CROSS-FLOW RADIATOR
COOLANT EXPANSION TANK

FIGURE 18–23 A series-type cooling system where the coolant first flows through the engine block, then to the heads, before returning to the radiator after passing through the thermostat.

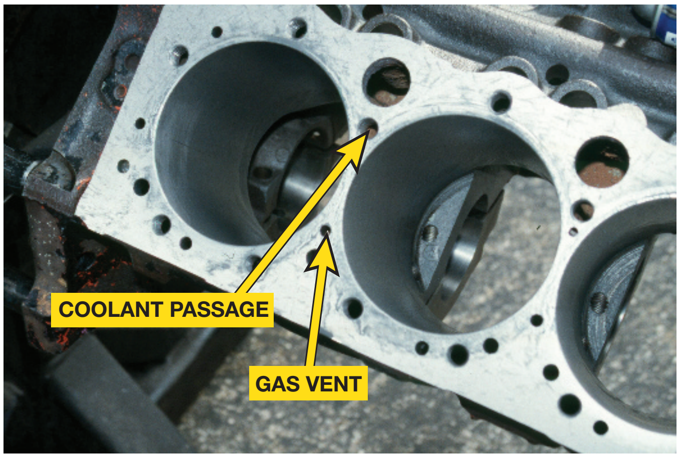

COOLANT PASSAGE
GAS VENT

FIGURE 18–24 A Chevrolet V-8 block that shows the large coolant holes and the smaller gas vent or bleed holes that must match the head gasket when the engine is assembled.

bleed holes or **steam slits** in the gasket, block, and head perform the function of letting out the steam.

COOLANT FLOW AND HEAD GASKET DESIGN Most V-type engines use cylinder heads that are interchangeable side to side, but not all engines. ● **SEE FIGURE 18–24**.

COOLING FANS

ELECTRONICALLY CONTROLLED COOLING FAN Two types of electric cooling fans used on many engines include

- One two-speed cooling fan
- Two cooling fans (one for normal cooling and one for high heat conditions)

The PCM commands low-speed fans on under the following conditions.

- Engine coolant temperature exceeds approximately 223°F (106°C).
- A/C refrigerant pressure exceeds 190 PSI (1,310 kPa).

The PCM commands the high-speed fan on under the following conditions.

- ECT reaches 230°F (110°C).
- A/C refrigerant pressure exceeds 240 PSI (1,655 kPa).
- Certain diagnostic trouble codes (DTCs) set.

To prevent a fan from cycling on and off excessively at idle, the fan may not turn off until the ignition switch is moved to the off position or the vehicle speed exceeds approximately 10 mph (16 km/h).

Many rear-wheel-drive vehicles and all transverse engines drive the fan with an electric motor. ● **SEE FIGURE 18–25**.

NOTE: Most electric cooling fans are computer controlled. To save energy, most cooling fans are turned off whenever the vehicle is traveling faster than 35 mph (55 km/h). The ram air caused by the vehicle speed is enough to keep the radiator cool. Of course, if the computer senses that the temperature is still too high, the computer will turn on the cooling fan, to "high," if possible, in an attempt to cool the engine to avoid severe engine damage.

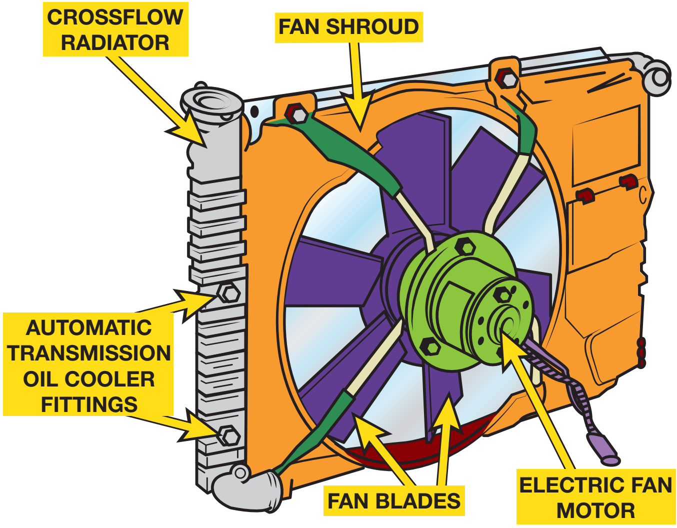

CROSSFLOW RADIATOR
FAN SHROUD
AUTOMATIC TRANSMISSION OIL COOLER FITTINGS
FAN BLADES
ELECTRIC FAN MOTOR

FIGURE 18–25 A typical electric cooling fan assembly showing the radiator and related components.

WARNING

Some electric cooling fans can come on, after the engine is off, without warning. Always keep hands and fingers away from the cooling fan blades unless the electrical connector has been disconnected to prevent the fan from coming on. Always follow all warnings and cautions.

THERMOSTATIC FANS On some rear-wheel-drive vehicles, a thermostatic cooling fan is driven by a belt from the crankshaft. It turns faster as the engine turns faster. Generally, the engine is required to produce more power at higher speeds. Therefore, the cooling system will also transfer more heat. Increased fan speed aids in the required cooling. Engine heat also becomes critical at low engine speeds in traffic where the vehicle moves slowly. The thermostatic fan is designed so that it uses little power at high engine speeds and minimizes noise. Two types of thermostatic fans include

1. **Silicone coupling.** The **silicone coupling** fan drive is mounted between the drive pulley and the fan.

NOTE: When diagnosing an overheating problem, look carefully at the cooling fan. If silicone is leaking, the fan may not be able to function correctly and should be replaced.

2. **Thermostatic spring.** A second type of thermal fan has a **thermostatic spring** added to the silicone coupling fan drive. The thermostatic spring operates a valve that allows the fan to freewheel when the radiator is cold. As the radiator warms to about 150°F (65°C), the air hitting the thermostatic spring will cause the spring to change its shape. The new shape of the spring opens a valve that allows the drive to operate like the silicone coupling drive. When the engine is very cold, the fan may operate at high speeds for a short time until the drive fluid warms slightly. The silicone fluid will then flow into a reservoir to let the fan speed drop to idle. ● **SEE FIGURE 18–26**.

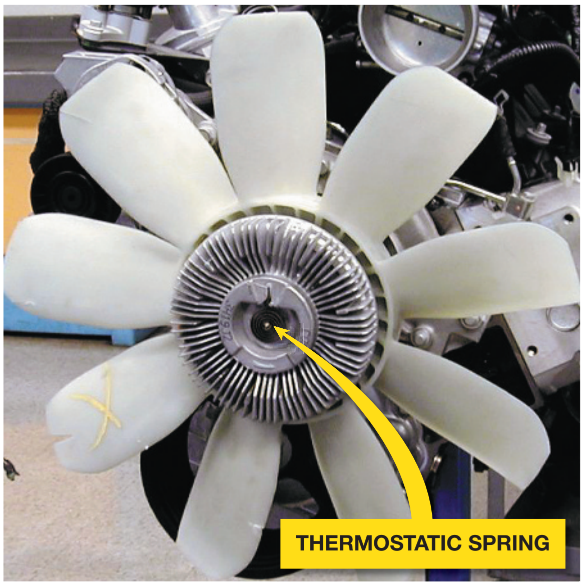


FIGURE 18–26 A typical engine-driven thermostatic spring cooling fan.

TECH TIP

Be Sure to Always Use a Fan Shroud

A fan shroud forces the fan to draw air through the radiator. If a fan shroud is not used, air is drawn from around the fan and will reduce the airflow through the radiator. Many overheating problems are a result of not replacing the factory shroud after engine work or body repair work to the front of the vehicle.

The fan is designed to move enough air at the lowest fan speed to cool the engine when it is at its highest coolant temperature. The fan shroud is used to increase the cooling system efficiency.

HEATER CORES

PURPOSE AND FUNCTION Most of the heat absorbed from the engine by the cooling system is wasted. Some of this heat, however, is recovered by the vehicle heater. Heated coolant is passed through tubes in the small core of the heater. Air is passed across the heater fins and is sent to the passenger compartment. In some vehicles, the heater and air conditioning work in series to maintain vehicle compartment temperature. ● **SEE FIGURE 18–27**.

HEATER PROBLEM DIAGNOSIS When the heater does not produce the desired amount of heat, many owners and technicians replace the thermostat before doing any other troubleshooting. It is true that a defective thermostat is the reason for the *engine* not to reach normal operating temperature, but there are many other causes besides a defective thermostat that can result in lack of heat from the heater. To determine the exact cause, follow this procedure.

STEP 1 After the engine has been operated, feel the upper radiator hose. If the engine is up to proper operating temperature, the upper radiator hose should be too hot to hold. The hose should also be pressurized.

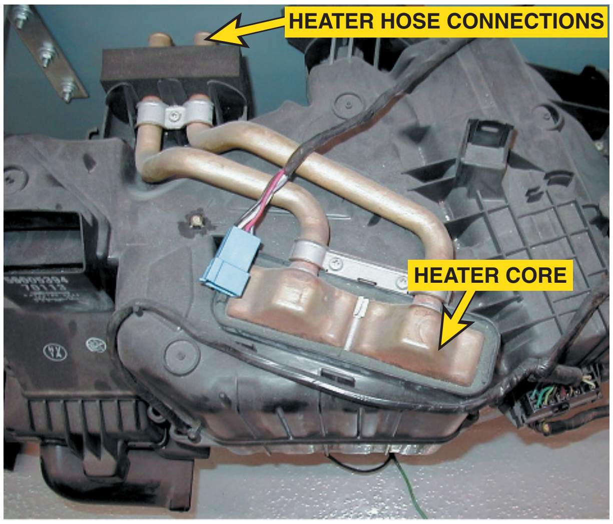


FIGURE 18–27 A typical heater core installed in a heating, ventilation, and air-conditioning (HVAC) housing assembly.

a. If the hose is not hot enough, replace the thermostat.

b. If the hose is not pressurized, test or replace the radiator pressure cap if it will not hold the specified pressure.

c. If okay, see step 2.

STEP 2 With the engine running, feel both heater hoses. (The heater should be set to the maximum heat position.) Both hoses should be too hot to hold. If both hoses are warm (not hot) or cool, check the heater control valve for proper operation (if equipped). If one hose is hot and the other (return) is just warm or cool, remove both hoses from the heater core or engine and flush the heater core with water from a garden hose.

STEP 3 If both heater hoses are hot and there is still a lack of heating concern, then the fault is most likely due to an airflow blend door malfunction. Check service information for the exact procedure to follow.

NOTE: Heat from the heater that "comes and goes" is most likely the result of low coolant level. Usually with the engine at idle, there is enough coolant flow through the heater. At higher engine speeds, however, the lack of coolant through the heads and block prevents sufficient flow through the heater.

COOLING SYSTEM TESTING

VISUAL INSPECTION Many cooling system faults can be found by performing a thorough visual inspection. Items that can be inspected visually include

- Water pump drive belt for tension or faults
- Cooling fan for faults
- Heater and radiator hoses for condition and leaks
- Coolant overflow or surge tank coolant level
- Evidence of coolant loss
- Radiator condition ● **SEE FIGURE 18–28**.

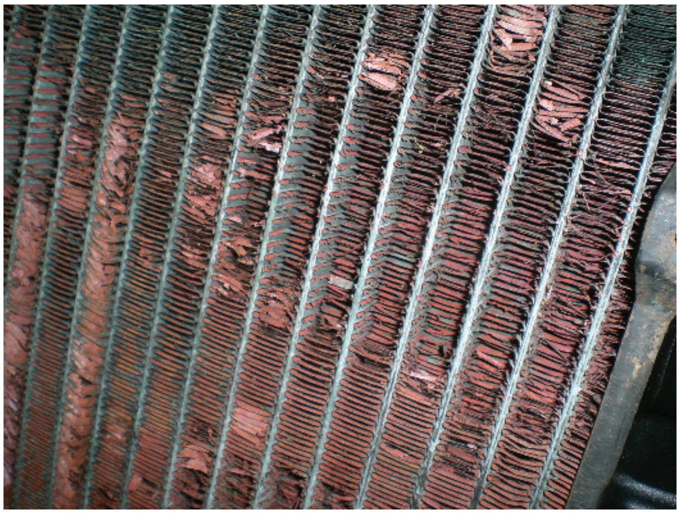


FIGURE 18–28 A heavily corroded radiator from a vehicle that was overheating. A visual inspection discovered that the corrosion had eaten away many of the cooling fins, yet did not leak. This radiator was replaced, and it solved the overheating problem.

PRESSURE TESTING Pressure testing using a hand-operated pressure tester is a quick and easy cooling system test. The radiator cap is removed (engine cold!) and the tester is attached in the place of the radiator cap. By operating the plunger on the pump, the entire cooling system is pressurized. ● **SEE FIGURE 18–29**.

CAUTION: Do not pump up the pressure beyond that specified by the vehicle manufacturer. Most systems should not be pressurized beyond 14 PSI (100 kPa). If a greater pressure is used, it may cause the water pump, radiator, heater core, or hoses to fail.

If the cooling system is free from leaks, the pressure should stay and not drop. If the pressure drops, look for evidence of leaks anywhere in the cooling system, including

1. Heater hoses
2. Radiator hoses
3. Radiator
4. Heater core
5. Cylinder head
6. Core plugs in the side of the block or cylinder head

Pressure testing should be performed whenever there is a leak or suspected leak. The pressure tester can also be used to test the radiator cap. An adapter is used to connect the pressure tester to the radiator cap. Replace any cap that will not hold pressure. ● **SEE FIGURE 18–30**.

COOLANT DYE LEAK TESTING One of the best methods to check for a coolant leak is to use a fluorescent dye in the coolant, one that is specifically designed for coolant. Operate the vehicle with the dye in the coolant until the engine reaches normal operating temperature. Use a black light to inspect all areas of the cooling system. When there is a leak, it will be easy to spot because the dye in the coolant will be seen as bright green. ● **SEE FIGURE 18–31**.

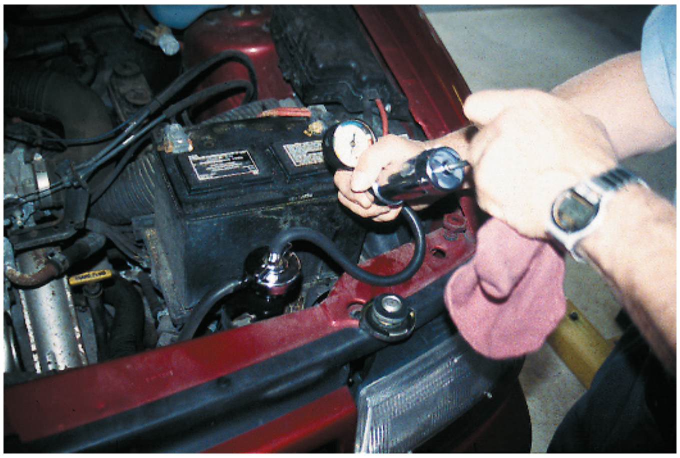


FIGURE 18–29 Pressure testing the cooling system. A typical hand-operated pressure tester applies pressure equal to the radiator cap pressure. The pressure should hold; if it drops, this indicates a leak somewhere in the cooling system. An adapter is used to attach the pump to the cap to determine if the radiator can hold pressure, and release it when pressure rises above its maximum rated pressure setting.

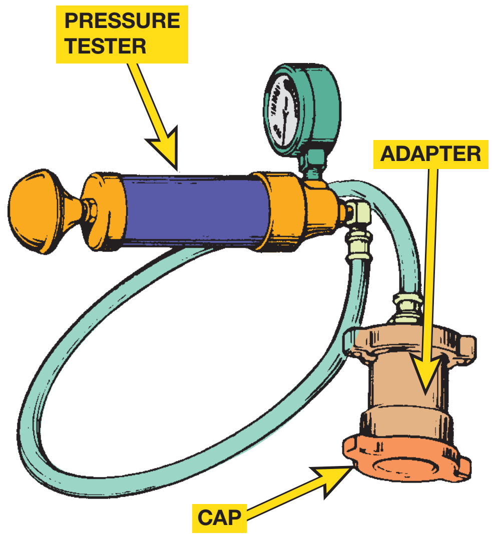


FIGURE 18–30 The pressure cap should be checked for proper operation using a pressure tester as part of the cooling system diagnosis.

GM
Goodwrench
Coolant System
Fluorescent Tracer
Dye
See Warning on Back Panel
NET CONTENTS
1 FL. OZ. (30cc)

FIGURE 18–31 Use dye specifically made for coolant when checking for leaks using a black light.

COOLANT TEMPERATURE WARNING LIGHT

PURPOSE AND FUNCTION Most vehicles are equipped with a heat sensor for the engine operating temperature indicator light. If the warning light comes on during driving (or the temperature gauge goes into the red danger zone), the coolant temperature is about 250°F to 258°F (120°C to 126°C), which is still *below* the boiling point of the coolant (assuming a properly operating pressure cap and system). ● **SEE FIGURE 18–32.**

PRECAUTIONS If the coolant temperature warning light comes on, follow these steps:

STEP 1 Shut off the air conditioning and turn on the heater. The heater will help rid the engine of extra heat. Set the blower speed to high.

STEP 2 If possible, shut the engine off and let it cool. (This may take over an hour.)

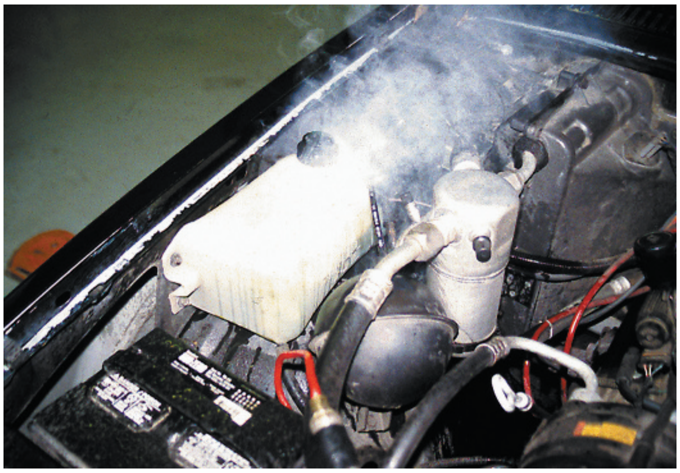


FIGURE 18–32 When an engine overheats, often the coolant overflow container boils.

STEP 3 Never remove the radiator cap when the engine is hot.

STEP 4 Do *not* continue to drive with the hot light on, or serious damage to your engine could result.

STEP 5 If the engine does not feel or smell hot, it is possible that the problem is a faulty hot light sensor or gauge. Continue to drive, but to be safe, stop occasionally and check for any evidence of overheating or coolant loss.

COMMON CAUSES OF OVERHEATING Overheating can be caused by defects in the cooling system, such as the following:

1. Low coolant level
2. Plugged, dirty, or blocked radiator
3. Defective fan clutch or electric fan
4. Low engine oil level
5. Broken fan drive belt
6. Defective radiator cap
7. Dragging brakes
8. Frozen coolant (in freezing weather)
9. Defective thermostat
10. Defective water pump (the impeller slipping on the shaft internally)
11. Blocked cooling passages in the block or cylinder head(s)

COOLING SYSTEM INSPECTION

COOLANT LEVEL The cooling system is one of the most maintenance-free systems in the engine. Normal maintenance involves an occasional check on the coolant level. It should also include a visual inspection for signs of coolant system leaks and for the condition of the coolant hoses and fan drive belts.

ACCESSORY DRIVE BELT TENSION Drive belt condition and proper installation are important for the proper operation of the cooling system.

There are four ways vehicle manufacturers specify that the belt tension is within factory specifications.

CASE STUDY

Highway Overheating

A vehicle owner complained of an overheating vehicle, but the problem occurred only while driving at highway speeds. The vehicle, equipped with a 4-cylinder engine, would run in a perfectly normal manner in city driving situations.

The technician flushed the cooling system and replaced the radiator cap and the water pump, thinking that restricted coolant flow was the cause of the problem. Further testing revealed coolant spray out of one cylinder when the engine was turned over by the starter with the spark plugs removed.

A new head gasket solved the problem. Obviously, the head gasket leak was not great enough to cause any problems until the engine speed and load created enough flow and heat to cause the coolant temperature to soar.

The technician also replaced the oxygen (O_2) sensor.

Summary:

Complaint—Customer stated that the engine would overheat, but only if driven at highway speed.
Cause—The root cause was determined to be a defective head gasket.
Correction—The head gasket was replaced and the oxygen sensor was also replaced because coolant can cause the sensor to read incorrectly. Replacing the oxygen sensor was done to be insured that the engine ran correctly.

1. **Belt tension gauge.** A belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on, to run in the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications or use ● **CHART 18–3** for an example of the proper tension based on the size of the belt. Replace any serpentine belt that has more than three cracks in any one rib that appears in a 3-inch span, or is worn based on a belt wear gauge test result. For more information, visit www.gates.com.
2. **Marks on the tensioner.** Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the location of the tensioner mark. ● **SEE FIGURE 18–33**.

NUMBER OF RIBS USED	TENSION RANGE (LB.)
3	45 to 60
4	60 to 80
5	75 to 100
6	90 to 125
7	105 to 145

CHART 18–3

The number of ribs determines the tension range of the belt.

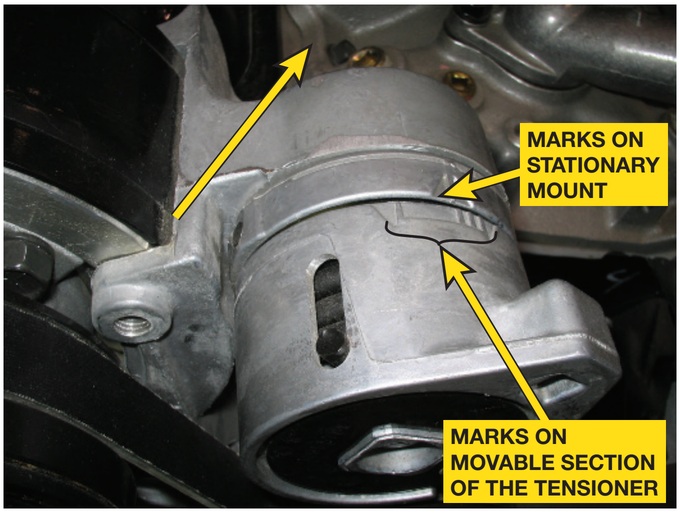

MARKS ON STATIONARY MOUNT
MARKS ON MOVABLE SECTION OF THE TENSIONER

FIGURE 18–33 Typical marks on an accessory drive belt tensioner.

TECH TIP

The Water Spray Trick

Lower-than-normal alternator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the Vs of the belt and the angle of the Vs on the pulley. A belt wears this interference angle off the edges of the V of the belt. As a result, the belt may start to slip and make a squealing sound even if tensioned properly.

A common trick to determine if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running. If the noise stops, the belt is the cause of the noise. The water quickly evaporates and therefore, water just finds the problem—it does not provide a short-term fix.

WARNING

The coolant level should only be checked when the engine is cool. Removing the pressure cap from a hot engine will release the cooling system pressure while the coolant temperature is above its atmospheric boiling temperature. When the cap is removed, the pressure will instantly drop to atmospheric pressure level, causing the coolant to boil immediately. Vapors from the boiling liquid will blow coolant from the system. Coolant will be lost, and someone may be injured or burned by the high-temperature coolant that is blown out of the filler opening.

3. **Torque wrench reading.** Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced.
4. **Deflection.** Depress the belt between the two pulleys that are the farthest apart and the flex or deflection should be 1/2 inch.

COOLING SYSTEM SERVICE

FLUSHING COOLANT Flushing the cooling system includes the following steps:

STEP 1 Drain the system (dispose of the old coolant correctly).

STEP 2 Fill the system with clean water and a flushing/cleaning chemical.

STEP 3 Start the engine until it reaches operating temperature with the heater on.

STEP 4 Drain the system and fill with clean water.

STEP 5 Repeat until drain water runs clear (any remaining flush agent will upset the pH).

STEP 6 Fill the system with 50/50 antifreeze/water mix or premixed coolant.

STEP 7 Start the engine until it reaches operating temperature with the heater on.

STEP 8 Adjust coolant level as needed.

Bleeding the air out of the cooling system is important because air can prevent proper operation of the heater and can cause the engine to overheat. Use a clear hose attached to the bleeder valve and the other end in a suitable container. This prevents coolant from getting on the engine and gives the technician a visual clue as to the color of coolant. ● **SEE FIGURE 18–34**.

Check service information for specific bleeding procedures and location of the air bleeder fittings.

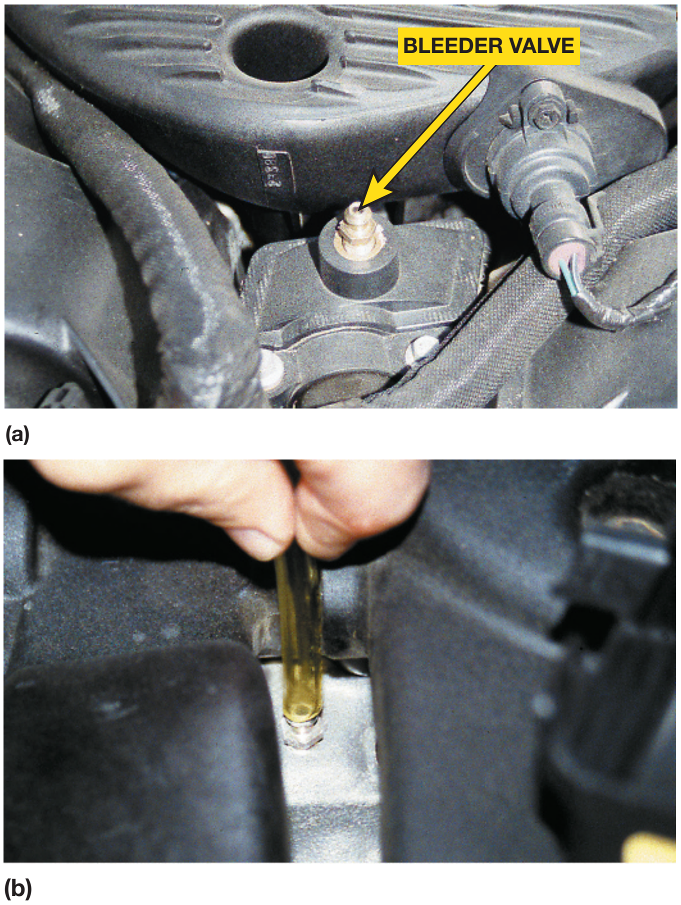


FIGURE 18–34 (a) Many vehicle manufacturers recommend that the bleeder valve be opened whenever refilling the cooling system. (b) Chrysler recommends that a clear plastic hose (1/4 inch ID) be attached to the bleeder valve and directed into a suitable container to keep from spilling coolant onto the ground and on the engine, and to allow the technician to observe the flow of coolant for any remaining air bubbles.

VACUUM FILL METHOD Trapped air in the cooling system leads to all kinds of problems, including

- Overheating
- Erratic temperature readings
- Possible PCM diagnostic trouble codes

A vacuum tool can be used to eliminate air from the cooling system by drawing a vacuum on the system, and then pull the fresh coolant into the system. The typical steps involved are as follows:

STEP 1 Connect an air compressor capable of supplying at least 90 PSI of air pressure.

STEP 2 Insert the vacuum lift tool into the neck of the radiator service port or reservoir tank using the appropriate adapter.

STEP 3 Connect the airline to the vacuum unit. The air blowing over the venturi valve draws a vacuum. Turn the unit off once the vacuum reaches 24–26 inches of vacuum.

STEP 4 Insert the fill hose into the coolant (50/50 pre-mix is recommended) container. Once the vacuum gauge reaches zero, the system is full.

COOLANT EXCHANGE MACHINE Many coolant exchange machines are able to perform one or more of the following operations:

- Exchange old coolant with new coolant
- Flush the cooling system
- Pressure or vacuum check the cooling system for leaks

The use of a coolant exchange machine pulls a vacuum on the cooling system, which helps eliminate air pockets from forming during coolant replacement. If an air pocket were to occur, the following symptoms may occur:

1. **Lack of heat from the heater.** Air rises and can form in the heater core, which will prevent coolant from flowing.
2. **Overheating.** The engine can overheat due to the lack of proper coolant flow through the system.

Always follow the operating instructions for the coolant exchange machine being used. ● **SEE FIGURE 18–35**.

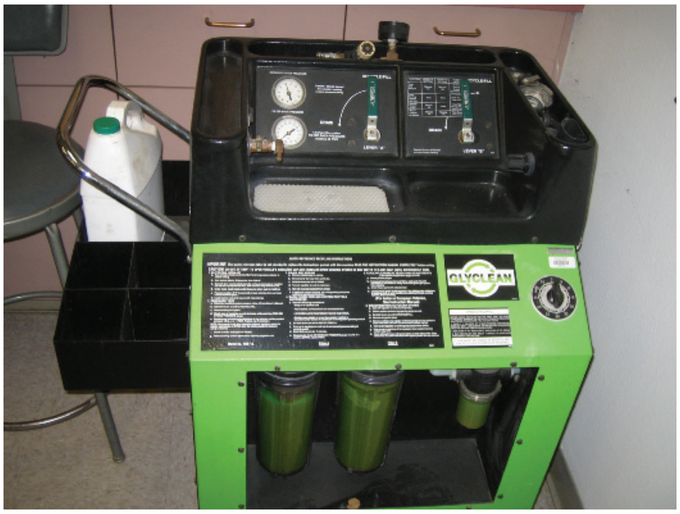


FIGURE 18–35 Using a coolant exchange machine helps eliminate the problem of air getting into the system, which can cause overheating or lack of heat due to air pockets getting trapped in the system.

TECH TIP

Always Replace the Pressure Cap

Replace the old radiator cap with a new cap with the same pressure rating. The cap can be located on the following:

1. Radiator
2. Coolant recovery reservoir
3. Upper radiator hose

WARNING: Never remove a pressure cap from a hot engine. When the pressure is removed from the system, the coolant will immediately boil and will expand upward, throwing scalding coolant in all directions. Hot coolant can cause serious burns.

HOSE INSPECTION Coolant system hoses are critical to engine cooling. As the hoses get old, they become either soft or brittle and sometimes swell in diameter. Their condition depends on their material and on the engine service conditions. If a hose breaks while the engine is running, all coolant will be lost. A hose should be replaced any time it appears to be abnormal.

NOTE: To make hose removal easier and to avoid possible damage to the radiator, use a utility knife and slit the hose lengthwise. Then simply peel the hose off.

The hose and hose clamp should be positioned so that the clamp is close to the bead on the neck. This is especially important on aluminum hose necks to avoid corrosion. When the hoses are in place and the drain petcock is closed, the cooling system can be refilled with the correct coolant mixture.

DISPOSING OF USED COOLANT Used coolant drained from vehicles should be disposed of according to state or local laws. Some communities permit draining into the sewer. Ethylene glycol will easily biodegrade. There could be problems with groundwater contamination, however, if coolant is spilled on open ground. Check with recycling companies authorized by local or state governments for the exact method recommended for disposal in your area.

CLEANING THE RADIATOR EXTERIOR Overheating can result from exterior and interior radiator plugging. External plugging is caused by dirt and insects. This type of plugging can be seen if you look straight through the radiator while a light is held behind it. It is most likely to occur on off-road vehicles. The plugged exterior of the radiator core can usually be cleaned with water pressure from a hose. The water is aimed at the *engine side* of the radiator. The water should flow freely through the core at all locations. If this does not clean the core, the radiator should be removed for cleaning at a radiator shop.

HOSE CLAMPS There are several types of hose clamps used, depending on the make, model, and year of the vehicle. The three basic types are as follows:

1. Worm drive (also called a screw band type)
2. Banded-type clamp
3. Wire clamp (spring type) ● **SEE FIGURE 18–36**.

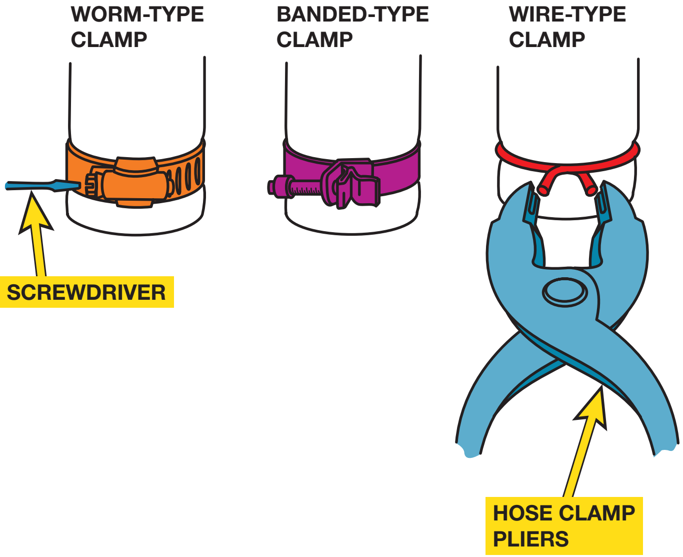


FIGURE 18–36 Hose clamps come in a variety of shapes and designs.

TECH TIP

Quick and Easy Cooling System Problem Diagnosis

1. If overheating occurs in slow stop-and-go traffic, the usual cause is low airflow through the radiator. Check for airflow blockages or cooling fan malfunction.
2. If overheating occurs at highway speeds, the cause is usually a radiator or coolant circulation problem. Check for a restricted or clogged radiator.

TECH TIP

Always Use Heater Hoses Designed for Coolant

Many heater hoses are sizes that can also be used for other purposes, such as oil lines. Always check and use hose that states it is designed for heater or cooling system use. ● **SEE FIGURE 18–37**.

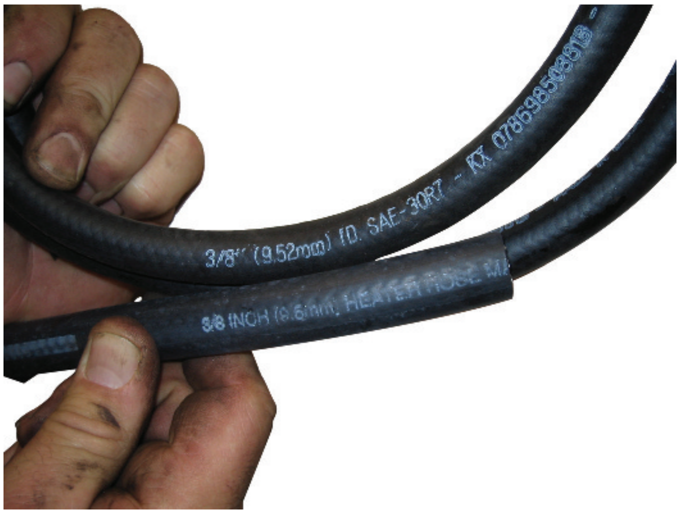

3/8" (9.52mm) I.D. SAE-30R7 - KX 0786985
3/8 INCH (9.5mm) HEATER HOSE

FIGURE 18–37 The top 3/8 inch hose is designed for oil and similar liquids, whereas the 3/8 inch hose below is labeled "heater hose" and is designed for coolant.

REVIEW QUESTIONS

1. What is normal operating coolant temperature?
2. How does coolant flow through the engine and radiator?
3. Why is a cooling system pressurized?
4. How is a heater problem diagnosed?
5. What are 10 common causes of overheating?

CHAPTER QUIZ

1. What diagnostic trouble code (DTC) could be set if the thermostat is defective?
   - **a.** P0300
   - **b.** P0171
   - **c.** P0440
   - **d.** P0128
2. What is the purpose of the lower air dam in the front of vehicles?
   - **a.** To help direct the air through the radiator
   - **b.** To direct the air to the automatic transmission
   - **c.** To improve the looks of the vehicle
   - **d.** Both b and c
3. What type of pump is a water pump?
   - **a.** Positive displacement
   - **b.** Centrifugal pump
   - **c.** Vane-type pump
   - **d.** Gear-type pump
4. Which of these tools is useful when testing the cooling system?
   - **a.** A pressure tester
   - **b.** A compression gauge
   - **c.** A vacuum gauge
   - **d.** All of the above
5. When the engine is hot, where does the excess coolant go when it expands in the radiator?
   - **a.** Drains on the ground
   - **b.** Gets trapped in the radiator
   - **c.** Into the recovery system
   - **d.** None of the above
6. The normal operating temperature (coolant temperature) of an engine equipped with a 195°F thermostat is ________.
   - **a.** 175°F to 195°F
   - **b.** 185°F to 205°F
   - **c.** 195°F to 215°F
   - **d.** 175°F to 215°F
7. The upper radiator hose collapses when the engine cools. What is the most likely cause?
   - **a.** Defective upper radiator hose
   - **b.** Missing spring from the upper radiator hose, which is used to keep it from collapsing
   - **c.** Defective thermostat
   - **d.** Defective radiator pressure cap
8. A customer complains that the heater works sometimes, but sometimes only cold air comes out while driving. Technician A says that the water pump is defective. Technician B says that the cooling system could be low on coolant. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. Technician A says that dirty or blocked radiator can cause the engine to overheat. Technician B says that overheating can be caused by a defective water pump. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. What can be done to prevent air from getting trapped in the cooling system when the coolant is replaced?
    - **a.** Pour the coolant into the radiator slowly.
    - **b.** Use a coolant exchange machine that draws a vacuum on the system.
    - **c.** Open the air bleeder valves while adding coolant.
    - **d.** Either b or c.

Chapter 19

ENGINE OIL AND FILTERS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and function of engine oil.
- Explain the purpose of engine oil additives.
- Discuss the properties of engine oil.
- Discuss SAE rating.
- Discuss API rating.
- Discuss ILSAC oil rating.
- Discuss the European oil rating system.
- Discuss synthetic oil.
- Discuss high mileage oils.
- Discuss vehicle-specific specifications.
- Discuss brand compatibility of oil.
- Discuss the purpose and function of oil filters.
- Describe the oil change procedure.

KEY TERMS:

Additive package 193 • American Petroleum Institute (API) 194 • Antidrainback valve 199 • Association des Constructeurs Européens d' Automobiles (ACEA) 196 • Bypass valve 199 • HTHS 196 • International Lubricant Standardization and Approval Committee (ILSAC) 196 • Miscible 194 • Pour point 194 • SAPS 196 • Society of Automotive Engineers (SAE) 194 • Viscosity index (VI) 194 • Zinc dialkyl dithiophosphate (ZDDP or ZDP) 199

PURPOSE AND FUNCTION OF ENGINE OIL

Engine oil has a major effect on the proper operation and life of any engine. Engine oil provides the following functions in every engine:

- Lubricates moving parts
- Helps cool engine parts
- Helps seal piston rings
- Helps to neutralize acids created by the by-products of combustion
- Reduces friction in the engine
- Helps to prevent rust and corrosion
- Acts as an hydraulic fluid to operate valve lifters and chain tensioners.

As a result of these many factors, the specified engine oil must be used and replaced at the specified mileage or time intervals.

ENGINE OIL ADDITIVES

Oil producers are careful to check the compatibility of the oil additives they use. A number of chemicals that will help each other can be used for each of the additive requirements. The balanced additives are called an **additive package**.

ADDITIVES TO IMPROVE THE BASE OIL

- **Viscosity index (VI) improver.** Modifies the viscosity of the base fluid so that it changes less as the temperature rises; allows the lubricant to operate over a wider temperature range (● **SEE FIGURE 19–1**.)
- **Pour point depressant.** Keeps the lubricant flowing at low temperatures
- **Antifoam agents.** Foam reduces the effectiveness of a lubricant. The antifoam agents reduce/stop foaming when the oil is agitated or aerated.

ADDITIVES TO PROTECT THE BASE OIL

- **Antioxidants.** Slow the breakdown of the base fluid caused by oxygen (air) and heat (Oxidation is the main cause of lubricant degradation in service.)
- **Oxidants.** Prevent acid formation (corrosion) in the form of sludges or varnishes
- **Total base number (TBN).** The reserve alkalinity used to neutralize the acids created during the combustion process (Typical TBN levels are between 60 and 100, which

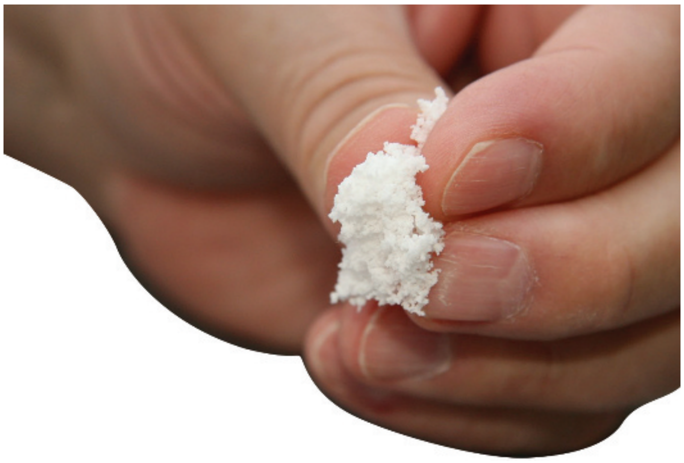


FIGURE 19–1 Viscosity index (VI) improver is a polymer and feels like finely ground foam rubber. When dissolved in the oil, it expands when hot to keep the oil from thinning.

is dependent on the fuel sulfur level. The higher the sulfur percentage in the fuel, the higher the TBN required. The higher the total base number of oil, the longer it can be used in an engine. Long-life oils usually have higher total base numbers than other oils.)

ADDITIVES TO PROTECT THE ENGINE

- **Rust inhibitor.** Inhibits the action of water on ferrous metal, such as steel
- **Corrosion inhibitor.** Protects nonferrous metals, such as copper
- **Antiwear additive.** Forms a protective layer on metal surfaces to reduce friction and prevent wear when no lubricant film is present
- **Extreme pressure additive.** Functions only when heavy loads and temperatures are occurring

PROPERTIES OF ENGINE OIL

The most important engine oil property is its thickness or viscosity.

- As oil is cooled, it gets thicker.
- As oil is heated, it gets thinner.

Therefore, its viscosity changes with temperature. The oil must not be too thick at low temperatures to allow the engine to start. The lowest temperature at which oil will pour is called its **pour point**. An index of the change in viscosity between the cold and hot extremes is called the **viscosity index (VI)**. All oils with a high viscosity index thin less with heat than do oils with a low viscosity index. Oils must also be **miscible**, meaning they are capable of mixing with other oils (brands and viscosities, for example) without causing any problems, such as sludge.

SAE RATING

TERMINOLOGY Engine oils are sold with a **Society of Automotive Engineers (SAE)** grade number, which indicates the viscosity range into which the oil fits. Oils tested at 212°F (100°C) have a number with no letter following. For example, SAE 30 indicates that the oil has only been checked at 212°F (100°C). This oil's viscosity falls within the SAE 30 grade number range when the oil is hot. Oils tested at low temperature, which varies with viscosity, are rated with a number and the letter *W*, which means *winter*, such as SAE 20W.

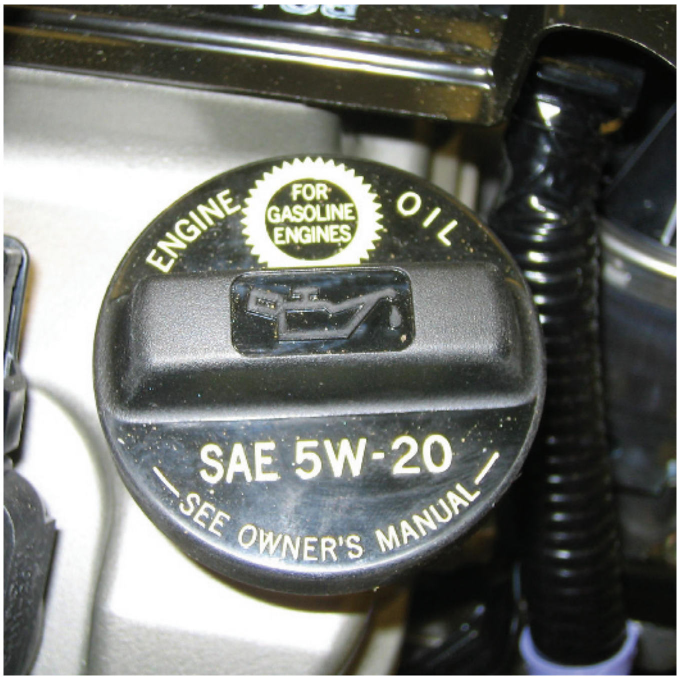


FIGURE 19–2 The SAE viscosity rating required is often printed on the engine oil filler cap. Most hybrid electric vehicles specify either SAE 0W-20 or SAE 5W-20 engine oil.

MULTIGRADE ENGINE OIL An SAE 5W-30 multigrade oil meets the SAE 5W viscosity specification when cooled to 0°F (−18°C), and meets the SAE 30 viscosity specification when tested at 212°F (100°C).

Most vehicle manufacturers recommend the following multiviscosity engine oils:

- SAE 0W-16
- SAE 0W-20
- SAE 5W-20
  ● **SEE FIGURE 19–2**.
- SAE 5W-30

Oil with a high viscosity has a higher resistance to flow and is thicker than lower viscosity oil. Thick oil is not necessarily good oil and thin oil is not necessarily bad oil. Generally, the following items can be considered in the selection of engine oil within the recommended viscosity range:

- Thinner oil
  1. Improved cold engine starting
  2. Improved fuel economy
- Thicker oil
  1. Improved protection at higher temperatures
  2. Reduced fuel economy

NOTE: Always use the specified viscosity engine oil.

API RATING

DEFINITION The **American Petroleum Institute (API)**, working with the engine manufacturers and oil companies, has established an engine oil performance classification. Oils are tested

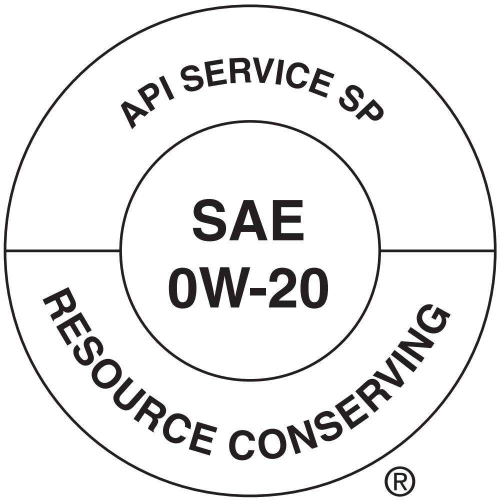


FIGURE 19–3 API doughnut for a SAE 0W-20, SP engine oil. When compared to a reference oil, "Resource Conserving" oils may result in an overall savings of fuel in the vehicle fleet as a whole.

and rated in production automotive engines. The oil container is printed with the API classification of the oil. The API performance or service classification and the SAE grade marking are the only information available to help determine which oil is satisfactory for use in an engine. ● **SEE FIGURE 19–3** for a typical API oil container "doughnut."

GASOLINE ENGINE RATINGS In gasoline engine ratings, the letter *S* means *service,* but can also indicate spark ignition engines. The rating system is open ended so that newer, improved ratings can be readily added as necessary (the letter I is skipped to avoid confusion with the number one).

SA	Straight mineral oil (no additives), not suitable for use in any engine
SB	Nondetergent oil with additives to control wear and oil oxidation
SC	Obsolete (1964)
SD	Obsolete (1968)
SE	Obsolete (1972)
SF	Obsolete (1980)
SG	Obsolete (1988)
SH	Obsolete (1993–1997)
SJ	Obsolete (1997–2001)
SL	2001–2003
SM	2004–2010
SN	2011
SN +	2018
SP	2020

NOTE: Vehicles built since about 1996 that use roller valve lifters can use the newer, higher-rated engine oil classifications where older, now obsolete ratings were specified. Newly overhauled antique cars or engines also can use the newer, improved oils, as the appropriate SAE viscosity grade is used for the anticipated temperature range. Engines older than about 1996 or those using flat-bottom lifters should use a zinc additive if using newer-rated oil.

CASE STUDY

The Case of the Wrong Oil Viscosity

A Dodge Durango 5.7 liter Hemi with a multiple displacement system (MDS) had the oil changed at a shop. SAE 10W-30 was used as this was the standard bulk oil in the shop. After the oil change, the vehicle was returned to the customer. Within a few minutes, however, the "check engine" light came on. The technician checked for diagnostic trouble codes (DTCs) and found a P0521 DTC stored. The technician checked service information and discovered that the code could be set if the incorrect viscosity engine oil had been used. The description of the P0521 read:

"Oil pressure not reaching specified at 1250 RPM."

The technician changed the oil and used the specified SAE 5W-20, then cleared the DTC. A test drive confirmed that the change to the correct viscosity oil solved the problem.

Summary:

Complaint—Customer stated that the "check engine" came on after an oil change.
Cause—The incorrect viscosity of oil was used.
Correction—The specified viscosity oil (SAE 5W-20) was used and the code cleared.

DIESEL ENGINE RATINGS Diesel classifications begin with the letter *C*, which stands for *commercial,* but can also indicate compression ignition or diesel engines.

CA	Obsolete
CB	Obsolete
CC	Obsolete
CD	Minimum rating for use in a diesel engine service
CF-4	High-speed four-stroke cycle diesel engine service
CG-4	Severe-duty high-speed four-stroke diesel engine service
CI-4	Severe-duty high-speed four-stroke diesel engine service
CJ-4	Required for use in all 2007 and newer diesels using ultra-low-sulfur diesel (ULSD) fuel
CK-4	Replaces CJ-4
FA-4	Designed for improved fuel economy

TECH TIP

Three Oil Change Facts

Three facts that are important to know when changing oil are

1. *Recommended SAE viscosity* (thickness) for the temperature range that is anticipated before the next oil change (such as SAE 5W-30)
2. *Quality rating* as recommended by the engine or vehicle manufacturer, such as API SM, and other specified rating, such as the ILSAC and vehicle manufacturer's specifications
3. *Recommended oil change interval* (time or mileage) (usually every 5,000 miles or every six months)

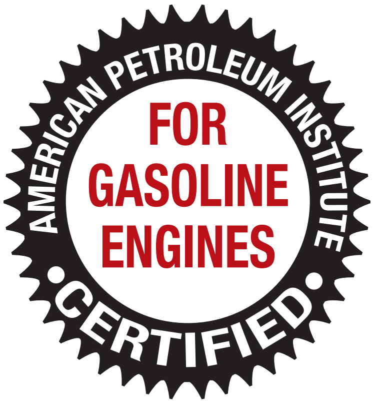


FIGURE 19–4 The International Lubricant Standardization and Approval Committee (ILSAC) starburst symbol. If this symbol is on the front of the container of oil, it is acceptable for use in almost any gasoline engine.

ILSAC OIL RATING

DEFINITION The **International Lubricant Standardization and Approval Committee (ILSAC)** developed an oil rating that consolidates the SAE viscosity rating and the API quality rating. If an engine oil meets the standards, a "starburst" symbol is displayed on the *front* of the oil container. If the starburst is present, the vehicle owner and technician know that the oil is suitable for use in almost any gasoline engine. ● **SEE FIGURE 19–4**.

ILSAC RATINGS

- The original GF-1 (gasoline fueled) rating in 1993
- Updated to GF-2 in 1997
- Updated to GF-3 in 2000
- Updated to GF-4 in 2004
- Updated to GF-5 in 2010
- GF-6 in 2019 (GF-6A is backward compatible for older vehicles. GF-6B is NOT backward compatible and to be used in 2019 or newer vehicles)
  For more information, visit www.gf-6.com.

EUROPEAN OIL RATING SYSTEM

DEFINITION The **Association des Constructeurs Européens d'Automobiles (ACEA)** rates the oil according to the following:

- Gasoline engine oils

ACEA A1	Low-friction low-viscosity oil (not suitable for some engines)
ACEA A2	General-purpose oil intended for normal oil change intervals; not suitable for some engines or extended oil drain intervals in any engine
ACEA A3	Designed for high-performance engines and/or extended oil drain intervals and under all temperature ranges
ACEA A4	Designed to meet the requirements for gasoline direct injection (GDI) engines
ACEA A5	Low-viscosity low-friction oil not suitable for some engines

- Diesel engine oils

ACEA B1	Low-viscosity oil designed for use in a passenger vehicle diesel engine that is equipped with an indirect injection system; not suitable for some diesel engines
ACEA B2	Designed for use in passenger vehicle diesel engines using indirect injection and using normal oil drain intervals
ACEA B3	Intended for use in a high-performance indirect injected passenger vehicle diesel engine and under extended oil drain interval conditions
ACEA B4	Intended for year-round use in direct injected passenger vehicle diesel engines; can be used in an indirect injected diesel engine
ACEA B5	Designed for extended oil drain intervals; not suitable for some engines
ACEA C1, C2, C3	Specifications for catalyst compatible oils, which have limits on the amount of sulfur, zinc, and other additives that could harm the catalytic converter

Starting in 2004, the ACEA began using combined ratings, such as A1/B1, A3/B3, A3/B4, and A5/B5.

- ACEA oil also requires low levels of sulfated ash, phosphorous, and sulfur, abbreviated **SAPS**, and has a high-temperature/high-shear rate viscosity, abbreviated **HTHS**.
- C ratings are catalytic converter-compatible oils and include
  C1: basically A5/B5 oil with low SAPS, low HTHS
  C2: A5/B5 with low HTHS and mid-level SAPS
  C3: A5/B5 with high HTHS and mid-level SAPS
  C4: low SAPS; high HTHS

● **SEE FIGURE 19–5**.

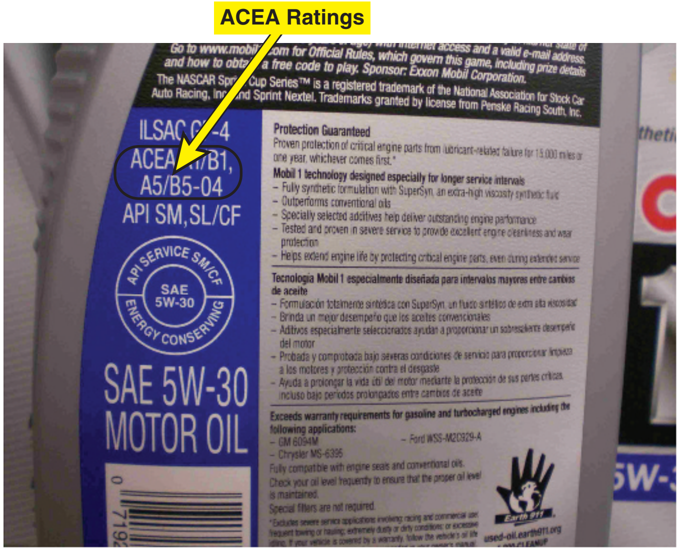


FIGURE 19–5 ACEA ratings are included on the back of the oil container if it meets any of the standards. ACEA ratings apply to European vehicles only, such as BMW, Mercedes, Audi, and VW.

SYNTHETIC OIL

DEFINITION The term *synthetic* means that it is a manufactured product and not refined from a naturally occurring substance, as engine oil (petroleum base) is refined from crude oil. Synthetic oil is processed from several different base stocks using several different methods.

API GROUPS According to the American Petroleum Institute, engine oil is classified into the following groups:

- **Group I.** Mineral, nonsynthetic base oil with few, if any, additives; suitable for light lubricating needs and rust protection, not for use in an engine
- **Group II.** Mineral oil with quality additive packages; includes most conventional engine oils
- **Group III.** Hydrogenated (hydroisomerized) synthetic compounds commonly referred to as hydrowaxes or hydrocracked oil; the lowest cost synthetic engine oil; includes Castrol Syntec
- **Group IV.** Synthetic oils made from mineral oil and monomolecular oil called polyalpholefin (POA); includes Mobil 1 (● **SEE FIGURE 19–6.**)
- **Group V.** Nonmineral sources, such as alcohol from corn, called diesters or polyolesters; includes Red Line synthetic oil

Groups III, IV, and V are considered to be synthetic because the molecular structure of the finished product does not occur naturally, but is made through chemical processes. All synthetic engine oils perform better than group II (mineral) oils, especially when tested according to the Noack Volatility Test ASTM D-5800. This test procedure measures the ability of an oil to stay in grade after it has been heated to 300°F (150°C) for one hour. The oil is then measured for percentage of weight loss. As the lighter components boil off, the oil's viscosity will increase.

ADVANTAGES OF SYNTHETICS The major advantage of using synthetic engine oil is its ability to remain fluid at very low temperatures. ● **SEE FIGURE 19–7**.

This characteristic of synthetic oil makes it popular in colder climates where cold-engine cranking is important.

DISADVANTAGES OF SYNTHETICS The major disadvantage is cost. The cost of synthetic engine oils can be four to five times the cost of **petroleum**-based engine oils.

Fully Synthetic
Mobil
1
5W-30
Motor Oil
4.73 L/5 U.S. Qts

FIGURE 19–6 Mobil 1 synthetic engine oil is used by several vehicle manufacturers in new engines.

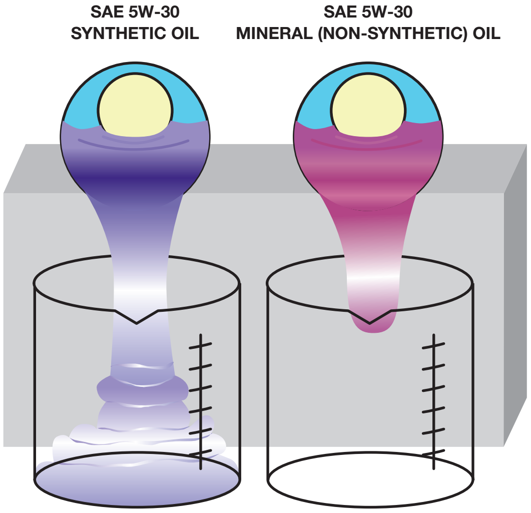


FIGURE 19–7 Both oils have been cooled to −20°F (−29°C). Notice that the synthetic oil on the left flows more freely than the mineral oil on the right, even though both are SAE 5W-30.

TECH TIP

Synthetic Good and Bad News

- In a true synthetic, such as base oils classified by API as a group IV or V, the molecules are all the same, and it does not have any sulfur that is present in crude oil and refined out. That is great, but API group III is also called a synthetic, and because its cost is lower than the other two synthetics, makes selecting an oil more difficult. However, according to lubrication engineers, service technicians and vehicle owners should not be concerned what molecules are in the oil, but instead should use oil that meets the vehicle specifications. For example, if an oil has a zero (0) as the first number, such as SAE 0W-20, the oil HAS to be a synthetic to be able to meet that specification. The synthetic could be a group III, IV, or V, but more likely a combination of all three. Check service information for the exact oil to use for the vehicle being serviced. ● **SEE FIGURE 19–8**.

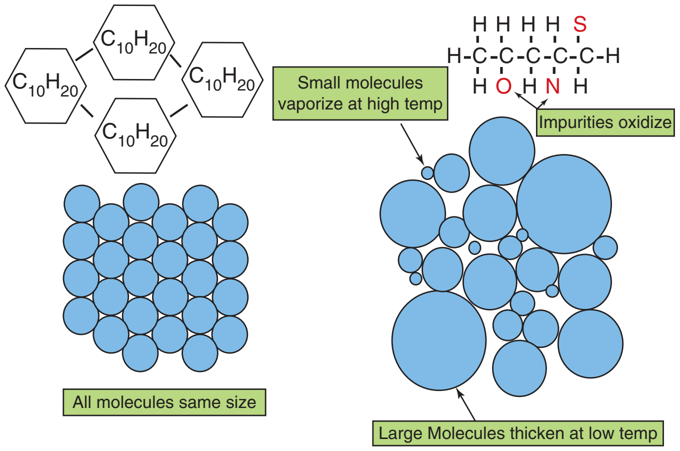


FIGURE 19–8 A true synthetic is made of a stable molecule that does not vary compared to mineral oils. However, regardless of the molecules, always use an oil that meets the vehicle manufacturer's specifications.

SYNTHETIC BLENDS A synthetic blend indicates that some synthetic oil is mixed with petroleum-base engine oil; however, the percentage of synthetic used in the blend is unknown.

HIGH MILEAGE OILS

DEFINITION A “high mileage oil” is sold for use in vehicles that have over 75,000 miles and are, therefore, nearing the eight-year, 80,000-mile catalytic converter warranty period.

Usually higher viscosity and lack of friction-reducing additives mean that most high mileage oils cannot meet ILSAC GF-4 rating and are, therefore, not recommended for use in most engines.

DIFFERENCES

- Esters are added to swell oil seals (main and valve-stem seals).
- The oil is used only in engines with higher than 75,000 miles.
- The oil usually does not have the energy rating of conventional oils (i.e., will not meet the specifications for use according to the owner manual in most cases).

VEHICLE-SPECIFIC SPECIFICATIONS

BACKGROUND Some oils can meet industry specifications, such as SAE, API, and/or ILSAC ratings, but not pass the tests specified by the vehicle manufacturer.

VEHICLE MANUFACTURER–SPECIFIC OIL SPECIFICATIONS

The oil used should meet the specifications of the vehicle manufacturer, which include the following:

- **BMW**

  Longlife-98 and longlife-01 (abbreviated LL-01), LL-04, LL-12FE, LL-14FE, (LL-17FE)
- **General Motors**

  GM 6094M

  GM 4718M (synthetic oil specification)

  Dexos 1 (all GM gasoline engines, 2011+)

  Dexos 2 (all GM diesel engines, 2011+)
- **Ford**

  WSS-M2C153-H

  WSS-M2C929-A (low viscosity rating, SAE 5W-20)

  WSS-M2C930-A

  WSS-M2C931-A

  WSS-M2C934-A
- **Chrysler**

  MS-6395 (2005+ vehicles)

  MS-10725 (2004 and older)
- **Honda/Acura**

  HTO-06 (turbocharged engine only)
- **Mercedes**

  229.3, 229.5, 229.1, 229.3, 229.31, 229.5, 229.51, and 229.52. (● **SEE FIGURE 19–9**.)

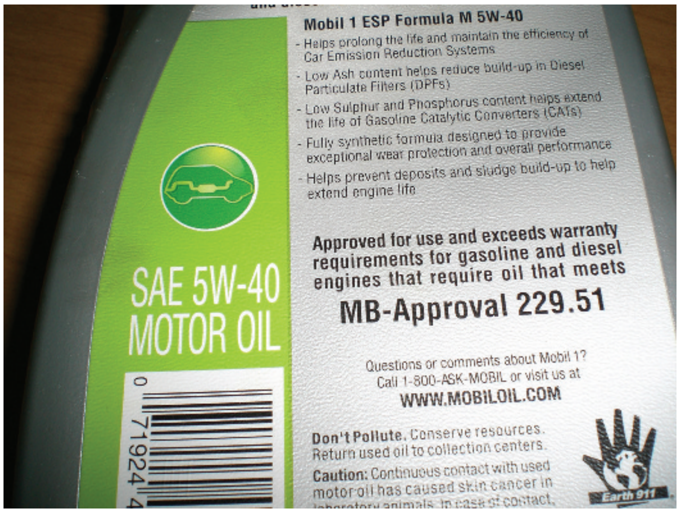

Mobil 1 ESP Formula M 5W-40
- Helps prolong the life and maintain the efficiency of Car Emission Reduction Systems
- Low Ash content helps reduce build-up in Diesel Particulate Filters (DPFs)
- Low Sulphur and Phosphorus content helps extend the life of Gasoline Catalytic Converters (CATs)
- Fully synthetic formula designed to provide exceptional wear protection and overall performance
- Helps prevent deposits and sludge build-up to help extend engine life
Approved for use and exceeds warranty requirements for gasoline and diesel engines that require oil that meets
MB-Approval 229.51
SAE 5W-40
MOTOR OIL
Questions or comments about Mobil 1?
Call 1-800-ASK-MOBIL or visit us at
WWW.MOBILOIL.COM
Don't Pollute. Conserve resources. Return used oil to collection centers.
Caution: Continuous contact with used motor oil has caused skin cancer in
Earth 911

FIGURE 19–9 European vehicle manufacturers usually specify engine oil with a broad viscosity range, such as SAE 5W-40, and their own unique standards, such as the Mercedes specification 229.51. Always use the oil specified by the vehicle manufacturer.

- **Volkswagen (VW and Audi)**

  502.00, 505.00, 505.01, 503, 503.01, 505, 506 diesel, 506.1 diesel, and 507 diesel

Be sure to use the oil that meets all of the specifications, especially during the warranty period.

NOTE: Most Asian-brand vehicle manufacturers do not specify any specifications other than SAE, API, and ILSAC. These vehicles include

- Acura/Honda
- Toyota/Lexus/Scion
- Kia
- Hyundai
- Nissan/Infiniti
- Mitsubishi
- Mazda
- Suzuki

OIL BRAND COMPATIBILITY

Many technicians and vehicle owners have their favorite brand of engine oil. The choice is often made as a result of marketing and advertising, as well as comments from friends, relatives, and technicians. If the brand of engine oil being used is not performing up to expectations, then maybe a change of brands may help. For example, some owners experience lower oil pressure with a certain brand than they do with other brands with the same SAE viscosity rating.

- Most experts agree that the oil changes are the most important regularly scheduled maintenance for an engine.
- It is also wise to check the oil level regularly and add oil when needed.
- According to SAE standard J-357, all engine oils must be miscible (compatible) with all other brands of engine oil.
- Therefore, any brand of engine oil can be used as long as it meets the viscosity and API standards recommended

by the vehicle manufacturer. Even though many people prefer a particular brand, be assured that, according to API and SAE, any major brand name engine oil can be used.

TECH TIP

Dirty Engine Oil Can Cause Oil Burning

Service technicians have known for a long time that some of their customers never change the engine oil. Often these customers believe that because their engine uses oil and they add a new quart every week, they are doing the same thing as changing the oil. But dirty, oxidized engine oil could cause piston rings to stick and not seal the cylinder. Therefore, when the oil and filter are changed, the clean oil may free the piston rings, especially if the vehicle is driven on a long trip during which the oil is allowed to reach the normal operating temperature. An engine that is mechanically sound, but burning oil, may be “fixed” by simply changing the oil and filter.

FREQUENTLY ASKED QUESTION

Can Newer Engine Oils Be Used in Engines That Use Flat-Bottom Lifters

No. Newer oil standards are designed to reduce phosphates in the engine oil that may leak past piston rings and end up in the exhaust system. These additives found in oil can damage the catalytic converter. The levels of phosphate and zinc, commonly referred to as **zinc dialkyl dithiophosphate** (**ZDDP** or **ZDP**), have been reduced because they can cause damage to the catalytic converter. Even though engines consume very little oil, if the oil contains zinc, the efficiency of the catalytic converter is reduced. The use of ZDDP was intended to reduce sliding friction in an engine. Sliding friction is usually found in engines that use flat-bottom lifters. Most, if not all, engines produced over the past 15 years have used roller lifters or cam followers, so using the new oil without ZDDP is not a concern. Even diesel oils have reduced amounts of the zinc, so many camshaft manufacturers are recommending the use of an additive. Older oils had up to 0.15% ZDDP and now SM-rated oils list the zinc at just 0.08%, or 800 parts per million.

- Engine oil had about 1200 PPM zinc prior to 2001.
- In 2001, the zinc was reduced to 1000 PPM; and in 2005, reduced again to the current 800 PPM.
- API ratings do not specify the zinc content, just oil performance.

If driving a vehicle with flat-bottom lifters, use engine oil specifically designed for older engines, such as Shell Rotella T, or use an additive, such as General Motor’s engine oil supplement (EOS), part number 1052367 or 88862586, or a zinc additive. Check with camshaft manufacturers for their recommended oil or additive to use. ● **SEE FIGURE 19–10**.

ZDDP
Restores ZDDP
Saves Engines
THIS PRODUCT IS INTENDED FOR USE ON PRE-OBD, OFF-ROAD, INDUSTRIAL, AGRICULTURAL AND RACING VEHICLES ONLY.
Net Wt 4 oz / 113.4 g

FIGURE 19–10 Using a zinc additive is important when using SM-rated oil in an engine equipped with a flat-bottom lifter, especially during the break-in period.

OIL FILTERS

CONSTRUCTION The oil within the engine is pumped from the oil pan through the filter before it goes into the engine lubricating system passages. The filter is made from either closely packed cloth fibers or a porous paper. Large particles are trapped by the filter. Microscopic particles will flow through the filter pores. These particles are so small that they can flow through the bearing oil film and not touch the surfaces, so they do no damage.

OIL FILTER VALVES Many oil filters are equipped with an **antidrainback valve** that prevents oil from draining out of the filter when the engine is shut off. ● **SEE FIGURE 19–11**.

This valve keeps oil in the filter and allows the engine to receive immediate lubrication as soon as the engine starts.

Either the engine or the filter is provided with a **bypass valve** that will allow the oil to go around the filter element. ● **SEE FIGURE 19–12**.

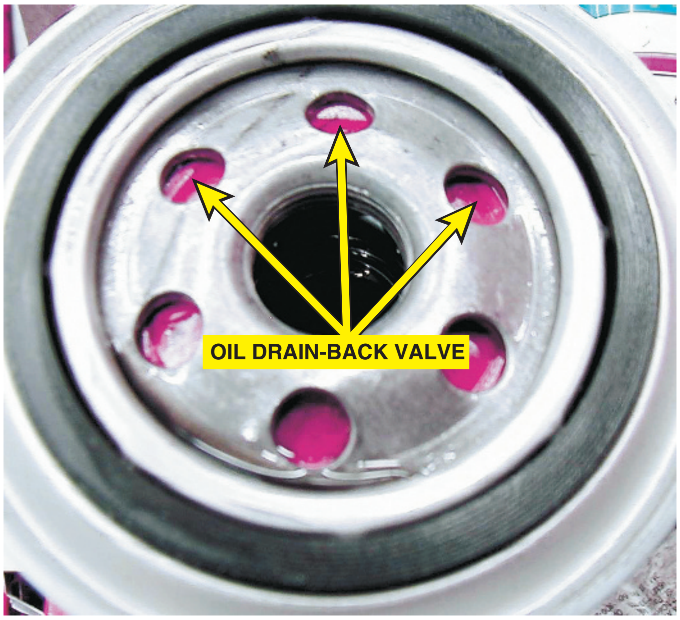


FIGURE 19–11 A rubber diaphragm acts as an antidrainback valve to keep the oil in the filter when the engine is stopped and the oil pressure drops to zero.

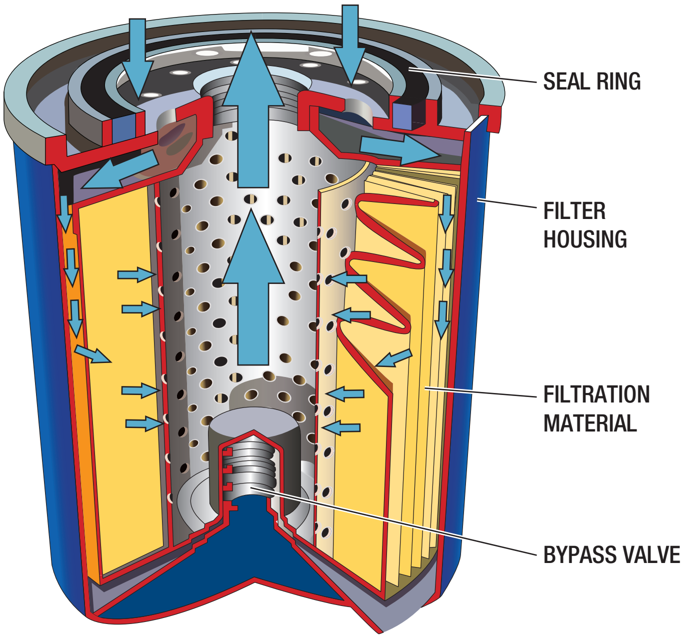


FIGURE 19–12 A cutaway of a typical spin-on oil filter. Engine oil enters the filter through the small holes around the center of the filter and flows through the pleated paper filtering media, and out the large hole in the center of the filter. The center metal cylinder with holes is designed to keep the paper filter from collapsing under the pressure. The bypass valve can be built into the center on the oil filter, or is part of the oil filter housing and located in the engine.

The bypass valve allows the engine to be lubricated with dirty oil, rather than having no lubrication, if the filter becomes plugged. The oil also goes through the bypass when the oil is cold and thick.

OIL FILTER DISPOSAL Oil filters should be crushed and/or drained of oil before discarding. After the oil has been drained, the filter can usually be disposed of as regular metal scrap. Always check and follow local, state, or regional oil filter disposal rules, regulations, and procedures. ● **SEE FIGURE 19–13**.

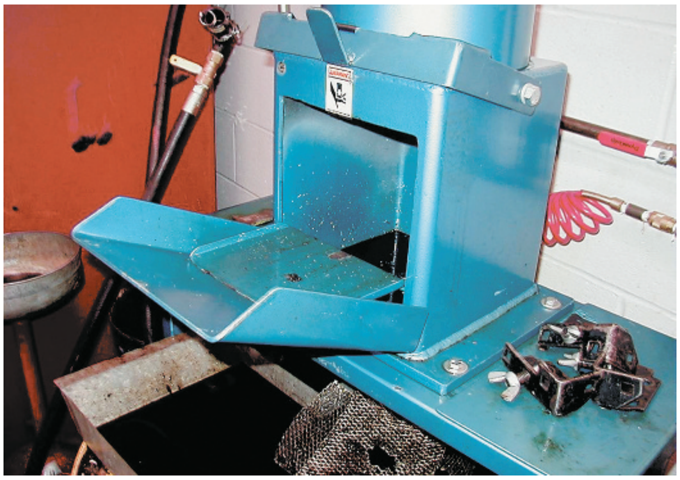


FIGURE 19–13 A typical filter crusher. The hydraulic ram forces out most of the oil from the filter. The oil is trapped underneath the crusher and is recycled.

OIL CHANGE

INTERVALS All vehicle and engine manufacturers recommend a maximum oil change interval. The recommended intervals are almost always expressed in terms of mileage or elapsed time (or hours of operation), whichever milestone is reached first.

Most vehicle manufacturers recommend an oil change interval of 7,500 to 12,000 miles (12,000 to 19,000 km) or every six months. If, however, *any one* of the conditions in the following list exists, the oil change interval recommendation drops to a more reasonable 2,000 to 3,000 miles (3,000 to 5,000 km) or every three months. The important thing to remember is that these are recommended *maximum* intervals and they should be shortened substantially if any of the following operating conditions exist:

1. Operating in dusty areas
2. Towing a trailer
3. Short-trip driving, especially during cold weather (The definition of a short trip varies among manufacturers, but it is usually defined as 4 to 15 miles (6 to 24 km) each time the engine is started.)
4. Operating in temperatures below freezing (32°F, 0°C)
5. Operating at idle speed for extended periods of time (such as normally occurs in police or taxi service)

Because most vehicles driven during cold weather are driven on short trips, technicians and automotive experts recommend changing the oil every 2,000 to 3,000 miles or every two to three months, whichever occurs first.

FREQUENTLY ASKED QUESTION

Why Change Oil If the Oil Filter Can Trap All the Dirt?

Many persons believe that oil filters will remove all dirt from the oil being circulated through the filtering material. Most oil filters will filter particles that are about 10 to 20 microns in size. A micron is one-millionth of a meter or 0.000039 inch. Most dirt and carbon particles that turn engine oil black are less than a micron in size. In other words, it takes about 3 million of these carbon particles to cover a pin head. To help visualize the smallness of a micron, consider that a typical human hair is 60 microns in diameter. In fact, anything smaller than 40 microns is not visible to the human eye.

The dispersants added to engine oil prevent dirt from adhering together to form sludge. It is the same dispersant additive that prevents dirt from being filtered or removed by other means. If an oil filter could filter particles down to 1 micron, it would be so restrictive that the engine would not receive sufficient oil through the filter for lubrication. Oil recycling companies use special chemicals to break down the dispersants, which permit the dirt in the oil to combine into larger units that can be filtered or processed out of the oil.

OIL LIFE MONITORS Most vehicles built since the mid-1990s are equipped with a warning system that lets the driver know when the engine oil should be changed. The two basic types of oil change monitoring systems include

- **Mileage only.** The service light will come on based on mileage only and may include a service "A" or "B" based on what service needs to be performed. The interval can be every 3,750 to 7,500 miles, or even longer in some cases where specialized engine oil is required.
- **Algorithm.** Computer programs contain algorithms that specify instructions a computer should perform (in a specific order) to carry out a task. This program uses the number of cold starts, the run time of the engine, and inputs from the engine coolant temperature (ECT) sensor to determine when the oil should be changed.

● **SEE FIGURE 19–14**.

OIL CHANGE PROCEDURE An oil change includes the following steps:

STEP 1 Check the oil level on the dipstick before hoisting the vehicle. Document the work order and notify the owner if the oil level is low before changing the oil.

STEP 2 Safely hoist the vehicle.

STEP 3 Position a drain pan under the drain plug, then remove the plug with care to avoid contact with hot oil.

STEP 4 Allow the oil to drain freely so that the contaminants come out with the oil. It is not critically important to get every last drop of oil from the engine oil pan, because a quantity of used oil still remains in the engine oil passages and oil pump.

STEP 5 While the engine oil is draining, the oil plug gasket should be examined. If it appears to be damaged, it should be replaced.

TECH TIP

Follow the Seasons

Vehicle owners often forget when they last changed the oil. This is particularly true of the person who owns or is responsible for several vehicles. A helpful method for remembering when the oil should be changed is to change it at the start of each season of the year.

- Fall (September 21)
- Winter (December 21)
- Spring (March 21)
- Summer (June 21)

Remembering that the oil needs to be changed on these dates helps owners budget for the expense and the time needed.

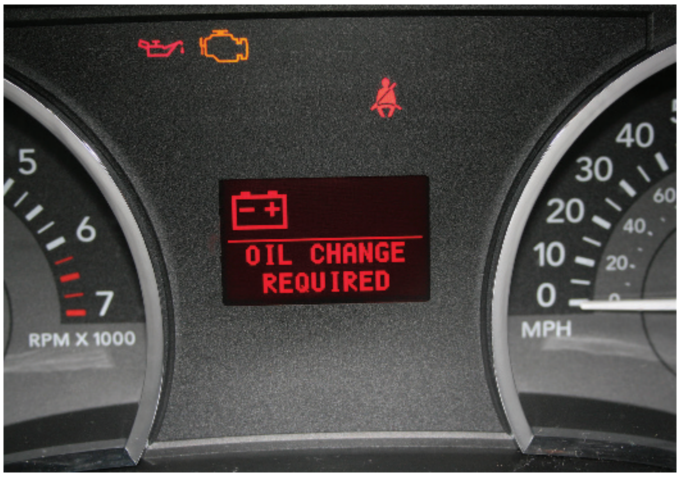


FIGURE 19–14 Many vehicle manufacturers can display the percentage of oil life remaining, whereas others simply turn on a warning lamp when it has been determined that an oil change is required.

TECH TIP

The Pick Trick

Removing an oil filter that is installed upside down can be a real mess. When this design filter is loosened, oil flows out from around the sealing gasket. To prevent this from happening, use a pick to poke a hole in the top of the filter.

This small hole allows air to get into the filter, thereby allowing the oil to drain back into the engine rather than remain in the filter. After punching a hole in the filter, be sure to wait several minutes to allow time for the trapped oil to drain down into the engine before loosening the filter.

TECH TIP

Change Oil Every Month?

A vehicle less than one year old came back to the dealer for some repair work. While writing the repair order, the service advisor noted that the vehicle had 88,000 miles on the odometer and was, therefore, out of warranty for the repair. Because the owner approved the repair anyway, the service advisor asked how he had accumulated so many miles in such a short time. The owner said that he was a traveling salesperson with a territory of "east of the Mississippi River."

Because the vehicle looked to be in new condition, the technician asked the salesperson how often he had the oil changed. The salesperson smiled and said proudly, "Every Month."

Many fleet vehicles put on over 2,000 miles per week. How about changing their oil based on the time since last changed instead of by mileage?

⚠ WARNING

Used engine oil has been determined to be harmful. Rubber gloves should be worn to protect the skin. If used engine oil gets on the skin, wash thoroughly with soap and water.

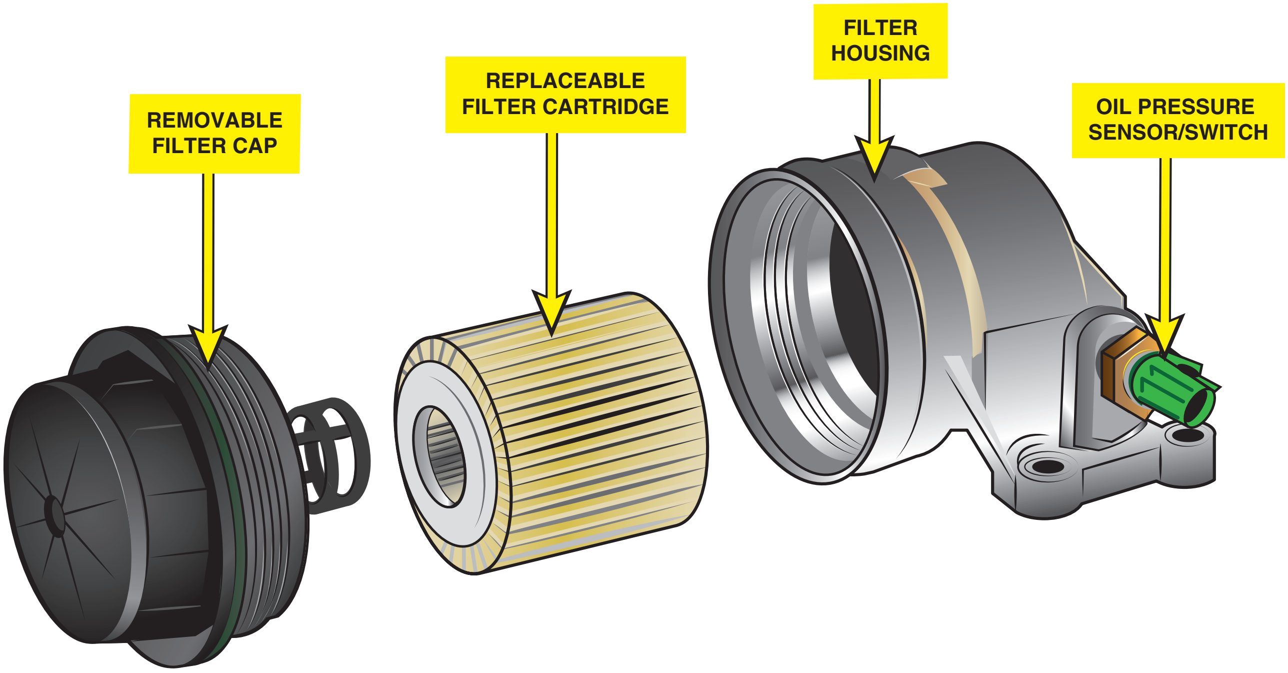

REMOVABLE FILTER CAP
REPLACEABLE FILTER CARTRIDGE
FILTER HOUSING
OIL PRESSURE SENSOR/SWITCH

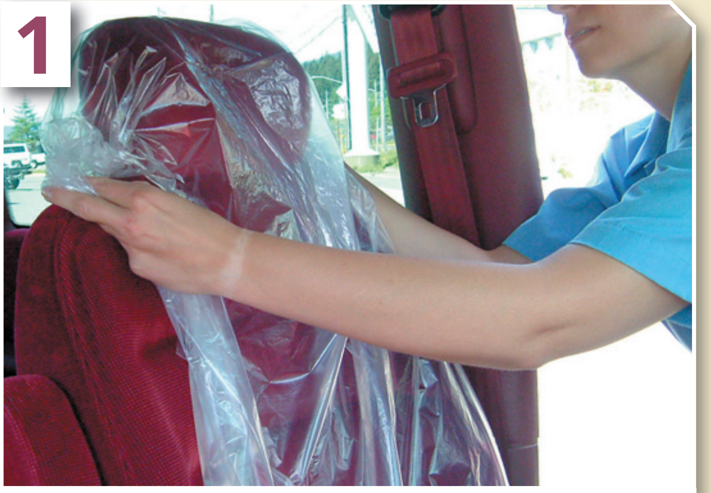
FIGURE 19–15 If replacing a cartridge-type oil filter, be sure to use the proper size wrench on the filter cap and tighten to factory specifications.

NOTE: Honda/Acura recommends that the oil drain plug gasket be replaced at every oil change on many of their vehicles. The aluminum sealing gasket does not seal once it has been tightened. Always follow the vehicle manufacturer's recommendations.

STEP 6 When the oil stops running and starts to drip, reinstall and tighten the drain plug to factory specifications using a torque wrench. Replace the oil filter. ● **SEE FIGURE 19–15**.

STEP 7 Refill the engine with the proper type, grade, and quantity of oil. Restart the engine and allow the engine to idle until it develops oil pressure; then check the engine for leaks, especially at the oil filter.

1



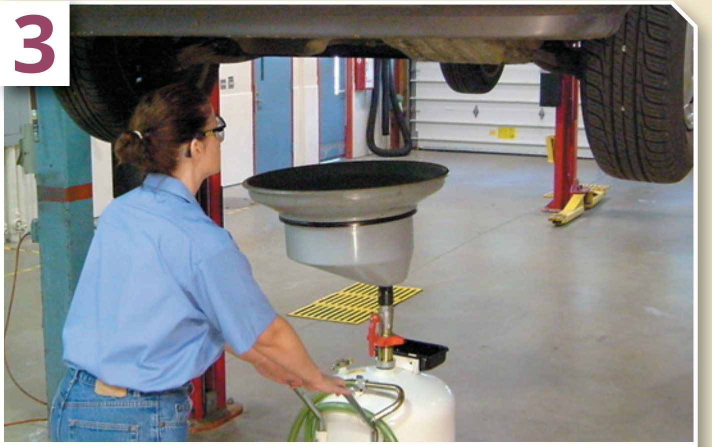
Before entering the customer's car for the first time, be sure to install a seat cover as well as a steering wheel cover to protect the vehicle's interior.

2

UNLEADED FUEL ONLY
P R N D 3 L

Run the engine until it is close to operating temperature. This will help the used oil drain more quickly and thoroughly.

3

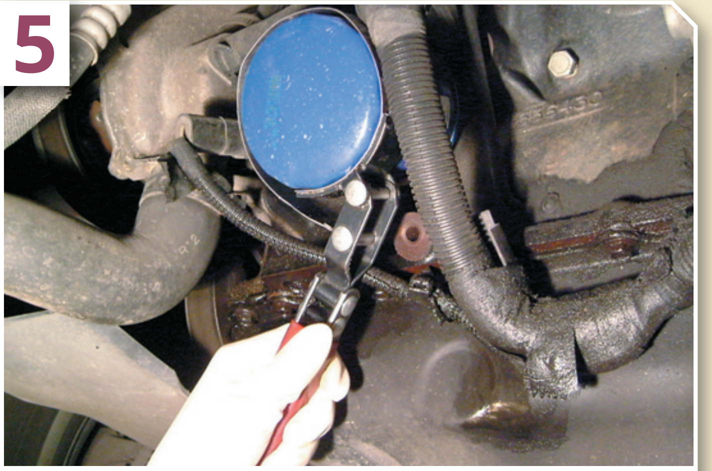


Raise the vehicle on a hoist and place the oil drain container in position under the oil drain plug. Be sure to wear protective gloves.

4

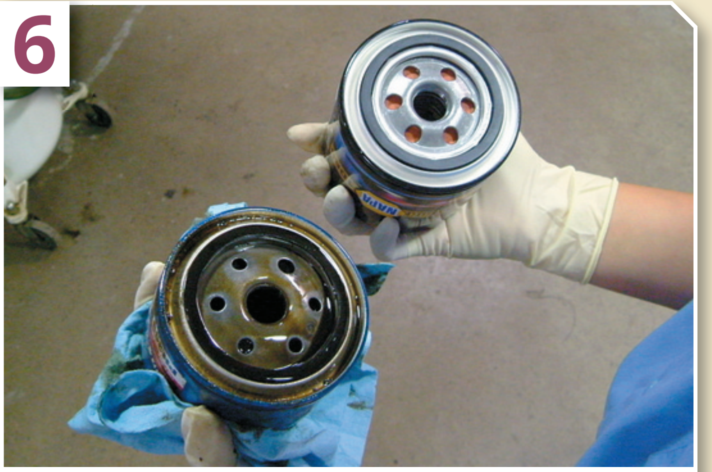
Remove the plug and allow the hot oil to drain from the engine. Use caution during this step as hot oil can cause painful burns!

5



While the engine oil continues to drain, remove the engine oil filter using a filter wrench. Some oil will drain from the filter, so be sure to have the oil drain container underneath when removing it.

6



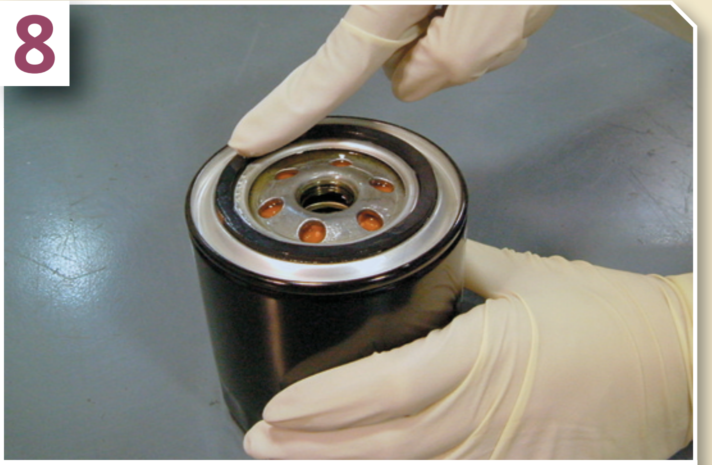
Compare the new oil filter with the old one to be sure that it is the correct replacement.

OIL CHANGE

7

The wise service technician adds oil to the oil filter whenever possible. This provides faster filling of the filter during start-up and a reduced amount of time that the engine does not have oil pressure.

8



Apply a thin layer of clean engine oil to the gasket of the new filter. This oil film will allow the rubber gasket to slide and compress as the oil filter is being tightened.

9

Clean the area where the oil filter gasket seats to be sure that no part of the gasket remains that could cause an oil leak.

10

Install the new oil filter and tighten it by hand. Do not use an oil filter wrench to tighten the filter! Most filters should be tightened 3/4 of a turn after the gasket contacts the engine.

11

Carefully inspect the oil drain plug and gasket. Replace the gasket as needed. Install the drain plug and tighten to factory specifications.

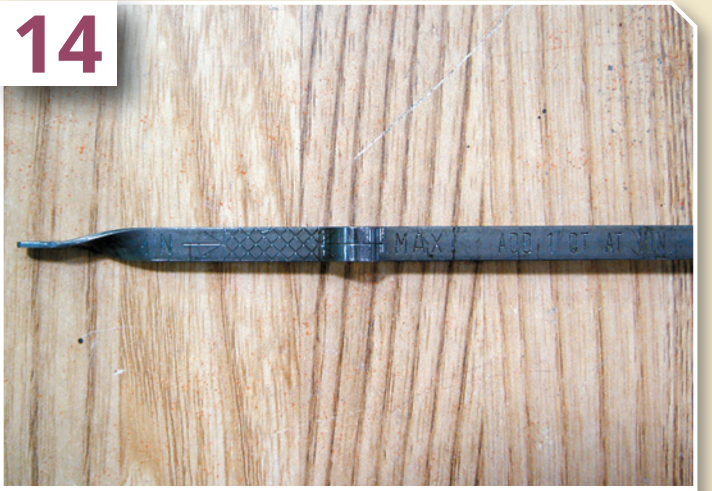
12

Use a funnel to add the specified amount of oil to the engine at the oil fill opening. When finished, replace the oil fill cap.

13

Remove the oil-level dipstick and wipe it clean with a shop cloth. Reinstall the oil-level dipstick. Remove the dipstick a second time and read the oil level.

14



The oil level should be between the MIN and the MAX lines. In this case, the oil level should be somewhere in the cross-hatched area of the dipstick.

REVIEW QUESTIONS

1. What property of oil does the SAE ratings reflect?
2. What additives are used in the base oil to improve the oil?
3. Why is the oil filter bypassed when the engine oil is cold and thick?
4. What are the steps in performing an oil change?
5. What additives are added to oil to help protect the engine?

CHAPTER QUIZ

1. Which of the following is true of the properties of engine oil?
   - **a.** Engine oil gets thinner when it is cooled.
   - **b.** Engine oils should not be miscible.
   - **c.** Engine oil viscosity changes with temperature.
   - **d.** Engine oil pour point is the highest temperature at which oil will pour.
2. Which of the following is NOT a characteristic of satisfactory engine oil?
   - **a.** Seals piston rings
   - **b.** Provides dry friction between moving parts
   - **c.** Cools engine parts
   - **d.** Reduces friction
3. The "W" in SAE 5W-20 means ______________.
   - **a.** weight
   - **b.** winter
   - **c.** with
   - **d.** without
4. Which rating is the ACEA rating specified for use by many European vehicle manufacturers?
   - **a.** SAE
   - **b.** A3/B3
   - **c.** SM
   - **d.** GF-4
5. Technician A says that some vehicle manufacturers recommend an ILSAC grade be used in the engine. Technician B says that an oil with the specified API rating *and* SAE viscosity rating should be used in an engine. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Most conventional (mineral) oil is made from what API group?
   - **a.** Group I
   - **b.** Group II
   - **c.** Group III
   - **d.** Group IV or V
7. Technician A says that all high mileage oils are synthetic. Technician B says that synthetic and mineral oils are miscible. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Two technicians are discussing oil filters. Technician A says that the oil will remain perfectly clean if just the oil filter is changed regularly. Technician B says that oil filters can filter particles smaller than the human eye can see. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. The purpose of the oil filter bypass valve is to ______________.
   - **a.** allow oil to bypass the filter if the filter becomes clogged
   - **b.** keep the oil from draining out of the filter when the engine is off and the oil pressure drops to zero
   - **c.** allow oil to bypass the oil filter when the oil is hot, to help cool the oil
   - **d.** Both a and b
10. Oil change intervals as specified by the vehicle manufacturer ______________.
    - **a.** are *maximum* time and mileage intervals
    - **b.** are *minimum* time and mileage intervals
    - **c.** only include miles driven between oil changes
    - **d.** generally only include time between oil changes

Chapter

20

LUBRICATION SYSTEM OPERATION AND DIAGNOSIS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose of the lubrication system.
- State the lubrication principles.
- Discuss engine lubrication systems.
- Describe the purpose and function of oil pumps.
- Discuss the purpose and function of oil passages.
- Discuss oil pans.
- Discuss the dry sump system.
- Discuss oil coolers.

KEY TERMS:

Boundary lubrication 207 • Cavitate 210 • Dry sump 213 • Gallery 212 • Gerotor 209 • Hydrodynamic lubrication 208 • Positive displacement pumps 209 • Pressure regulating valve 210 • Sump 213 • Wet sump 213 • Windage tray 213

INTRODUCTION

Engine oil is the lifeblood of any engine. The purposes of a lubrication system include the following:

1. Lubricating all moving parts to prevent wear
2. Helping to cool the engine
3. Helping to seal piston rings
4. Cleaning, and holding dirt in suspension in the oil until it can be drained from the engine
5. Neutralizing acids that are formed as a result of the combustion process
6. Reducing friction
7. Preventing rust and corrosion

LUBRICATION PRINCIPLES

PURPOSE Lubrication between two moving surfaces results from an oil film that separates the surfaces and supports the load. ● **SEE FIGURE 20–1**.

Although oil does not compress, it does leak out around the oil clearance between the shaft and the bearing. In some cases, the oil film is thick enough to keep the surfaces from seizing but can allow some contact to occur. This condition is called **boundary lubrication**. The specified oil viscosity and oil clearances must be adhered to during service to help prevent boundary lubrication and wear from occurring, which usually happens when the engine is under a heavy load and low speeds. The movement of the shaft helps prevent contact with the bearing. If oil were put on a flat surface and a heavy block were pushed across the surface, the block would slide more easily than if it were pushed across a dry surface. The reason for this is that a wedge-shaped oil film is built up between the moving block and the surface, as illustrated in ● **FIGURE 20–2**.

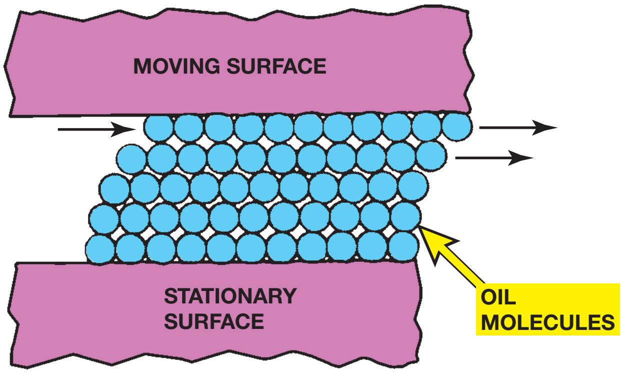


FIGURE 20–1 Oil molecules cling to metal surfaces but easily slide against each other.

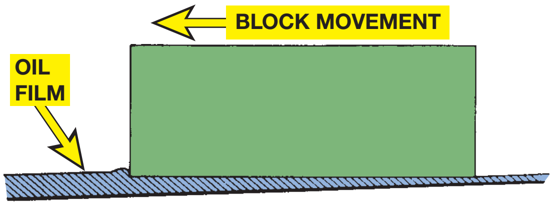


FIGURE 20–2 Wedge-shaped oil film developed below a moving block.

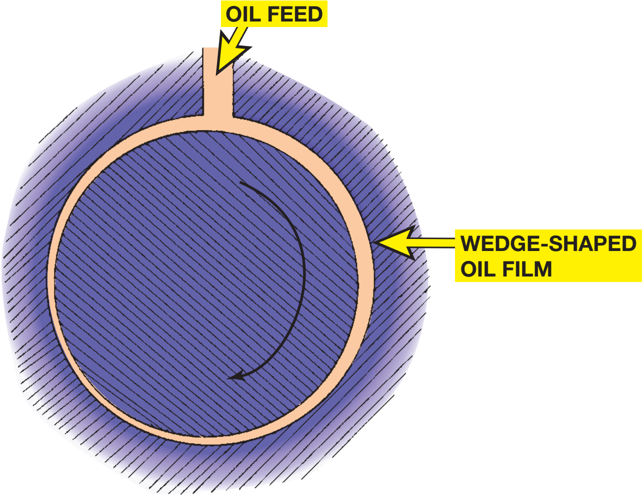


FIGURE 20–3 Wedge-shaped oil film curved around a bearing journal.

HYDRODYNAMIC LUBRICATION

This wedging action is called **hydrodynamic lubrication** and depends on the force applied to the rate of speed between the objects and the thickness of the oil. Thickness of oil is called the *viscosity,* and is defined as the ability of the oil to resist flow. High-viscosity oil is thick and low-viscosity oil is thin.

- The prefix *hydro* refers to liquids, as in hydraulics.
- The term *dynamic* refers to moving materials.

Hydrodynamic lubrication occurs when a wedge-shaped film of lubricating oil develops between two surfaces that have relative motion between them. ● **SEE FIGURE 20–3**.

The engine oil pressure system feeds a continuous supply of oil into the lightly loaded part of the bearing oil clearance. Hydrodynamic lubrication takes over as the shaft rotates in the bearing to produce a wedge-shaped hydrodynamic oil film that is curved around the bearing. The pressure between the bearings and the crankshaft can exceed 1,000 PSI (6,900 kPa) due to hydrodynamic lubrication, as created by the wedging action between the bearing and the crankshaft journal. Most bearing wear occurs during the initial start-up and continues until a hydrodynamic film is established.

ENGINE LUBRICATION SYSTEMS

FUNCTION

The primary function of the engine lubrication system is to maintain a positive and continuous oil supply to the bearings. Engine oil pressure must be high enough to get the oil to the bearings with enough force to cause the oil flow that is required for proper cooling.

FIGURE 20–4 The dash oil pressure gauge may be a good indicator of engine oil pressure. If there is any concern about the oil pressure, always use a mechanical gauge to be sure.

NORMAL OIL PRESSURE

The normal engine oil pressure range is from 10 to 60 PSI (200 to 400 kPa) or 10 PSI per 1,000 engine RPM. It is normal to see the following:

- Higher oil pressure when the engine is cold due to the oil being cold and at a higher viscosity
- Lower oil pressure when the engine is at normal operating temperature due to the oil becoming thinner even though it is multiviscosity oil
- Lower oil pressures at idle and higher pressures at higher engine speeds because oil pumps are “positive displacement” pumps

The relatively low engine oil pressures obviously could not support these high bearing loads without hydrodynamic lubrication. Oil pressure measurements only show the oil pump pressure and not the pressure created between the bearings and the crankshaft journal due to hydrodynamic forces. ● **SEE FIGURE 20–4**.

OIL TEMPERATURE

Excessive temperatures, either too low or too high, are harmful to any engine. If the oil is too cold, it could be too thick to flow through the oil passages and lubricate all engine parts. If the oil is too hot, it could become too thin to provide the film strength necessary to prevent metal-to-metal contact and wear. Estimated oil temperature can be determined with the following formula:

Estimated oil temperature = **Outside air temperature** + **120°F**

For example, 90°F outside air temperature + 120°F = 210°F estimated oil temperature.

During hard acceleration (or high-power demand activities such as trailer towing), the oil temperature will quickly increase. Oil temperature should not exceed 300°F (150°C).

OIL PUMPS

PURPOSE

All production automobile engines have a full-pressure oil system. The oil pump is required to

- Provide 3 to 6 gallons per minute of engine oil to lubricate the engine
- Maintain pressure, by forcing the oil into the lubrication system under pressure

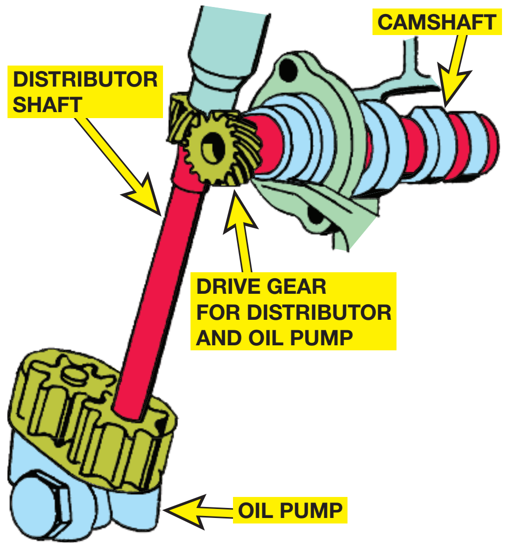


FIGURE 20–5 An oil pump driven by the camshaft.

PARTS AND OPERATION On crankshaft-driven oil pump systems, the oil pump assembly is often made as part of the engine's front cover so that it turns at the same speed as the crankshaft. On older engines that use a distributor, the distributor drive gear meshes with a gear on the camshaft. ● **SEE FIGURE 20–5**.

TYPES OF OIL PUMPS All oil pumps are called **positive displacement pumps**, and each rotation of the pump delivers the same volume of oil; therefore, everything that enters must exit. Also a positive displacement pump will deliver more oil and higher pressure as the speed of the pump increases. Most automotive engines use one of two types of oil pumps, either gear or rotor.

- **External gear type.** A gear-type oil pump is usually driven by a shaft from the distributor, which is driven by the camshaft. As a result, this type of pump rotates at half engine (crankshaft) speed. The gear-type oil pump consists of two spur gears in a close-fit housing—one gear is driven while the other idles. As the gear teeth come out of mesh, they tend to leave a space, which is filled by oil drawn through the pump inlet. When the pump is pumping, oil is carried around the *outside* of each gear in the space between the gear teeth and the housing. As the teeth mesh in the center, oil is forced from the teeth into an oil passage, thus producing oil pressure. ● **SEE FIGURE 20–6**.
- **Internal/external gear type.** This type of oil pump is driven by the crankshaft and operates at engine speed. In this style of oil pump, two gears and a crescent stationary element are used. ● **SEE FIGURE 20–7**.
- **Rotor type.** This rotor-type oil pump is driven by the crankshaft and uses a special lobe-shape gear meshing with the inside of a lobed rotor. The center lobed section is driven and the outer section idles. As the lobes separate, oil is drawn in just as it is drawn into gear-type pumps. As the pump rotates, it carries oil around and between the lobes. As the lobes mesh, they force the oil out from between them under pressure in the same manner as the gear-type pump. The pump is sized so that it will maintain a pressure of at least 10 PSI (70 kPa) in the oil gallery when the engine is hot and idling. Pressure will increase because the engine-driven pump also rotates faster. ● **SEE FIGURE 20–8**.

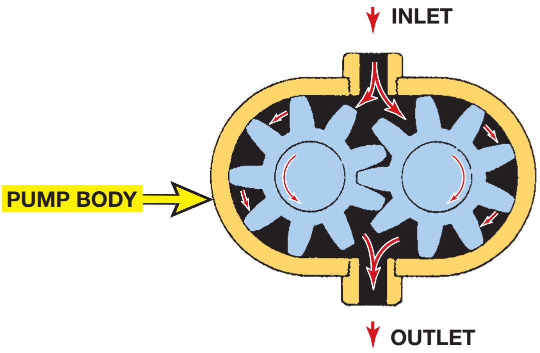


FIGURE 20–6 In an external gear-type oil pump, the oil flows through the pump around the outside of each gear. This is an example of a positive displacement pump, wherein everything entering the pump must leave the pump.

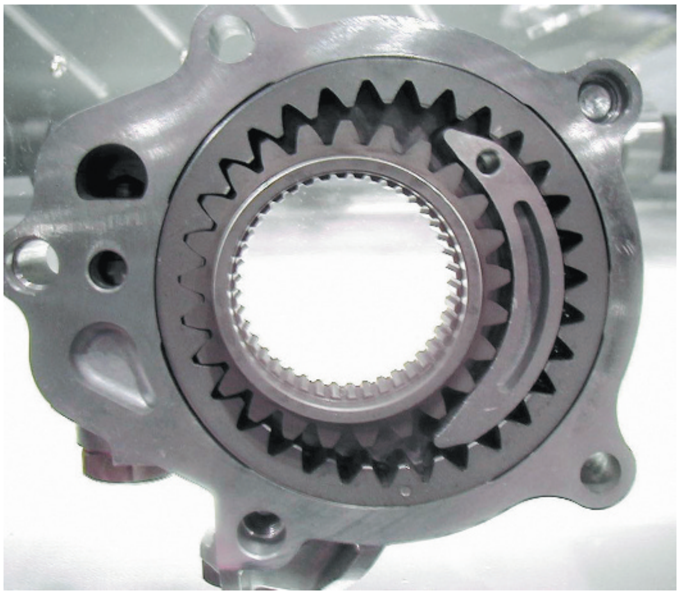
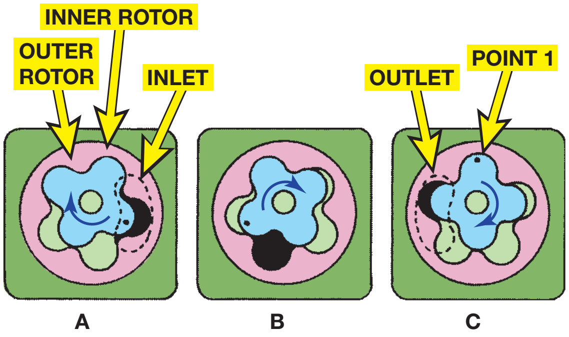


FIGURE 20–7 A typical internal/external oil pump mounted in the front cover of the engine that is driven by the crankshaft.



A. OIL IS PICKED UP IN LOBE OF OUTER ROTOR.
B. OIL IS MOVED IN LOBE OF OUTER ROTOR TO OUTLET.
C. OIL IS FORCED OUT OF OUTLET BECAUSE THE INNER AND OUTER ROTORS MESH TOO TIGHTLY AT POINT 1 AND THE OIL CANNOT PASS THROUGH.

FIGURE 20–8 The operation of a rotor-type oil pump.

- **Gerotor type.** This type of positive displacement oil pump uses an inner and an outer rotor. The term is derived from two words: "*ge*nerated *rotor*," or **gerotor**. The inner rotor has one fewer tooth than the outer rotor and both rotate. ● **SEE FIGURE 20–9**.

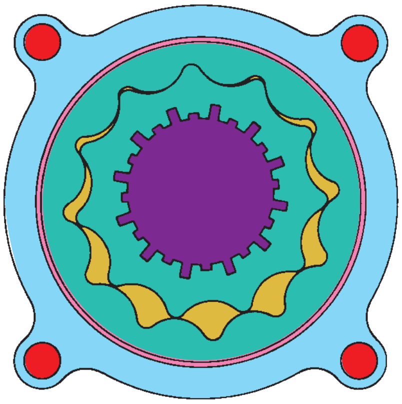
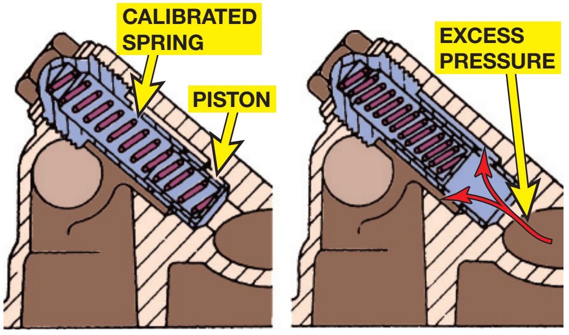


FIGURE 20–9 Gerotor-type oil pump driven by the crankshaft.



CLOSED OPEN

FIGURE 20–10 Oil pressure relief valves are spring loaded. The stronger the spring tension, the higher the oil pressure.

OIL PRESSURE REGULATION In engines with a full-pressure lubricating system, maximum pressure is limited with a pressure *relief valve.* The relief valve (sometimes called the **pressure regulating valve**) is located at the outlet of the pump. The relief valve controls maximum pressure by bleeding off oil to the inlet side of the pump. ● **SEE FIGURE 20–10**.

The relief valve spring tension determines the maximum oil pressure. If a pressure relief valve is not used, the engine oil pressure will continue to increase as the engine speed increases. Maximum pressure is usually limited to the lowest pressure that will deliver enough lubricating oil to all engine parts that need to be lubricated.

The oil pump is made so that it is large enough to provide pressure at low engine speeds and small enough that it will not **cavitate** at high speed. Cavitation occurs when the pump tries to pull oil faster than it can flow from the pan to the pickup. When it cannot get enough oil, it will pull air. This puts air pockets or cavities in the oil stream. A pump is cavitating when it is pulling air or vapors.

NOTE: The reason for sheet metal covers over the pickup screen is to prevent cavitation. Oil is trapped under the cover, which helps prevent the oil pump from drawing in air, especially during sudden stops or during rapid acceleration.

After the oil leaves the pump, it first flows through the oil filter and then is delivered to the moving parts through drilled oil passages. ● **SEE FIGURE 20–11**.

FACTORS AFFECTING OIL PRESSURE Oil pressure can only be produced when the oil pump has a capacity larger than all the "leaks" in the engine.

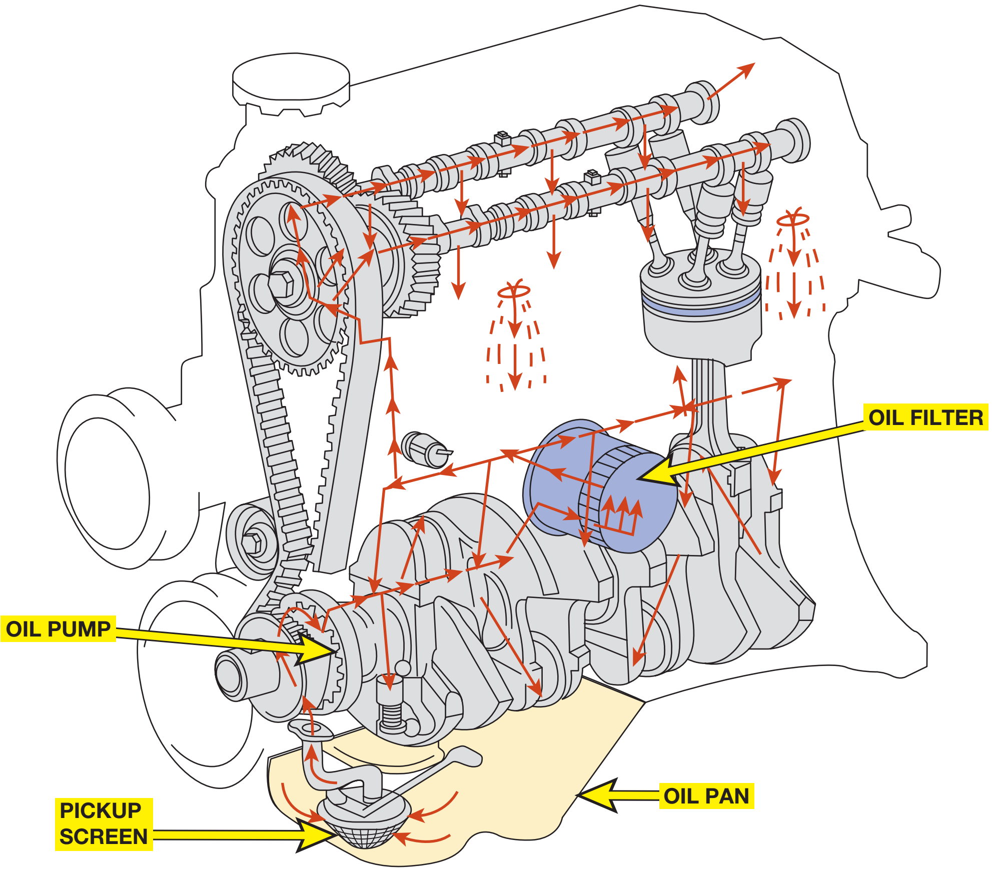


FIGURE 20–11 A typical engine design that uses both pressure and splash lubrication. Oil travels under pressure through the galleries (passages) to reach the top of the engine. Other parts are lubricated as the oil flows back down into the oil pan or is splashed onto parts. In typical engine lubrication systems, the valve train components are the last to receive oil and the first to suffer from a lack of oil or oil pressure.

- **Leaks.** The leaks are the clearances at end points of the lubrication system. The end points are at the edges of bearings, the rocker arms, the connecting rod spit holes, and so on. These clearances are designed into the engine and are necessary for its proper operation. As the engine parts wear and clearance becomes greater, more oil will leak out. In other words, worn main or rod bearings are often the cause of lower than normal oil pressure.
- **Oil pump capacity.** The oil pump must supply extra oil for any leaks. The capacity of the oil pump results from its size, rotating speed, and physical condition. When the pump is rotating slowly as the engine idles, oil pump capacity is low. *If the leaks are greater than the pump capacity, engine oil pressure is low.* As the engine speed increases, the pump capacity increases and the pump tries to force more oil out of the leaks. This causes the pressure to rise until it reaches the regulated maximum pressure.

NOTE: A clogged oil pump pickup screen can cause lower than normal oil pressure because the amount of oil delivered by the pump is reduced by the clogged screen.

- **Viscosity of the engine oil.** The viscosity of the oil affects both the pump capacity and the oil leakage. Thin oil or oil of very low viscosity slips past the edges of the pump and flows freely from the leaks. Hot oil has a low viscosity, and therefore, a hot engine often has low oil pressure. Cold oil is more viscous (thicker) than hot oil. This results in higher pressures, even with the cold engine idling. High oil pressure occurs with a cold engine, because the oil relief valve must open farther to release excess oil than is necessary with a hot engine. This larger opening increases the spring compression force, which in turn increases the oil pressure. Putting higher viscosity oil in an engine will raise the engine oil pressure to the regulated setting of the relief valve at a lower engine speed.

FREQUENTLY ASKED QUESTION

Is a High-Pressure or High-Volume Oil Pump Needed?

No. Engine parts need pressure after the oil reaches the parts that are to be lubricated. The oil film between the parts is developed and maintained by hydrodynamic lubrication. Excessive oil pressure requires more horsepower and provides no better lubrication than the minimum effective pressure. A high-volume pump is physically larger and pumps more oil with each revolution. A high-volume pump is used mostly in race engines where the main and rod bearing clearances are much greater than normal and therefore would need a great volume of oil to make up for the oil leaking from the wide clearances.

OIL PUMP CHECKS The cover is removed to check the condition of the oil pump.

- **Visual inspection.** The gears and housing are examined for scoring. If the gears and housing are heavily scored, the entire pump should be replaced. ● **SEE FIGURE 20–12**.
- **Measurements.** If they are lightly scored, the clearances in the pump should be measured. These clearances include the space between the gears and housing, the space between the teeth of the two gears, and the space between the side of the gear and the pump cover. A feeler gauge is often used to make these measurements. Gauging plastic can be used to measure the space between the side of the gears and the cover. The oil pump should be replaced when excessive clearance or scoring is found.

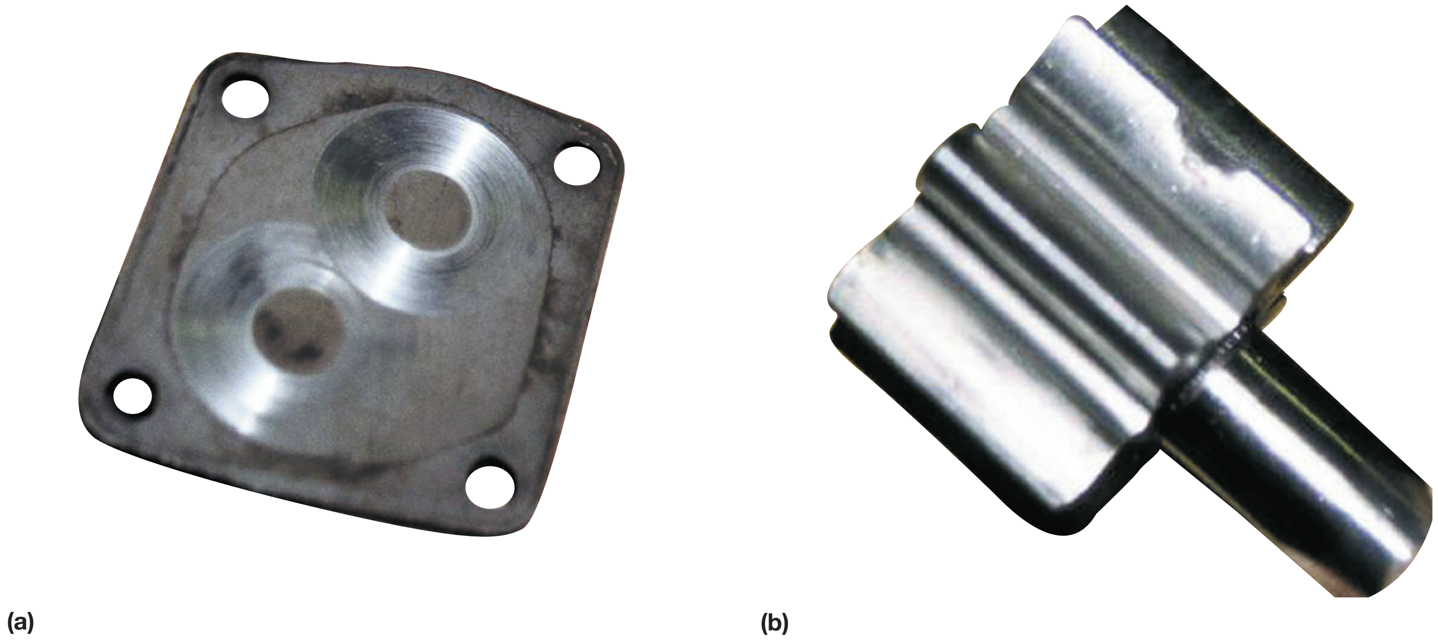


FIGURE 20–12 (a) A visual inspection indicated that this pump cover was worn. (b) An embedded particle of something was found on one of the gears, making this pump worthless except for scrap metal.

On most engines, the oil pump should be replaced as part of any engine work, especially if the cause for the repair is lack of lubrication.

NOTE: The oil pump is the "garbage pit" of the entire engine. Any and all debris is often forced through the gears and housing of an oil pump.

Always refer to the manufacturer's specifications when checking the oil pump for wear. Typical oil pump clearances include the following:

1. End plate clearance: 0.0015 inch (0.04 mm)
2. Side (rotor) clearance: 0.012 inch (0.30 mm)
3. Rotor tip clearance: 0.010 inch (0.25 mm)
4. Gear end play clearance: 0.004 inch (0.10 mm)

All parts should also be inspected closely for wear. Check the relief valve for scoring and check the condition of the spring. When installing the oil pump, coat the sealing surfaces with engine assembly lubricant. This lubricant helps draw oil from the oil pan on initial start-up.

OIL PASSAGES

PURPOSE AND FUNCTION Oil from the oil pump first flows through the oil filter and then goes through a drilled hole that intersects with a drilled main oil **gallery**, or longitudinal header. This is a long hole drilled from the front of the block to the back.

- Inline engines use one oil gallery.
- V-type engines may use two or three galleries.

Passages drilled through the block bulkheads allow the oil to go from the main oil gallery to the main and cam bearings. ● **SEE FIGURE 20–13**.

In some engines, oil goes to the cam bearings first, and then to the main bearings. It is important that the oil holes in the bearings match with the drilled passages in the bearing saddles so that the bearing can be properly lubricated. Over a long period of use, bearings will wear. This wear causes excess clearance. The excess clearance will allow too much oil to leak from the side of the bearing. When this happens, there will be little or no oil left for bearings located farther downstream in the lubricating system. This is a major cause of bearing failure. To aid in bearing failure diagnosis, on most engines, the last rod bearing to receive oil pressure is typically the bearing farthest from the oil pump. If this bearing fails, suspect low oil pressure as the probable cause.

VALVE TRAIN LUBRICATION The oil gallery may intersect or have drilled passages to the valve lifter bores to lubricate the lifters. When hydraulic lifters are used, the oil pressure in the gallery keeps refilling them. On some engines, oil from the lifters goes up the center of a hollow pushrod to lubricate the pushrod ends,

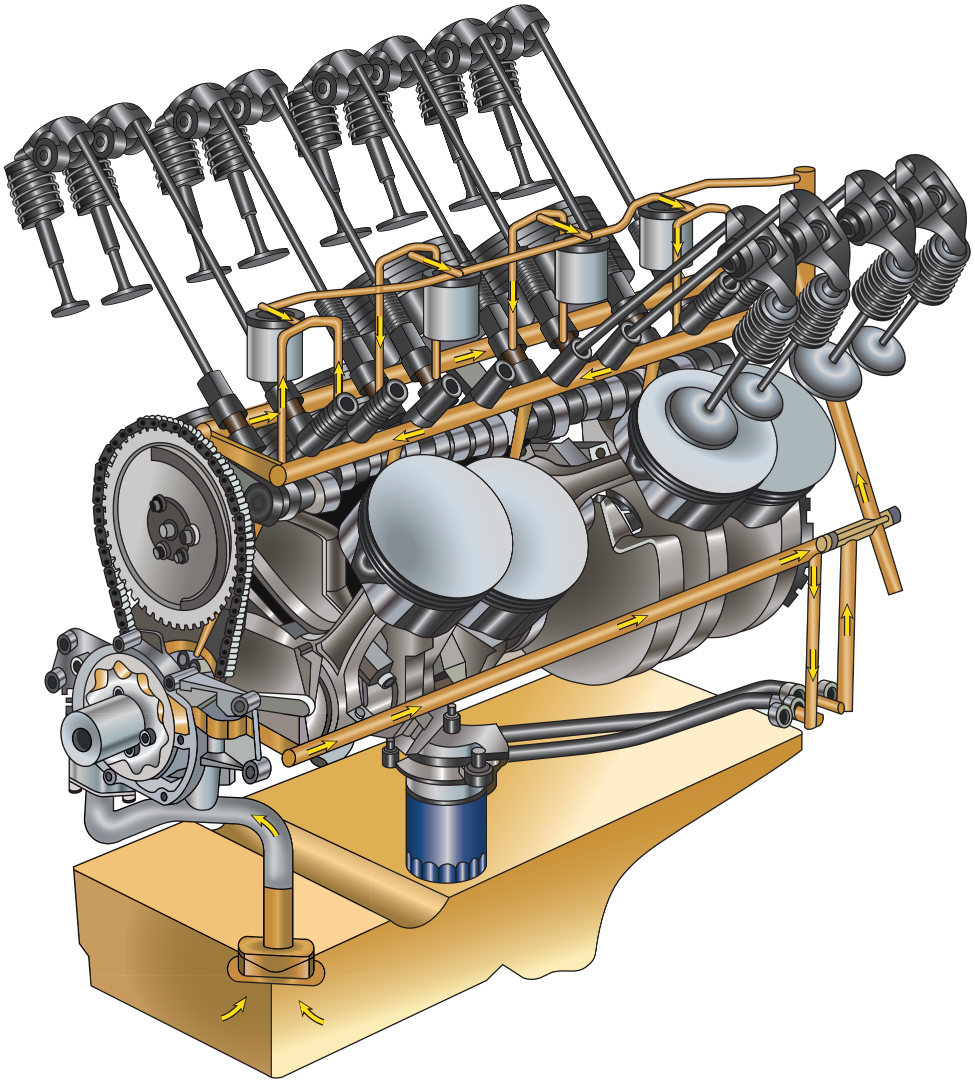


FIGURE 20–13 A V-8 with a crankshaft-driven oil pump showing the flow of oil through the entire engine.

the rocker arm pivot, and the valve stem tip. In other engines, an oil passage is drilled from either the gallery or a cam bearing to the block deck, where it matches with a head gasket hole and a hole drilled in the head to carry the oil to a rocker arm shaft. Some engines use an enlarged bolt hole to carry lubrication oil around the rocker shaft cap screw to the rocker arm shaft.

Holes in the bottom of the rocker arm shaft allow lubrication of the rocker arm pivot. Rocker arm assemblies need only a surface coating of oil, so the oil flow to the rocker assembly is minimized using restrictions or metered openings. The restriction or metering disk is in the lifter when the rocker assembly is lubricated through the pushrod. Oil that seeps from the rocker assemblies is returned to the oil pan through drain holes. These oil drain holes are often placed so that the oil drains on the camshaft or cam drive gears to lubricate them. Oil drain holes can be either machined or cast into the cylinder heads and block. ● **SEE FIGURE 20–14**.

Some engines have the means of directing a positive oil flow to the cam drive gears or chain. This may include either of the following:

- Nozzle
- Chamfer on a bearing parting surface, which allows oil to spray on the loaded portion of the cam drive mechanism

TECH TIP

The Hemi Engine Oiling System

The Chrysler Hemi V-8 engine uses a unique oiling system because the valve lifters are fed oil from the top of the cylinder heads and through the pushrods. While it is normal to have oil flowing through hollow pushrods, it is unique that in the Hemi V-8 the oil flows backward from normal and from the head *down* the hollow pushrods to the lifters. Be sure to use the specified viscosity of oil as this is critical for proper lubrication of the valve lifters.

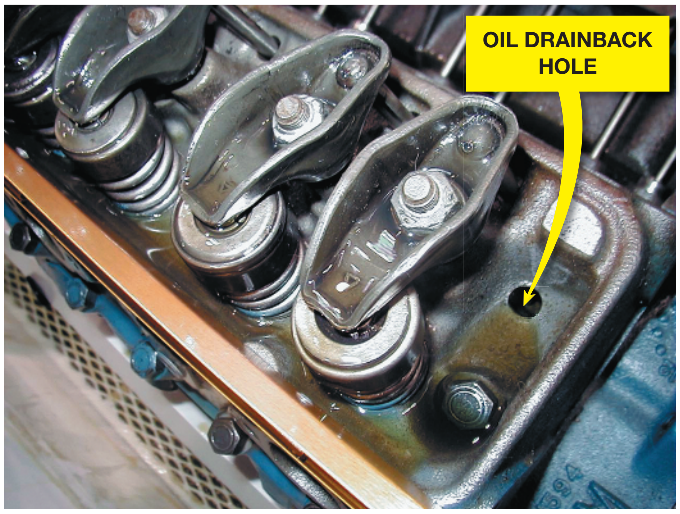


FIGURE 20–14 Oil is sent to the rocker arms on this Chevrolet V-8 engine through the hollow pushrods. The oil returns to the oil pan through the oil drainback holes in the cylinder head.

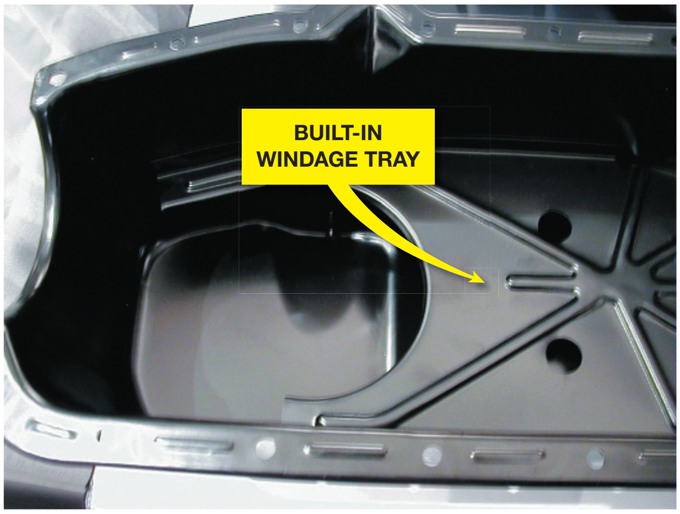


FIGURE 20–15 A typical oil pan with a built-in windage tray used to keep oil from being churned up by the rotating crankshaft.

OIL PANS

PURPOSE AND FUNCTION The oil pan is where engine oil is used for lubricating the engine. Another name for the oil pan is a **sump**. As the vehicle accelerates, brakes, or turns rapidly, the oil tends to move around in the pan. Pan baffles and oil pan shapes are often used to keep the oil inlet under the oil at all times. As the crankshaft rotates, it acts like a fan and causes air within the crankcase to rotate with it. This can cause a strong draft on the oil, churning it so that air bubbles enter the oil, which causes oil foaming. Oil with air will not lubricate like liquid oil, so oil foaming can cause bearings to fail. A baffle or **windage tray** is sometimes installed in engines to eliminate the oil churning problem. This may be an added part, as shown in ● **FIGURE 20–15**, or it may be a part of the oil pan.

Windage trays have the good side effect of reducing the amount of air disturbed by the crankshaft, so that less power is drained from the engine at high crankshaft speeds.

DRY SUMP SYSTEM

CONSTRUCTION AND OPERATION The term *sump* is used to describe a location where oil is stored or held. In most engines, oil is held in the oil pan and the oil pump draws the oil from the bottom. This type of system is called a **wet sump** oil system. In a **dry sump** system, the oil pan is shallow and the oil is pumped into a remote reservoir. In this reservoir, the oil is cooled and any trapped air is allowed to escape before being pumped back to the engine. A dry sump system uses an externally mounted oil reservoir.

ADVANTAGES The advantages of a dry sump system are as follows:

1. A shallow oil pan allows the engine to be mounted lower in the vehicle to improve cornering.
2. The oil capacity can be greatly expanded because the size of the reservoir is not limited. A larger quantity of oil means that the oil temperature can be controlled.

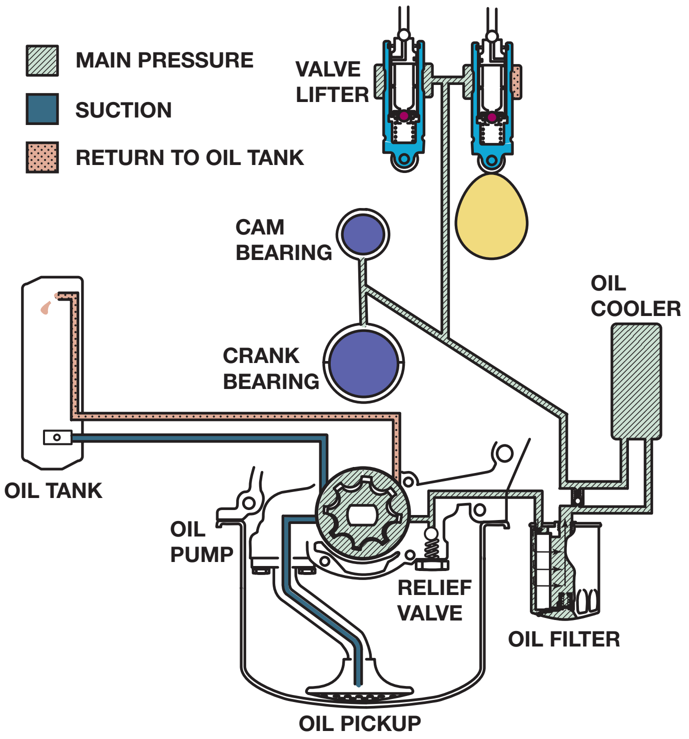


FIGURE 20–16 A dry sump system as used in a Chevrolet Corvette.

3. A dry sump system allows the vehicle to corner and brake for long periods, which is not able to be done with a wet sump system due to the oil being thrown to one side and away from the oil pickup.
4. A dry sump system also allows the engine to develop more power as the oil is kept away from the moving crankshaft.

DISADVANTAGES A dry sump system has the following disadvantages:

1. The system is expensive as it requires components and plumbing not needed in a wet sump system.
2. The system is complex because the plumbing and connections, plus the extra components, result in more places where oil leaks can occur and change the way routine maintenance is handled. A dry sump oil system is used in most motor sport vehicles and is standard on certain high-performance production vehicles, such as some models of the Chevrolet Corvette, Porsche, and BMW. ● **SEE FIGURE 20–16**.

OIL COOLERS

Oil temperature must be controlled on many high-performance or turbocharged engines. A larger capacity oil pan helps to control oil temperature. Some engines use remote mounted oil coolers. Coolant flows through the oil cooler to help warm the oil when the engine is cold and cool the oil when the engine is hot. Oil temperature should be

- Above 212°F (100°C) to boil off any accumulated moisture
- Below 280°F to 300°F (138°C to 148°C)

● **SEE FIGURE 20–17**.

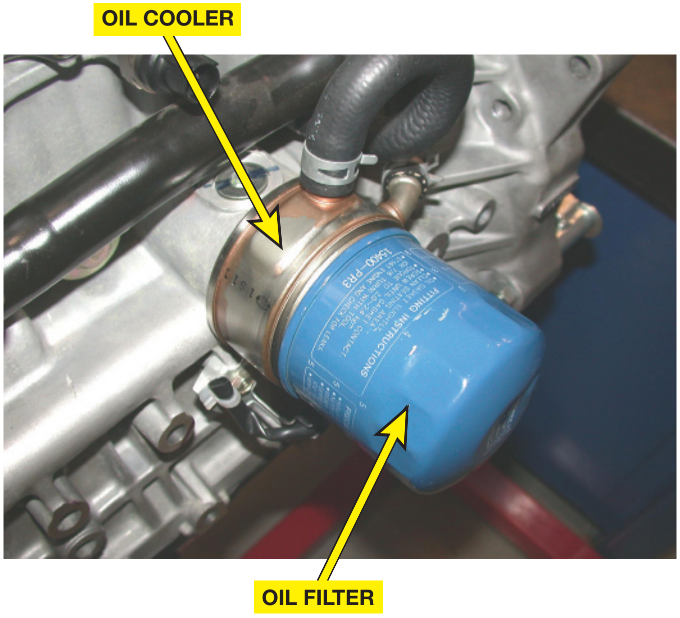


FIGURE 20–17 Oil is cooled by the flow of coolant through the oil filter adaptor.

FREQUENTLY ASKED QUESTION

What Is Acceptable Oil Consumption?

There are a number of opinions regarding what is acceptable oil consumption. Most vehicle owners do not want their engine to use any oil between oil changes even if they do not change it more often than every 7,500 miles (12,000 km). Engineers have improved machining operations and piston ring designs to help eliminate oil consumption.

Many stationary or industrial engines are not driven on the road, so they do not accumulate miles but still may consume excessive oil.

A general rule for "acceptable" oil consumption is that it should be about 0.002 to 0.004 pound per horsepower per hour. To figure, use the following:

$$\frac{\mathbf{1.82 \times Quarts\ used}}{\mathbf{Operating\ hp \times Total\ hours}} = \mathbf{Pound/hp/hr}$$

Therefore, oil consumption is based on the amount of work an engine performs. Although the formula may not be viable for vehicle engines used for daily transportation, it may be for the marine or industrial engine builder. Generally, oil consumption that is greater than 1 quart for every 600 miles (1 liter per 1,000 km) is considered to be excessive with a motor vehicle.

REVIEW QUESTIONS

1. What causes a wedge-shaped film to form in the oil?
2. What is hydrodynamic lubrication?
3. How does internal engine leakage affect oil pressure?
4. How does the oil flow from the oil pump, through the filter and main engine bearings, to the valve train?
5. What is the purpose of a windage tray?

CHAPTER QUIZ

1. Normal oil pump pressure in an engine is _________ PSI.
   - **a.** 3 to 7
   - **b.** 10 to 60
   - **c.** 100 to 150
   - **d.** 180 to 210
2. Two technicians are discussing oil pumps. Technician A says that many oil pumps are driven directly off the front of the crankshaft. Technician B says that some are driven from the distributor if the engine uses a distributor-type ignition system. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. A typical oil pump can pump how many gallons per minute?
   - **a.** 3 to 6 gallons
   - **b.** 6 to 10 gallons
   - **c.** 10 to 60 gallons
   - **d.** 50 to 100 gallons
4. In typical engine lubrication systems, what components are the last to receive oil and the first to suffer from a lack of oil or oil pressure?
   - **a.** Main bearings
   - **b.** Rod bearings
   - **c.** Valve train components
   - **d.** Oil filters
5. Hydrodynamic lubrication created by the wedging action of oil between the crankshaft journal and the bearing can be as high as _________ PSI.
   - **a.** 60
   - **b.** 120
   - **c.** 500
   - **d.** 1,000
6. What type of oil pump is driven by the crankshaft?
   - **a.** Gerotor
   - **b.** Internal/external gear
   - **c.** External gear
   - **d.** Both a and b
7. Lower than specified oil pressure is measured on a high mileage engine. Technician A says that worn main or rod bearings could be the cause. Technician B says that a clogged oil pump pickup screen could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Oil passages in an engine block are usually called _________.
   - **a.** galleries
   - **b.** holes
   - **c.** runners
   - **d.** pathways
9. Why is a dry sump system used in some high-performance vehicles?
   - **a.** It allows the vehicle to corner or brake for long periods.
   - **b.** It allows the engine to develop more power.
   - **c.** It allows for a greater oil capacity so that oil temperatures can be controlled.
   - **d.** All of the above.
10. An engine oil cooler uses what to cool the oil?
    - **a.** Coolant
    - **b.** Air
    - **c.** Air-conditioning evaporator output
    - **d.** Automatic transmission fluid after it flows through the radiator

Chapter

21

INTAKE AND EXHAUST SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain air intake filtration.
- Define intake manifolds.
- Discuss the design and construction of intake manifolds.
- Describe the purpose and function of variable intake manifolds.
- Discuss exhaust gas recirculation passages.
- Discuss exhaust manifolds.
- Describe the purpose and function of exhaust system components.

KEY TERMS:

EGR 220 • Hangers 224 • Helmholtz resonator 218 • Micron 217 • Plenum 219

AIR INTAKE FILTRATION

NEED FOR AIR FILTERING Gasoline must be mixed with air to form a combustible mixture. Air movement into an engine occurs due to low pressure (vacuum) being created in the engine. ● **SEE FIGURE 21–1**.

Air contains dirt and other materials that cannot be allowed to reach the engine. Just as fuel filters are used to clean impurities from gasoline, an air cleaner and filter are used to remove contaminants from the air. The three main jobs of the air cleaner and filter include

1. Clean the air before it is mixed with fuel
2. Silence intake noise
3. Act as a flame arrester in case of a backfire

The automotive engine uses about 9,000 gallons (34,000 liters) of air for every gallon of gasoline burned at an air–fuel ratio of 14.7:1 by weight. Without proper filtering of the air before it enters the engine, dust and dirt in the air can seriously damage engine parts and shorten engine life.

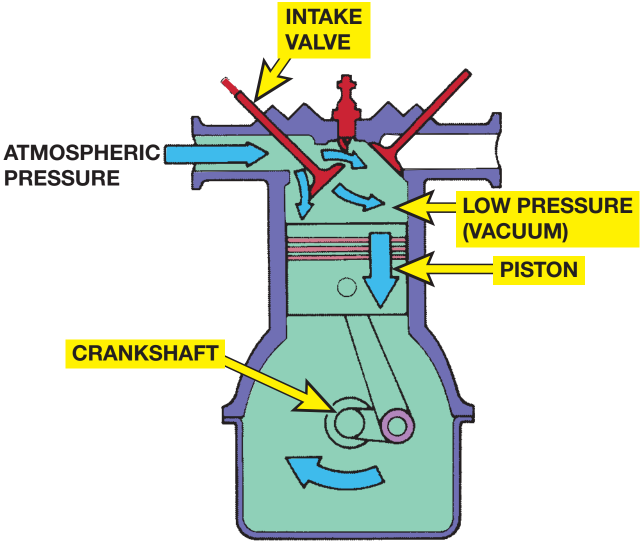


FIGURE 21–1 Downward movement of the piston lowers the air pressure inside the combustion chamber. The pressure differential between the atmosphere and the inside of the engine forces air into the engine.

Abrasive particles can cause wear any place inside the engine where two surfaces move against each other, such as piston rings against the cylinder wall. The dirt particles then pass by the piston rings and into the crankcase. From the crankcase, the particles circulate throughout the engine in the oil. Large amounts of abrasive particles in the oil can damage other moving engine parts.

The filter that cleans the intake air is in a two-piece air cleaner housing made either of

- stamped steel or
- composite (usually nylon-reinforced plastic) materials

AIR FILTER ELEMENTS The paper air filter element is the most common type of filter. It is made of a chemically treated paper stock that contains tiny passages in the fibers. These passages form an indirect path for the airflow to follow. The airflow passes through several fiber surfaces, each of which traps microscopic particles of dust, dirt, and carbon. Most air filters are capable of trapping dirt and other particles larger than 10 to 25 microns in size. One **micron** is equal to 0.000039 inch.

NOTE: A person can only see objects that are 40 microns or larger in size. A human hair is about 50 microns in diameter.

● **SEE FIGURE 21–2**.

AIR FILTER HOUSING AND DUCTS The filter that cleans the intake air is in a two-piece air cleaner housing made of composite (usually nylon-reinforced plastic) materials. Air filter housing and duct design depend on several factors, such as the size, shape, and location of other engine compartment components, as well as the vehicle body structure.

Fuel-injection systems generally use a horizontally mounted throttle body with a mass airflow (MAF) sensor between the throttle body and the air cleaner. Because placing the air cleaner housing next to the throttle body would cause engine and vehicle design problems, it is more efficient to use a remote air cleaner placement. ● **SEE FIGURE 21–3**.

Turbocharged engines present a similar problem. The air cleaner connects to the air inlet elbow at the turbocharger. However, the heat generated by the turbocharger makes it impractical to place the air cleaner housing too close to the turbocharger.

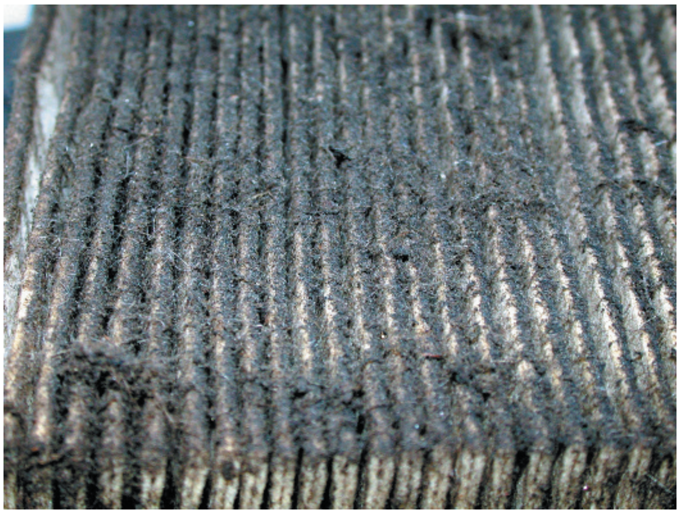


FIGURE 21–2 Dust and dirt in the air are trapped in the air filter so they do not enter the engine.

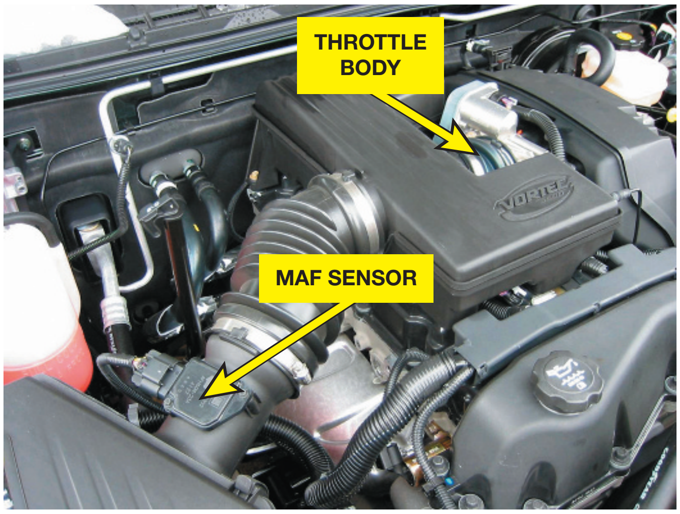


FIGURE 21–3 Most air filter housings are located on the side of the engine compartment and use flexible rubber hose to direct the airflow into the throttle body of the engine.

Remote air cleaners are connected to the turbocharger air inlet elbow or throttle body by composite ducting that is usually retained by clamps. The ducting used may be rigid or flexible but all connections must be airtight.

FILTER REPLACEMENT Manufacturers recommend cleaning or replacing the air filter element at periodic intervals, usually listed in terms of distance driven or months of service. The distance and time intervals are based on so-called normal driving. More frequent air filter replacement is necessary when the vehicle is driven under dusty, dirty, or other severe conditions.

It is best to replace a filter element before it becomes too dirty to be effective. A dirty air filter that passes contaminants can cause engine wear.

AIR FILTER RESTRICTION INDICATOR Some vehicles, especially pickup trucks that are often driven in dusty conditions, are equipped with an air filter restriction indicator. The purpose of this device is to give a visual warning when the air filter is restricted and needs to be replaced. The device operates by detecting the slight drop in pressure that occurs when an air filter is restricted.

Some air filter restriction indicators, especially on diesel engines, include an electrical switch used to light a dash-mounted warning lamp when the air filter needs to be replaced. ● **SEE FIGURE 21–4**.

TECH TIP

Always Check the Air Filter

Always inspect the air filter and the air intake system carefully during routine service. Debris or objects deposited by animals can cause a restriction to the airflow and can reduce engine performance. ● **SEE FIGURE 21–5**.

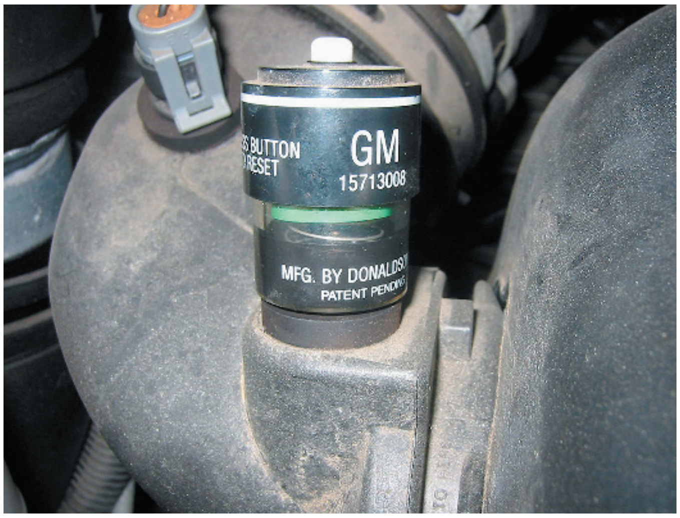


FIGURE 21–4 A typical air filter restriction indicator used on a General Motors truck engine. The indicator turns red when it detects enough restriction to require a filter replacement.

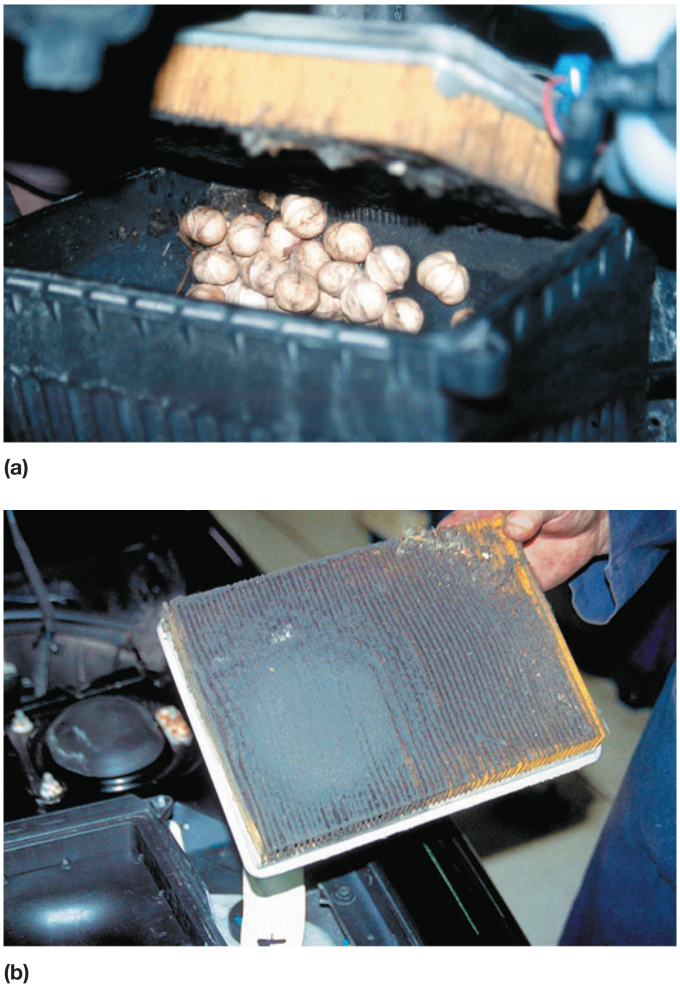


FIGURE 21–5 (a) Note the discovery as the air filter housing was opened during service on a Buick. The nuts were obviously deposited by squirrels (or some other animal). (b) Not only was the housing filled with nuts, but also this air filter was extremely dirty, indicating that this vehicle had not been serviced for a long time.

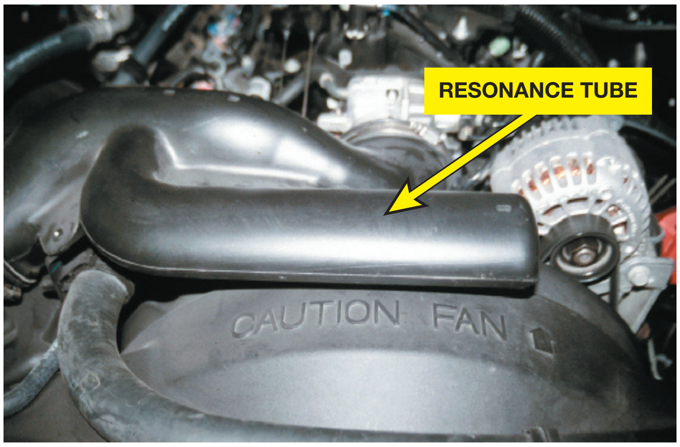


FIGURE 21–6 A resonance tube, called a Helmholtz resonator, is used on the intake duct between the air filter and the throttle body to reduce air intake noise during engine acceleration.

FREQUENTLY ASKED QUESTION

What Does This Tube Do?

What is the purpose of the odd-shape tube attached to the inlet duct between the air filter and the throttle body, as seen in ● **FIGURE 21–6**?

The tube shape is designed to dampen out certain resonant frequencies that can occur at specific engine speeds. The length and shape of this tube are designed to absorb shock waves that are created in the air intake system and to provide a reservoir for the air that will then be released into the airstream during cycles of lower pressure. This resonance tube is often called a **Helmholtz resonator**, named for the discoverer of the relationship between shape and value of frequency, Herman L. F. von Helmholtz (1821–1894) of the University of Hönizsberg in East Prussia. The overall effect of these resonance tubes is to reduce the noise of the air entering the engine.

INTAKE MANIFOLDS

TERMINOLOGY The size and shape of port fuel-injected engine intake manifolds can be optimized because the only thing in the manifold is air. The fuel injector is located in the intake manifold about 3 to 4 inches (70 to 100 mm) from the intake valve or in the combustion chamber (direct injected engines). Therefore, the runner length and shape are designed for tuning only. There is no need to keep an air–fuel mixture thoroughly mixed (homogenized) as was required in the older TBI-type injection systems. Intake manifold runners are tuned to improve engine performance.

- Long runners build low-RPM torque.
- Shorter runners provide maximum high-RPM power. ● **SEE FIGURES 21–7 AND 21–8.**

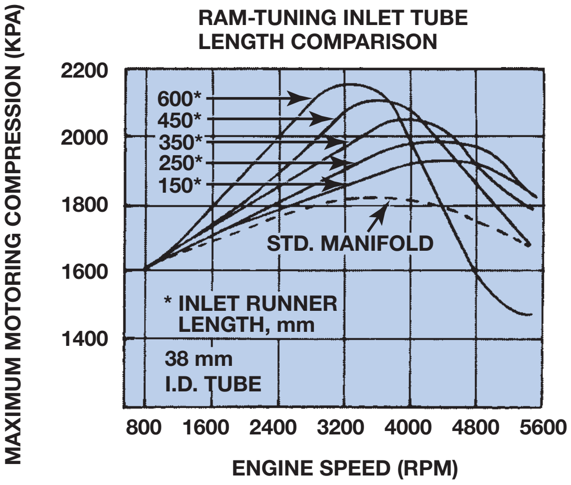


FIGURE 21–7 The graph shows the effect of sonic tuning of the intake manifold runners. The longer runners increase the torque peak and move it to a lower RPM. The 600 mm intake runner is about 24 inches long.

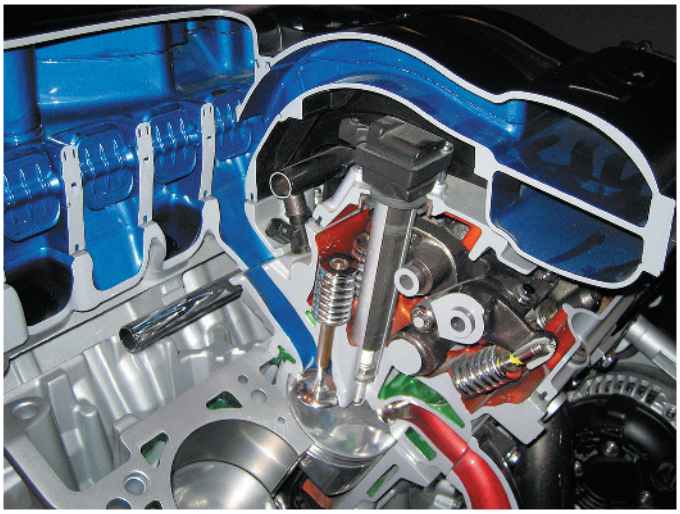


FIGURE 21–9 The air flowing into the engine can be directed through long or short runners for best performance and fuel economy.

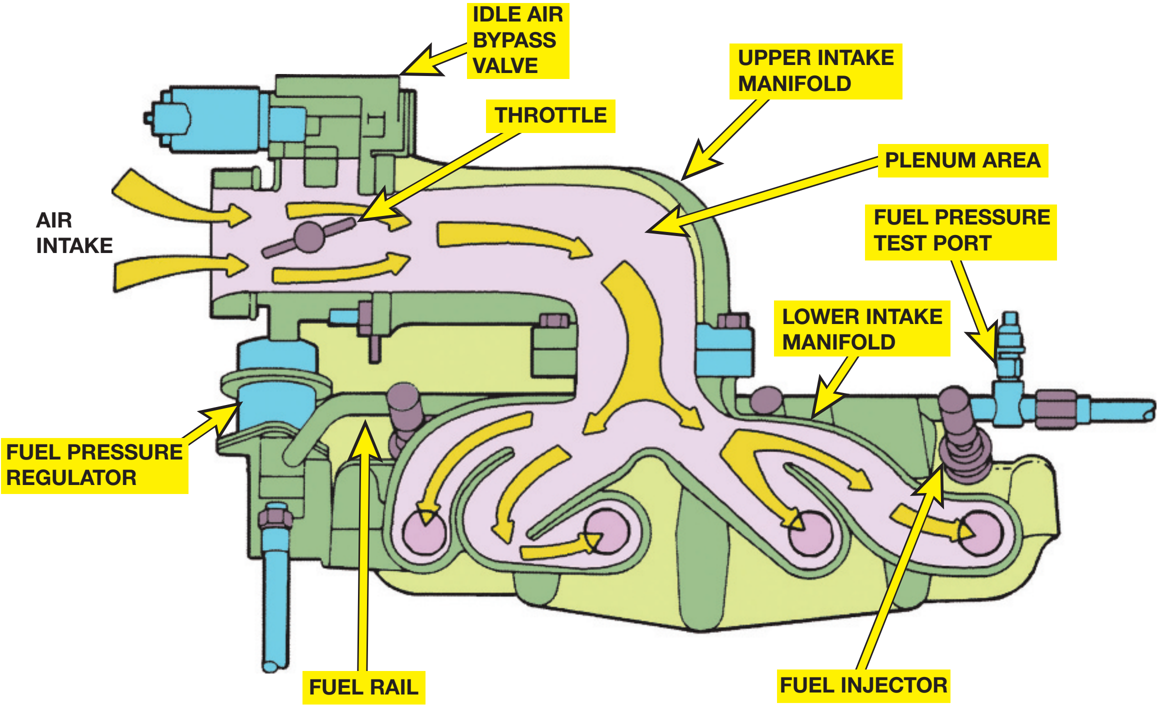


FIGURE 21–8 Airflow through the large-diameter upper intake manifold is distributed to smaller-diameter individual runners in the lower manifold in this two-piece manifold design.

INTAKE MANIFOLD DESIGN

PLASTIC INTAKE MANIFOLDS Most intake manifolds are made from thermoplastic molded from fiberglass-reinforced nylon by either casting or by injection molding. Some manifolds are molded in two parts and bonded together. Plastic intake manifolds are lighter than aluminum manifolds and can better insulate engine heat from the fuel injectors.

Plastic intake manifolds have smoother interior surfaces than do other types of manifolds, resulting in greater airflow. ● **SEE FIGURES 21–9 AND 21–10.**

UPPER AND LOWER INTAKE MANIFOLDS Many intake manifolds are constructed in two parts.

- A lower section attaches to the cylinder heads and includes passages from the intake ports.
- An upper manifold, usually called the **plenum**, connects to the lower unit and includes the long passages needed to help provide the ram effect that helps the engine deliver maximum torque at low engine speeds. The throttle body attaches to the upper intake.

The use of a two-part intake manifold allows for easier manufacturing, as well as assembly, but can create additional locations for leaks.

If the lower intake manifold gasket leaks, not only could a vacuum leak occur, affecting the operation of the engine, but a coolant leak or an oil leak can also occur if the manifold has coolant flowing through it. A leak at the gasket(s) of the upper intake manifold usually results in a vacuum (air) leak only.

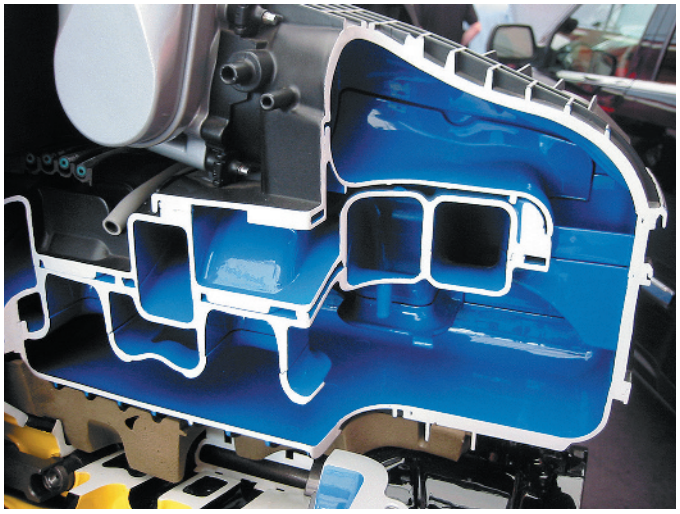


FIGURE 21–10 Many plastic intake manifolds are constructed using many parts glued together to form complex passages for airflow into the engine.

VARIABLE INTAKE MANIFOLDS

PURPOSE AND FUNCTION **Variable intake manifolds**, commonly called a *variable-length intake manifold (VLIM),* allow the engine to produce a higher level of torque and horsepower over a wide range of engine speeds. Most variable intake manifolds use two separate pathways for the flow of air into the engine each controlled by a valve that is used to control the path of airflow.

A long path is used to allow the engine to produce a higher torque at lower engine speeds and to increase fuel economy.

A short path is used to allow the engine to produce higher power at higher engine speeds. ● **SEE FIGURE 21–11**.

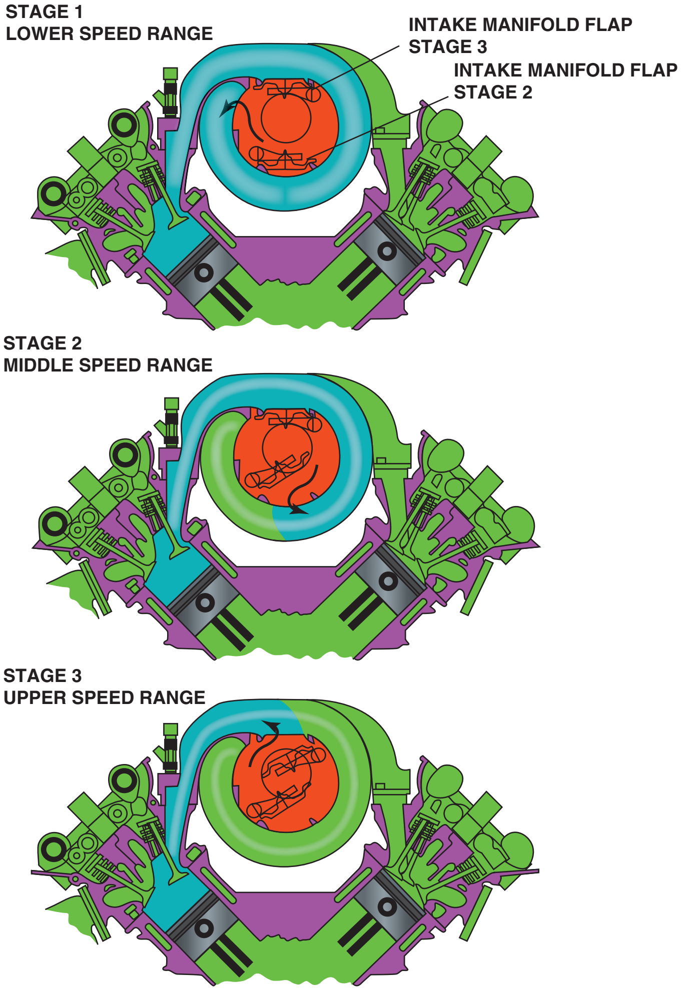


FIGURE 21–11 A typical variable intake manifold where the length of the intake passage is changed using a valve to change the direction of the airflow.

TERMINOLOGY Vehicle manufacturers use different terms for their design of variable intake manifolds, such as *variable intake system (VIS)* or *variable intake manifold (VIM)*. Some examples of vehicle manufacturer specific terms include

Acura–Variable Volume Induction (VVI)

BMW–Differential Air Intake, or Differentiated Variable Air Intake

Dodge/Chrysler–Manifold Tuning valve (MTV)

Ford–Dual-Stage Intake (DSI), or the Intake Manifold Runner Control (IMRC) for four-valve engines, and the Charge Motion Control Valve (CMCV) for three-valve engines.

Land Rover–Variable Geometry Induction (VGI)

Mazda–Variable Inertia Charging System (VICS)

Mitsubishi–Mitsubishi Variable Induction Management (MVIM)

Toyota–Toyota Variable Induction System (T-VIS) or Acoustic Control Induction System (ACIS)

VARIABLE INTAKE SYSTEM DIAGNOSIS Because the variable intake manifold system is used to enhance rather than control engine operation, unless there is a stored diagnostic trouble code (DTC), such as P0660 and the check engine light on, the average driver may or may not notice that the system is not operating correctly. However, some drivers may notice some or all of the following symptoms if the variable intake manifold system is not working:

- Lower than normal engine performance
- Rough or unstable idle
- Lower than normal fuel economy

If any of these symptoms are reported by the driver or a related DTC is stored, check the system by performing a thorough visual inspection. Always follow the vehicle manufacturer's recommended testing and service procedures.

EXHAUST GAS RECIRCULATION PASSAGES

PURPOSE AND FUNCTION To reduce the emission of oxides of nitrogen (NO_x), engines have been equipped with **exhaust gas recirculation (EGR)** valves. From 1973 until recently, they were used on almost all vehicles. Most EGR valves are mounted on the intake manifold. Because of the efficiency of computer-controlled fuel injection, some newer engines do not require an EGR system to meet emission standards. As an alternative to the EGR valve, the new engines trap some exhaust in the cylinder by closing the exhaust valve sooner.

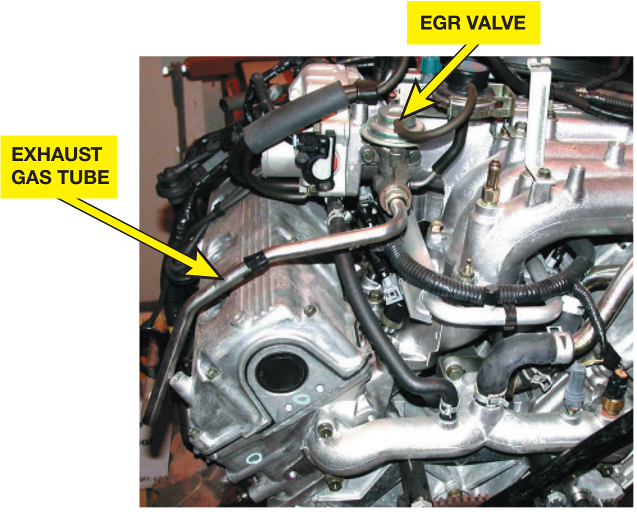


FIGURE 21–12 A typical long exhaust gas line used to cool the exhaust gases before being recirculated back into the intake manifold.

On engines with EGR systems, the EGR valve opens at speeds above idle on a warm engine. When open, the valve allows a small portion of the exhaust gas (5% to 10%) to enter the intake manifold.

The EGR system has some means of interconnecting of the exhaust and intake manifolds. The EGR valve controls the gas flow through the passages.

- On V-type engines, the intake manifold crossover is used as a source of exhaust gas for the EGR system. A cast passage connects the exhaust crossover to the EGR valve.
- On inline-type engines, an external tube is generally used to carry exhaust gas to the EGR valve.

EXHAUST GAS COOLERS The exhaust gases are more effective in reducing NO$_X$ emissions if the exhaust is cooled before being drawn into the cylinders. This tube is often designed to be long so that the exhaust gas is cooled before it enters the EGR valve. ● **SEE FIGURE 21–12**.

EXHAUST MANIFOLDS

PURPOSE AND FUNCTION The exhaust manifold is designed to collect high-temperature spent gases from the individual head exhaust ports and directs them into a single outlet connected to the exhaust system. ● **SEE FIGURE 21–13**.

The hot gases are sent to an exhaust pipe, then to a catalytic converter, to the muffler, to a resonator, and on to the tailpipe, where they are vented to the atmosphere. The exhaust system is designed to meet the following needs:

- Provide the least possible amount of restriction or backpressure
- Keep the exhaust noise at a minimum

Exhaust gas temperature will vary according to the power produced by the engine. The manifold must be designed to operate at both engine idle and continuous full power. Under full-power conditions, the exhaust manifold can become red-hot, causing a great deal of expansion.

The temperature of an exhaust manifold can exceed 1,500°F (815°C).

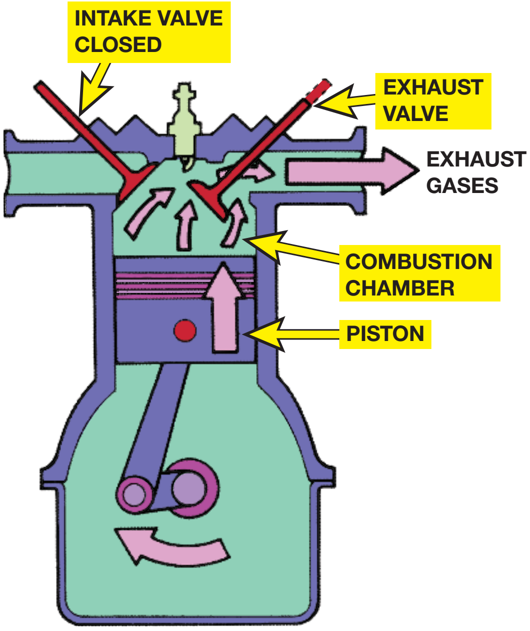


FIGURE 21–13 The exhaust gases are pushed out of the cylinder by the piston on the exhaust stroke.

CONSTRUCTION Most exhaust manifolds are made from the following:

- Cast iron
- Steel tubing

During vehicle operation, manifold temperatures usually reach the high-temperature extremes. The manifold is bolted to the head in a way that will allow expansion and contraction. In some cases, hollow-headed bolts are used to maintain a gas-tight seal, while still allowing normal expansion and contraction.

Many exhaust manifolds have heat shields to help keep exhaust heat off the spark plug wires and to help keep the heat from escaping to improve exhaust emissions. ● **SEE FIGURE 21–14**.

Exhaust systems are especially designed for the engine–chassis combination. The exhaust system length, pipe size, and silencer are designed, where possible, to make use of the tuning effect within the exhaust system. Tuning occurs when the exhaust pulses from the cylinders are emptied into the manifold between the pulses of other cylinders. ● **SEE FIGURE 21–15**.

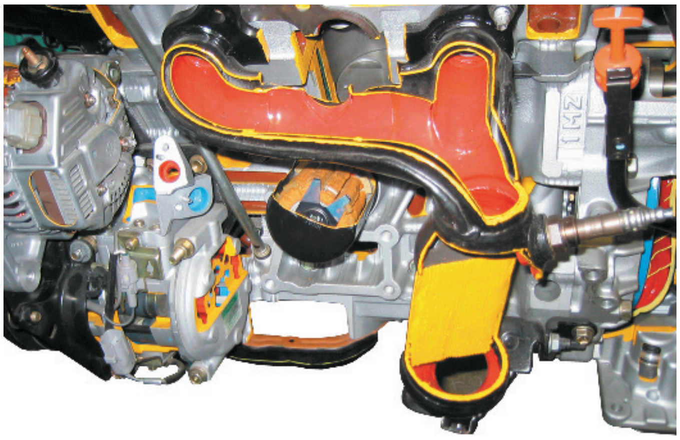


FIGURE 21–14 This exhaust manifold (red area) is equipped with a heat shield to help retain heat and reduce exhaust emissions.

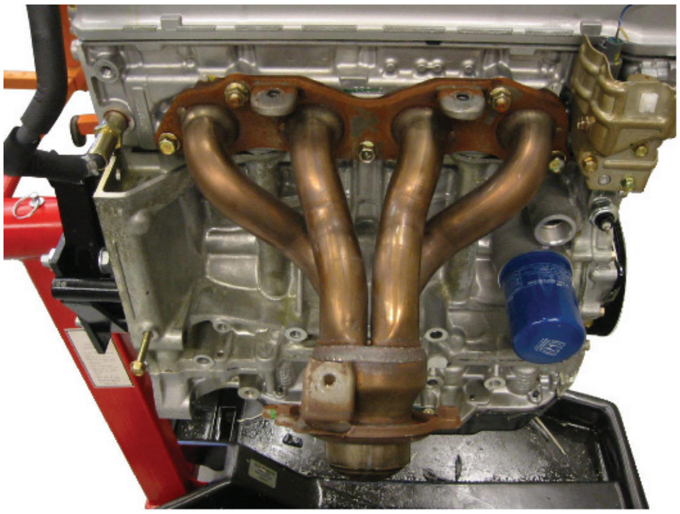


FIGURE 21–15 Many exhaust manifolds are constructed of steel tubing and are free flowing to improve engine performance.

FREQUENTLY ASKED QUESTION

How Can a Cracked Exhaust Manifold Affect Engine Performance?

Cracks in an exhaust manifold will not only allow exhaust gases to escape and cause noise, but also allow air to enter the exhaust manifold. ● **SEE FIGURE 21–16**.

Exhaust flows from the cylinders as individual puffs or pressure pulses. Behind each of these pressure pulses, a low pressure (below atmospheric pressure) is created. Outside air at atmospheric pressure is then drawn into the exhaust manifold through the crack. This outside air contains 21% oxygen and is measured by the oxygen sensor (O2S). The air passing the O2S signals the engine computer that the engine is operating too lean (excess oxygen) and the computer, not knowing that the lean indicator is false, adds additional fuel to the engine. The result is that the engine will be operating richer (more fuel than normal) and spark plugs could become fouled by fuel, causing poor engine operation.

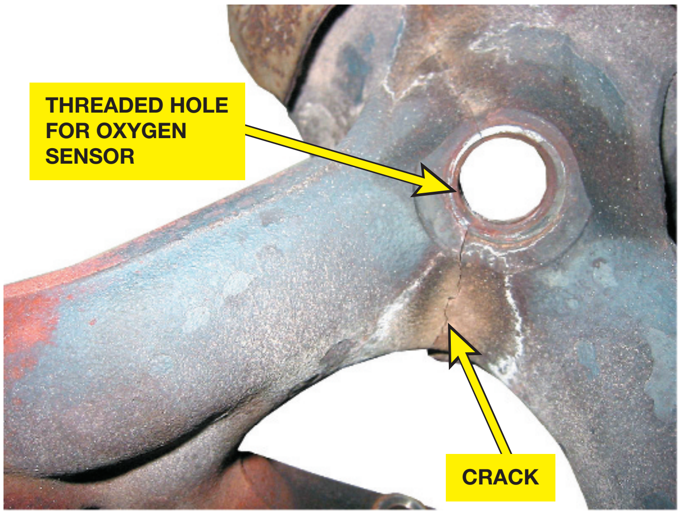


FIGURE 21–16 A crack in an exhaust manifold is often not visible because a heat shield usually covers the area. A crack in the exhaust manifold upstream of the oxygen sensor can fool the sensor and affect engine operation.

EXHAUST MANIFOLD GASKETS Exhaust heat will expand the manifold more than it will expand the head. The heat causes the exhaust manifold to slide on the sealing surface of the head. The heat also causes thermal stress. When the manifold is removed from the engine for service, the stress is relieved, which may cause the manifold to warp slightly. Exhaust manifold gaskets are included in gasket sets to seal slightly warped exhaust manifolds. These gaskets *should* be used, even if the engine did not originally use exhaust manifold gaskets. When an exhaust manifold gasket has facing on one side only, put the facing side against the head and put the manifold against the perforated metal core. The manifold can slide on the metal of the gasket just as it slid on the sealing surface of the head.

Gaskets are used on new engines with tubing- or header-type exhaust manifolds. They may have several layers of steel for high-temperature sealing. The layers are spot welded together. Some are embossed where special sealing is needed. ● **SEE FIGURE 21–17**.

Many new engines do not use gaskets with cast exhaust manifolds. The flat surface of the new cast-iron exhaust manifold fits tightly against the flat surface of the new head.

TECH TIP

Using the Correct Tool Saves Time

When cast-iron exhaust manifolds are removed, the stresses built up in the manifolds often cause the manifolds to twist or bend. This distortion even occurs when the exhaust manifolds have been allowed to cool before removal. Attempting to reinstall distorted exhaust manifolds is often a time-consuming and frustrating exercise.

However, special spreading jacks can be used to force the manifold back into position so that the fasteners can be lined up with the cylinder head. ● **SEE FIGURE 21–18**.

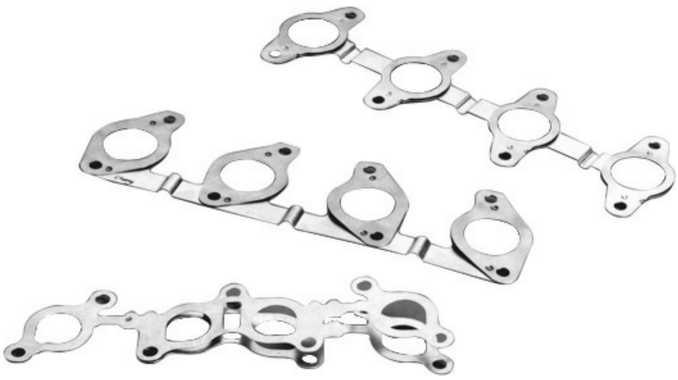


FIGURE 21–17 Typical exhaust manifold gaskets. Note how they are laminated to allow the exhaust manifold to expand and contract due to heating and cooling.

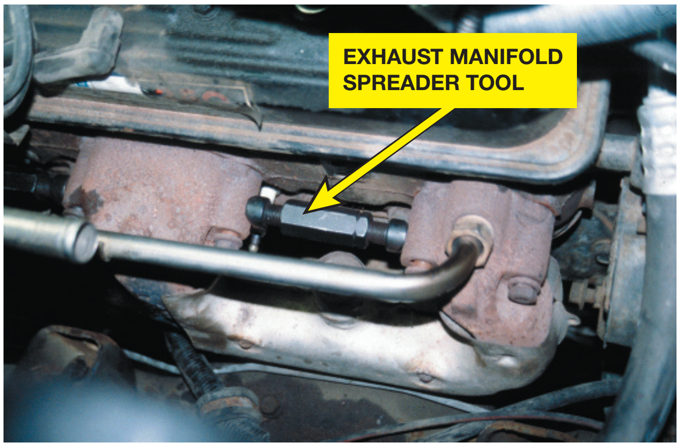

EXHAUST MANIFOLD SPREADER TOOL

FIGURE 21–18 An exhaust manifold spreader tool.

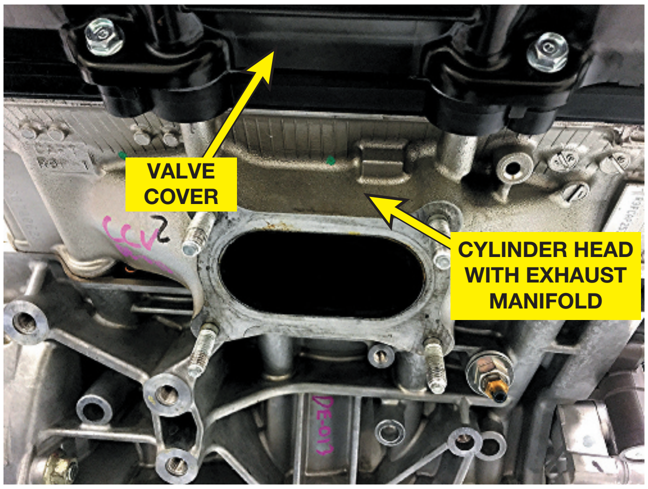

VALVE COVER
CYLINDER HEAD WITH EXHAUST MANIFOLD

FIGURE 21–19 The "exhaust manifold" on this Honda is actually part of the cylinder head and not a separate part. The catalytic converter is attached directly to the cylinder head using four studs.

EXHAUST SYSTEM COMPONENTS

CATALYTIC CONVERTER The catalytic converter is placed as close to the engine as possible so that the heat can help the converter work most efficiently. Some engines do not use a separate exhaust manifold and instead use a manifold that is cast as part of the cylinder head. In this situation, the catalytic converter is attached directly to the cylinder head. ● **SEE FIGURE 21–19**.

EXHAUST PIPES The exhaust pipes from the catalytic converter rearward are used to conduct the hot exhaust gases to the rear of the vehicle. The pipes are usually constructed of aluminized or stainless steel to resist rust and corrosion.

HEAT SHIELDS AND HANGERS Exhaust systems are equipped with heat shields in several locations to

- Help prevent the heat from the exhaust system moving upward toward the floor of the vehicle.
- Help prevent the heat from the catalytic converter from touching possible flammable tall grass if the vehicle is being driven off of a paved road.

Hangers are used to isolate heat and vibrations in the exhaust system (cylinder firing pulses) from entering the body of the vehicle. They also allow the exhaust system to move as the exhaust system gets hotter, which causes the pipes to grow in length. The flexible hangers allow for this movement. ● **SEE FIGURE 21–20**.

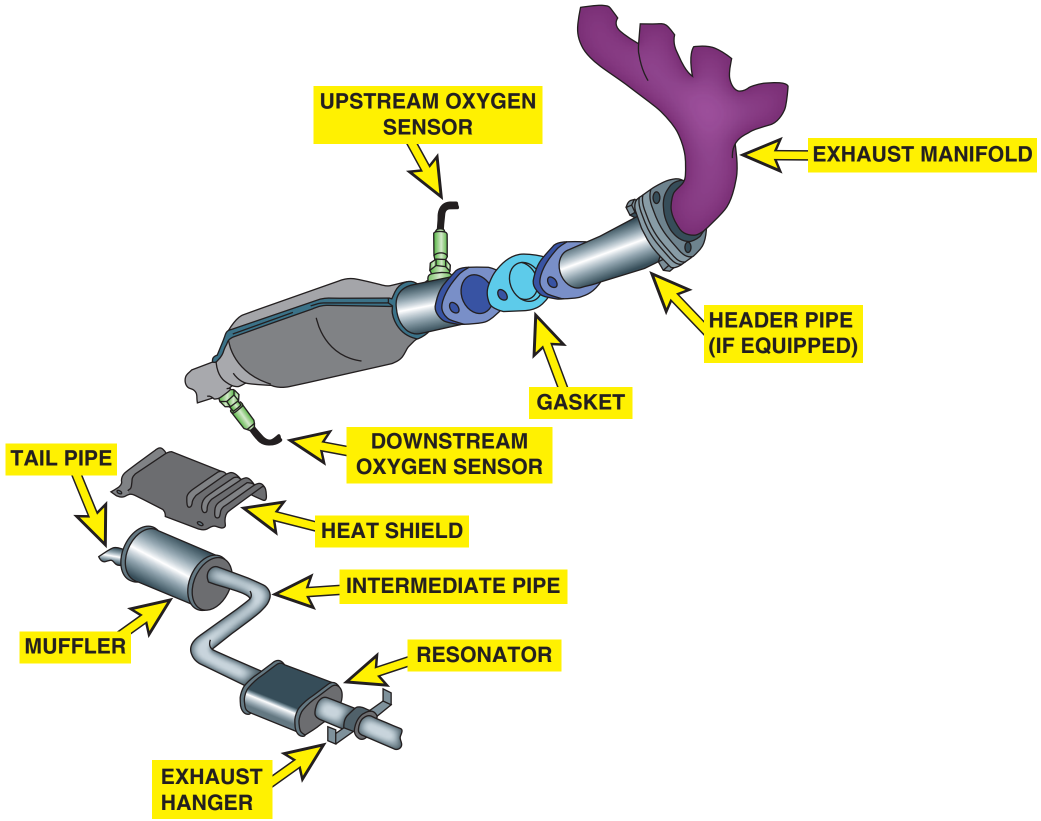

UPSTREAM OXYGEN SENSOR
EXHAUST MANIFOLD
HEADER PIPE (IF EQUIPPED)
GASKET
DOWNSTREAM OXYGEN SENSOR
TAIL PIPE
HEAT SHIELD
INTERMEDIATE PIPE
MUFFLER
RESONATOR
EXHAUST HANGER

FIGURE 21–20 A typical exhaust system showing the heat shields and hangers used to isolate exhaust system vibrations from the vehicle body, and to control the movement as the exhaust system changes in length due to heat.

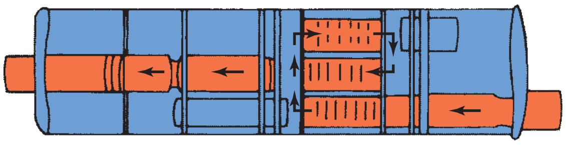


FIGURE 21–21 Exhaust gases expand and cool as they travel through passages in the muffler.

MUFFLERS When the exhaust valve opens, it rapidly releases high-pressure gas. This sends a strong air pressure wave through the atmosphere inside the exhaust system, which produces a sound we call an explosion. It is the same sound produced when the high-pressure gases from burned gunpowder are released from a gun. In an engine, the pulses are released one after another. The explosions come so fast that they blend together in a steady roar.

Sound is air vibration. When the vibrations are large, the sound is loud. The muffler catches the large bursts of high-pressure exhaust gas from the cylinder, smoothing out the pressure pulses and allowing them to be released at an even and constant rate. It does this through the use of perforated tubes within the muffler chamber. The smooth-flowing gases are released to the tailpipe. In this way, the muffler silences engine exhaust noise. ● **SEE FIGURE 21–21**.

Most mufflers have a larger inlet diameter than outlet diameter. As the exhaust enters the muffler, it expands and cools. The cooler exhaust is denser and occupies less volume. The diameter of the outlet of the muffler and the diameter of the tailpipe can be reduced with no decrease in efficiency.

Sometimes resonators are used in the exhaust system and the catalytic converter also acts as a muffler. They provide additional expansion space at critical points in the exhaust system to smooth out the exhaust gas flow.

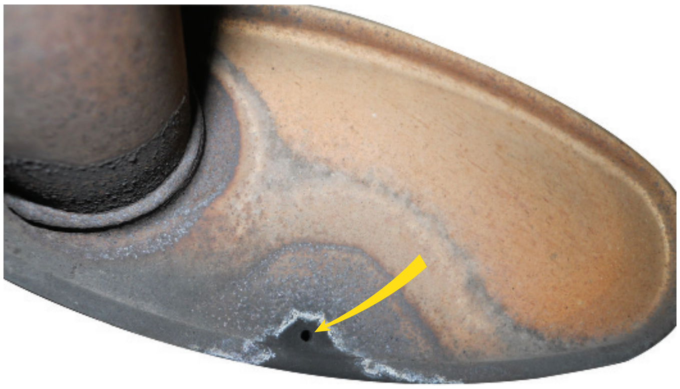


FIGURE 21–22 A hole in the muffler allows condensed water to escape.

The tailpipe carries the exhaust gases from the muffler to the air, away from the vehicle. In most cases, the tailpipe exit is at the rear of the vehicle, below the rear bumper. In some cases, the exhaust is released at the side of the vehicle, just ahead of or just behind the rear wheel.

The muffler and tailpipe are supported with brackets, called **hangers**, which help to isolate the exhaust noise from the rest of the vehicle. The types of exhaust system hangers include the following:

- Rubberized fabric with metal ends that hold the muffler and tailpipe in position so that they do not touch any metal part, to isolate the exhaust noise from the rest of the vehicle
- Rubber material that looks like large rubber bands, which slip over the hooks on the exhaust system, and the hooks are attached to the body of the vehicle

FREQUENTLY ASKED QUESTION

Why Is There a Hole in My Muffler?

Many mufflers are equipped with a small hole in the lower rear part to drain accumulated water. About 1 gallon of water is produced in the form of steam for each gallon of gasoline burned. The water is formed when gasoline is burned in the cylinder. Water consists of two molecules of hydrogen and one of oxygen (H_2O). The hydrogen (H) comes from the fuel and the oxygen (O) comes from the air. During combustion, the hydrogen from the fuel combines with some of the oxygen in the air to form water vapor. The water vapor condenses on the cooler surfaces of the exhaust system, especially in the muffler, until the vehicle has been driven long enough to fully warm the exhaust above the boiling point of water (212°F [100°C]). ● **SEE FIGURE 21–22**.

TECH TIP

Perform an Exhaust System Tap Test

The condition of an exhaust system is often hard to determine by visual inspection only. Many professional service technicians use a rubber mallet and tap each section of the exhaust system. This test often finds broken heat shields that rattle when the system is tapped, or a loose hanger, or even a section of the exhaust that has corroded from the inside out and the weak area could not be seen. To perform an exhaust tap test, start at the front of the vehicle and lightly tap on each section using a small rubber mallet. Continue taping each section to the rear. If any rattles are heard, then further inspection is needed in that area to find the root cause. Fix or repair as needed.

REVIEW QUESTIONS

1. What are the three main jobs of the air cleaner and filter?
2. How can fuel-injected engine intake manifolds be tuned to improve engine performance?
3. What is a variable intake manifold?
4. How does a muffler quiet exhaust noise?
5. What is the purpose and function of exhaust system hangers?

CHAPTER QUIZ

1. The air filter restriction indicator uses what to detect when it signals to replace the filter?
   - **a.** Number of hours of engine operation
   - **b.** Number of miles of vehicle travel
   - **c.** The amount of light that can pass through the filter
   - **d.** The amount of restriction measured in inches of water
2. Air filters can remove particles and dirt as small as ______________.
   - **a.** 5 to 10 microns
   - **b.** 10 to 25 microns
   - **c.** 30 to 40 microns
   - **d.** 40 to 50 microns
3. Why do many port fuel-injected engines use long intake manifold runners?
   - **a.** To reduce exhaust emissions
   - **b.** To heat the incoming air
   - **c.** To increase high-RPM power
   - **d.** To increase low-RPM torque
4. The upper portion of a two-part intake manifold is often called the ______________.
   - **a.** housing
   - **b.** lower part
   - **c.** plenum
   - **d.** vacuum chamber
5. Which of the following is/are terms for a variable intake manifold?
   - **a.** Variable intake system (VIS)
   - **b.** Variable volume induction (VVI)
   - **c.** Dual-stage intake (DSI)
   - **d.** Any of the above
6. Why are the EGR gases cooled before entering the engine on some engines?
   - **a.** Cool exhaust gas is more effective at controlling NO_x emissions
   - **b.** To help prevent the exhaust from slowing down
   - **c.** To prevent damage to the intake valve
   - **d.** To prevent heating the air–fuel mixture in the cylinder
7. Technician A says that a cracked exhaust manifold can affect engine operation. Technician B says that a leaking lower intake manifold gasket could cause a vacuum leak. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Technician A says that some intake manifolds are plastic. Technician B says that some intake manifolds are constructed in two parts or sections: upper and lower. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. Why is the catalytic converter placed as close to the engine as possible?
   - **a.** For easier access when working on the engine
   - **b.** So the heat can help the converter work most efficiently
   - **c.** To allow the exhaust pipes from the catalytic converter rearward to be as long as possible
   - **d.** To prevent the heat from the exhaust system moving upward toward the floor of the vehicle
10. The ______________ smoothes out the pressure pulses in the exhaust system, allowing them to be released at an even and constant rate.
    - **a.** exhaust manifold
    - **b.** muffler
    - **c.** intake manifold
    - **d.** exhaust gas recirculation valve

Chapter

22

TURBOCHARGING AND SUPERCHARGING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss airflow requirements and volumetric efficiency of engines.
- Explain forced induction principles.
- Discuss superchargers.
- Discuss turbochargers.
- Discuss turbocharger failures.
- Explain boost control.

KEY TERMS:

Boost 227 • BOV 233 • Bypass valve 229 • CBV 233 • Charge density 227 • Dump valve 233 • Forced induction systems 227 • Intercooler 232 • Naturally (normally) aspirated 227 • Positive displacement 229 • Roots supercharger 228 • Supercharger 228 • Turbocharger 230 • Turbo lag 231 • Vent valve 233 • Volumetric efficiency 226 • Wastegate 232

INTRODUCTION

AIRFLOW REQUIREMENTS Naturally aspirated engines with throttle plates use atmospheric pressure to push an air-fuel mixture into the combustion chamber vacuum created by the down stroke of a piston. The mixture is then compressed before ignition to increase the force of the burning, expanding gases. The greater the compression of the air–fuel mixture, the higher the engine power output resulting from combustion.

A four-stroke engine can take in only so much air, and how much fuel it needs for proper combustion depends on how much air it takes in. Engineers calculate engine airflow requirements using three factors:

1. Engine displacement
2. Engine revolutions per minute (RPM)
3. Volumetric efficiency

VOLUMETRIC EFFICIENCY **Volumetric efficiency** is a measure of how well an engine breathes. It is a comparison of the actual volume of air–fuel mixture drawn into an engine to the theoretical maximum volume that could be drawn in. Volumetric efficiency is expressed as a percentage. If the engine takes in the airflow volume slowly, a cylinder might fill to capacity. It takes a definite amount of time for the airflow to pass through all the curves of the intake manifold and intake port. Therefore, volumetric efficiency decreases as engine speed increases due to the shorter amount of time for the cylinders to be filled with air during the intake stroke. At high speed, it may drop to as low as 50%.

The average stock gasoline engine never reaches 100% volumetric efficiency. A new engine is about 85% efficient. A race engine usually has 95% or better volumetric efficiency. These figures apply only to naturally aspirated engines. However, with either turbochargers or superchargers, engines can easily achieve more than 100% volumetric efficiency. Many vehicles are equipped with a supercharger or a turbocharger from the factory to increase power. ● **SEE FIGURES 22–1 AND 22–2.**

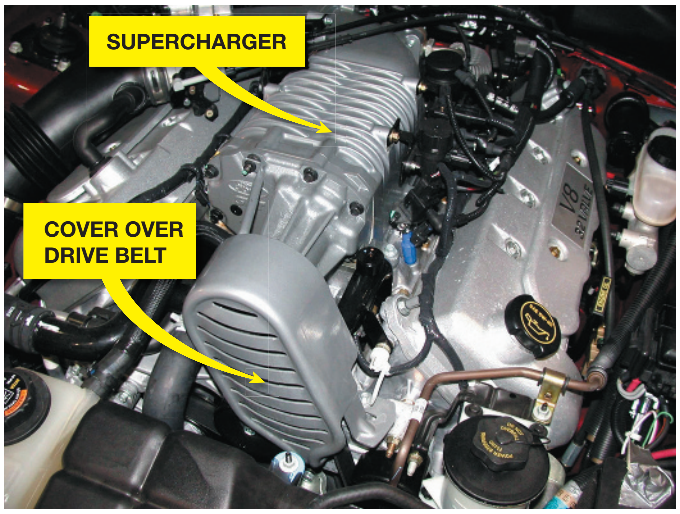


FIGURE 22–1 A supercharger on a Ford V-8.

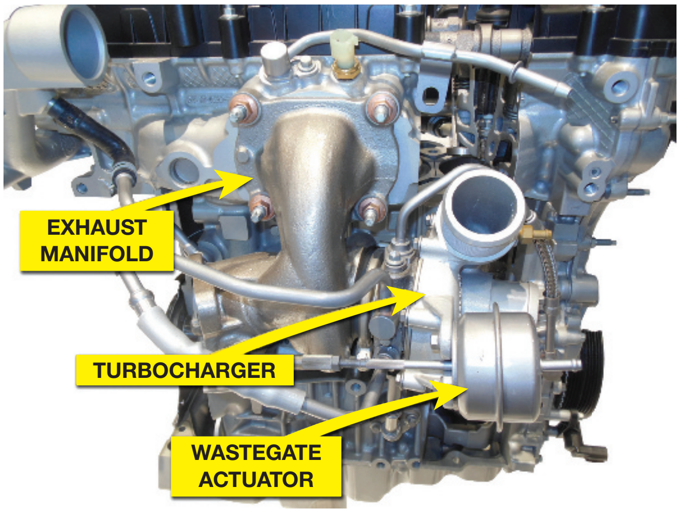


FIGURE 22–2 A turbocharged Ford three-cylinder 1.0 liter Eco Boost engine.

FORCED INDUCTION PRINCIPLES

PURPOSE AND FUNCTION The amount of force an air–fuel charge produces when it is ignited is largely a function of the charge density. **Charge density** is a term used to define the amount of the air–fuel charge introduced into the cylinders. Density is the mass of a substance in a given amount of space. ● **SEE FIGURE 22–3**.

The greater the density of an air–fuel charge forced into a cylinder, the greater the force it produces when ignited, and the greater the engine power.

An engine that uses atmospheric pressure for its intake charge is called a **naturally (normally) aspirated** engine. A better way to increase air density is to use some type of air pump, such as a turbocharger or supercharger.

When air is pumped into the cylinder, the combustion chamber receives an increase of air pressure known as **boost**, and can be measured in the following units:

- Pounds per square inch (PSI)
- Atmospheres (ATM) (1 atmosphere is 14.7 PSI)
- Bars (1 bar is 14.7 PSI)

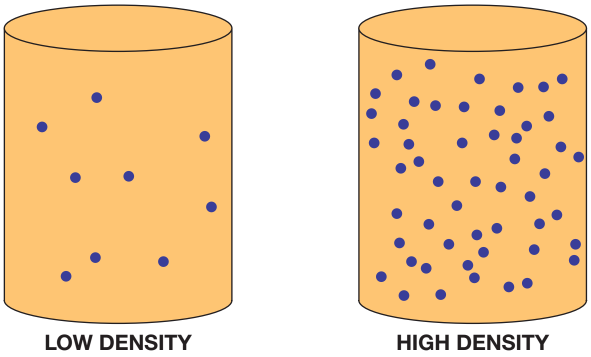


FIGURE 22–3 The more air and fuel that can be packed in a cylinder, the greater the density of the air–fuel charge.

While boost pressure increases air density, friction heats air in motion and causes an increase in temperature. This increase in temperature works in the opposite direction, decreasing air density. Because of these and other variables, an increase in pressure does not always result in greater air density.

FORCED INDUCTION PRINCIPLES **Forced induction systems** use an air pump to pack a denser air–fuel charge into the cylinders. Because the density of the air–fuel charge is greater, the following occurs:

- The weight of the air–fuel charge is higher.
- Power is increased because it is directly related to the weight of an air–fuel charge consumed within a given time period.

Pumping air into the intake system under pressure forces it through the bends and restrictions of the air intake system at a greater speed than it would travel under normal atmospheric pressure. This added pressure allows more air to enter the intake port before the intake valve closes. By increasing the airflow into the intake, more fuel can be mixed with the air, while still maintaining the same air–fuel ratio. The denser the air–fuel charge entering the engine during its intake stroke, the greater the potential energy released during combustion. In addition to the increased power resulting from combustion, there are several other advantages of supercharging an engine, including the following:

- It increases the air–fuel charge density to provide high-compression pressure when power is required, but allows the engine to run on lower pressures when additional power is not required.
- The pumped air pushes the remaining exhaust from the combustion chamber during intake and exhaust valve overlap. (Overlap is when both the intake and exhaust valves are partially open when the piston is near the top at the end of the exhaust stroke and the beginning of the intake stroke.)
- The forced airflow and removal of hot exhaust gases lowers the temperature of the cylinder head, pistons, and valves, and helps extend the life of the engine.

A supercharger or turbocharger pressurizes air to greater than atmospheric pressure. The pressurization above atmospheric pressure, or boost, can be measured in the same way as atmospheric pressure. Atmospheric pressure drops as altitude increases, but boost pressure remains the same. If a supercharger develops 12 PSI (83 kPa) boost at sea level, it will develop the same amount at a 5,000 ft altitude because boost pressure is measured inside the intake manifold. ● **SEE FIGURE 22–4**.

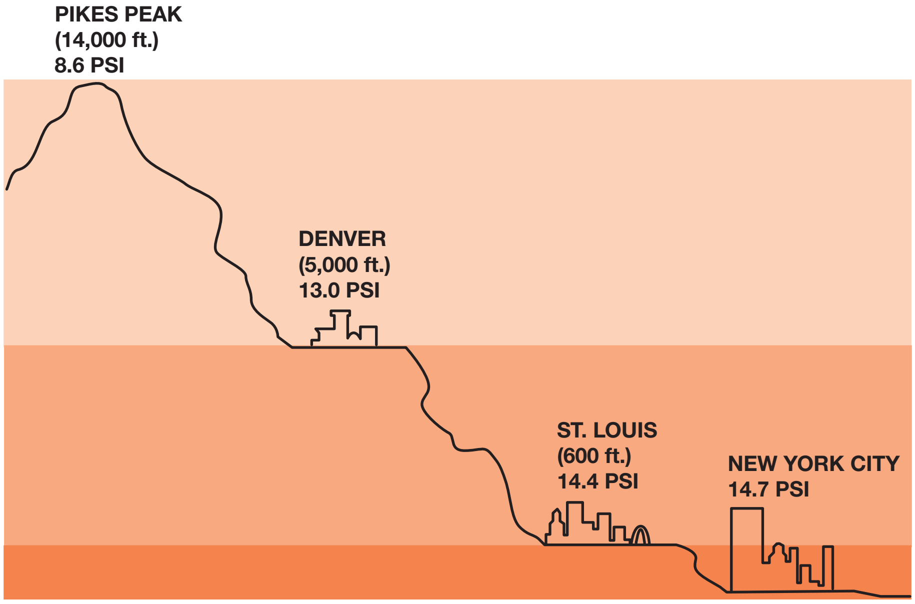


FIGURE 22–4 Atmospheric pressure decreases with increases in altitude.

FINAL COMPRESSION RATIO CHART AT VARIOUS BOOST LEVELS

	BLOWER BOOST (PSI)									
Comp Ratio	2	4	6	8	10	12	14	16	18	20
6.5	7.4	8.3	9.2	10	10.9	11.8	12.7	13.6	14.5	15.3
7	8	8.9	9.9	10.8	11.8	12.7	13.6	14.5	15.3	16.2
7.5	8.5	9.5	10.6	11.6	12.6	13.6	14.6	15.7	16.7	17.8
8	9.1	10.2	11.3	12.4	13.4	14.5	15.6	16.7	17.8	18.9
8.5	9.7	10.8	12	13.1	14.3	15.4	16.6	17.8	18.9	19.8
9	10.2	11.4	12.7	13.9	15.1	16.3	17.6	18.8	20	21.2
9.5	10.8	12.1	13.4	14.7	16	17.3	18.5	19.8	21.1	22.4
10	11.4	12.7	14.1	15.4	16.8	18.2	19.5	20.9	22.2	23.6

CHART 22–1

The effective compression ratio compared to the boost pressure.

BOOST AND COMPRESSION RATIOS

Boost increases the amount of air drawn into the cylinder during the intake stroke. This extra air causes the effective compression ratio to be greater than the mechanical compression ratio designed into the engine. The higher the boost pressure, the greater the compression ratio. This means that any engine that uses a supercharger or turbocharger must use all of the following engine components:

- Forged pistons, to withstand the increased combustion pressures
- Stronger than normal connecting rods
- Piston oil squirters that direct a stream of oil to the underneath part of the piston, to keep piston temperatures under control
- Lower compression ratio compared to a naturally aspirated engine

● **SEE CHART 22–1**.

SUPERCHARGERS

INTRODUCTION

A **supercharger** is an engine-driven air pump that supplies more than the normal amount of air into the intake manifold, and boosts engine torque and power. A supercharger provides an instantaneous increase in power without any delay. However, a supercharger, because it is driven by the engine, requires horsepower to operate and is not as efficient as a turbocharger.

A supercharger is an air pump mechanically driven by the engine itself. Gears, shafts, chains, or belts from the crankshaft can all be used to turn the pump. This means the air pump or supercharger pumps air in direct relation to engine speed.

TYPES OF SUPERCHARGERS

There are three general types of superchargers.

- **Roots type.** Named for Philander and Francis Roots, two brothers from Connersville, Indiana, the **Roots supercharger**

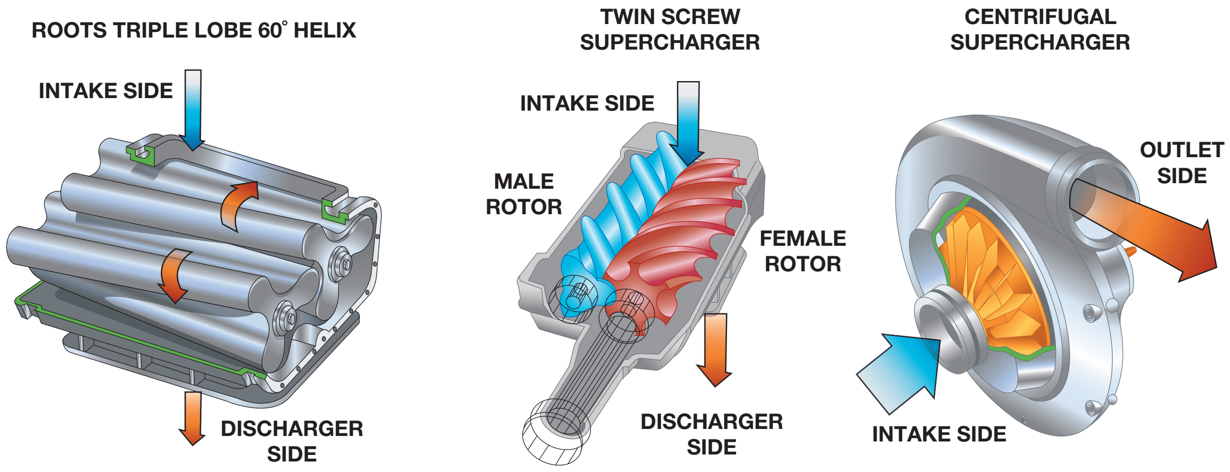

ROOTS TRIPLE LOBE 60° HELIX
INTAKE SIDE
DISCHARGER SIDE
TWIN SCREW SUPERCHARGER
INTAKE SIDE
MALE ROTOR
FEMALE ROTOR
DISCHARGER SIDE
CENTRIFUGAL SUPERCHARGER
OUTLET SIDE
INTAKE SIDE

FIGURE 22–5 A Roots-type supercharger (left) compared to a twin screw type in the center and a centrifugal type on the right.

was patented in 1860 as a type of water pump to be used in mines. Later, it was used to move air and is used today on two-stroke-cycle Detroit diesel engines and other supercharged engines. The Roots-type supercharger is called a **positive displacement** design, because all of the air that enters is forced through the unit. Examples of a Roots-type supercharger include the GMC 6-71 (used originally on GMC diesel engines that had 6 cylinders each with 71 cubic inch).

- **Twin screw.** The twin screw compresses the air between the rotors. Air enters the supercharger through the rear or top rear and is "compressed" internally between the rotors. The male rotor rotates clockwise as the female rotor rotates counter clockwise trapping and compressing the air between them and channeling the air toward the front where it is discharged.
- **Centrifugal supercharger.** A centrifugal supercharger is similar to a turbocharger, but is mechanically driven by the engine instead of being powered by the hot exhaust gases. A centrifugal supercharger is not a positive displacement pump and all of the air that enters is not forced through the unit. Air enters a centrifugal supercharger housing in the center and exits at the outer edges of the compressor wheels at a much higher speed due to centrifugal force. The speed of the blades has to be higher than engine speed, so a smaller pulley is used on the supercharger, and the crankshaft overdrives the impeller through an internal gear box, achieving about seven times the speed of the engine. Examples of centrifugal superchargers include Vortech and Paxton. ● **SEE FIGURE 22–5**.

SUPERCHARGER BOOST CONTROL Many factory installed superchargers are equipped with a **bypass valve** that allows intake air to flow directly into the intake manifold, bypassing the supercharger. The computer controls the bypass valve actuator. ● **SEE FIGURE 22–6**.

The airflow is directed around the supercharger whenever any of the following conditions occur:

- The boost pressure, as measured by the MAP sensor, indicates that the intake manifold pressure is reaching the predetermined boost level.
- During deceleration, to prevent excessive pressure buildup in the intake.
- Reverse gear is selected.

SUPERCHARGER SERVICE Superchargers are usually lubricated with synthetic engine oil inside the unit. This oil level should be checked and replaced as specified by the vehicle or supercharger manufacturer. The drive belt should also be inspected and replaced as necessary. The air filter should be replaced regularly, and always use the filter specified for a supercharged engine.

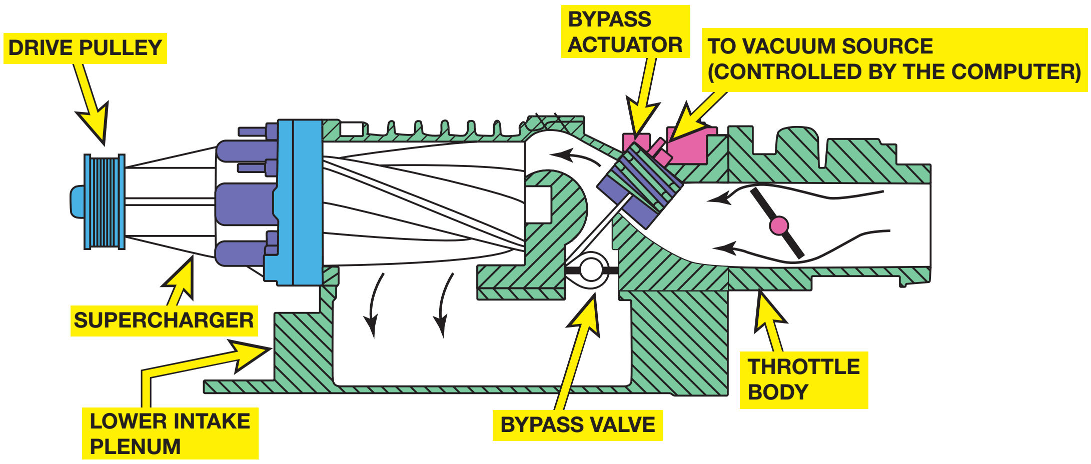

DRIVE PULLEY
BYPASS ACTUATOR
TO VACUUM SOURCE (CONTROLLED BY THE COMPUTER)
SUPERCHARGER
LOWER INTAKE PLENUM
BYPASS VALVE
THROTTLE BODY

FIGURE 22–6 The bypass actuator opens the bypass valve to control boost pressure.

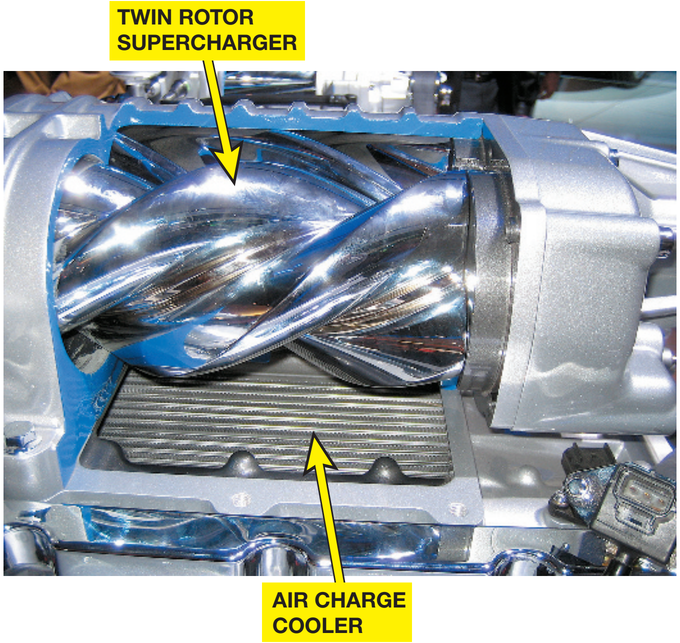


FIGURE 22–7 A Ford supercharger cutaway display showing the Roots-type blower and air charge cooler (intercooler). The air charge cooler is used to reduce the temperature of the compressed air before it enters the engine to increase the air charge density.

TECH TIP

Faster Moves More Air

One of the high-performance measures that can be used to increase horsepower on a supercharged engine is to install a smaller diameter pulley. The smaller the pulley diameter, the faster the supercharger will rotate and the higher the potential boost pressure will be. The change will require a shorter belt, and the extra boost could cause serious engine damage.

Many factory supercharger systems use a separate cooling system for the air charge cooler, located under the supercharger. Check service information for the exact service procedures to follow. ● **SEE FIGURE 22–7**.

TURBOCHARGERS

INTRODUCTION The major disadvantage of a supercharger is that it takes some of the engine power to drive the unit. In some installations, as much as 20% of the engine power is used by a mechanical supercharger. A **turbocharger** uses the heat of the exhaust to power a turbine wheel and, therefore, does not directly reduce engine power. In a naturally aspirated engine, about half of the heat energy contained in the fuel goes out the exhaust system. However, some engine power is lost due to the exhaust restriction. This loss in power is regained, to perform other work, and the combustion heat energy lost in the engine exhaust (as much as 40% to 50%) can be harnessed to do useful work. Another 25% is lost through radiator cooling. Only about 25% is actually converted to mechanical power. A mechanically driven pump uses some of this mechanical output, but a turbocharger gets its energy from the exhaust gases, converting more of the fuel's heat energy into useful mechanical energy. ● **SEE FIGURE 22–8**.

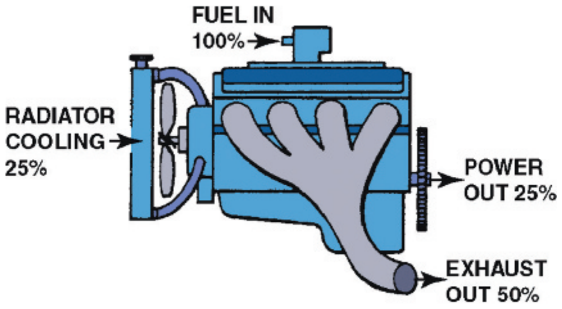


FIGURE 22–8 A turbocharger uses some of the heat energy that would normally be wasted.

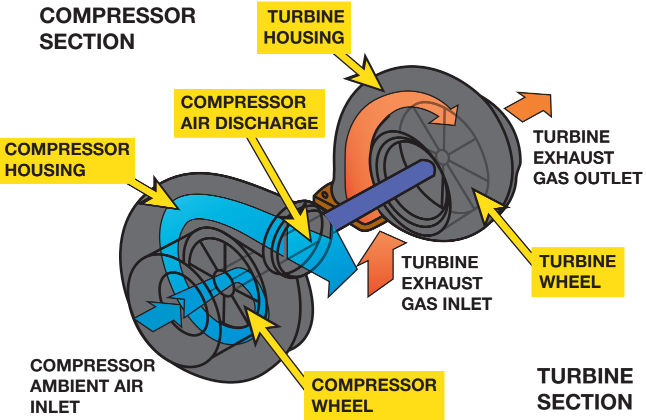


FIGURE 22–9 A turbine wheel is turned by the expanding exhaust gases.

PARTS INVOLVED A turbocharger turbine looks much like a typical centrifugal pump used for supercharging.

Hot exhaust gases flow from the combustion chamber to the *turbine wheel*. The gases are heated and expanded as they leave the engine. It is not the speed of force of the exhaust gases that forces the turbine wheel to turn, as is commonly thought, but the expansion of hot gases against the turbine wheel's blades.

A turbocharger consists of two chambers connected with a center housing. The two chambers contain a turbine wheel and an *impeller* (compressor) *wheel* connected by a shaft which passes through the center housing. ● **SEE FIGURE 22–9**.

To take full advantage of the exhaust heat that provides the rotating force, a turbocharger must be positioned as close as possible to the exhaust manifold. This allows the hot exhaust to pass directly into the unit with minimal heat loss. As exhaust gas enters the turbocharger, it rotates the turbine blades. The turbine wheel and compressor wheel are on the same shaft, so they turn at the same speed. Rotation of the compressor wheel draws air in through a central inlet and centrifugal force pumps it through an outlet at the edge of the housing. A pair of bearings in the center housing supports the turbine and compressor wheel shaft, and is lubricated by engine oil. ● **SEE FIGURE 22–10**.

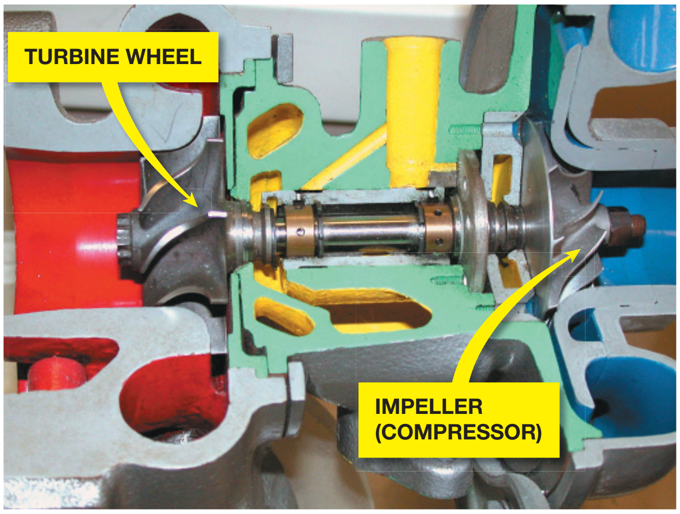


FIGURE 22–10 The exhaust drives the turbine wheel on the left, which is connected to the impeller wheel on the right through a shaft. The bushings that support the shaft are lubricated with engine oil under pressure.

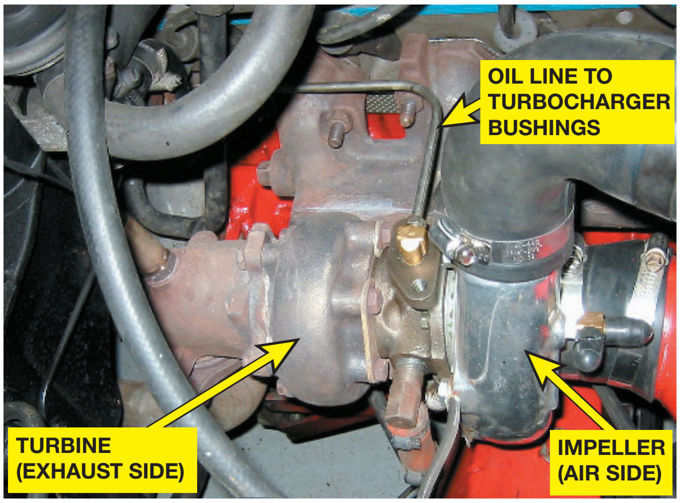


FIGURE 22–11 Engine oil is fed to the center of the turbocharger to lubricate the bushings and returns to the oil pan through a return line.

Both the turbine and compressor wheels must operate with extremely close clearances to minimize possible leakage around the blades. Any leakage around the turbine blades causes a dissipation of the heat energy required for compressor rotation. Leakage around the compressor blades prevents the turbocharger from developing its full boost pressure.

TURBOCHARGER OPERATION When the engine is started and runs at low speed, both exhaust heat and pressure are low and the turbine runs at a low speed (approximately 1000 RPM). Because the compressor does not turn fast enough to develop boost pressure, air simply passes through it, and the engine works like any naturally aspirated engine. As the engine runs faster or load increases, both exhaust heat and flow increase, causing the turbine and compressor wheels to rotate faster. Since there is no brake and very little rotating resistance on the turbocharger shaft, the turbine and compressor wheels accelerate as the exhaust heat energy increases. When an engine is running at full power, the typical turbocharger rotates at speeds between 100,000 and 150,000 RPM. The turbocharger is lubricated by engine oil through an oil line to the center bearing assembly. ● **SEE FIGURE 22–11**.

Engine deceleration from full power to idle requires only a second or two because of its internal friction, pumping resistance, and drivetrain load. The turbocharger, however, has no such load on its shaft, and is already turning many times faster than the engine at top speed. As a result, it can take as much as a minute or more after the engine has returned to idle speed before the turbocharger also has returned to idle. If the engine is decelerated to idle and then shut off immediately, engine lubrication stops flowing to the center housing bearings while the turbocharger is still spinning at thousands of RPM. The oil in the center housing is subjected to extreme heat and can gradually “coke” or oxidize. The coked oil can clog passages and will reduce the life of the turbocharger.

The high rotating speeds and extremely close clearances of the turbine and compressor wheels in their housings require equally critical bearing clearances. The bearings must keep radial clearances of 0.003 to 0.006 inch (0.08 to 0.15 mm). Axial clearance (endplay) must be maintained at 0.001 to 0.003 inch (0.025 to 0.08 mm). If properly maintained, the turbocharger also is a trouble-free device. However, to prevent problems, the following must be met:

- The turbocharger bearings must be constantly lubricated with clean engine oil. Turbocharged engines usually have specified oil changes at more frequent intervals than nonturbocharged engines. Always use the specified engine oil, which is likely to be vehicle specific and synthetic.
- Dirt particles and other contamination must be kept out of the intake and exhaust housings.
- Whenever a basic engine bearing (crankshaft or camshaft) has been damaged, the turbocharger must be flushed with clean engine oil after the bearing has been replaced.
- If the turbocharger is damaged, the engine oil must be drained and flushed, and the oil filter replaced as part of the repair procedure.

Late-model turbochargers all have liquid-cooled center bearings to prevent heat damage. In a liquid-cooled turbocharger, engine coolant is circulated through passages cast in the center housing to draw off the excess heat. This allows the bearings to run cooler and minimize the probability of oil coking when the engine is shut down.

TURBOCHARGER SIZE AND RESPONSE TIME A time lag occurs between an increase in engine speed and the increase in the speed of the turbocharger. This delay between acceleration and turbo boost is called **turbo lag**. Like any material, moving exhaust gas has inertia. Inertia also is present in the turbine and compressor wheels, as well as the intake airflow. Unlike a supercharger, the turbocharger cannot supply an adequate amount of boost at low speed.

Turbocharger response time is directly related to the size of the turbine and compressor wheels. Small wheels accelerate rapidly; large wheels accelerate slowly. While small wheels would seem to have an advantage over larger ones, they may not have enough airflow capacity for an engine. To minimize turbo lag, the intake and exhaust breathing capacities of an engine must be matched to the exhaust and intake airflow capabilities of the turbocharger.

TURBOCHARGER FAILURES

SYMPTOMS OF FAILURE When turbochargers fail to function correctly, a noticeable drop in power occurs. To restore proper operation, the turbocharger must be rebuilt, repaired, or replaced. It is not possible to simply remove the turbocharger, seal any openings, and maintain decent driveability. Bearing failure is a common cause of turbocharger failure, and replacement bearings are usually only available to rebuilders. Another common turbocharger problem is excessive and continuous oil consumption, resulting in blue exhaust smoke. Turbochargers use small rings similar to piston rings on the shaft to prevent exhaust (combustion gases) from entering the central bearing. Because there are no seals to keep oil in, excessive oil consumption is usually caused by the following:

1. Plugged positive crankcase ventilation (PCV) system, resulting in excessive crankcase pressures forcing oil into the air inlet. (This failure is not related to the turbocharger, but the turbocharger is often blamed.)
2. Clogged air filter, which causes a low-pressure area in the inlet, drawing oil past the turbo shaft rings and into the intake manifold.
3. Clogged oil return (drain) line from the turbocharger to the oil pan (sump), which can cause the engine oil pressure to force oil past the turbocharger's shaft rings and into the intake *and* exhaust manifolds. (Obviously, oil being forced into both the intake and exhaust would create lots of smoke.)

PREVENTING TURBOCHARGER FAILURES To help prevent turbocharger failures, the wise vehicle owner should follow the vehicle manufacturer's recommended routine service procedures. The most critical of these services include the following functions:

- Regular oil changes (synthetic oil would be best)
- Regular air filter replacement intervals
- Performing any other inspections and services recommended, such as cleaning the intercooler

BOOST CONTROL

PURPOSE AND FUNCTION Both supercharged and turbocharged systems are designed to provide a pressure greater than atmospheric pressure in the intake manifold. This increased pressure forces additional amounts of air into the combustion chamber over what would normally be forced in by atmospheric pressure. This increased charge increases engine power. The amount of "boost" (or pressure in the intake manifold) is measured in PSI, in inches of mercury (inch Hg), in bars, or in atmospheres. The following values will vary due to altitude and weather conditions (barometric pressure):

1 atmosphere = 14.7 PSI
1 atmosphere = 29.50 in. Hg
1 atmosphere = 1 bar
1 bar = 14.7 PSI

BOOST CONTROL FACTORS The higher the level of boost (pressure), the greater the horsepower output potential. However, other factors must be considered when increasing boost pressure.

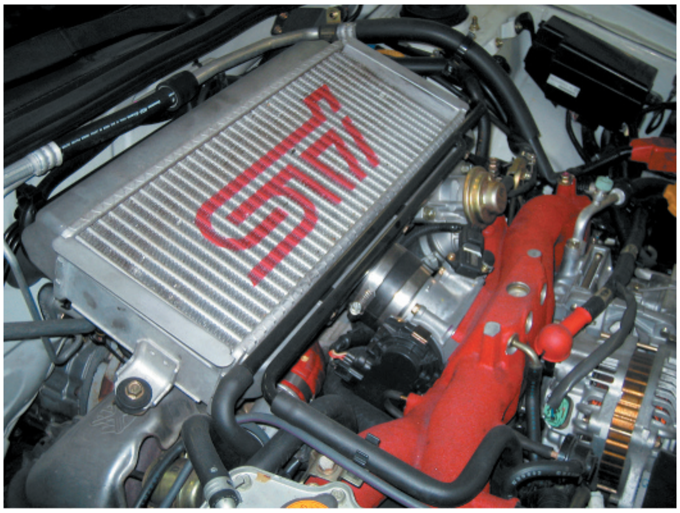


FIGURE 22–12 The unit on top of this Subaru that looks like a radiator is the intercooler, which cools the air after it has been compressed by the turbocharger.

1. As boost pressure increases, the temperature of the air also increases.
2. As the temperature of the air increases, combustion temperatures also increase, as well as the possibility of detonation.
3. Power can be increased by cooling the compressed air after it leaves the turbocharger. *The power can be increased about 1% per 10°F by which the air is cooled.* A typical cooling device is called an **intercooler**. It is similar to a radiator, wherein outside air can pass through, cooling the pressurized heated air. An intercooler is located between the turbocharger and the intake manifold. ● **SEE FIGURE 22–12**. Some intercoolers use engine coolant to cool the hot compressed air that flows from the turbocharger to the intake.
4. As boost pressure increases, combustion temperature and pressures increase, which, if not limited, can do severe engine damage. The maximum exhaust gas temperature must be 1,550°F (840°C). Higher temperatures decrease the durability of the turbocharger *and* the engine.

WASTEGATE Turbochargers use exhaust gases to increase boost, which causes the engine to make more exhaust gases, which in turn increases the boost from the turbocharger. To prevent overboost and severe engine damage, most turbocharger systems use a wastegate. A **wastegate** is a valve similar to a door that can open and close. It is a bypass valve at the exhaust inlet to the turbine, which allows all of the exhaust into the turbine, or it can route part of the exhaust past the turbine to the exhaust system. If the valve is closed, all of the exhaust travels to the turbocharger. When a predetermined amount of boost pressure develops in the intake manifold, the wastegate valve is opened. As the valve opens, most of the exhaust flows directly out the exhaust system, bypassing the turbocharger. With less exhaust flowing across the vanes of the turbocharger, the turbocharger decreases in speed, and boost pressure is reduced. When the boost pressure drops, the wastegate valve closes to direct the exhaust over the turbocharger vanes to again allow the boost pressure to rise. Wastegate operation is a continuous process to control boost pressure.

The wastegate is the pressure control valve of a turbocharger system. It is usually controlled by the engine control computer through a boost control solenoid, also called a wastegate control valve. ● **SEE FIGURE 22–13**.

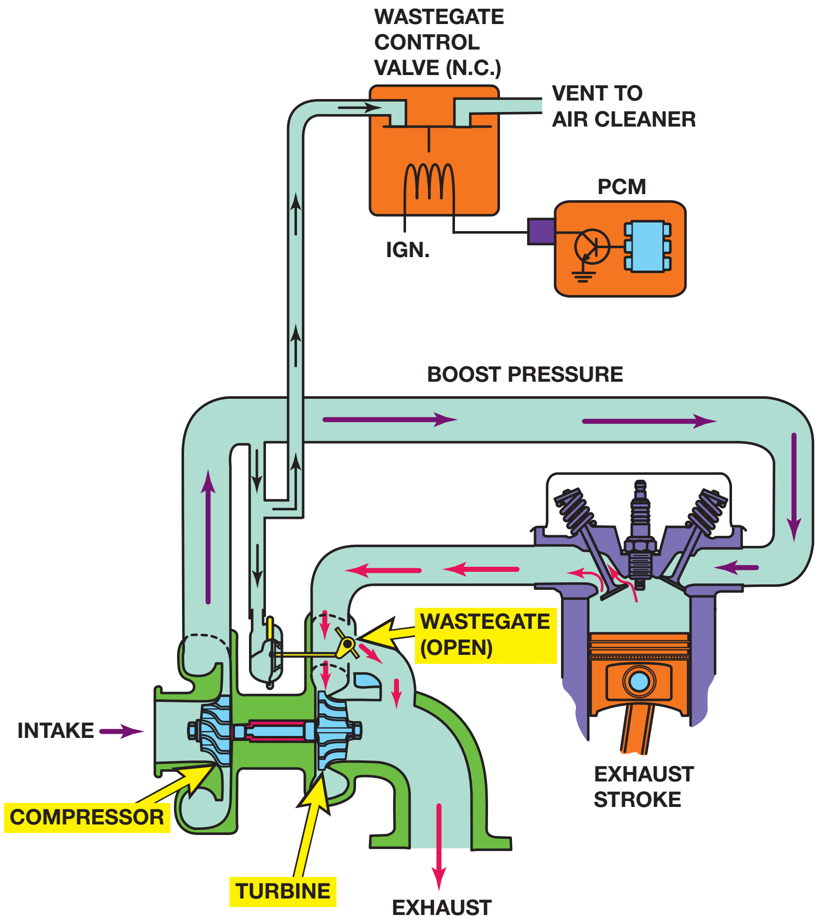


FIGURE 22–13 A wastegate is used on many turbocharged engines to control maximum boost pressure. The wastegate is controlled by a computer-controlled valve.

TECH TIP

Boost Is the Result of Restriction

The boost pressure of a turbocharger (or supercharger) is commonly measured in pounds per square inch. If a cylinder head is restricted because of small valves and ports, the turbocharger will quickly provide boost. Boost results when the air being forced into the cylinder heads cannot flow into the cylinders fast enough and "piles up" in the intake manifold, increasing boost pressure. If an engine had large valves and ports, the turbocharger could provide a much greater *amount* of air into the engine at the same boost pressure as an identical engine with smaller valves and ports. Therefore, by increasing the size of the valves, a turbocharged or supercharged engine will be capable of producing much greater power.

RELIEF VALVES A wastegate controls the exhaust side of the turbocharger. A relief valve controls the intake side. A relief valve vents pressurized air from the connecting pipe between the outlet of the turbocharger and the throttle whenever the throttle is closed during boost, such as during shifts. If the pressure is not released, the turbocharger turbine wheel will slow down, creating a lag when the throttle is opened again after a shift has been completed. There are two basic types of relief valves:

1. **Compressor bypass valve (CBV)**. This type of relief valve routes the pressurized air to the inlet side of the turbocharger for reuse and is quiet during operation.
2. **Blow-off valve (BOV)**. Also called a **dump valve** or **vent valve**, the BOV features an adjustable spring design that keeps the valve closed until a sudden release of the throttle. The resulting pressure increase opens the valve and vents the pressurized air directly into the atmosphere. This type of relief valve is noisy in operation and creates a whooshing sound when the valve opens. ● **SEE FIGURE 22–14**.

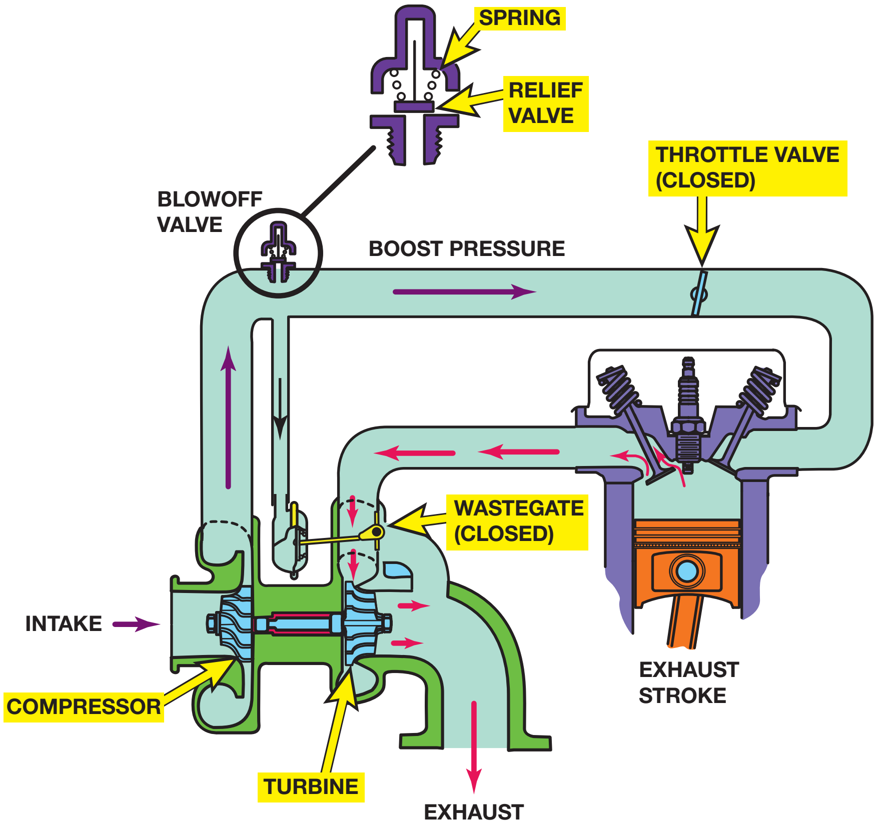

SPRING
RELIEF VALVE
THROTTLE VALVE (CLOSED)
BLOWOFF VALVE
BOOST PRESSURE
WASTEGATE (CLOSED)
INTAKE
COMPRESSOR
EXHAUST STROKE
TURBINE
EXHAUST

FIGURE 22–14 A blow-off valve is used in some turbocharged systems to relieve boost pressure during deceleration.

REVIEW QUESTIONS

1. What are the reasons why supercharging increases engine power?
2. How does the bypass valve work on a supercharged engine?
3. What are the advantages and disadvantages of supercharging?
4. What are the advantages and disadvantages of turbocharging?
5. What turbocharger control valves are needed for proper engine operation?

CHAPTER QUIZ

1. The term “volumetric efficiency” refers to the ability of an engine to _____________.
   - **a.** create emissions
   - **b.** create heat
   - **c.** pull in air
   - **d.** distribute air evenly
2. Boost pressure is generally measured in _____________.
   - **a.** inch Hg
   - **b.** PSI
   - **c.** inch H_2O
   - **d.** inch pound
3. Which valve is used on a factory supercharger to limit boost?
   - **a.** Bypass valve
   - **b.** Wastegate
   - **c.** Blow-off valve
   - **d.** Air valve
4. How are most superchargers lubricated?
   - **a.** By engine oil under pressure through lines from the engine
   - **b.** By an internal oil reservoir
   - **c.** By greased bearings
   - **d.** No lubrication is needed because the incoming air cools the supercharger
5. How are most turbochargers lubricated?
   - **a.** By engine oil under pressure through lines from the engine
   - **b.** By an internal oil reservoir
   - **c.** By greased bearings
   - **d.** No lubrication is needed because the incoming air cools the supercharger

6. Two technicians are discussing the term *turbo lag*. Technician A says that it refers to the delay between when the exhaust leaves the cylinder and when it contacts the turbine blades of the turbocharger. Technician B says that it refers to the delay in boost pressure that occurs when the throttle is first opened. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Technician A says that a stuck-open wastegate can cause the engine to burn oil. Technician B says that a clogged PCV system can cause the engine to burn oil. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. What service operation is *most* important on engines equipped with a turbocharger?
   - **a.** Replacing the air filter regularly
   - **b.** Replacing the fuel filter regularly
   - **c.** Regular oil changes
   - **d.** Regular exhaust system maintenance
9. What is the purpose of an intercooler?
   - **a.** To reduce the temperature of the air entering the engine
   - **b.** To cool the turbocharger
   - **c.** To cool the engine oil on a turbocharged engine
   - **d.** To cool the exhaust before it enters the turbocharger
10. The delay between acceleration and turbo boost is called ______________.
    - **a.** boost
    - **b.** turbo lag
    - **c.** waste gate delay
    - **d.** blowout valve delay

Chapter

23

ENGINE CONDITION DIAGNOSIS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss typical engine-related complaints.
- Discuss engine smoke diagnosis.
- Discuss the importance of the driver's description.
- Discuss visual checks.
- Discuss engine noise diagnosis.
- Explain oil pressure testing and the purpose of oil pressure warning lamps.
- Describe the cylinder contribution test.
- Describe the relative compression test.
- Describe compression testing.
- Describe wet compression tests.
- Describe running compression tests.
- Describe the cylinder leakage test.
- Describe the cylinder power balance test.
- Explain vacuum tests.
- Explain how to test back pressure with a vacuum gauge and a pressure gauge.
- Explain how to diagnose head gasket failure.
- Discuss the operation of dash warning lights.

KEY TERMS:

Back pressure 248 • Compression test 241 • Cranking vacuum test 246 • Cylinder leakage test 245 • Dynamic compression test 244 • Idle vacuum test 246 • Inches of mercury (inch Hg) 246 • Paper test 242 • Power balance test 245 • Restricted exhaust 248 • Relative compression test 241 • Running compression test 244 • Vacuum test 246 • Wet compression test 243

TYPICAL ENGINE-RELATED COMPLAINTS

Many driveability problems are *not* caused by engine mechanical problems. A thorough inspection and testing of the ignition and fuel systems should be performed before testing for mechanical engine problems.

Typical engine mechanical-related complaints include the following:

- Excessive oil consumption
- Engine misfiring
- Loss of power
- Smoke from the engine or exhaust ● **SEE FIGURE 23–1**.
- Engine noise

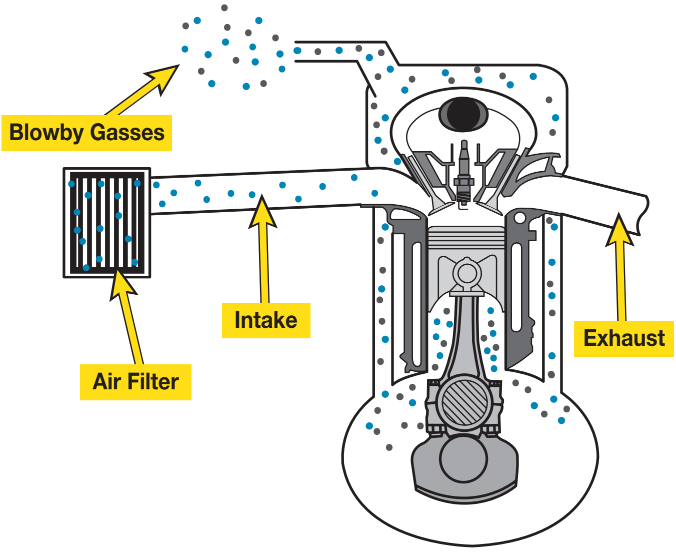


FIGURE 23–1 Blow-by is created by combustion gases leaking past the piston rings. These gases are recirculated into the intake system through the positive crankcase ventilation (PCV) system. Excessive blow-by indicates worn piston rings.

ENGINE SMOKE DIAGNOSIS

The color of engine exhaust smoke can indicate what engine problem might exist.

Typical Exhaust Smoke Color	Possible Causes
Blue	Blue exhaust indicates that the engine is burning oil. Oil is getting into the combustion chamber either past the piston rings or past the valve stem seals. Blue smoke only after start-up is usually due to defective valve stem seals.
Black	Black exhaust smoke is due to excessive fuel being burned in the combustion chamber. Typical causes include a leaking fuel injector or excessive fuel-pump pressure.
White (steam)	White smoke or steam from the exhaust is normal during cold weather and represents condensed steam. Every engine creates about 1 gallon of water for each gallon of gasoline burned. If the steam from the exhaust is excessive, then water (coolant) is getting into the combustion chamber. Typical causes include a defective cylinder head gasket, a cracked cylinder head, or in severe cases a cracked block. ● **SEE FIGURE 23–2**.

THE DRIVER IS YOUR BEST RESOURCE

The driver of the vehicle knows a lot about the vehicle and how it is driven. *Before* diagnosis is started, always ask the following questions:

- When did the problem first occur?
- Under what conditions does it occur?
  1. Cold or hot?
  2. Acceleration, cruise, or deceleration?
  3. How far was it driven?
  4. What recent repairs have been performed?

After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed.

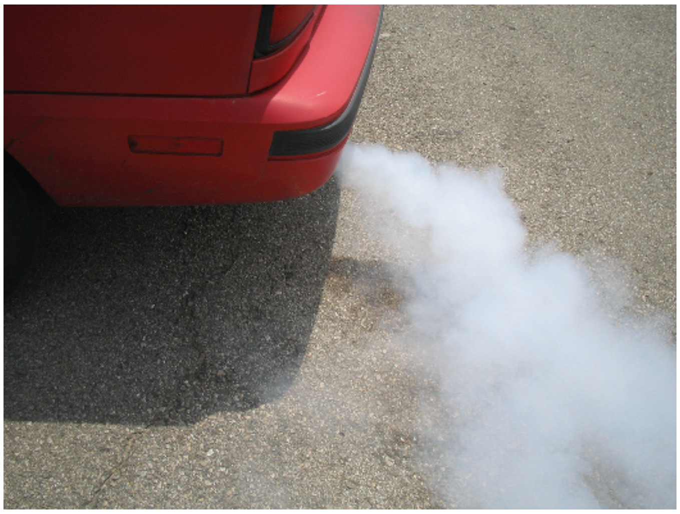


FIGURE 23–2 White steam is usually an indication of a blown (defective) cylinder head gasket that allows engine coolant to flow into the combustion chamber where it is turned into steam.

TECH TIP

Your Nose Knows

Whenever diagnosing any vehicle, try to use all senses including smell. Some smells and their cause include

- **Gasoline.** If the exhaust smells like gasoline or unburned fuel, a fault with the ignition system is a likely cause. Unburned fuel due to lean air–fuel mixture, causing a lean misfire is also possible.
- **Sweet smell.** A coolant leak often gives off a sweet smell, especially if the leaking coolant flows onto the hot exhaust.
- **Exhaust smell.** Check for an exhaust leak, including a possible cracked exhaust manifold, which can be difficult to find because it often does not make noise.

VISUAL CHECKS

The first and most important "test" that can be performed is a careful visual inspection.

OIL LEVEL AND CONDITION The first area for visual inspection is oil level and condition.

1. Oil level—oil should be to the proper level
2. Oil condition
   a. Using a match or lighter, try to light the oil on the dipstick; if the oil flames up, gasoline is present in the engine oil.
   b. Drip some of the engine oil from the dipstick onto the hot exhaust manifold. If the oil bubbles or boils, there is coolant (water) in the oil.
   c. Check for grittiness by rubbing the oil between your fingers.

COOLANT LEVEL AND CONDITION Most mechanical engine problems are caused by overheating. The proper operation of the cooling system is critical to the life of any engine.

1. The coolant level in the coolant recovery container should be within the limits indicated on the overflow bottle. If this level is too low or the coolant recovery container is empty, check the level of coolant in the radiator (only when cool) and also check the operation of the pressure cap.

WARNING

Check the coolant level in the radiator only if the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately and can cause severe burns when the coolant explosively expands upward and outward from the radiator opening.

TECH TIP

What's Leaking?

The color of the leaks observed under a vehicle can help the technician determine and correct the cause. Some leaks, such as condensate (water) from the air-conditioning system, are normal, whereas a brake fluid leak is very dangerous. The following are colors of common leaks.

Color	What's Leaking
Sooty black	Engine Oil
Yellow, green, blue, or orange	Antifreeze (coolant)
Red	Automatic transmission fluid
Murky brown	Brake or power steering fluid or very neglected antifreeze (coolant)
Clear	Air-conditioning condensate (water) (normal)

2. The coolant should be checked with a hydrometer or refractometer for boiling and freezing temperatures. This test indicates if the concentration of the antifreeze is sufficient for proper protection.
3. Pressure test the cooling system and look for leakage. Coolant leakage can often be seen around hoses or cooling system components because it will often cause
    - **a.** A grayish-white stain
    - **b.** A rust-colored stain
    - **c.** Dye stains from antifreeze (greenish or yellowish depending on the type of coolant)
4. Check for cool areas of the radiator indicating clogged sections.
5. Check operation and condition of the fan clutch, fan, and coolant pump drive belt.

OIL LEAKS Oil leaks can lead to severe engine damage if the resulting low oil level is not corrected. Besides causing an oily mess where the vehicle is parked, the oil leak can cause blue smoke to occur under the hood as leaking oil drips on the exhaust system. *Finding* the location of the oil leak can often be difficult. ● **SEE FIGURES 23–3 AND 23–4**. To help find the source of oil leaks follow these steps:

STEP 1 Clean the engine or area around the suspected oil leak. Use a high-powered hot-water spray to wash the engine. While the engine is running, spray the entire engine and the engine compartment. Avoid letting the water come into direct contact with the air inlet and ignition distributor or ignition coil(s).

NOTE: If the engine starts to run rough or stalls when the engine gets wet, the secondary ignition wires (spark plug wires) may be defective or have weak insulation. Be certain to wipe all wires and the distributor cap dry with a soft, dry cloth if the engine stalls.

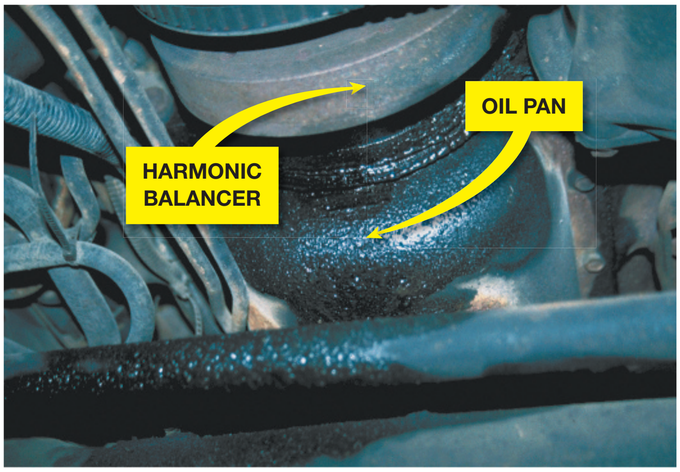


FIGURE 23–3 What looks like an oil pan gasket leak can be a rocker cover gasket leak. Always look for the highest and most forward place you see oil leaking; that should be repaired first.

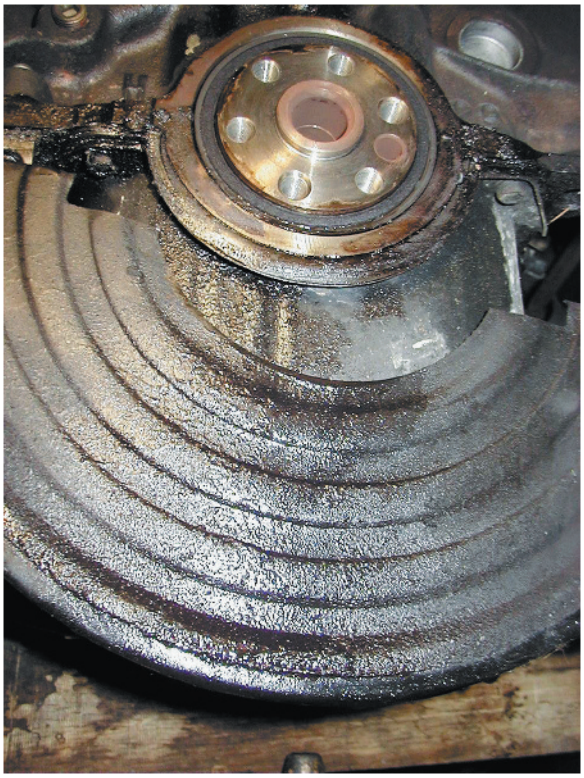


FIGURE 23–4 The transmission and flexplate (flywheel) were removed to check the exact location of this oil leak. The rear main seal and/or the oil pan gasket could be the cause of this leak.

An alternative method is to spray a degreaser on the engine, then start and run the engine until warm. Engine heat helps the degreaser penetrate the grease and dirt. Use a water hose to rinse off the engine and engine compartment.

STEP 2 If the oil leak is not visible or oil seems to be coming from "everywhere," use a white talcum powder. The leaking oil will show as a dark area on the white powder. See the Tech Tip, "The Foot Powder Spray Trick."

STEP 3 Fluorescent dye can be added to the engine oil. Add about 1/2 oz (15 cc) of dye per 5 quarts of engine oil.

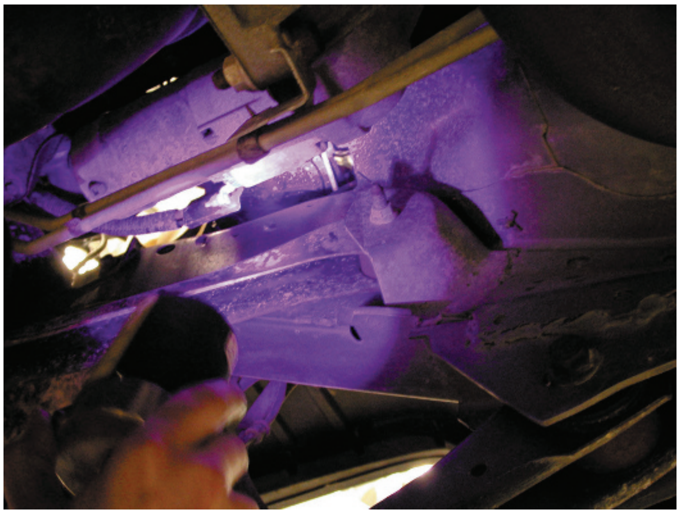


FIGURE 23–5 Using a black light to spot leaks after adding dye to the oil.

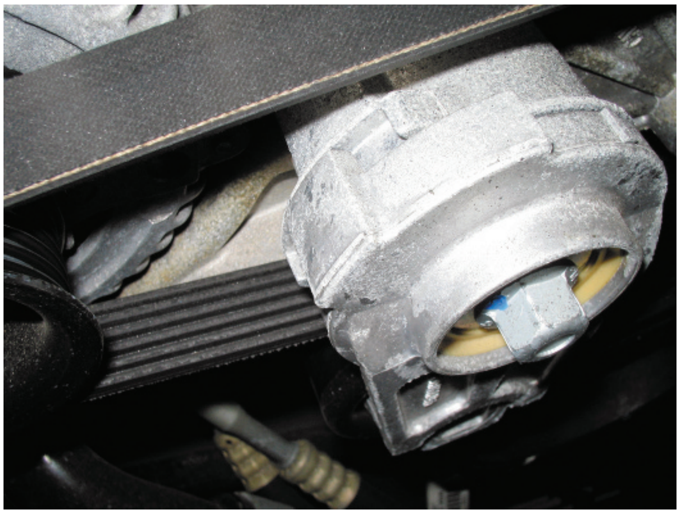


FIGURE 23–6 An accessory belt tensioner. Anything wrong with the belt or tensioner can cause noise.

Start the engine and allow it to run about 10 minutes to thoroughly mix the dye throughout the engine. A black light can then be shown around every suspected oil leak location. The black light will easily show all oil leak locations because the dye will show as a bright yellow/green area. ● **SEE FIGURE 23–5**.

NOTE: Fluorescent dye works best with clean oil.

ENGINE NOISE DIAGNOSIS

Engine noises are often difficult to diagnose. Several items that can cause an engine noise include the following:

- **Valves clicking.** This can happen because of lack of oil to the lifters. This noise is most noticeable at idle when the oil pressure is the lowest.
- **Torque converter.** The attaching bolts or nuts may be loose on the flex plate. This noise is most noticeable at idle or when there is no load on the engine.
- **Cracked flex plate.** The noise of a cracked flex plate is often mistaken for a rod- or main-bearing noise.
- **Loose or defective drive belts or tensioners.** If an accessory drive belt is loose or defective, the flopping noise often sounds similar to a bearing knock. ● **SEE FIGURE 23–6**.
- **Piston pin knock.** This knocking noise is usually not affected by load on the cylinder. If the clearance is too great, a double knock noise is heard when the engine idles. If all cylinders are grounded out one at a time, and the noise does not change, a defective piston pin could be the cause.
- **Piston slap.** A piston slap is usually caused by an undersized or improperly shaped piston or oversized cylinder bore. A piston slap is most noticeable when the engine is cold and tends to decrease or stop making noise as the piston expands during engine operation.
- **Timing chain noise.** An excessively loose timing chain can cause a severe knocking noise when the chain hits the timing chain cover. This noise can often sound like a rod-bearing knock.
- **Rod-bearing noise.** The noise from a defective rod bearing is usually load sensitive and changes in intensity as the load on the engine increases and decreases. A rod-bearing failure can often be detected by grounding out the

TECH TIP

The Foot Powder Spray Trick

The source of an oil or other fluid leak is often difficult to determine. A quick and easy method that works is the following. First, clean the entire area. This can best be done by using a commercially available degreaser to spray the entire area. Let it soak to loosen all accumulated oil and greasy dirt. Clean off the degreaser with a water hose. Let the area dry. Start the engine, and using spray foot powder or other aerosol powder product, spray the entire area. The leak will turn the white powder dark. The exact location of any leak can be quickly located.

NOTE: Most oil leaks appear at the bottom of the engine due to gravity. Look for the highest, most forward location for the source of the leak.

TECH TIP

Engine Noise and Cost

A light ticking noise often heard at one-half engine speed and associated with valve train noise is a less serious problem than many deep-sounding knocking noises. Generally, the deeper the sound of the engine noise, the more the owner will have to pay for repairs. A light "tick tick tick," though often not cheap, is usually far less expensive than a deep "knock knock knock" from the engine.

spark plugs one cylinder at a time. If the knocking noise decreases or is eliminated when a particular cylinder is grounded (disabled), the grounded cylinder is the one from which the noise is originating.

- **Main-bearing knock.** A main-bearing knock often cannot be isolated to a particular cylinder. The sound can vary in intensity and may disappear at times, depending on engine load.

Typical Noises	Possible Causes
Clicking noise—like the clicking of a ballpoint pen	1. Loose spark plug 2. Loose accessory mount (for air-conditioning compressor, alternator, power steering pump, etc.) 3. Loose rocker arm 4. Worn rocker arm pedestal 5. Worn camshaft 6. Exhaust leak ● **SEE FIGURE 23–7**.
Clacking noise—like tapping on metal	1. Worn piston pin 2. Broken piston 3. Excessive valve clearance 4. Timing chain hitting cover
Knock—like knocking on a door	1. Rod bearing(s) 2. Main bearing(s) 3. Thrust bearing(s) 4. Loose torque converter 5. Cracked flex plate (drive plate)
Rattle—like a baby rattle	1. Broken harmonic balancer 2. Loose accessory mounts 3. Loose accessory drive belt or tensioner
Clatter—like rolling marbles	1. Rod bearings 2. Piston pin 3. Loose timing chain
Whine—like an electric motor running	1. Alternator bearing 2. Drive belt 3. Power steering 4. Belt noise (accessory or timing)
Clunk—like a door closing	1. Engine mount 2. Drive axle shaft U-joint or constant velocity (CV) joint

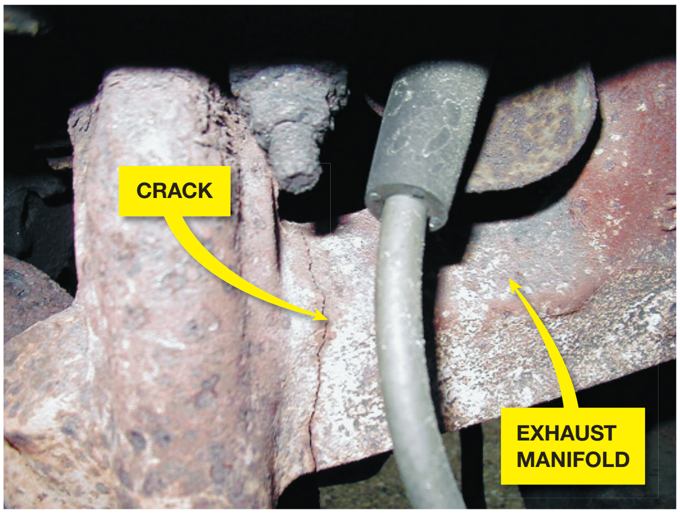


FIGURE 23–7 A cracked exhaust manifold on a Ford V-8.

Regardless of the type of loud knocking noise, after the external causes of the knocking noise have been eliminated, the engine should be disassembled and carefully inspected to determine the exact cause.

OIL PRESSURE TESTING

Proper oil pressure is very important for the operation of any engine. *Low oil pressure can cause engine wear, and engine wear can cause low oil pressure.*

If main thrust or rod bearings are worn, oil pressure is reduced because of leakage of the oil around the bearings. Oil pressure testing is usually performed with the following steps:

STEP 1 Operate the engine until normal operating temperature is achieved.

STEP 2 With the engine off, remove the oil pressure sending unit or sender, usually located near the oil filter. Thread an oil pressure gauge into the threaded hole. ● **SEE FIGURE 23–8.**

NOTE: An oil pressure gauge can be made from another gauge, such as an old air-conditioning gauge and a flexible brake hose. The threads are often the same as those used for the oil pressure sending unit.

STEP 3 Start the engine and observe the gauge. Record the oil pressure at idle and at 2500 RPM. Most vehicle manufacturers recommend a minimum oil pressure of 10 PSI per 1000 RPM. Therefore, at 2500 RPM, the oil pressure should be at least 25 PSI. Always compare your test results with the manufacturer's recommended oil pressure.

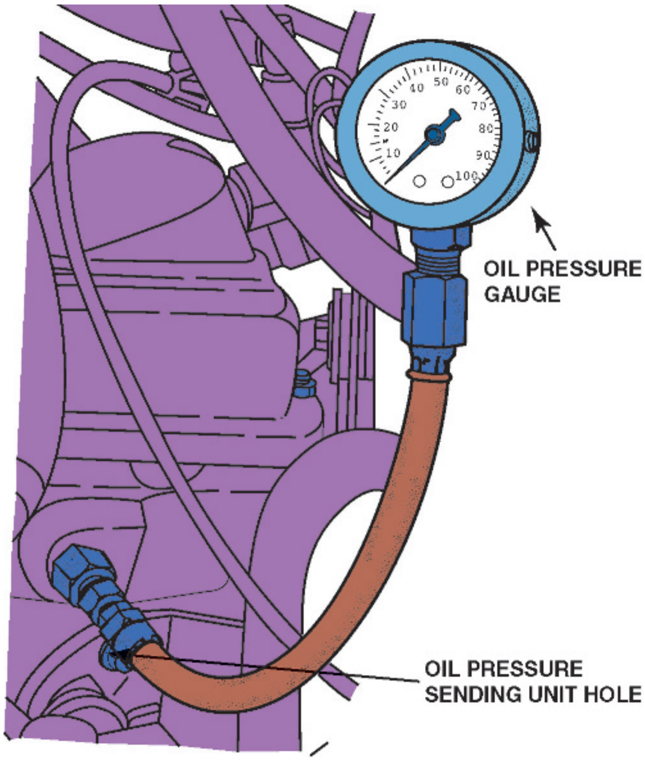


FIGURE 23–8 To measure engine oil pressure, remove the oil pressure sending (sender) unit usually located near the oil filter. Screw the pressure gauge into the oil pressure sending unit hole.

Besides engine bearing wear, other possible causes for low oil pressure include the following:

- Low oil level
- Diluted oil
- Stuck oil pressure relief valve

OIL PRESSURE WARNING LAMP The red oil pressure warning lamp in the dash usually lights when the oil pressure is less than 4 to 7 PSI, depending on vehicle and engine. The oil light should not be on during driving. If the oil warning lamp is on, stop the engine immediately. Always confirm oil pressure with a reliable mechanical gauge before performing engine repairs. The sending unit or circuit may be defective.

CYLINDER CONTRIBUTION TEST

One of the fastest ways to check to see if all cylinders are mechanically able to contribute to the operation of the engine is to perform a cylinder contribution test using a scan tool. A cylinder contribution test, also called a power balance test, is an automated test that a scan tool performs by turning a fuel injector off to one cylinder at the time and monitoring the drop, or increase in engine speed. This change in engine speed should be the same for all cylinders if all cylinders are working correctly. For example, a Ford IDS scan tool can be used by selecting this function and following the on-screen instructions. ● **SEE FIGURE 23–10**.

TECH TIP

Use a Scan Tool to Check for Misfires

Many factory or factory-level scan tools can display cylinder misfire data. The wise service technician checks for misfire codes and misfire counter information using a scan tool before checking the engine using labor intensive procedures, such as compression testing or cylinder leakage tests. These can be done on just the cylinder or cylinders that the PCM has detected as being at fault. ● **SEE FIGURE 23–9**.

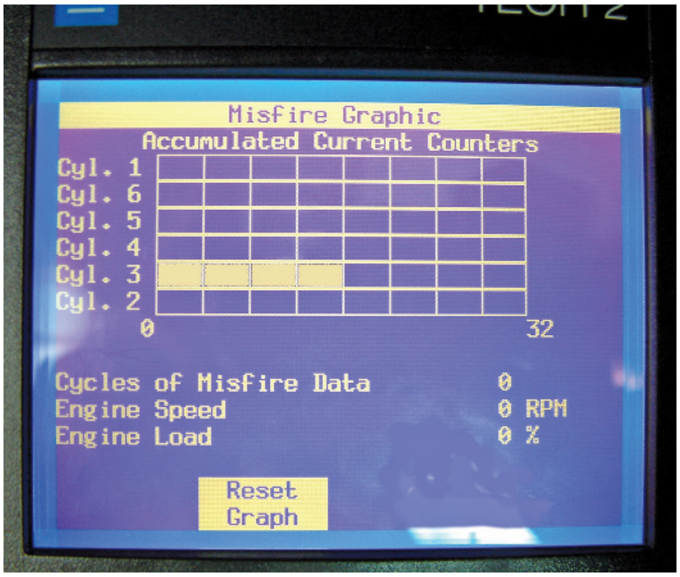

Misfire Graphic
Accumulated Current Counters
Cyl. 1
Cyl. 6
Cyl. 5
Cyl. 4
Cyl. 3
Cyl. 2
0 32
Cycles of Misfire Data 0
Engine Speed 0 RPM
Engine Load 0 %
Reset Graph

FIGURE 23–9 A Tech 2 scan tool display showing a fault with cylinder 3. Once the cylinder has been identified, then more detailed tests can be performed to determine the root cause, which could be an ignition, fuel or mechanical issue.

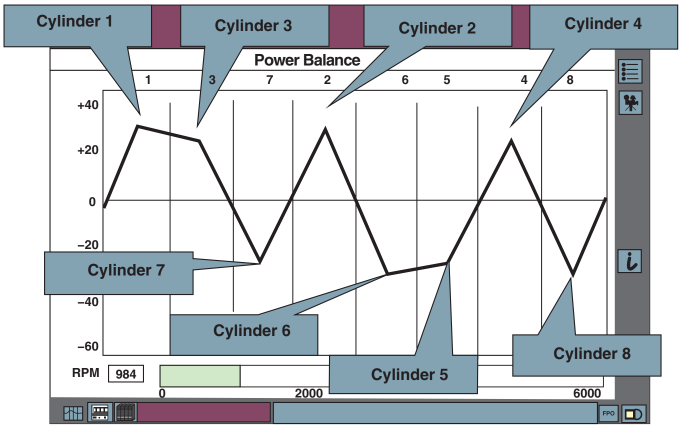


FIGURE 23–10 The Ford IDS scan tool has a graph function that allows the technician to view the data on the cylinder contribution test visually, making diagnosis easier. In this example, the cylinders on bank 2 on a Ford V-8 (cylinders 7, 6, 5, and 8) are weak.

RELATIVE COMPRESSION TEST

A quick and easy way to help determine the relative health of an engine without requiring the removal of the spark plugs is to perform a relative compression test. A digital storage oscilloscope (DSO) and a current clamp is used to measure the change in current that occurs when an engine is cranking to determine the relative compression. This **relative compression test** uses the starter motor current to determine the compression values of all cylinders. The advantage of a relative compression test is that no pressure sensors are needed to check each individual cylinder and all cylinders can be tested at the same time. Most DSOs have this function built into the unit and the test can be performed by following the on-screen instructions. The scope records the relative current flow needed to crank the engine and uses this data to display relative compression.

- If a cylinder has high compression, the starter motor will draw more current.
- If a cylinder has lower compression, the starter motor will draw less current.

The scope software then compares the highest current draw cylinder and flags that as having a relative compression of 100%.

The other cylinders are displayed as a percentage of the best cylinder. ● **SEE FIGURE 23–11**.

COMPRESSION TEST

An engine **compression test** is one of the fundamental engine diagnostic tests that can be performed. For smooth engine operation, all cylinders must have equal compression. An engine can lose compression by leakage of air through one or more of only three routes.

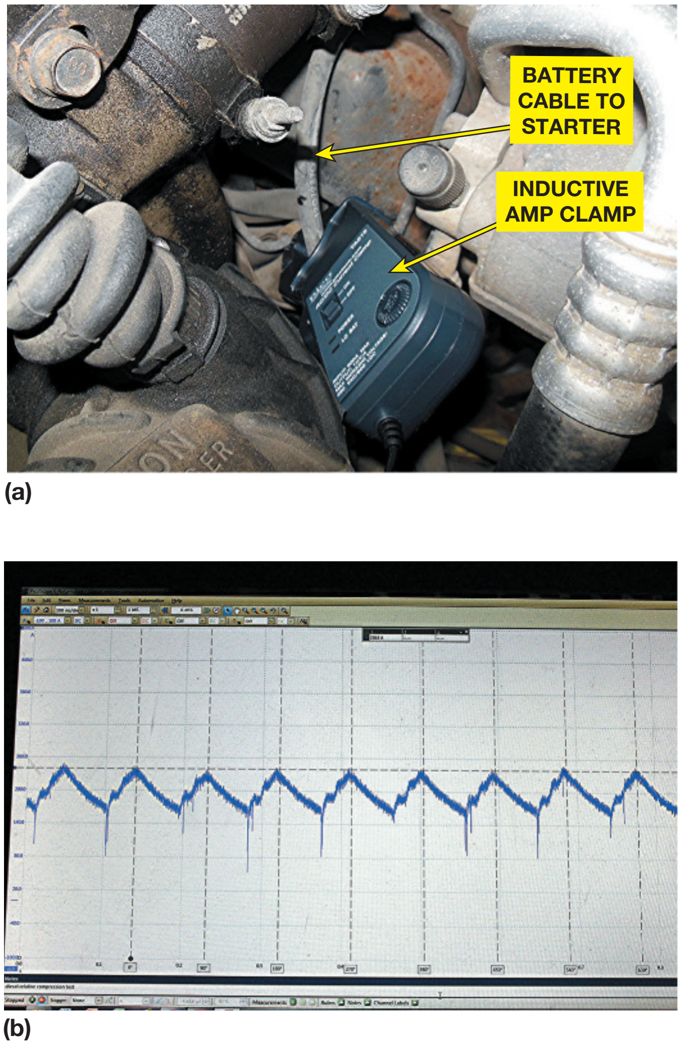


FIGURE 23–11 (a) A relative compression test using an amp clamp around the starter motor power cable and a Pico scope. (b) The result is a waveform that displays the current needed for each cylinder under compression. This test indicates that all cylinders are requiring the same current to rotate the starter motor which indicates that all cylinders have the same relative compression.

- Intake or exhaust valve
- Piston rings (or piston, if there is a hole)
- Cylinder head gasket

For best results, the engine should be warmed to normal operating temperature before testing. An accurate compression test should be performed as follows:

STEP 1 Remove all spark plugs. This allows the engine to be cranked to an even speed. Be sure to label all spark plug wires.

CAUTION: Disable the ignition system by disconnecting the primary leads from the ignition coil or module or by grounding the coil wire after removing it from the center of the distributor cap. Also disable the fuel-injection system to prevent the squirting of fuel into the cylinder.

STEP 2 Block open the throttle. This permits the maximum amount of air to be drawn into the engine. This step also ensures consistent compression test results. If the engine is equipped with an electronic throttle, check service information for the exact procedure to follow.

TECH TIP

The Paper Test

A soundly running engine should produce even and steady exhaust at the tailpipe. You can test this with the paper test. Hold a piece of paper or a 3" × 5" index card (even a dollar bill works) within 1 inch (25 mm) of the tailpipe with the engine running at idle. ● **SEE FIGURE 23–12**.

The paper should blow out evenly without "puffing." If the paper is drawn *toward* the tailpipe at times, the exhaust valves in one or more cylinders could be burned. Other reasons why the paper might be sucked toward the tailpipe include the following:

1. The engine could be misfiring because of a lean condition that could occur normally when the engine is cold.
2. Pulsing of the paper toward the tailpipe could also be caused by a hole in the exhaust system. If exhaust escapes through a hole in the exhaust system, air could be drawn in during the intervals between the exhaust puffs from the tailpipe to the hole in the exhaust, causing the paper to be drawn toward the tailpipe.
3. Ignition fault causing misfire.

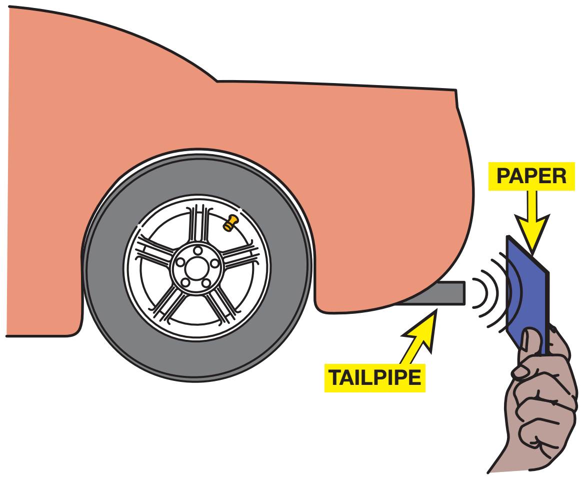


FIGURE 23–12 The paper test involves holding a piece of paper near the tailpipe of an idling engine. A good engine should produce even, outward puffs of exhaust. If the paper is sucked in toward the tailpipe, a burned valve is a possibility.

STEP 3 Thread a compression gauge into one spark plug hole and crank the engine. ● **SEE FIGURE 23–13**.

Continue cranking the engine through *four* compression strokes. Each compression stroke makes a puffing sound.

NOTE: Note the reading on the compression gauge after the first puff. This reading should be at least one-half the final reading. For example, if the final, highest reading is 150 PSI, the reading after the first puff should be higher than 75 PSI. A low first-puff reading indicates possible weak piston rings. Release the pressure on the gauge and repeat for the other cylinders.

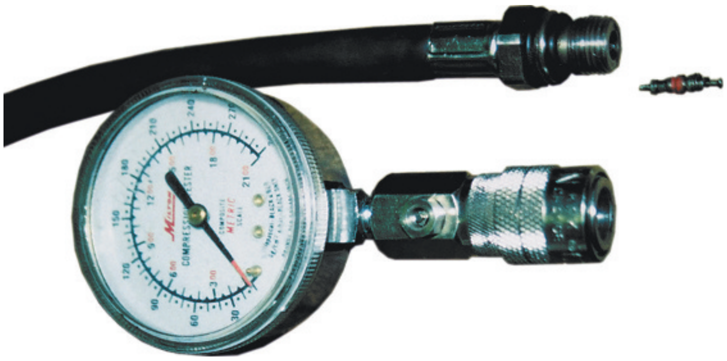


FIGURE 23–13 A two-piece compression gauge set. The threaded hose is screwed into the spark plug hole after removing the spark plug. The gauge part is then snapped onto the end of the hose.

STEP 4 Record the highest readings and compare the results. Most vehicle manufacturers specify the minimum compression reading and the maximum allowable variation among cylinders. Most manufacturers specify a maximum difference of 20% between the highest reading and the lowest reading. For example:

If the high reading is	150 PSI
Subtract 20%	−30 PSI
Lowest allowable compression is	120 PSI

NOTE: To make the math quick and easy, think of 10% of 150, which is 15 (move the decimal point to the left one place). Now double it: 15 × 2 = 30. This represents 20%.

NOTE: During cranking, the oil pump cannot maintain normal oil pressure. Extended engine cranking, such as that which occurs during a compression test, can cause hydraulic lifters to collapse. When the engine starts, loud valve clicking noises may be heard. This should be considered normal after performing a compression test, and the noise should stop after the vehicle has been driven a short distance.

TECH TIP

The Hose Trick

Installing spark plugs can be made easier by using a rubber hose on the end of the spark plug. The hose can be a vacuum hose, fuel line, or even an old spark plug wire end. ● **SEE FIGURE 23–14.**

The hose makes it easy to start the threads of the spark plug into the cylinder head. After starting the threads, continue to thread the spark plug for several turns. Using the hose eliminates the chance of crossthreading the plug. This is especially important when installing spark plugs in aluminum cylinder heads.

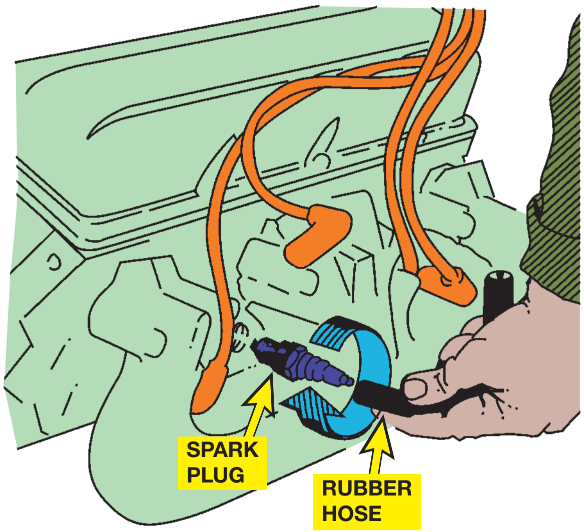


FIGURE 23–14 Use a vacuum or fuel line hose over the spark plug to install it without danger of cross-threading the cylinder head.

WET COMPRESSION TEST

If the compression test reading indicates low compression on one or more cylinders, add three squirts of oil to the cylinder and retest. This is called a **wet compression test**, when oil is used to help seal around the piston rings.

CAUTION: Do not use more oil than three squirts from a hand-operated oil squirt can. Too much oil can cause a hydrostatic lock, which can damage or break pistons or connecting rods, or even crack a cylinder head.

Perform the compression test again and observe the results. If the first-puff readings greatly improve and the readings are much higher than without the oil, the cause of the low compression is worn or defective piston rings. If the compression readings increase only slightly (or not at all), the cause of the low compression is usually defective valves. ● **SEE FIGURE 23–15.**

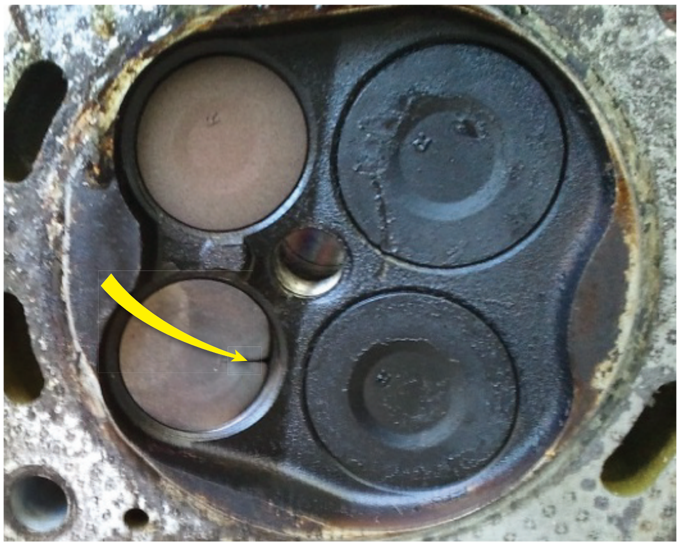


FIGURE 23–15 Badly burned exhaust valve. A compression test could have detected a problem, and a cylinder leakage test (leak-down test) could have been used to determine the exact problem.

NOTE: During both the dry and wet compression tests, be sure that the battery and starting system are capable of cranking the engine at normal cranking speed.

RUNNING (DYNAMIC) COMPRESSION TEST

PURPOSE OF THE TEST A compression test is commonly used to help determine engine condition and is usually performed with the engine cranking.

What is the RPM of a cranking engine? An engine idles at about 600 to 900 RPM, and the starter motor obviously cannot crank the engine as fast as the engine idles. Most manufacturers' specifications require the engine to crank at 80 to 250 cranking RPM. Therefore, a check of the engine's compression at cranking speed determines the condition of an engine that does not run at such low speeds.

But what should be the compression of a running engine? Some would think that the compression would be substantially higher because the valve overlap of the cam is more effective at higher engine speeds, which would tend to increase the compression.

A **running compression test**, also called a **dynamic compression test**, is done with the engine running rather than during engine cranking as is done in a regular compression test.

Actually, the compression pressure of a running engine is much *lower* than cranking compression pressure. This results from the volumetric efficiency. The engine is revolving faster, and therefore, there is less *time* for air to enter the combustion chamber. With less air to compress, the compression pressure is lower. Typically, the higher the engine RPM, the lower the running compression. For most engines, the value ranges are as follows:

Compression during cranking:	125 to 160 PSI
Compression at idle:	60 to 90 PSI
Compression at 2000 RPM:	30 to 60 PSI

As with cranking compression, the running compression of all cylinders should be equal. Therefore, a problem is not likely to be detected by single compression values, but by *variations* in running compression values among the cylinders. Broken valve springs, worn valve guides, bent pushrods, and worn cam lobes are some items that would be indicated by a low running compression test reading on one or more cylinders.

PERFORMING A RUNNING COMPRESSION TEST To perform a running compression test, remove just one spark plug at a time. With one spark plug removed from the engine, use a jumper wire to *ground* the spark plug wire to a good engine ground. This prevents possible ignition coil damage. Start the engine, push the pressure release on the gauge, and read the compression. Increase the engine speed to about 2000 RPM and push the pressure release on the gauge again. Read the gauge. Stop the engine, reinstall the spark plug, reattach the spark plug wire, and repeat the test for each of the remaining cylinders. Just like the cranking compression test, the running compression test can inform a technician of the *relative* compression of all the cylinders.

CASE STUDY

The Case of the Chevrolet Equinox 2.4L

A Chevrolet Equinox equipped with a 2.4-liter four-cylinder engine was towed to shop because it would not start. The technician verified that the engine would crank very rapidly and would not start. Because of the rapid cranking speed, the technician thought that the engine did not have any compression. The technician performed a compression test and discovered that all cylinders had very low compression. The technician then checked for cam rotation and it was found not to be turning when the engine was cranked. When the front cover was removed, it was observed that the smaller cam chain guide had broken and the chain had fallen off the sprockets. ● **SEE FIGURE 23–16(a)**.

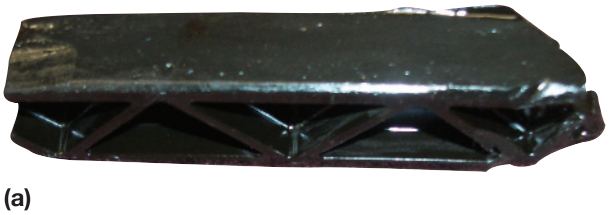
The timing chain and guides were replaced and the engine checked for interference between the pistons and valves. No damage to valves this time. ● **SEE FIGURE 23–16(b)**.

Summary:

Complaint—Customer complained that the engine would not start.

Cause—The smaller cam chain guide had broken and the chain fell off the sprockets.

Correction—Replaced the timing chain and guides and checked for interference between the pistons and valves. No damage was done to the valves this time.



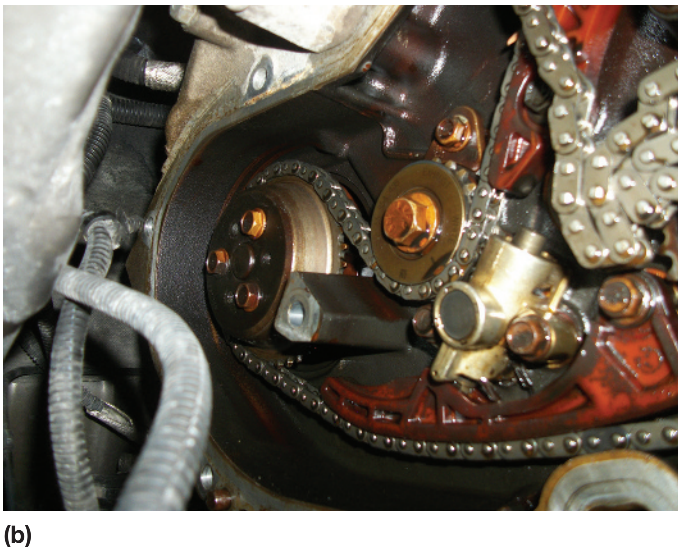


FIGURE 23–16 (a) The broken guide caused the chain to fall off of the crankshaft sprocket. (b) A new timing chain and guide was needed to fix this engine.

SNAP TEST To check for possible intake or exhaust restrictions, perform a snap test using the following procedure:

- With the compression gauge installed in a cylinder, and the engine running, snap the throttle wide open, then close as quickly as possible.
- The snap reading should be 80% of the cranking compression reading.
- If the reading is higher, the exhaust is restricted.
- If the reading is less, the intake is restricted.

NOTE: This does not work on an engine equipped with electronic throttle control systems.

CYLINDER LEAKAGE TEST

PROCEDURE One of the best tests used to determine engine condition is the **cylinder leakage test**. This test involves injecting air under pressure into the cylinders one at a time. The amount and location of any escaping air helps the technician determine the condition of the engine. The air is injected into the cylinder through a cylinder leakage gauge into the spark plug hole. ● **SEE FIGURE 23–17**. To perform the cylinder leakage test, take the following steps:

STEP 1 For best results, the engine should be at normal operating temperature (upper radiator hose hot and pressurized).

STEP 2 The cylinder being tested must be at top dead center (TDC) of the compression stroke. ● **SEE FIGURE 23–18**.

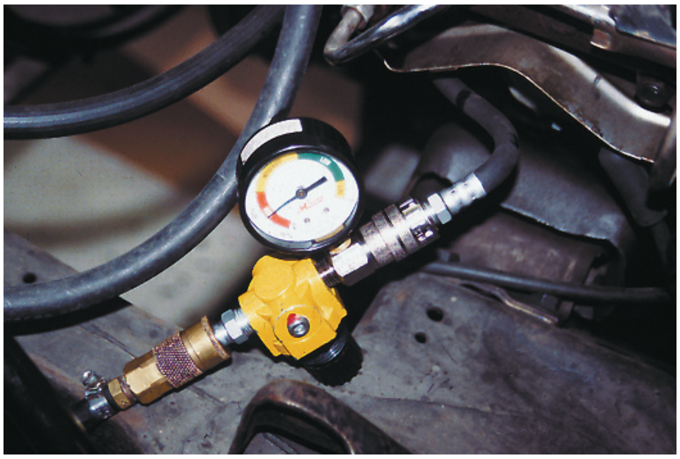


FIGURE 23–17 A typical handheld cylinder leakage tester.

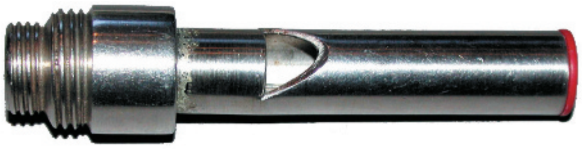


FIGURE 23–18 A whistle stop used to find top dead center. Remove the spark plug and install the whistle stop, then rotate the engine by hand. When the whistle stops making a sound, the piston is at the top.

NOTE: The greatest amount of wear occurs at the top of the cylinder because of the heat generated near the top of the cylinders. The piston ring flex also adds to the wear at the top of the cylinder.

STEP 3 Calibrate the cylinder leakage unit as per manufacturer's instructions.

STEP 4 Inject air into the cylinders one at a time, rotating the engine as necessitated by firing order to test each cylinder at TDC on the compression stroke.

STEP 5 Evaluate the results:
Less than 10% leakage: good
Less than 20% leakage: acceptable
Less than 30% leakage: poor
More than 30% leakage: definite problem

NOTE: If leakage seems unacceptably high, repeat the test, being certain that it is being performed correctly and that the cylinder being tested is at TDC on the compression stroke.

STEP 6 Check the source of air leakage.

- **a.** If air is heard escaping from the oil filler cap, the *piston rings* are worn or broken.
- **b.** If air is observed bubbling out of the radiator, there is a possible blown *head gasket* or cracked *cylinder head*.
- **c.** If air is heard coming from the throttle body or air inlet on fuel-injection-equipped engines, there is a defective *intake valve(s)*.
- **d.** If air is heard coming from the tailpipe, there is a defective *exhaust valve(s)*.

CYLINDER POWER BALANCE TEST

PURPOSE The purpose of a cylinder **power balance test** is to determine if all cylinders are contributing power equally. It determines this by shorting out one cylinder at a time. If the engine speed (RPM) does not drop as much for one cylinder as for other cylinders of the same engine, the shorted cylinder must be weaker than the other cylinders. For example:

Cylinder Number	RPM Drop When Ignition Is Shorted
1	75
2	70
3	15
4	65
5	75
6	70

Cylinder 3 is the weak cylinder.

NOTE: Most automotive test equipment uses automatic means for testing cylinder balance. Be certain to correctly identify the offending cylinder. Cylinder 3 as identified by the equipment may be the third cylinder in the firing order instead of the actual cylinder 3.

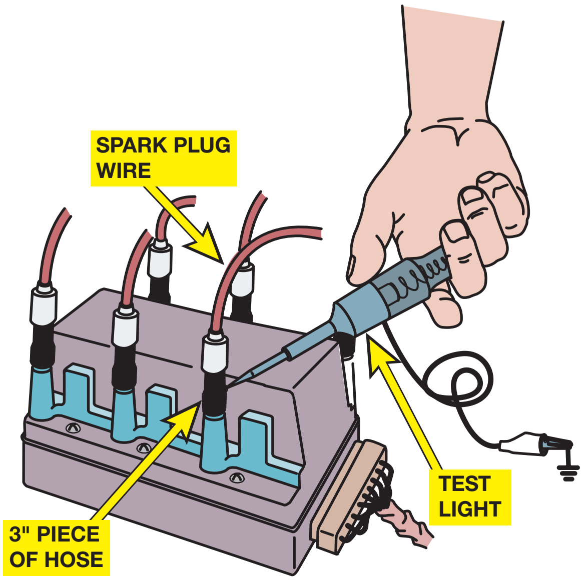


FIGURE 23–19 Using short lengths of vacuum hose and a test light to ground one cylinder at a time on a distributorless ignition system. This works on all types of ignition systems and provides a method for grounding out one cylinder at a time without fear of damaging any component. To avoid possible damage to the catalytic converter, do not short out a cylinder for longer than five seconds. Use a standard light bulb-type test light. An electronic test light will be destroyed by the high voltage.

POWER BALANCE TEST PROCEDURE When point-type ignition was used on all vehicles, the common method for determining which, if any, cylinder was weak was to remove a spark plug wire from one spark plug at a time while watching a tachometer and a vacuum gauge. This method is not recommended on any vehicle with any type of electronic ignition. If any of the spark plug wires are removed from a spark plug with the engine running, the ignition coil tries to supply increasing levels of voltage attempting to jump the increasing gap as the plug wires are removed. This high voltage could easily track the ignition coil, damage the ignition module, or both.

The acceptable method of canceling cylinders, which will work on all types of ignition systems, including distributorless, is to *ground* the secondary current for each cylinder. ● **SEE FIGURE 23–19**. The cylinder with the least RPM drop is the cylinder not producing its share of power.

VACUUM TESTS

TERMINOLOGY Vacuum is pressure below atmospheric pressure and is measured in **inches** (or millimeters) **of mercury (Hg).** An engine in good mechanical condition will run with high manifold vacuum. Manifold vacuum is developed by the pistons as they move down on the intake stroke to draw the charge from the throttle body and intake manifold. Air to refill the manifold comes past the throttle plate into the manifold. Vacuum will increase anytime the engine turns faster or has better cylinder sealing while the throttle plate remains in a fixed position. Manifold vacuum will decrease when the engine turns more slowly or when the cylinders no longer do an efficient job of pumping. **Vacuum tests** include testing the engine for **cranking vacuum**, **idle vacuum**, and vacuum at 2500 RPM.

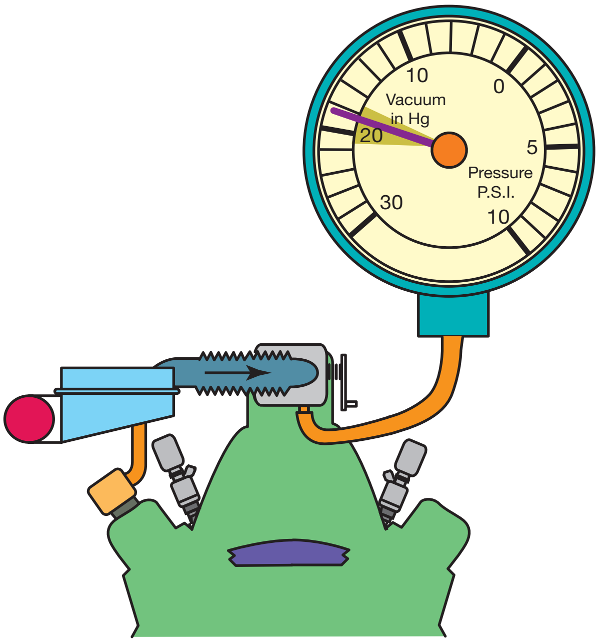


FIGURE 23–20 An engine in good mechanical condition should produce 17 to 21 inch Hg of vacuum at idle at sea level.

CRANKING VACUUM TEST Measuring the amount of manifold vacuum during cranking is a quick and easy test to determine if the piston rings and valves are properly sealing. (For accurate results, the engine should be warm and the throttle closed.) To perform the **cranking vacuum test**, take the following steps:

STEP 1 Disable the ignition or fuel injection.

STEP 2 Connect the vacuum gauge to a manifold vacuum source.

STEP 3 Crank the engine while observing the vacuum gauge.

Cranking vacuum should be higher than 2.5 inch Hg. (Normal cranking vacuum is 3 to 6 inch Hg.) If it is lower than 2.5 inch Hg, the following could be the cause:

- Too slow a cranking speed
- Worn piston rings
- Leaking valves
- Excessive amounts of air bypassing the throttle plate (This could give a false low vacuum reading. Common sources include a throttle plate partially open or a high-performance camshaft with excessive overlap.)

IDLE VACUUM TEST An engine in proper condition should idle with a steady vacuum between 17 and 21 inch Hg. ● **SEE FIGURE 23–20**.

NOTE: Engine vacuum readings vary with altitude. A reduction of 1 inch Hg per 1,000 feet (300 m) of altitude should be subtracted from the expected values if testing a vehicle above 1,000 feet (300 m).

LOW AND STEADY VACUUM If the vacuum is lower than normal, yet the gauge reading is steady, the most common causes include the following:

- Retarded ignition timing
- Retarded cam timing (check timing chain for excessive slack or timing belt for proper installation) ● **SEE FIGURE 23–21**.

FLUCTUATING VACUUM If the needle drops, then returns to a normal reading, then drops again, and again returns, this indicates a sticking valve. A common cause of sticking valves is lack of lubrication of the valve stems. ● **SEE FIGURES 23–22 THROUGH 23–30**. If the vacuum gauge fluctuates above and below a center point, burned valves or weak valve springs may be indicated. If the fluctuation is slow and steady, unequal fuel mixture could be the cause.

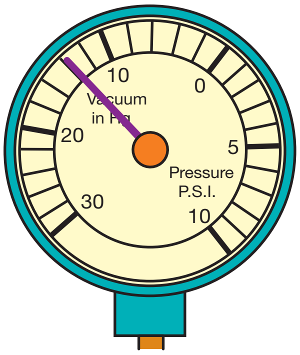

10
0
Vacuum
in Hg
20
5
Pressure
P.S.I.
30
10

FIGURE 23–21 A steady but low reading could indicate retarded valve or ignition timing.

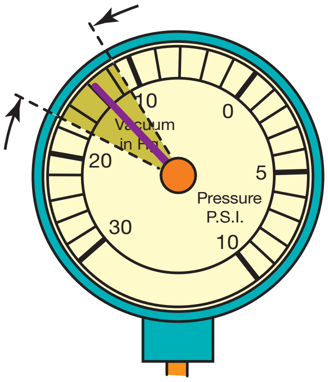

10
0
Vacuum
in Hg
20
5
Pressure
P.S.I.
30
10

FIGURE 23–22 A gauge reading with the needle fluctuating 3 to 9 Hg below normal often indicates a vacuum leak in the intake system.

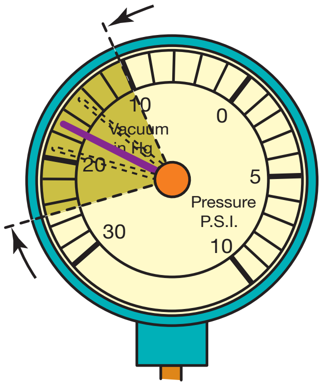

10
0
Vacuum
in Hg
20
5
Pressure
P.S.I.
30
10

FIGURE 23–23 A leaking head gasket can cause the needle to vibrate as it moves through a range from below to above normal.

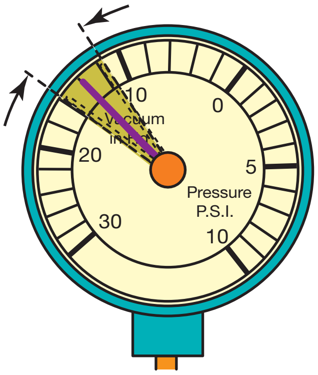

10
0
Vacuum
in Hg
20
5
Pressure
P.S.I.
30
10

FIGURE 23–24 An oscillating needle 1 or 2 inch Hg below normal could indicate an incorrect air–fuel mixture (either too rich or too lean).

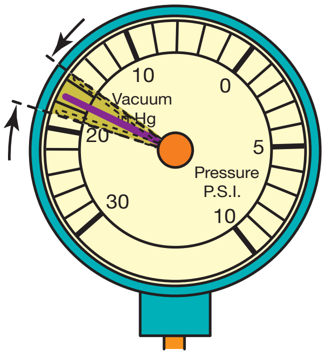

10
0
Vacuum
in Hg
20
5
Pressure
P.S.I.
30
10

FIGURE 23–25 A rapidly vibrating needle at idle that becomes steady as engine speed is increased indicates worn valve guides.

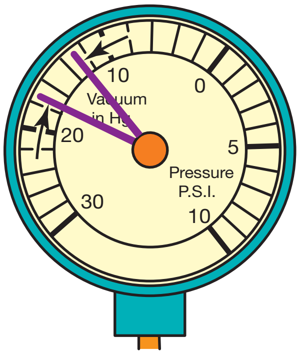

10
0
Vacuum
in Hg
20
5
Pressure
P.S.I.
30
10

FIGURE 23–26 If the needle drops 1 or 2 inch Hg from the normal reading, one of the engine valves is burned or not seating properly.

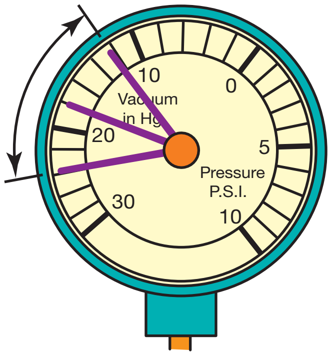

10
0
Vacuum
in Hg
20
5
Pressure
P.S.I.
30
10

FIGURE 23–27 Weak valve springs will produce a normal reading at idle, but as engine speed increases, the needle will fluctuate rapidly between 12 and 24 inch Hg.

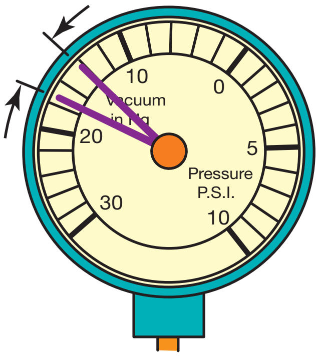

10
0
Vacuum
in Hg
20
5
Pressure
P.S.I.
30
10

FIGURE 23–28 A steady needle reading that drops 2 or 3 inch Hg when the engine speed is increased slightly above idle indicates that the ignition timing is retarded.

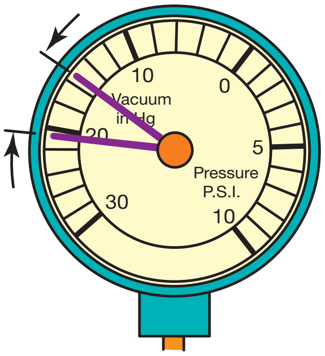


FIGURE 23–29 A steady needle reading that rises 2 or 3 inch Hg when the engine speed is increased slightly above idle indicates that the ignition timing is advanced.

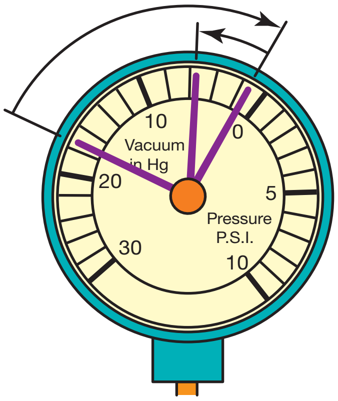


FIGURE 23–30 A needle that drops to near zero when the engine is accelerated rapidly and then rises slightly to a reading below normal indicates an exhaust restriction.

EXHAUST RESTRICTION TEST

PURPOSE OF THE TEST If the exhaust system is restricted, the engine will be low on power, yet smooth. Common causes of **restricted exhaust** include the following:

- **Clogged catalytic converter.** Always check the ignition and fuel-injection systems for faults that could cause excessive amounts of unburned fuel to be exhausted. Excessive unburned fuel can overheat the catalytic converter and cause the beads or structure of the converter to fuse together, creating the restriction. A defective fuel delivery system could also cause excessive unburned fuel to be dumped into the converter.
- **Clogged or restricted muffler.** This can cause low power. Often a defective catalytic converter will shed particles that can clog a muffler. Broken internal baffles can also restrict exhaust flow.
- **Damaged or defective piping.** This can reduce the power of any engine. Some exhaust pipe is constructed with double walls, and the inside pipe can collapse and form a restriction that is not visible on the outside of the exhaust pipe.

TESTING BACK PRESSURE WITH A VACUUM GAUGE A vacuum gauge can be used to measure manifold vacuum at a high idle (2000 to 2500 RPM). If the exhaust system is restricted, pressure increases in the exhaust system. This pressure is called **back pressure**. Manifold vacuum will drop gradually if the engine is kept at a constant speed, if the exhaust is restricted.

The reason the vacuum will drop is that all exhaust leaving the engine at the higher engine speed cannot get through the restriction. After a short time (within one minute), the exhaust tends to "pile up" above the restriction and eventually remains in the cylinder of the engine at the end of the exhaust stroke. Therefore, at the beginning of the intake stroke, when the piston traveling downward should be lowering the pressure (raising the vacuum) in the intake manifold, the extra exhaust in the cylinder *lowers* the normal vacuum. If the exhaust restriction is severe enough, the vehicle can become undriveable because cylinder cannot be filled with outside air except at idle.

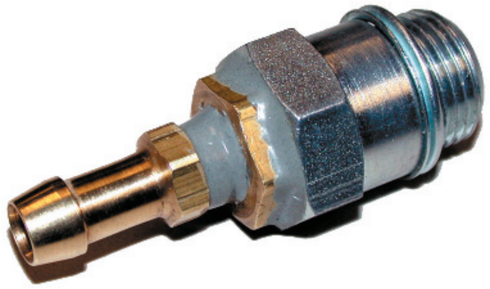


FIGURE 23–31 A technician-made adapter used to test exhaust system back pressure.

TESTING BACK PRESSURE WITH A PRESSURE GAUGE Exhaust system back pressure can be measured directly by installing a pressure gauge into an exhaust opening. This can be accomplished in one of the following ways:

- **With an oxygen sensor.** Use a back pressure gauge and adapter or remove the inside of an old, discarded oxygen sensor and thread in an adapter to convert to a vacuum or pressure gauge.

NOTE: An adapter can be easily made by inserting a metal tube or pipe. A short section of brake line works great. The pipe can be brazed to the oxygen sensor housing or it can be glued in with epoxy. An 18 mm compression gauge adapter can also be adapted to fit into the oxygen sensor opening. ● SEE FIGURE 23–31.

- **With the exhaust gas recirculation (EGR) valve.** Remove the EGR valve and fabricate a plate to connect to a pressure gauge.

At idle, the maximum back pressure should be less than 1.5 PSI (10 kPa), and it should be less than 2.5 PSI (15 kPa) at 2500 RPM.

DIAGNOSING HEAD GASKET FAILURE

Several items can be used to help diagnose a head gasket failure.

- **Exhaust gas analyzer.** With the radiator cap removed, place the probe from the exhaust analyzer above the radiator filler neck. If the HC reading increases, the exhaust (unburned hydrocarbons) is getting into the coolant from the combustion chamber.
- **Chemical test.** A chemical tester using blue liquid is also available. The liquid turns yellow if combustion gases are present in the coolant. ● **SEE FIGURE 23–32.**
- **Bubbles in the coolant.** Remove the coolant pump belt to prevent pump operation. Remove the radiator cap and

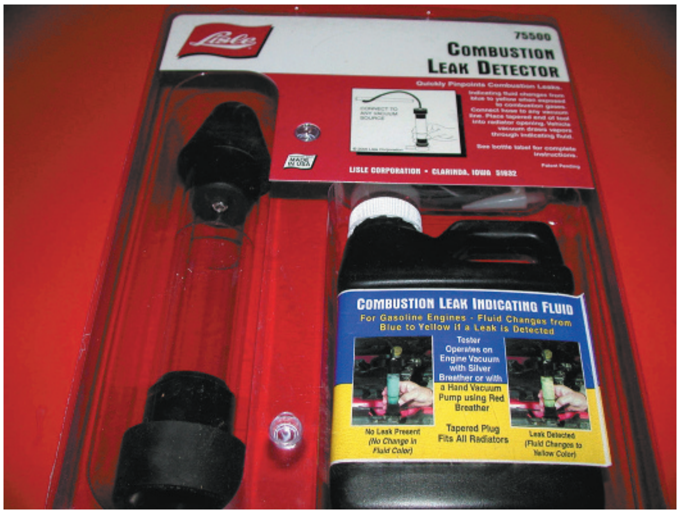

75500
Combustion Leak Detector
Lisle Corporation • Clarinda, Iowa 51632
Combustion Leak Indicating Fluid
For Gasoline Engines - Fluid Changes from Blue to Yellow if a Leak is Detected

FIGURE 23–32 A tester that uses a blue liquid to check for exhaust gases in the exhaust, which would indicate a head gasket leak problem.

start the engine. If bubbles appear in the coolant before it begins to boil, a defective head gasket or cracked cylinder head is indicated.

- **Excessive exhaust steam.** If excessive water or steam is observed coming from the tailpipe, coolant is getting into the combustion chamber from a defective head gasket or a cracked head. If there is leakage between cylinders, the engine usually misfires and a power balancer test and/or compression test can be used to confirm the problem.

DASH WARNING LIGHTS

Most vehicles are equipped with several dash warning lights often called "telltale" lights. These lights are often the only warning a driver receives that there may be engine problems. A summary of typical dash warning lights and their meanings follows. ● **SEE FIGURE 23–33**.

OIL (ENGINE) LIGHT The red oil light indicates that the engine oil pressure is too low (usually lights when oil pressure is 4 to 7 PSI [20 to 50 kPa]). Normal oil pressure should be 10 to 60 PSI (70 to 400 kPa) or 10 PSI per 1000 engine RPM.

When this light comes on, the driver should shut off the engine immediately and check the oil level and condition for possible dilution with gasoline caused by a fuel system fault. If the oil level is okay, there is a possible serious engine problem or a possible defective oil pressure sending (sender) unit. The automotive technician should always check the oil pressure using a reliable mechanical oil pressure gauge if low oil pressure is suspected.

NOTE: Some automobile manufacturers combine the dash warning lights for oil pressure and coolant temperature into one light, usually labeled "engine." Therefore, when the engine light comes on, the technician should check for possible coolant temperature and/or oil pressure problems.

COOLANT TEMPERATURE LIGHT Most vehicles are equipped with a coolant temperature gauge or dash warning light. The warning light may be labeled "coolant," "hot," or "temperature." If the coolant temperature warning light comes on during driving, this usually indicates that the coolant temperature is above a safe level, or above about 250°F (120°C). Normal coolant temperature should be about 200°F to 220°F (90°C to 105°C).

If the coolant temperature light comes on during driving, the following steps should be followed to prevent possible engine damage:

1. Turn off the air conditioning and turn on the heater. The heater will help get rid of some of the heat in the cooling system.
2. Raise the engine speed in neutral or park to increase the circulation of coolant through the radiator.
3. If possible, turn the engine off and allow it to cool (this may take over an hour).
4. Do not continue driving with the coolant temperature light on (or the gauge reading in the red warning section or above 260°F [126°C]) or serious engine damage may result.

NOTE: If the engine does not feel or smell hot, it is possible that the problem is a faulty engine coolant temperature (ECT) sensor or gauge.

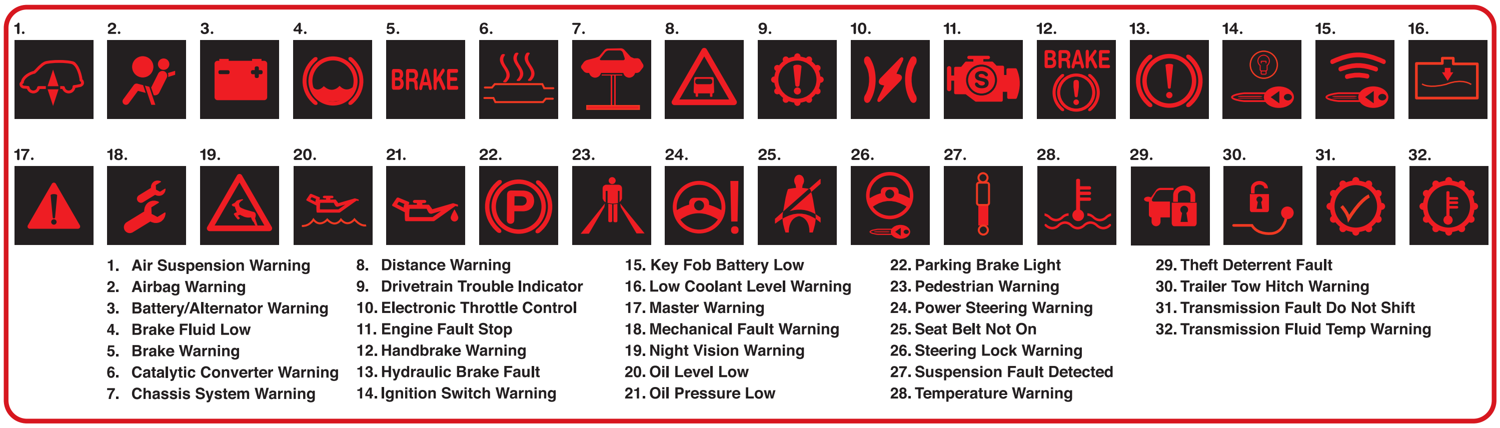
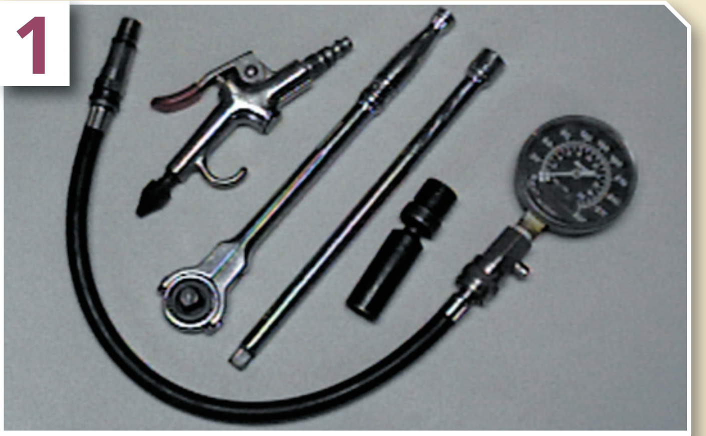

1. Air Suspension Warning
2. Airbag Warning
3. Battery/Alternator Warning
4. Brake Fluid Low
5. Brake Warning
6. Catalytic Converter Warning
7. Chassis System Warning
8. Distance Warning
9. Drivetrain Trouble Indicator
10. Electronic Throttle Control
11. Engine Fault Stop
12. Handbrake Warning
13. Hydraulic Brake Fault
14. Ignition Switch Warning
15. Key Fob Battery Low
16. Low Coolant Level Warning
17. Master Warning
18. Mechanical Fault Warning
19. Night Vision Warning
20. Oil Level Low
21. Oil Pressure Low
22. Parking Brake Light
23. Pedestrian Warning
24. Power Steering Warning
25. Seat Belt Not On
26. Steering Lock Warning
27. Suspension Fault Detected
28. Temperature Warning
29. Theft Deterrent Fault
30. Trailer Tow Hitch Warning
31. Transmission Fault Do Not Shift
32. Transmission Fluid Temp Warning
BRAKE

FIGURE 23–33 Red dash symbols are used to warn the driver of a fault requiring immediate action.

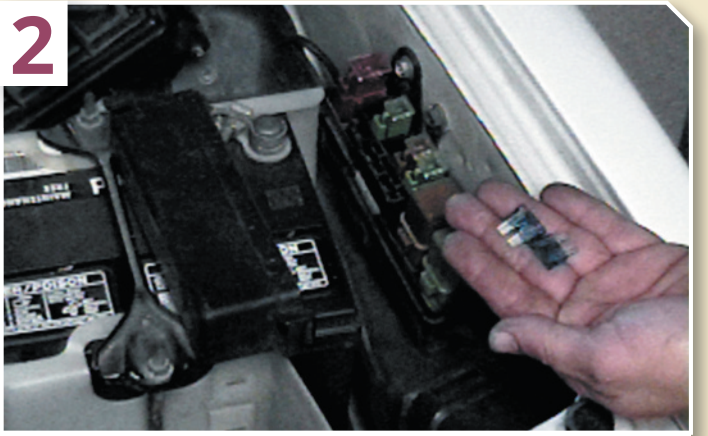
COMPRESSION TEST

1



The tools and equipment needed to perform a compression test include a compression gauge, an air nozzle, and the socket ratchets and extensions that may be necessary to remove the spark plugs from the engine.

2

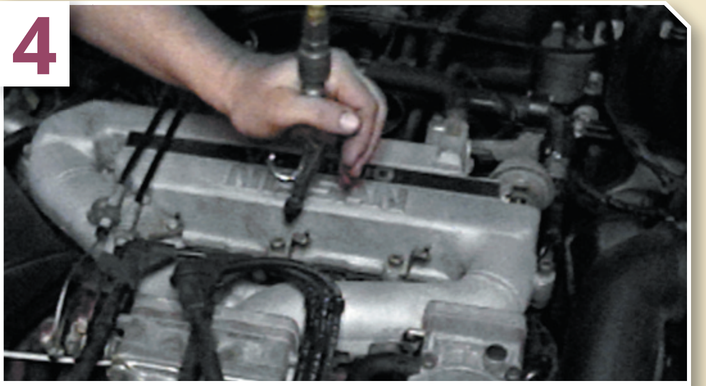


To prevent ignition and fuel-injection operation while the engine is being cranked, remove both the fuel-injection fuse and the ignition fuse. If the fuses cannot be removed, disconnect the wiring connectors for the injectors and the ignition system.

3

Block open the throttle (and choke, if the engine is equipped with a carburetor). Here a screwdriver is being used to wedge the throttle linkage open. Keeping the throttle open ensures that enough air will be drawn into the engine so that the compression test results will be accurate.

4

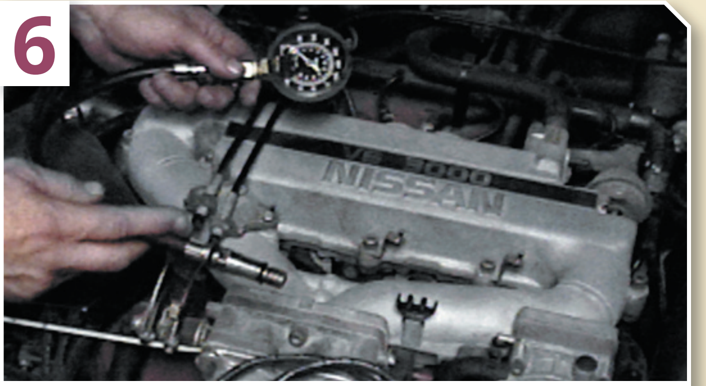


Before removing the spark plugs, use an air nozzle to blow away any dirt that may be around the spark plug. This step helps prevent debris from getting into the engine when the spark plugs are removed.

5

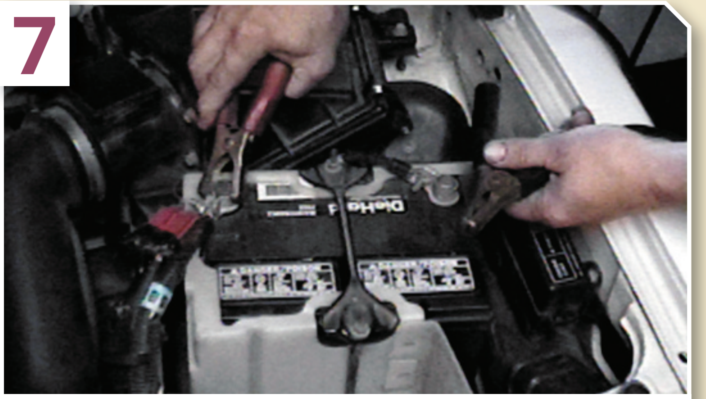
Remove all of the spark plugs. Be sure to mark the spark plug wires so that they can be reinstalled onto the correct spark plugs after the compression test has been performed.

6



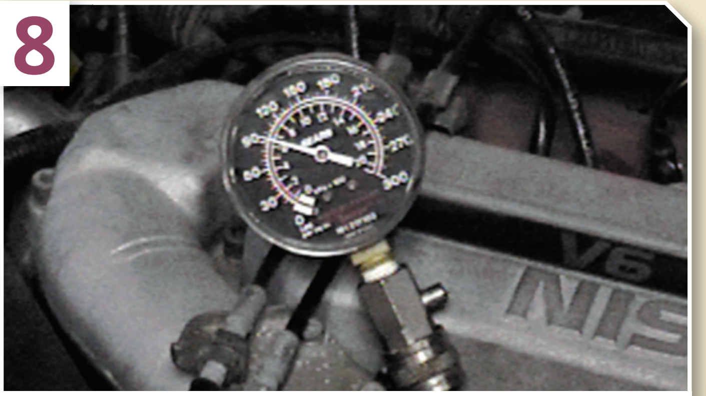
Select the proper adapter for the compression gauge. The threads on the adapter should match those on the spark plug.

7



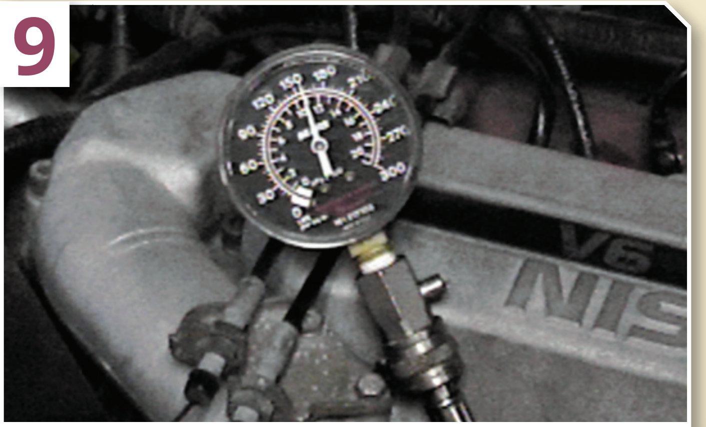
If necessary, connect a battery charger to the battery before starting the compression test. It is important that consistent cranking speed be available for each cylinder being tested.

8


30
60
90
120
150
180
210
240
270
300
SEARS
V6
NIS

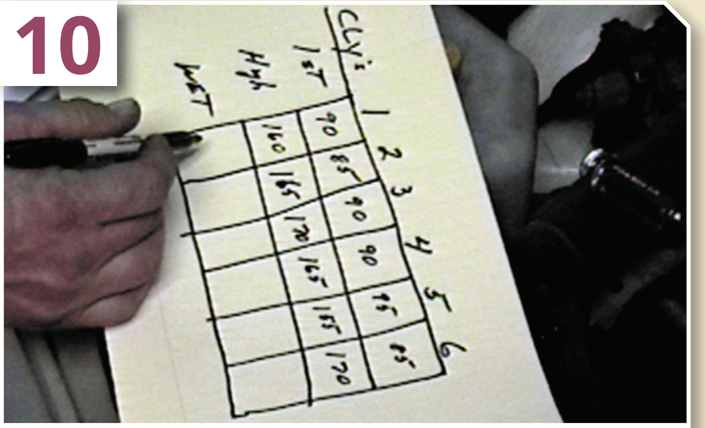
Make a note of the reading on the gauge after the first "puff," which indicates the first compression stroke that occurred on that cylinder as the engine was being rotated. If the first puff reading is low and the reading gradually increases with each puff, weak or worn piston rings may be indicated.

9


30
60
90
120
150
180
210
240
270
300
SEARS
V6
NIS

After the engine has been cranked for four "puffs," stop cranking the engine and observe the compression gauge.

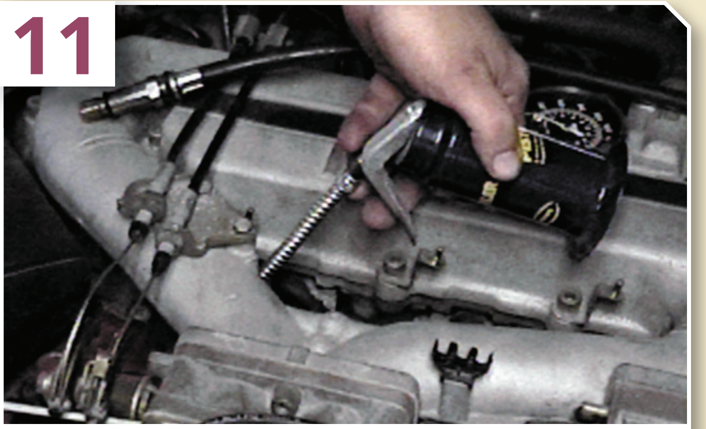
10



CLY's	1	2	3	4	5	6
1ST	90	85	90	90	75	85
Hgh	160	165	170	165	155	170
WET						

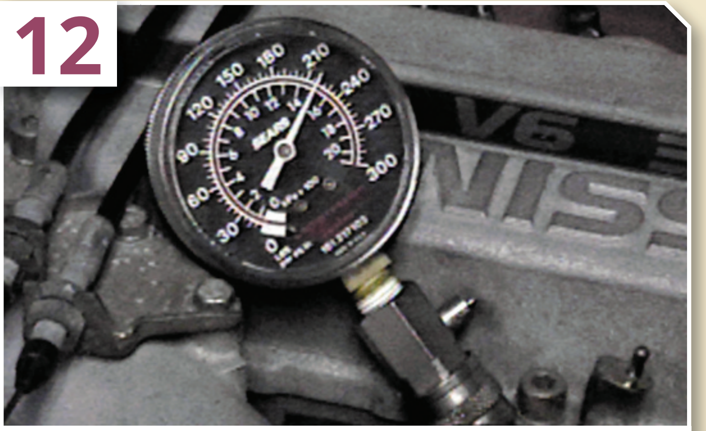
Record the first puff and this final reading for each cylinder. The final readings should all be within 20% of each other.

11



If a cylinder(s) is lower than most of the others, use an oil can and squirt two squirts of engine oil into the cylinder and repeat the compression test. This is called performing a wet compression test.

12


30
60
90
120
150
180
210
240
270
300
SEARS
V6
NIS

If the gauge reading is now much higher than the first test results, the cause of the low compression is due to worn or defective piston rings. The oil in the cylinder temporarily seals the rings which causes the higher reading.

REVIEW QUESTIONS

1. What visual checks should be performed on an engine if a mechanical malfunction is suspected?
2. How can a compression test to determine what is wrong with an engine?
3. How is a cylinder leakage test performed?
4. How would a vacuum gauge indicate that the valves were sticking in their guides?
5. What is the test procedure for determining if the exhaust system is restricted (clogged) using a vacuum gauge?

CHAPTER QUIZ

1. Which of these smoke colors indicates excessive fuel being burned in the combustion chamber?
   - **a.** Blue
   - **b.** Black
   - **c.** White
   - **d.** Gray
2. Two technicians are discussing oil leaks. Technician A says that an oil leak can be found using a fluorescent dye in the oil with a black light to check for leaks. Technician B says clean the engine with a degreaser when trying to locate oil leaks. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Which of the following is the *least likely* to cause an engine noise?
   - **a.** Carbon on the pistons
   - **b.** Cracked exhaust manifold
   - **c.** Loose accessory drive belt
   - **d.** Vacuum leak
4. Engine oil pressure at 3500 RPM should be at least ________ PSI.
   - **a.** 10
   - **b.** 25
   - **c.** 35
   - **d.** 42
5. A good engine should produce how much compression during a running (dynamic) compression test at idle?
   - **a.** 150 to 200 PSI
   - **b.** 100 to 150 PSI
   - **c.** 60 to 90 PSI
   - **d.** 30 to 60 PSI
6. A cylinder contribution test uses a __________ to locate a potential weak cylinder.
   - **a.** scan tool
   - **b.** DSO
   - **c.** DMM
   - **d.** vacuum gauge
7. Technician A says that during a power balance test, the cylinder that causes the biggest RPM drop is the weak cylinder. Technician B says that if one spark plug wire is grounded out and the engine speed does not drop, a weak or dead cylinder is indicated. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. *Cranking* vacuum should be __________.
   - **a.** 2.5 inch Hg or higher
   - **b.** over 25 inch Hg
   - **c.** 17 to 21 inch Hg
   - **d.** 6 to 16 inch Hg
9. Technician A says that a leaking head gasket can be tested using a chemical tester. Technician B says that a leaking head gasket can be found using an exhaust gas analyzer. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. The low oil pressure warning light usually comes on __________.
    - **a.** whenever an oil change is required
    - **b.** whenever oil pressure drops dangerously low (4 to 7 PSI)
    - **c.** whenever the oil filter bypass valve opens
    - **d.** whenever the oil filter anti-drain back valve opens

Chapter 24

IN-VEHICLE ENGINE SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain thermostat replacement in engines.
- Explain water pump replacement in engines.
- Discuss intake manifold gasket inspection.
- Discuss intake manifold gasket replacement.
- Describe the steps involved in timing belt replacement.
- Discuss hybrid engine precautions.
- Discuss gasoline direct-injection engine concerns.

KEY TERMS:

EREV 256 • Fretting 254 • HEV 256 • Idle stop 256 • Skewed 253

THERMOSTAT REPLACEMENT

FAILURE PATTERNS All thermostat valves move during operation to maintain the desired coolant temperature. Thermostats can fail in the following ways:

- **Stuck open.** If a thermostat fails open or partially open, the operating temperature of the engine will be less than normal. ● **SEE FIGURE 24–1**.
- **Stuck closed.** If the thermostat fails closed or almost closed, the engine will likely overheat.
- **Stuck partially open.** This will cause the engine to warm up slowly if at all. This condition can cause the powertrain control module (PCM) to set a P0128 diagnostic trouble code (DTC) which means that the engine coolant temperature does not reach the specified temperature.
- **Skewed.** A **skewed** thermostat works, but not within the correct temperature range. Therefore, the engine could overheat or operate cooler than normal or even do both.

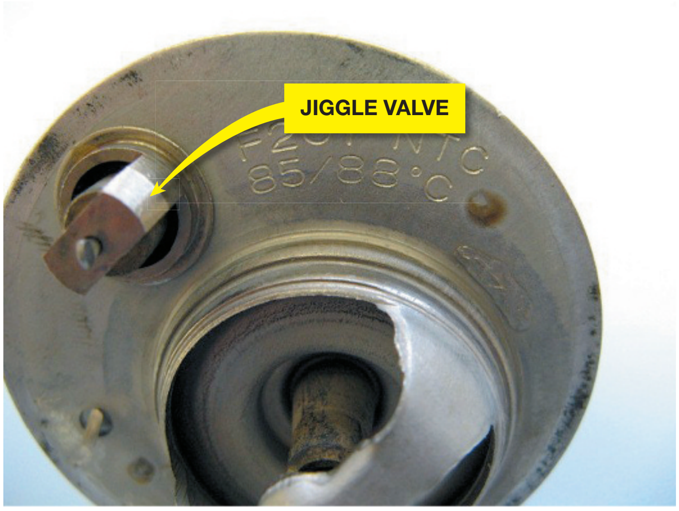


FIGURE 24–1 If the thermostat has a jiggle valve, it should be placed toward the top to allow air to escape. If a thermostat were to become stuck open or open too soon, this can set a diagnostic trouble code P0128 (coolant temperature below thermostat regulating temperature).

REPLACEMENT PROCEDURE Before replacing the thermostat, double-check that the cooling system problem is not due to another fault, such as being low on coolant or an inoperative cooling fan. Check service information for the specified procedure to follow to replace the thermostat. Most recommended procedures include the following steps:

STEP 1 Allow the engine to cool for several hours so the engine and the coolant are at room temperature.

STEP 2 Drain the coolant into a suitable container. Most vehicle manufacturers recommend that new coolant be used and the old coolant disposed of properly or recycled.

STEP 3 Remove any necessary components to get access to the thermostat.

STEP 4 Remove the thermostat housing and thermostat.

STEP 5 Replace the thermostat housing gasket and thermostat. Torque all fasteners to specifications.

STEP 6 Refill the cooling system with the specified coolant and bleed any trapped air from the system.

STEP 7 Pressurize the cooling system to verify that there are no leaks around the thermostat housing.

STEP 8 Run the engine until it reaches normal operating temperature and check for leaks.

STEP 9 Verify that the engine is reaching correct operating temperature.

WATER PUMP REPLACEMENT

NEED FOR REPLACEMENT A water pump will require replacement if any of the following conditions are present:

- Leaking coolant from the weep hole
- Bearing noisy or loose
- Lack of proper coolant flow caused by worn or slipping impeller blades

REPLACEMENT GUIDELINES After diagnosis has been confirmed that the water pump requires replacement, check service information for the exact procedure to follow. The steps usually include the following:

STEP 1 Allow the engine to cool to room temperature.

STEP 2 Drain the coolant and dispose of properly or recycle.

STEP 3 Remove engine components to gain access to the water pump as specified in service information.

STEP 4 Remove the water pump assembly.

STEP 5 Clean the gasket surfaces and install the new water pump using a new gasket or seal as needed. ● **SEE FIGURE 24–2**. Torque all fasteners to factory specifications.

STEP 6 Install removed engine components.

STEP 7 Fill the cooling system with the specified coolant.

STEP 8 Run the engine, check for leaks, and verify proper operation.

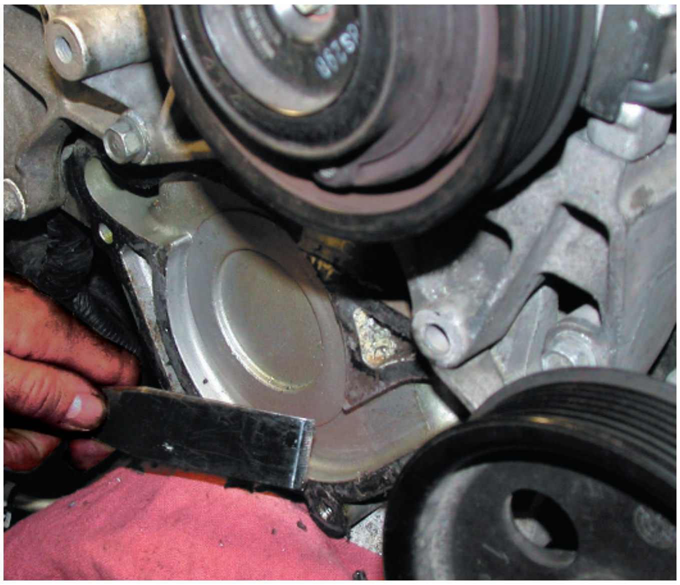


FIGURE 24–2 Use caution if using a steel scraper to remove a gasket from aluminum parts. It is best to use a wood or plastic scraper.

INTAKE MANIFOLD GASKET INSPECTION

CAUSES OF FAILURE Many V-type engines leak oil, coolant, or experience an air (vacuum) leak caused by a leaking intake manifold gasket. This failure can be contributed to one or more of the following:

1. Expansion/contraction rate difference between the cast-iron head and the aluminum intake manifold can cause the intake manifold gasket to be damaged by the relative motion of the head and intake manifold. This type of failure is called **fretting**.
2. Plastic (Nylon 6.6) gasket deterioration caused by the coolant. ● **SEE FIGURE 24–3**.

DIAGNOSIS OF LEAKING INTAKE MANIFOLD GASKET Because intake manifold gaskets are used to seal oil, air, and coolant in most causes, determining that the intake manifold

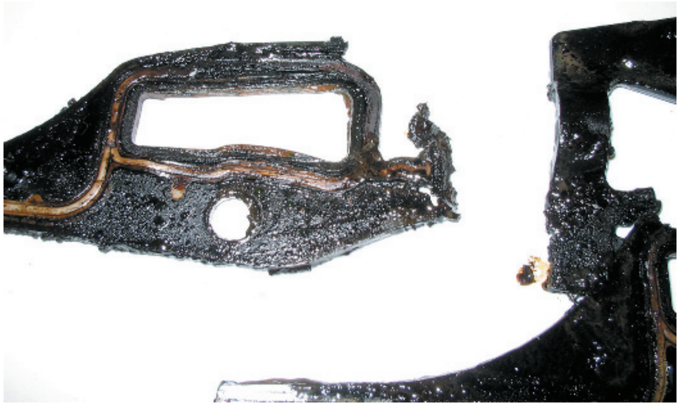


FIGURE 24–3 An intake manifold gasket that failed and allowed coolant to be drawn into the cylinder(s).

gasket is the root cause can be a challenge. To diagnose a possible leaking intake manifold gasket, perform the following tests:

Visual inspection. Check for evidence of oil or coolant between the intake manifold and the cylinder heads.

Coolant level. Check the coolant level and determine if the level has been dropping. A leaking intake manifold gasket can cause coolant to leak and then evaporate, leaving no evidence of the leak.

Air (vacuum) leak. If there is a stored diagnostic trouble code (DTC) for a lean exhaust (P0171, P0172, or P0174), a leaking intake manifold gasket could be the cause. Use propane to check if the engine changes when dispensed around the intake manifold gasket. If the engine changes in speed or sound, then this test verifies that an air leak is present.

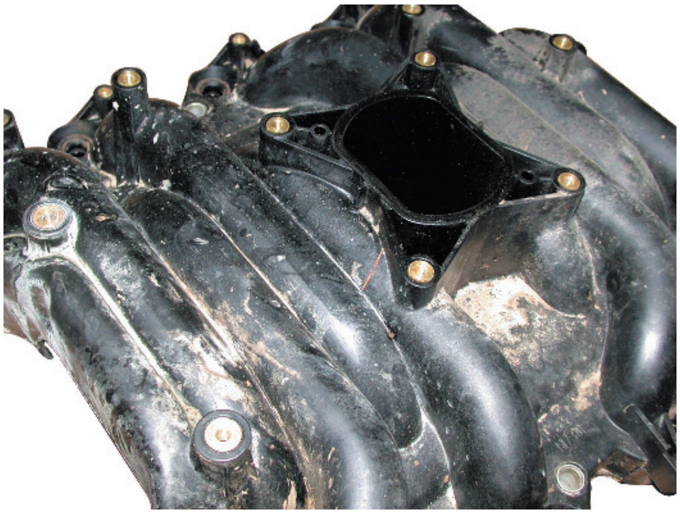


FIGURE 24–5 The upper intake manifold, often called a plenum, attaches to the lower intake manifold.

INTAKE MANIFOLD GASKET REPLACEMENT

When replacing the intake manifold gasket, always check service information for the exact procedure to follow. The steps usually include the following:

STEP 1 Be sure the engine has been off for about an hour and then drain the coolant into a suitable container.

STEP 2 Remove covers and other specified parts needed to get access to the retaining bolts.

STEP 3 To help ensure that the manifold does not warp when removed, loosen all fasteners in the reverse order of the tightening sequence. This means that the bolts should be loosened starting at the ends and working toward the center.

STEP 4 Remove the upper intake manifold (plenum), if equipped, and inspect for faults. ● **SEE FIGURES 24–4 AND 24–5**.

STEP 5 Remove the lower intake manifold, using the same bolt removal procedure of starting at the ends and working toward the center.

STEP 6 Thoroughly clean the area and replace the intake manifold if needed. Check that the correct replacement manifold is being used, and even the current part could look different from the original. ● **SEE FIGURE 24–6**.

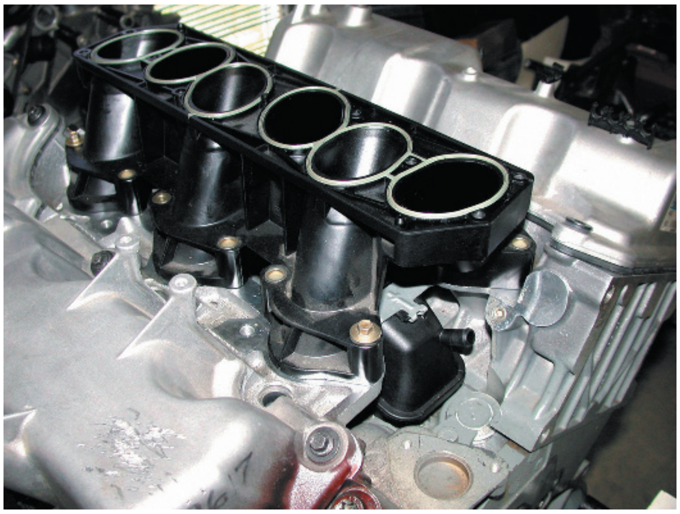


FIGURE 24–4 The lower intake manifold attaches to the cylinder heads.

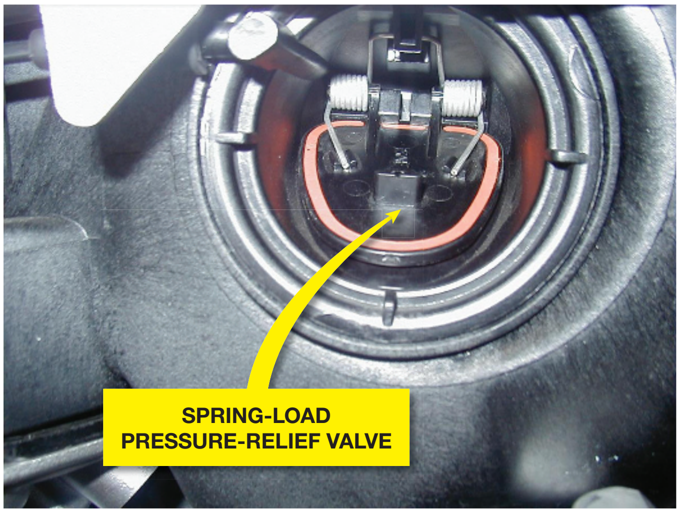


FIGURE 24–6 Some plastic intake manifolds are equipped with a pressure relief valve that would open in the event of a backfire condition to prevent the higher internal pressures from causing damage to the manifold.

STEP 7 Install the intake manifold using new gaskets as specified. Some designs use gaskets that are reusable. Replace as needed.

STEP 8 Torque all fasteners to factory specifications and in the proper sequences. The tightening sequences usually start at the center and work outward to the ends.

CAUTION: Double-check the torque specifications and be sure to use the correct values. Many intake manifolds use fasteners that are torqued to values expressed in pound-inches and not pound-feet.

STEP 9 Reinstall all parts needed to allow the engine to start and run, including refilling the coolant if needed.

STEP 10 Start the engine and check for leaks and proper engine operation.

STEP 11 Reset or relearn the idle if specified, using a scan tool.

STEP 12 Install all of the remaining parts and perform a test drive to verify proper operation and no leaks.

STEP 13 Check and replace the air filter if needed.

STEP 14 Change the engine oil if the intake manifold leak could have caused coolant to leak into the engine, which would contaminate the oil.

TIMING BELT REPLACEMENT

NEED FOR REPLACEMENT Timing belts have a limited service and a specified replacement interval ranging from 60,000 miles (97,000 km) to about 100,000 miles (161,000 km). Timing belts are required to be replaced if any of the following conditions occur:

- Meets or exceeds the vehicle manufacturer's recommended timing belt replacement interval.
- The timing belt has been contaminated with coolant or engine oil.
- The timing belt has failed (missing belt teeth or broken).

TIMING BELT REPLACEMENT GUIDELINES Before replacing the timing belt, check service information for the recommended procedure to follow. Most timing belt replacement procedures include the following steps:

STEP 1 Allow the engine to cool before starting to remove components to help eliminate the possibility of personal injury or warpage of the parts.

STEP 2 Remove all necessary components to gain access to the timing belt and timing marks.

STEP 3 If the timing belt is not broken, rotate the engine until the camshaft and crankshaft timing marks are aligned according to the specified marks. ● **SEE FIGURE 24–7**.

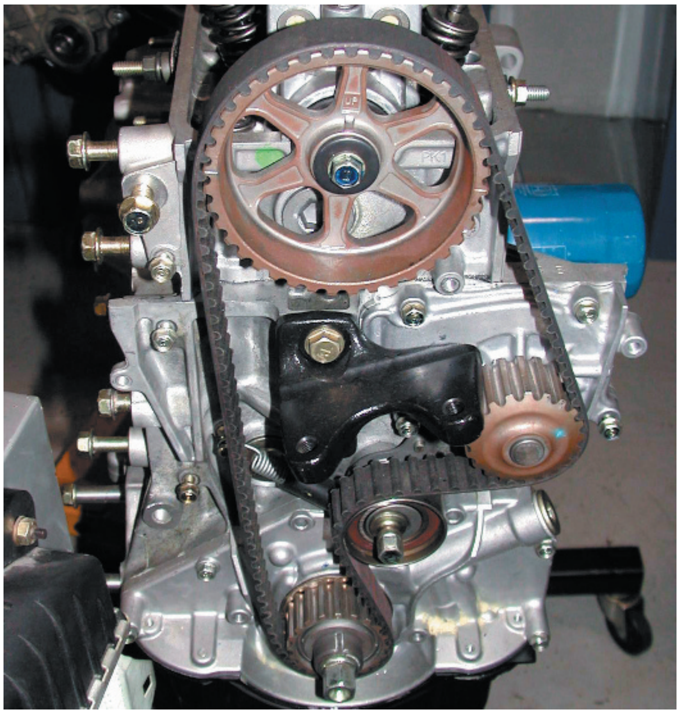


FIGURE 24–7 A single overhead camshaft engine with a timing belt that also rotates the water pump.

STEP 4 Loosen or remove the tensioner as needed to remove the timing belt.

STEP 5 Replace the timing belt and any other recommended items. Components that some vehicle manufacturers recommend replacing in addition to the timing belt include the following:

- Tensioner assembly
- Water pump
- Camshaft oil seal(s)
- Front crankshaft seal

STEP 6 Check (verify) that the camshaft timing is correct by rotating the engine several revolutions.

STEP 7 Install enough components to allow the engine to start to verify proper operation. Check for any leaks, especially if seals have been replaced.

STEP 8 Complete the reassembly of the engine and perform a test drive before returning the vehicle to the customer.

HYBRID ENGINE PRECAUTIONS

HYBRID VEHICLE ENGINE OPERATION Gasoline engines used in **hybrid electric vehicles (HEVs)** and in **extended range electric vehicles (EREVs)** can be a hazard to be around under some conditions. These vehicles are designed to stop the gasoline engines unless needed. This feature is called **idle stop**. This means that the engine is not running, but could start at any time if the computer detects the need to charge the hybrid batteries or other issue that requires the gasoline engine to start and run.

PRECAUTIONS Always check service information for the exact procedures to follow when working around or under the hood of a hybrid electric vehicle. These precautions could include the following:

- Before working under the hood or around the engine, be sure that the ignition is off and the key is out of the ignition.
- Check that the "Ready" light is off. ● **SEE FIGURE 24–8**.

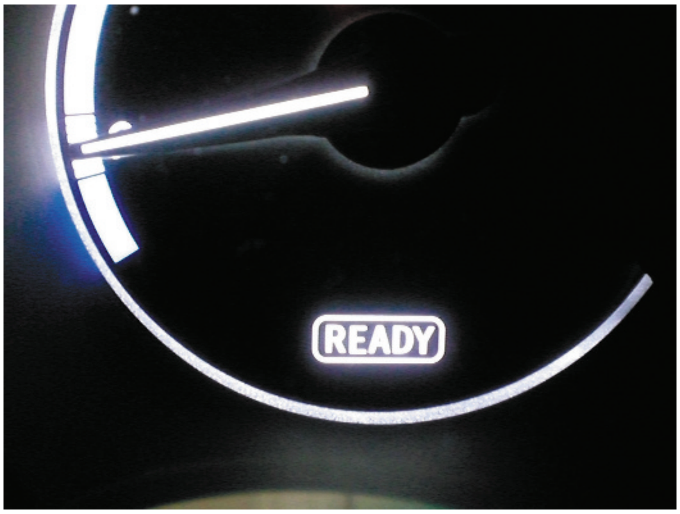


FIGURE 24–8 A Toyota/Lexus hybrid electric vehicle has a ready light. If the ready light is on, the engine can start at anytime without warning.

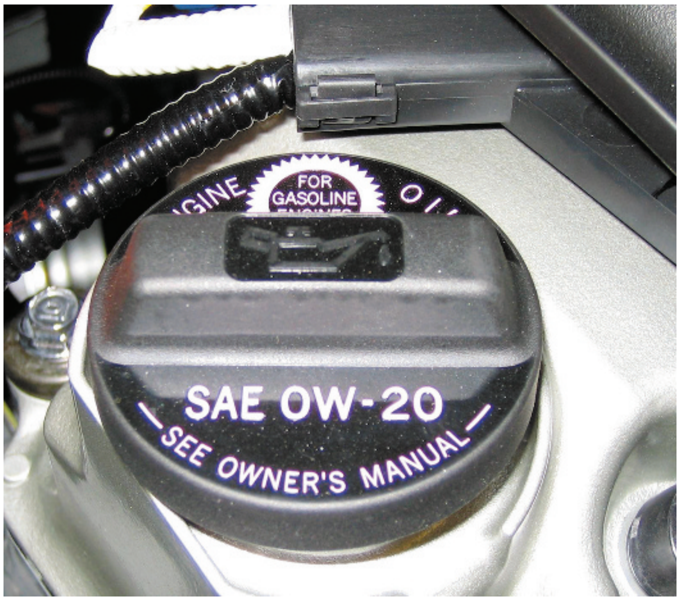


FIGURE 24–9 Always use the viscosity of oil as specified on the oil fill cap or published in service information or the owner's manual.

- Do not touch any circuits that have orange electrical wires or conduit. The orange color indicates dangerous high-voltage wires, which could cause serious injury or death if touched.
- Always use high-voltage linesman's gloves whenever depowering the high-voltage system.

HYBRID ENGINE SERVICE The gasoline engine in most hybrid electric vehicles specifies low-viscosity engine oil as a way to achieve maximum fuel economy. ● **SEE FIGURE 24–9**. The viscosity required is often

- SAE 0W-16
- SAE 0W-20
- SAE 5W-20

Many shops do not keep this viscosity in stock so preparations need to be made to get and use the specified engine oil.

In addition to engine oil, some hybrid electric vehicles such as the Honda Insight (1999–2004) require special spark plugs. Check service information for the specified service procedures and parts needed if a hybrid electric vehicle is being serviced.

GASOLINE DIRECT INJECTION CONCERNS

NOISE ISSUES Gasoline direct-injection systems operate at high pressure and the injectors can often be heard with the engine running and the hood open. This noise can be a customer concern because the clicking sound is similar to noisy valves. If a noise issue is the customer concern, check the following:

- Check a similar vehicle to determine if the sound is louder or more noticeable than normal.
- Check that nothing under the hood is touching the fuel rail. If another line or hose is in contact with the fuel rail, the sound of the injectors clicking can be transmitted throughout the engine, making the sound more noticeable.
- Check for any technical service bulletins (TSBs) that may include new clips or sound insulators to help reduce the noise.

CARBON ISSUES Carbon deposits are often an issue in engines equipped with gasoline direct-injection systems. ● **SEE FIGURE 24–10**. Check service information for the specified procedures to follow. Specified processes and procedures will likely restore power if the intake valves are coated.

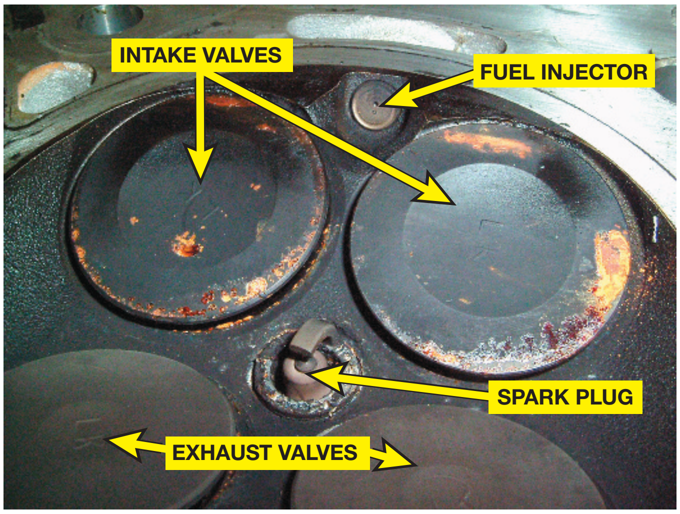


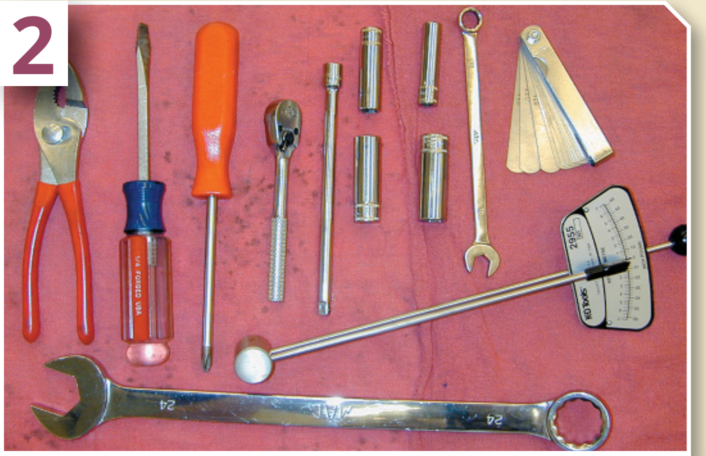
FIGURE 24–10 There may be a driveability issue because the gasoline direct-injection injector is exposed to combustion carbon and fuel residue.

VALVE ADJUSTMENT

1

Before starting the process of adjusting the valves, look up the specifications and exact procedures. The technician is checking this information from a computer CD-ROM-based information system.

2

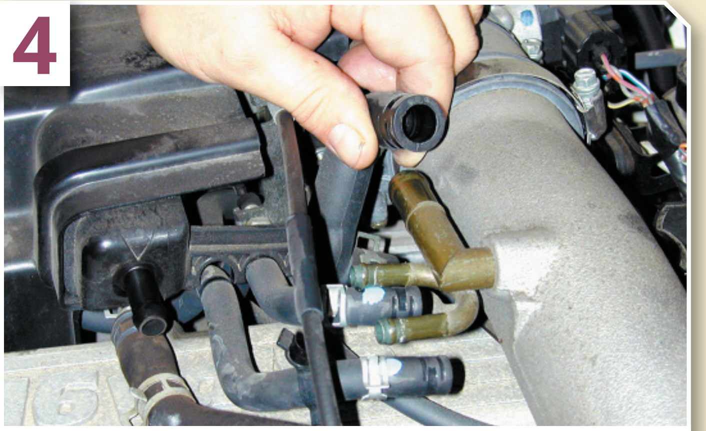


The tools necessary to adjust the valves on an engine with adjustable rocker arms include basic hand tools, feeler gauge, and a torque wrench.

3

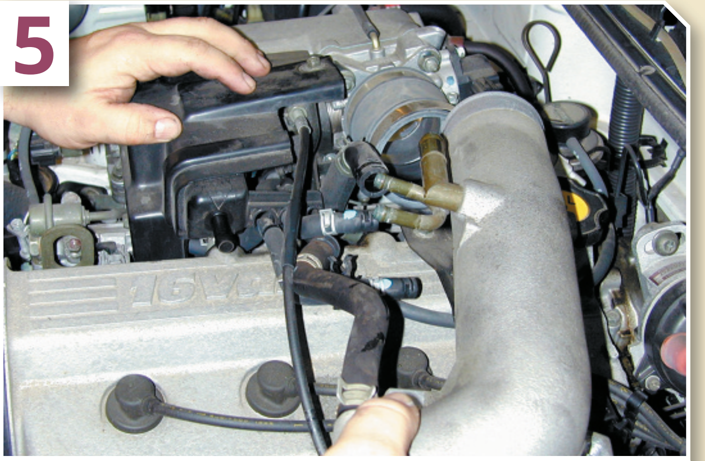
An overall view of the 4-cylinder engine that is due for a scheduled valve adjustment according to the vehicle manufacturer's recommendations.

4



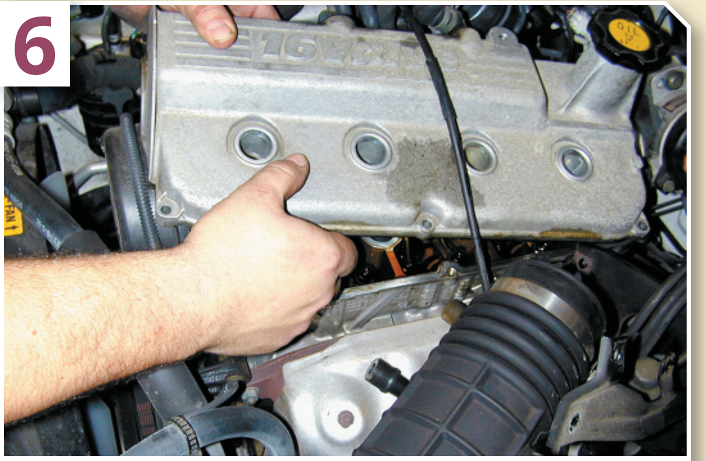
Start the valve adjustment procedure by first disconnecting and labeling, if necessary, all vacuum lines that need to be removed to gain access to the valve cover.

5



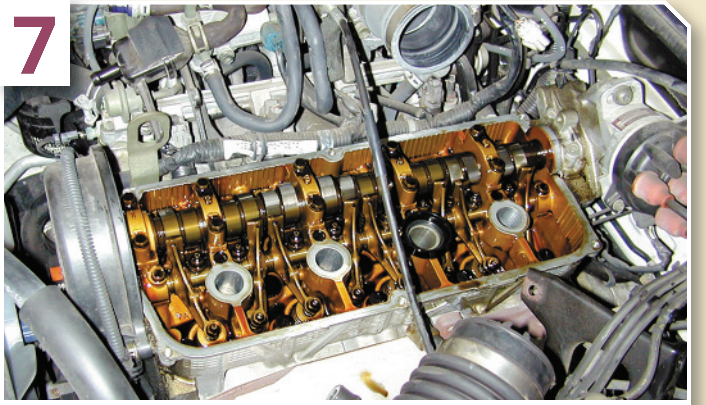
The air intake tube is being removed from the throttle body.

6



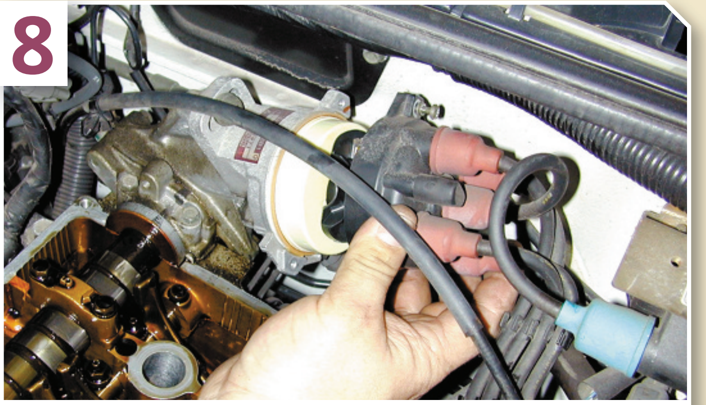
With all vacuum lines and the intake tube removed, the valve cover can be removed after removing all retaining bolts.

7



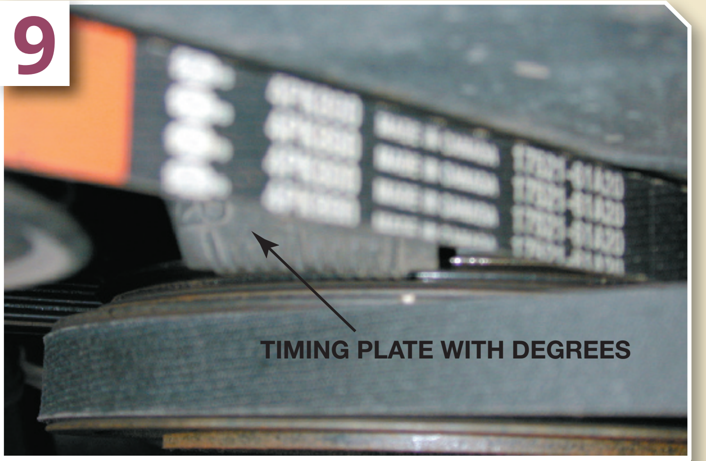
Notice how clean the engine appears. This is a testament of proper maintenance and regular oil changes by the owner.

8



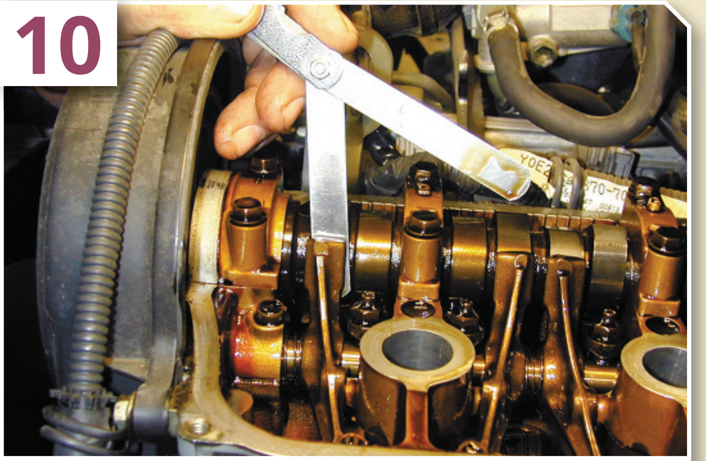
To help locate how far the engine is being rotated, the technician is removing the distributor cap to be able to observe the position of the rotor.

9



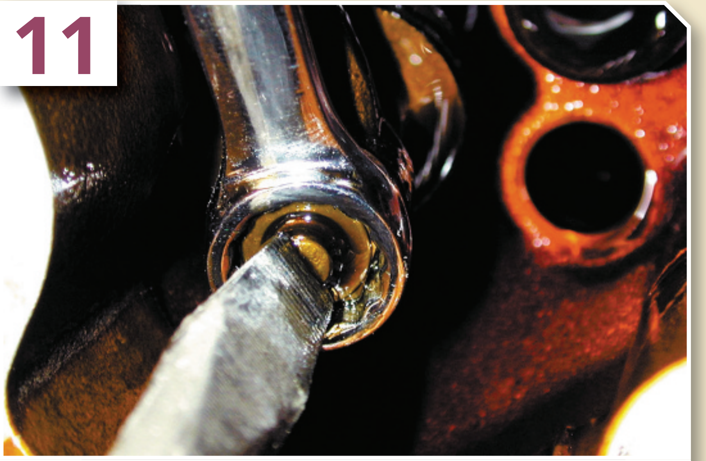
The engine is rotated until the timing marks on the front of the crankshaft line up with zero degrees—top dead center (TDC)—with both valves closed on #1 cylinder.

10



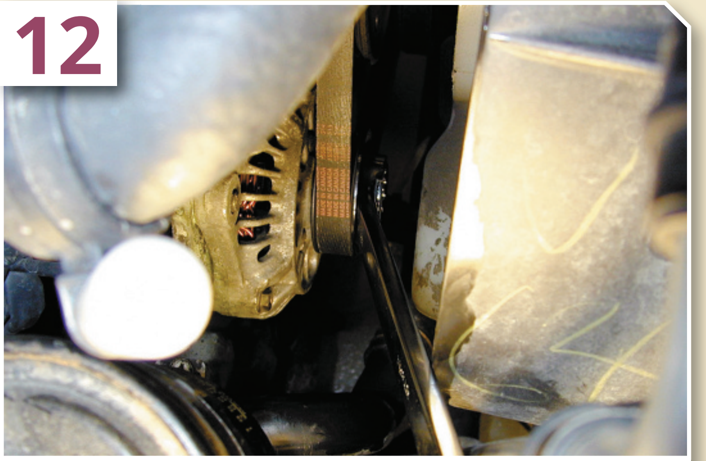
With the rocker arms contacting the base circle of the cam, insert a feeler gauge of the specified thickness between the camshaft and the rocker arm. There should be a slight drag on the feeler gauge.

11



If the valve clearance (lash) is not correct, loosen the retaining nut and turn the valve adjusting screw with a screwdriver to achieve the proper clearance.

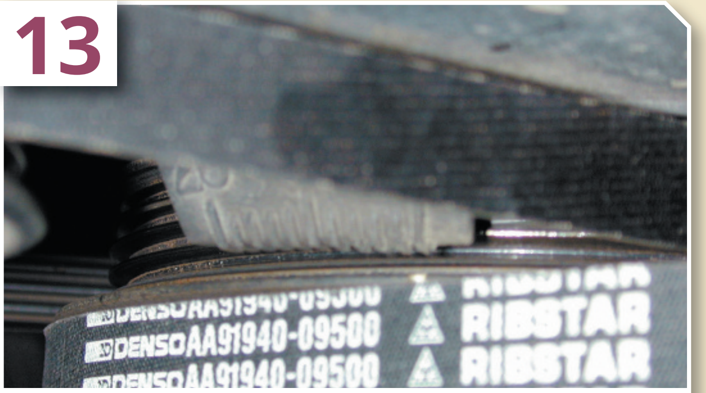
12



After adjusting the valves that are closed, rotate the engine one full rotation until the engine timing marks again align.

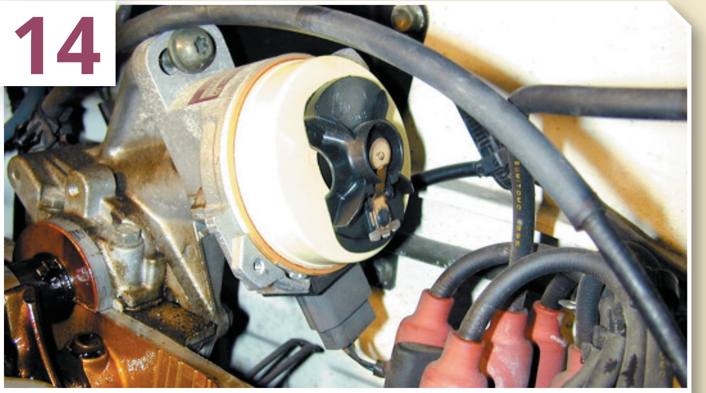
VALVE ADJUSTMENT

13



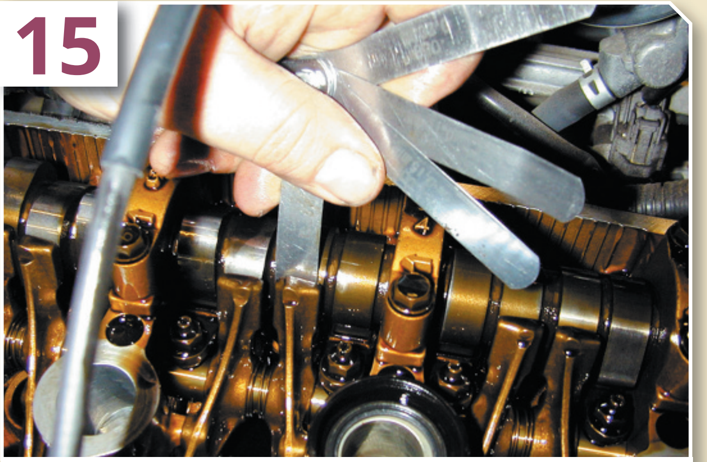
The engine is rotated until the timing marks again align indicating that the companion cylinder will now be in position for valve clearance measurement.

14



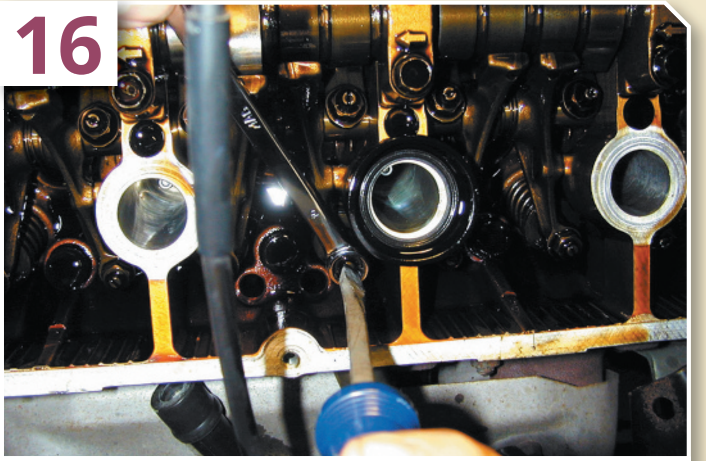
On some engines, it is necessary to watch the direction the rotor is pointing to help determine how far to rotate the engine. Always follow the vehicle manufacturer's recommended procedure.

15



The technician is using a feeler gauge that is one-thousandth of an inch thinner and another one thousandth of an inch thicker than the specified clearance as a double-check that the clearance is correct.

16

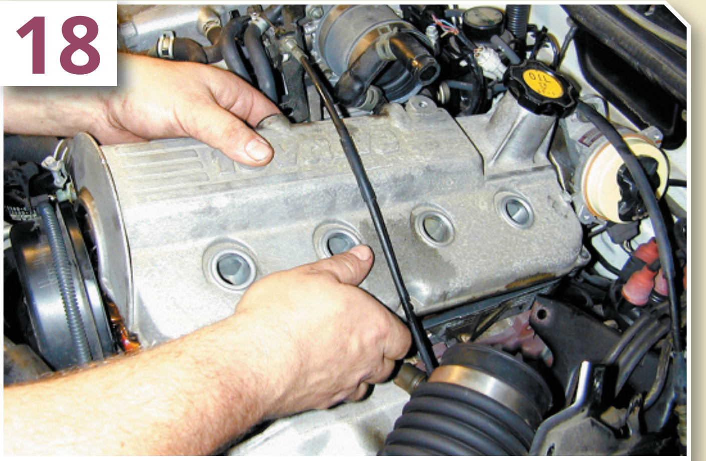


Adjusting a valve takes both hands—one to hold the wrench to loosen and tighten the lock nut and one to turn the adjusting screw. Always double check the clearance after an adjustment is made.

17

After all valves have been properly measured and adjusted as necessary, start the reassembly process by replacing all gaskets and seals as specified by the vehicle manufacturer.

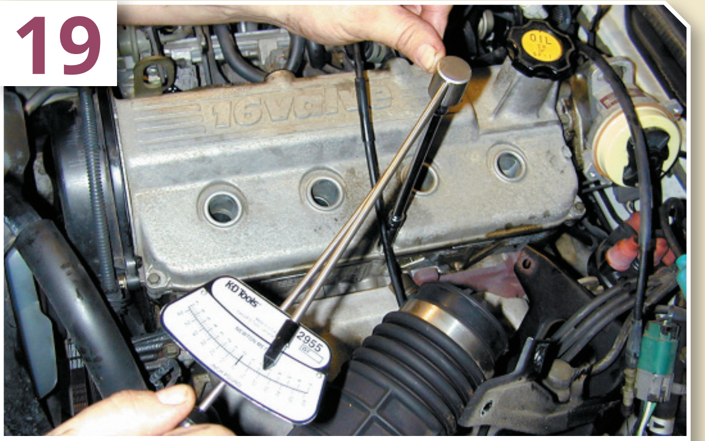
18



Reinstall the valve cover being careful to not pinch a wire or vacuum hose between the cover and the cylinder head.

STEP BY STEP

19

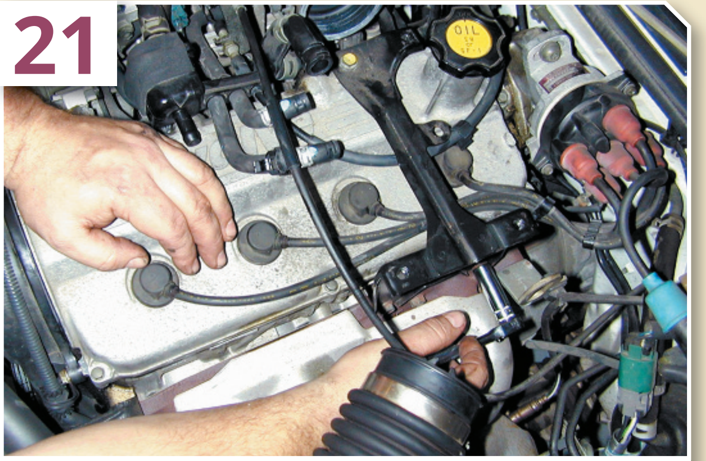


Use a torque wrench and torque the valve cover retaining bolts to factory specifications.

20

Reinstall the distributor cap.

21

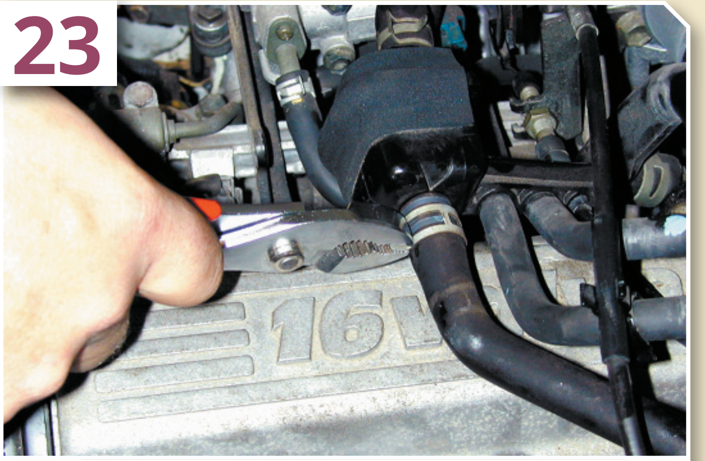


Reinstall the spark plug wires and all brackets that were removed to gain access to the valve cover.

22

Reconnect all vacuum and air hoses and tubes. Replace any vacuum hoses that are brittle or swollen with new ones.

23



Be sure that the clips are properly installed. Start the engine and check for proper operation.

24

Double-check for any oil or vacuum leaks after starting the engine.

REVIEW QUESTIONS

1. How can a thermostat fail?
2. How can a water pump fail requiring replacement?
3. What will happen to the engine if the intake manifold gasket fails?
4. Why must timing belts be replaced?
5. Why is it important that the READY light be out on the dash before working under the hood of a hybrid electric vehicle?

CHAPTER QUIZ

1. A thermostat can fail in what way?
   - **a.** Stuck open
   - **b.** Stuck closed
   - **c.** Stuck partially open
   - **d.** Any of the above
2. A skewed thermostat means it is ____________.
   - **a.** working, but not at the correct temperature
   - **b.** not working
   - **c.** missing the thermo wax in the heat sensor
   - **d.** contaminated with coolant
3. A gasoline direct-injected engine normally produces ____________ when running.
   - **a.** a whirring sound
   - **b.** strong exhaust smells
   - **c.** a clicking noise
   - **d.** vibrations
4. A water pump can fail to provide the proper amount of flow of coolant through the cooling system if what has happened?
   - **a.** The coolant is leaking from the weep hole.
   - **b.** The bearing is noisy.
   - **c.** The impeller blades are worn or slipping on the shaft.
   - **d.** A bearing failure has caused the shaft to become loose.
5. Intake manifold gaskets on a V-type engine can fail due to what factor?
   - **a.** Fretting
   - **b.** Coolant damage
   - **c.** Relative movement between the intake manifold and the cylinder head
   - **d.** All of the above
6. A defective thermostat can cause the powertrain control module to set what diagnostic trouble code (DTC)?
   - **a.** P0171
   - **b.** P0172
   - **c.** P0128
   - **d.** P0300
7. What steps are needed to adjust valves?
   - **a.** Check service information for the exact procedure to follow
   - **b.** Remove the valve (cam) cover
   - **c.** Rotate engine until the rocker arm or lifter is contacting the base circle of the cam
   - **d.** All of the above
8. The torque specifications for many plastic intake manifolds are in what unit?
   - **a.** Pound-inches
   - **b.** Pound-feet
   - **c.** Ft-lb per minute
   - **d.** Lb-ft per second
9. When replacing a timing belt, many experts and vehicle manufacturers recommend that what other part(s) should be replaced?
   - **a.** Tensioner assembly
   - **b.** Water pump
   - **c.** Camshaft oil seal(s)
   - **d.** All of the above
10. Hybrid electric vehicles usually require special engine oil of what viscosity?
    - **a.** SAE 5W-30
    - **b.** SAE 10W-30
    - **c.** SAE 0W-20
    - **d.** SAE 5W-40

Chapter 25

ENGINE REMOVAL AND DISASSEMBLY

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the different engine repair options.
- Explain the engine removal procedure.
- Explain the engine disassembly procedure.
- Explain disassembly of the short block.
- Explain rotating engine assemblies removal.
- Explain cylinder head disassembly.

KEY TERMS:

Freshening 263 • Long block 264 • Rebuilding 264 • Short block 264 • Vibration damper 268

ENGINE REPAIR OPTIONS

TECHNICIAN AND OWNER DECISION The decision to repair an engine should be based on all the information about the engine that is available to the service technician and the vehicle owner.

- In some cases, the engine might not be worth repairing. It is the responsibility of the technician to discuss the advantages and disadvantages of the different repair options with the customer.
- The customer, who is paying for the repair, must make the final decision on the reconditioning procedure to be used. The repair might involve replacing a worn component instead of reconditioning. The decision will be based on the recommendation of the service technician.

REPAIR OPTIONS Most customers want to spend the least amount of money possible, so they have only the faulty component repaired. This is the correct procedure in many cases. Examples of component repairs include the following:

- **Component replacement.** Timing chain replacement is an example of a component repair due to wear that can cause a loss of engine performance. If testing indicates that the timing chain has excessive slack, the front of the engine can be disassembled and the actual slack measured. Usually a slack of 0.5 inch (13 mm) or more indicates that the timing chain and gears need to be replaced. ● **SEE FIGURE 25–1**.
- **Valve job.** Valve leakage is corrected by doing a valve job. This does not necessarily correct the customer's concerns, however. Stopping valve leakage improves manifold vacuum. After completing a valve job, the greater manifold vacuum may draw the oil past worn piston rings and into the combustion chamber during the intake stroke, causing oil consumption to increase.
- **Minor overhaul.** A minor overhaul can usually be done without removing the engine from the chassis. It requires removal of both the head and the oil pan. The overhaul is usually done when the engine lacks power, has poor fuel economy, uses an excessive amount of oil, produces visible tailpipe emissions, runs rough, or is hard to start. It is still only a repair procedure. Parts normally replaced include the piston rings, rod bearings, and gaskets, as well as a valve job. Other engine problems may be noticed after the oil pan is removed and the piston and rod assemblies are taken out. The customer should be informed about any other engine problem in order to authorize the service that the engine requires. In the high-performance industry, this procedure is called **freshening** the engine.

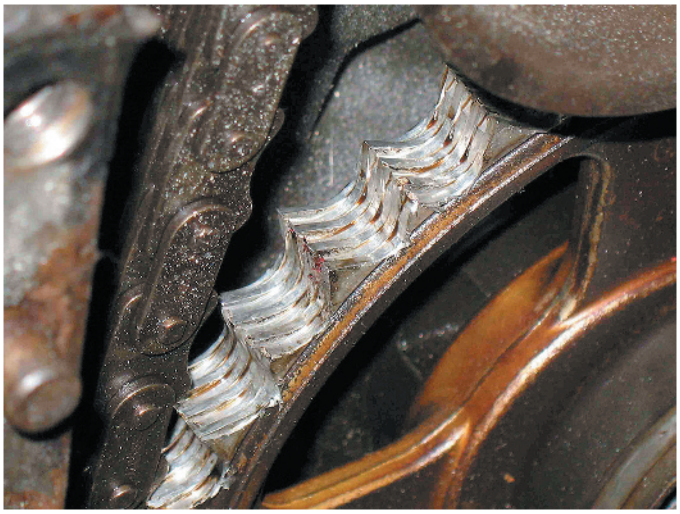


FIGURE 25–1 A worn timing sprocket that resulted in a retarded valve timing and reduced engine performance.

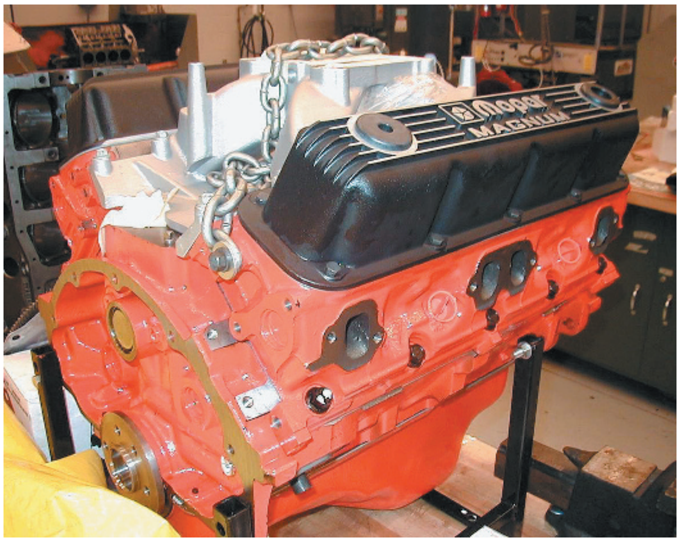


FIGURE 25–2 A crate engine from Chrysler to be used in a restored muscle car. Using a complete new engine costs more than rebuilding an existing engine, but it has a warranty and uses all new parts.

- **Major overhaul.** A complete engine reconditioning job is called **rebuilding**. Sometimes, this type of reconditioning is called a major overhaul. To rebuild the engine, the engine must be removed from the chassis and be completely disassembled. All serviceable parts are reconditioned to either new or service standards. All bearings, gaskets, and seals are replaced. When the reconditioning is done properly, a rebuilt engine should operate like a new engine.
- **Short block.** The quickest way to get a vehicle back in service is to exchange the faulty engine for a different one. In an older vehicle, the engine may be replaced with a used engine from a salvage yard. In some cases, only a reconditioned block, including the crankshaft, rods, and pistons, is used. This replacement assembly is called a **short block**. The original heads, valve train, oil pump, and all external components are reconditioned and used on the short block.
- **Long block.** The replacement assembly is called a **long block** when the reconditioned assembly includes the heads and valve train. Many automotive machine shops maintain a stock of short and long blocks of popular engines. Usually, the original engine, called the *core*, is exchanged for the reconditioned assembly. The core parts are reconditioned by the automotive machine shop and put back in stock for the next customer.
- **Crate engines.** Crate engines are new engines built by the engine manufacturer and sold through vehicle dealers. ● **SEE FIGURE 25–2**.
- **Remanufactured engines.** Some engines are remanufactured and can be replaced in a day or two, greatly reducing the amount of time the customer is without a vehicle. The engine cores are completely disassembled, and each serviceable part is reconditioned with specialized machinery. Engines are then assembled on an engine assembly line, similar to the original manufacturer's assembly line. The parts that are assembled together as an engine have not come out of the same engine. The remanufactured engine usually has new pistons, valves, and lifters, together with other parts that are normally replaced in a rebuilt engine. All clearances and fits in the remanufactured engine are the same as in a new engine. A remanufactured engine should give service as good as that of a new engine, and it will cost about half as much. Remanufactured engines usually carry a warranty. This means they will be replaced if they fail during the period of the warranty. They may even cost less than a rebuilt engine because much of the reconditioning is done by specialized machines rather than by expensive skilled labor.

ENGINE REMOVAL

CHECK SERVICE INFORMATION Whenever any engine-related work is being performed, always print out the specified procedure as published in service information to avoid doing any harm to the vehicle or the engine.

USUAL ENGINE REMOVAL PROCEDURES The procedures that are usually specified include

- **Remove the hood.** Removing the hood allows easier access to all of the components around the engine. Store the hood in a place where it will not be damaged. Some technicians place a fender cover on the roof of the vehicle and then place the hood upside down on top of the fender cover.
- **Clean the engine area.** The engine exterior and the engine compartment should be cleaned before work is begun. Using a power washer is the most commonly used way to clean the engine compartment area. A clean engine is easier to work on, and the cleaning not only helps to keep dirt out of the engine, but also minimizes accidental damage from slipping tools.
- **Disconnect the negative (−) battery cable.** Remove the battery from the vehicle if it could interfere with the removal of the engine.
- **Remove the air cleaner assembly.** Remove the hoses and other components of the air intake system. Mark or bag and tag all fasteners.

- **Remove all accessories.** Those that usually need to be removed include the alternator, engine driven fan, and AIR pump, if equipped.
- **Drain the coolant.** Draining coolant from the radiator and the engine block helps reduce the chance of coolant getting into the cylinders when the cylinder head is removed. Dispose of the used coolant properly.
- **Remove the radiator.** Disconnect the transmission oil cooler lines and radiator hoses from the radiator. Removing the radiator helps provide room for moving the engine during removal and helps prevent the possibility of damage.
- **Disconnect the exhaust system.** On some engines, it may be easier to remove the exhaust manifold(s) from the cylinder head(s), whereas on others, it may be easier to disconnect the exhaust pipe from the manifold(s).
- **Recover the air-conditioning refrigerant.** Set the air-conditioning compressor aside and do not open the system unless absolutely necessary. If the air-conditioning system has to be opened to remove components, the refrigerant must be recovered. Tape or cover all open refrigerant fittings and hoses to prevent contaminants from entering the A/C system. Check service information for the exact procedures to follow.
- **Remove the power steering pump.** Remove the fasteners to the power steering pump and set aside the pump and hoses.
- **Drain the engine oil.** Draining the engine oil and removing the oil filter also helps prevent fluid loss during the removal process.
- **Disconnect fuel lines.** Disconnect and plug all fuel supply and return lines.
- **Disconnect wiring and vacuum hoses.** Mark and remove all vacuum hoses and electrical wiring attached to the engine.

PROCEDURE FOR ENGINE REMOVAL There are two ways to remove the engine.

1. The engine can be lifted out of the chassis with the transmission/transaxle attached.
2. The transmission/transaxle can be separated from the engine and left in the chassis.

The method to be used must be determined before the engine is removed from the vehicle.

TECH TIP

A Picture Is Worth a Thousand Words

Take pictures with a cell phone camera, digital camera, or a video camcorder of the engine being serviced. These pictures will be worth their weight in gold when it comes time to reassemble or reinstall the engine. It is very difficult for anyone to remember the *exact* location of every bracket, wire, and hose. Referring back to the photos of the engine before work was started will help you restore the vehicle to like-new condition.

- **Rear-wheel-drive vehicle.** The removal procedure for most rear-wheel-drive vehicles includes the following steps:

STEP 1 Under the vehicle, remove the driveshaft (propeller shaft) and disconnect the exhaust pipes. Also remove the engine (motor) mounts. In some installations, it may be necessary to loosen the steering linkage idler arm to give clearance. The transmission controls and wiring need to be disconnected at the connectors, and clutch linkages disconnected and labeled.

STEP 2 Attach a sling, either a chain or lift cable, to one of the following:

- Factory-installed lifting hooks
- Intake manifold
- Cylinder head bolts, on top of the engine

An engine lift hoist chain or cable is attached and snugged to take most of the weight. This leaves the engine resting on the mounts.

NOTE: For the best results, use the factory-installed lifting hooks that are attached to the engine. These hooks are used in the assembly plant to install the engine and are usually in the best location to remove the engine.

STEP 3 Remove the rear cross-member and lower the transmission. Cover the extension housing with a plug or a plastic bag to help prevent the automatic transmission fluid from leaking during the removal process. If the engine alone is being removed, the transmission retaining bolts and torque converter fasteners will need to be removed. Check service information for exact procedures to follow when removing an automatic transmission.

STEP 4 The front of the engine must come almost straight up as the transmission slides from under the floor pan. The engine and transmission are hoisted free of the automobile, swung clear, and lowered on an open floor area. ● **SEE FIGURE 25–3**.

- **Front-wheel-drive vehicle.** Check service information for the exact procedure to follow to remove the engine from a front-wheel-drive vehicle. Depending on the vehicle, the engine could be removed from the top or lowered and removed from underneath on many front-wheel-drive vehicles. Typical steps include

STEP 1 Disconnect units that might interfere with engine removal, including the steering unit, engine electrical harness, and radiator.

TECH TIP

Tag and Bag

All components and fasteners should be marked for future reference. Large components should be marked or a tag installed that identifies the part. Smaller parts and fasteners should be placed in plastic bags and labeled as to what they are used for, such as the water pump bolts.

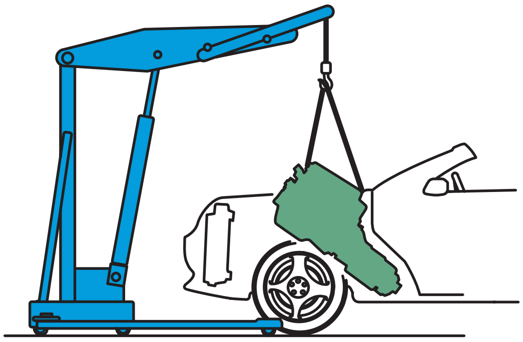


FIGURE 25–3 An engine must be tipped as it is pulled from the chassis.

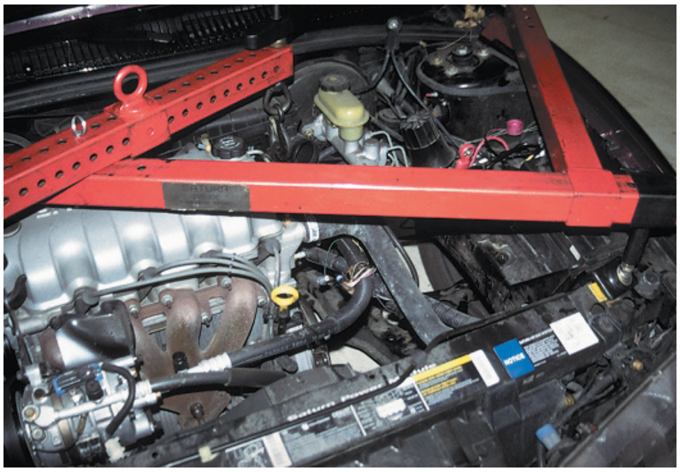


FIGURE 25–4 When removing just the engine from a front-wheel-drive vehicle, the transaxle must be supported. Shown here is a typical fixture that can be used to hold the engine, if the transaxle is removed, or to hold the transaxle, if the engine is removed.

STEP 2 If removing the engine from underneath, the upper strut and lower engine cradle fasteners will have to be removed.

STEP 3 Disconnect the torque converter and bell housing bolts and clutch linkage, if required.

STEP 4 Often special holding fixtures are required to help hold the transaxle in place while removing the engine. ● **SEE FIGURES 25–4 AND 25–5**.

ENGINE DISASSEMBLY

MOUNTING THE ENGINE ON A STAND Engines should be installed to a sturdy engine stand. For safety, always check the following:

- Always use at least four grade-8 bolts when mounting an engine to an engine stand. Using low-quality nongraded bolts, or fewer than four bolts, can cause the engine to fall. Also, check to ensure that the proper threads of bolts are being used. Some engines use fractional threads, whereas others use metric threads.
- Install the bolts so that at least 1/2 inch (13 mm) of thread is engaged in the back of the engine to ensure that the fasteners are securely attached to the engine block.

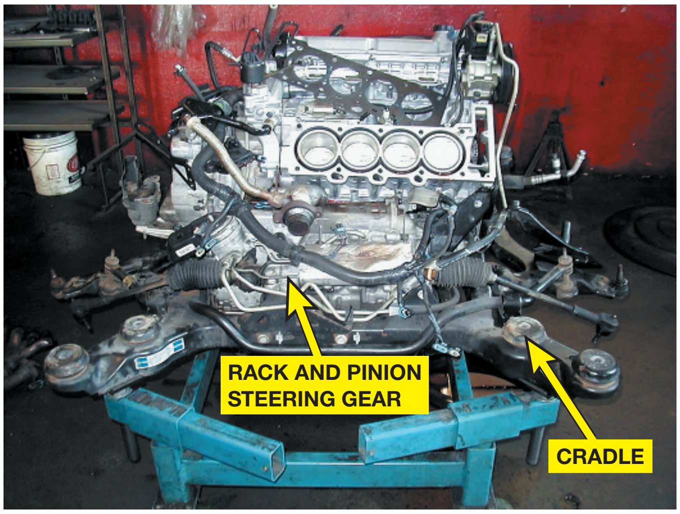


FIGURE 25–5 The entire cradle, which included the engine, transaxle, and steering gear, was removed and placed onto a stand. The rear cylinder head has been removed to check for the root cause of a coolant leak.

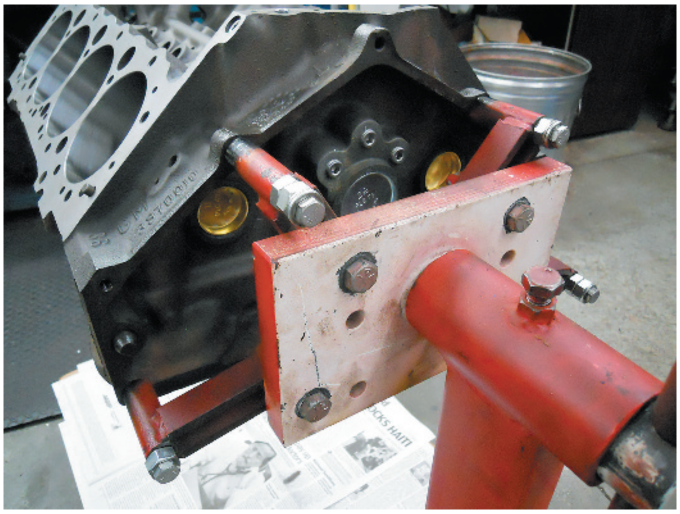


FIGURE 25–6 Always use graded bolts—either grade 5 or 8 bolts—whenever mounting an engine to a stand.

- Check that the engine is properly balanced on the engine stand before work is started on the engine. ● **SEE FIGURE 25–6**.

DISASSEMBLING A CAM-IN-BLOCK (OHV) ENGINE Check service information for the specified engine disassembly procedure. Read, understand, and follow all safety instructions. Following are the usual steps involved:

STEP 1 Engines should be cold before disassembly to minimize the chance of warpage of the components that are being removed.

STEP 2 Removal of the rocker arm covers gives the first opportunity to see inside a part of the engine. Examine the rocker arms, valve springs, and valve tips for obvious defects. Remove the rocker arms and pushrods and, if they are to be reused, place them in a location so that the rockers and the pushrods can be installed back to their original location. ● **SEE FIGURE 25–7**.

STEP 3 Remove the intake manifold bolts and lift off the manifold. Use care to avoid damaging the parting surface as the

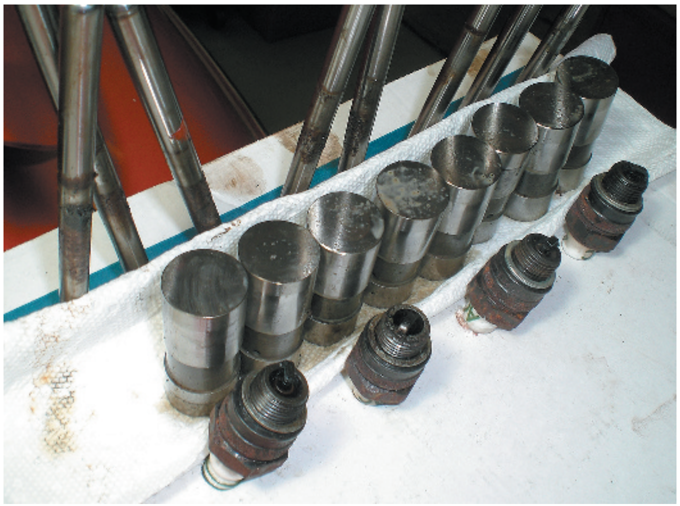


FIGURE 25–7 Keeping the pushrods and the lifters sorted by cylinder, including the spark plugs, is a wise way to proceed when disassembling the cylinder heads.

gasket is loosened. When the intake manifold and lifter valley cover (if equipped) are off of V-type engines, the technician has another opportunity to examine the interior of the engine. On some V-type engines, it is possible to see the condition of the cam at the bottom of the lifter valley.

STEP 4 The lifters can be removed at this time if they are causing the problem, or if the engine valve train is to be serviced.

STEP 5 Remove the cylinder head bolts (also called cap screws) following the reverse of the installation procedure. Loosening the fasteners at the ends of the cylinder head first, then working toward the center, helps reduce the chance of warpage to the cylinder head. Be sure to notice and mark the head bolt locations, as they are often different lengths, depending on their location in the head. Carefully lift the head from the block deck. If the head gasket is stuck, carefully pry the head to loosen the gasket. Use care not to scratch the block or head machined surfaces. The combustion chamber in the head and the top of the piston should be given a thorough visual examination. ● **SEE FIGURE 25–8**.

- Check the cylinder head and head gasket for signs of leakage.
- A normal combustion chamber is coated with a layer of hard, light-colored deposits.
- If the combustion chamber has been running too hot, the deposits will be very thin and white.

TECH TIP

Disassembly Is the Reverse Order of Assembly

Cylinder heads often warp upward in the center. Loosening the center head bolts first will tend to increase the warpage, especially if the head is being removed to replace a head gasket because of overheating. Always follow the torque table backward, starting with the highest-number bolt and working toward the lowest number. In other words, always loosen fasteners starting at the end or outside of the component and work toward the inside or center of the component.

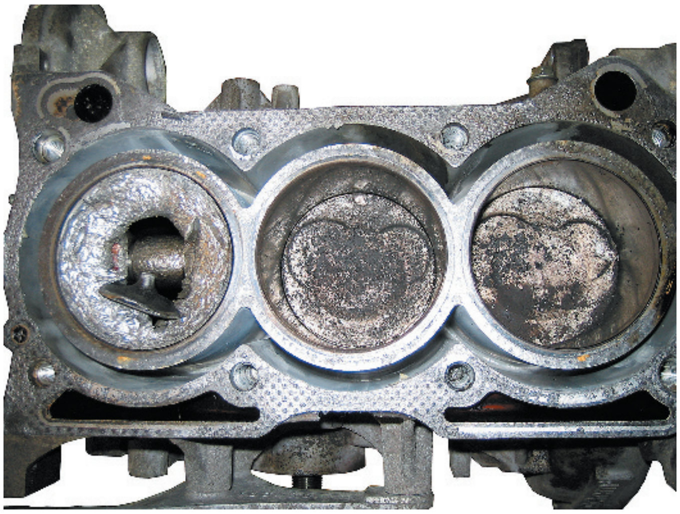


FIGURE 25–8 Sometimes, after the cylinder head has been removed, the engine condition is discovered to be so major that the entire engine may need to be replaced, rather than overhauled.

OVERHEAD CAMSHAFT (OHC) ENGINE DISASSEMBLY

Disassembling an overhead camshaft engine differs from a cam-in-block (OHV) engine. Check service information for the specified disassembly procedure for the engine being serviced. Read, understand, and follow all safety notices and warnings included in the instructions to help avoid causing damage to parts or components during the disassembly process. The usual steps include

STEP 1 Remove the intake and exhaust manifolds, if they have not already been removed, and bag and tag all fasteners.

STEP 2 Remove the crankshaft harmonic balancer pulley that will allow access to the timing chain or belt cover.

STEP 3 Remove the timing belt/chain cover(s) and then the timing belt(s) or chain(s).

STEP 4 With most overhead camshaft engines, the camshaft(s) must be removed before removing the cylinder head due to location of the head bolts.

STEP 5 Remove the cylinder head by removing the cylinder head bolts in the opposite order of assembly. This means to loosen the outermost fasteners first, then work toward the center of the cylinder head.

STEP 6 Carefully lift the cylinder head from the block.

DISASSEMBLY OF THE SHORT BLOCK

REMOVING THE OIL PAN To remove the oil pan, turn the engine upside down.

NOTE: Some engine builders prefer to remove the oil pan before turning it upside down so the technician can see the oil pan deposits first.

Deposits are a good indication of the condition and care taken of the engine. Heavy sludge indicates infrequent oil changes; hard carbon indicates overheating. The oil pump pickup screen should be checked to see how much plugging exists.

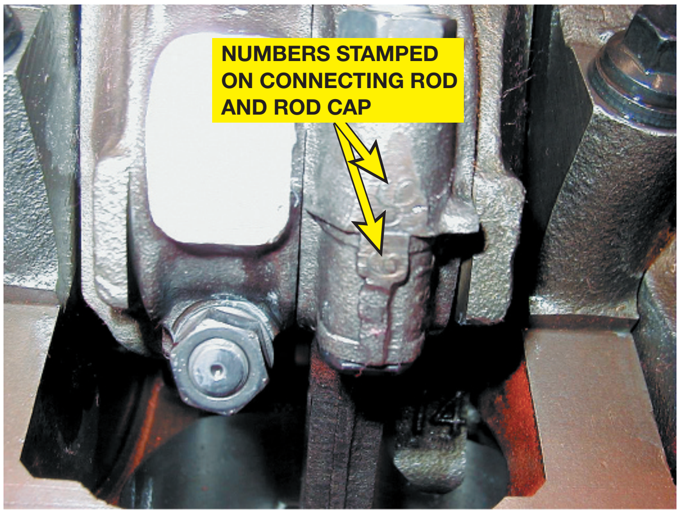


FIGURE 25–9 These connecting rods were numbered from the factory. If they are not, then they should be marked.

MARKING CONNECTING RODS AND CAPS The connecting rod caps should be marked (numbered) so that they can be reassembled in exactly the same position. If the connecting rods are not marked from the factory, they should be marked using a number stamp, electric pencil, or permanent marker. ● **SEE FIGURE 25–9**.

CAUTION: Some vehicle manufacturers warn not to use a punch or an electric pencil on powdered metal connection rods. Use only a permanent marker to label powdered metal rods. If in doubt as to the type of rod that is in the engine, use a marker to be safe.

REMOVING THE CYLINDER RIDGE Before the pistons can be removed from the block, the ridge must be removed. Piston wear against the cylinder wall leaves an upper ridge, because the top ring does not travel all the way to the top of the cylinder. Ridge removal is necessary to avoid catching a ring on the ridge and breaking the piston. ● **SEE FIGURE 25–10**.

The ridge is removed with a cutting tool that has a guide to help prevent accidental cutting below the ridge. ● **SEE FIGURE 25–11**.

PISTON REMOVAL Removing the piston and rod assembly includes the following steps:

STEP 1 Rotate the engine until the piston that is to be removed is at bottom dead center (BDC).

TECH TIP

Measure the Cylinder Bore before Further Disassembly

As soon as the cylinder head has been removed from the engine, take a measurement of the cylinder bore. This is done for the following reasons:

- To verify that the engine size is the same as specified by the vehicle identification number (VIN)
- To measure the bore and compare it to factory specifications, to help the technician determine if the cylinder(s) is too worn to use or cannot be restored

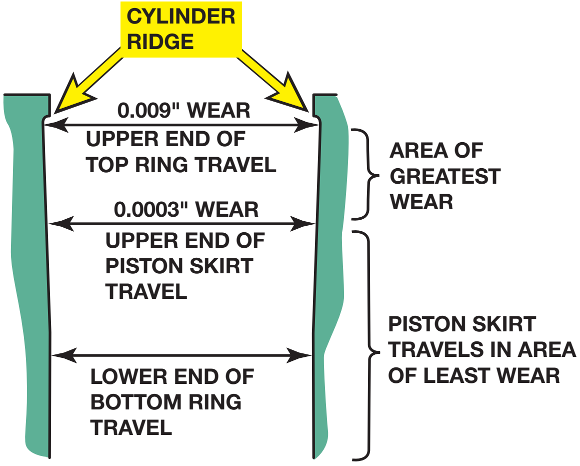

CYLINDER RIDGE
0.009" WEAR
UPPER END OF TOP RING TRAVEL
0.0003" WEAR
UPPER END OF PISTON SKIRT TRAVEL
LOWER END OF BOTTOM RING TRAVEL
AREA OF GREATEST WEAR
PISTON SKIRT TRAVELS IN AREA OF LEAST WEAR

FIGURE 25–10 Most of the cylinder wear is on the top inch just below the cylinder ridge. This wear is due to the heat and combustion pressures that occur when the piston is near the top of the cylinder.

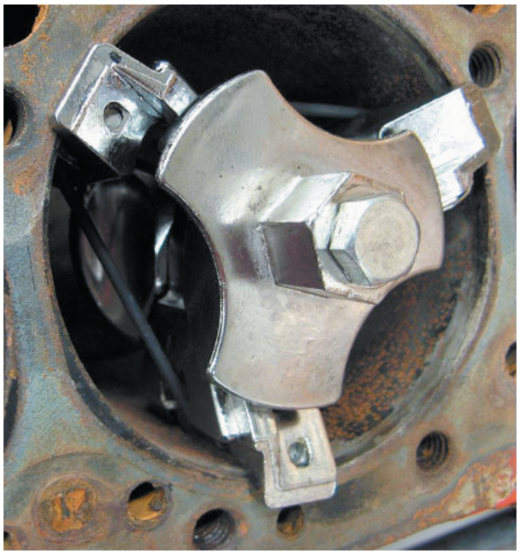


FIGURE 25–11 This ridge is being removed with one type of ridge reamer before the piston assemblies are removed from the engine.

STEP 2 Remove connecting rod nuts from the rod so that the rod cap with its bearing half can be removed.

STEP 3 Fit the rod bolts with protectors to keep the bolt threads from damaging the crankshaft journals, and then carefully remove the piston and rod assemblies.

STEP 4 After removal of each piston, replace the rod cap and nuts to avoid losing or mismatching them.

ROTATING ENGINE ASSEMBLIES REMOVAL

HARMONIC BALANCER REMOVAL The next step after the water pump has been removed is to remove the crankshaft **vibration damper** (also called a *harmonic balancer*). The bolt and washer that hold the damper are removed. The damper should be removed only with a threaded puller. ● **SEE FIGURE 25–12**.

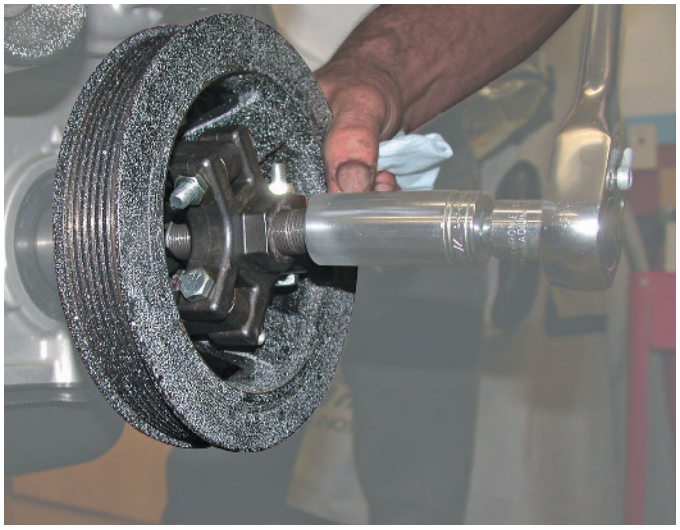


FIGURE 25–12 Puller being used to pull the vibration damper from the crankshaft.

If a hook-type puller is used around the edge of the damper, it may pull the damper ring from the hub. If this happens, the damper assembly will have to be replaced with a new assembly. With the damper assembly off, the timing cover can be removed, exposing the timing gear or timing chain. Examine these parts for excessive wear and looseness. ● **SEE FIGURE 25–13**.

Bolted cam sprockets can be removed to free the timing chain. On some engines, this will require removal of the crankshaft gear at the same time. Pressed-on gears and sprockets are removed from the shaft *only* if they are faulty. They are removed after the camshaft is removed from the block. The camshaft thrust plate retaining screws are also removed, when they are used.

CAMSHAFT REMOVAL The camshaft and balance shafts, if equipped, can be removed at this time, or they can be removed after the crankshaft is out. For best results, insert a long bolt into one of the camshaft threaded holes to serve as handles for removing (or installing) a camshaft. It must be carefully eased from the engine to avoid damaging the cam bearings or cam lobes. This is done most easily with the front of the engine pointing up. Bearing surfaces are soft and scratch easily, and the cam lobes are hard and can chip easily.

CRANKSHAFT AND MAIN BEARING REMOVAL The main bearing caps should be checked for position markings before they are removed. If they are not marked, use steel number stamps to mark them, and also be sure to indicate which side of each main cap faces to the front of the engine. ● **SEE FIGURE 25–14**.

They have been machined in place and will not fit perfectly in any other location. After marking, they can be removed to free the crankshaft. When the crankshaft is removed, the main bearing caps and bearings are reinstalled on the block to reduce the chance of damage to the caps.

BLOCK INSPECTION After the pistons and crankshaft have been removed, remove all cups and plugs and carefully inspect the block for faults that could affect whether the engine can be rebuilt. ● **SEE FIGURE 25–15**.

Further detailed inspection should be completed after the components have been cleaned.

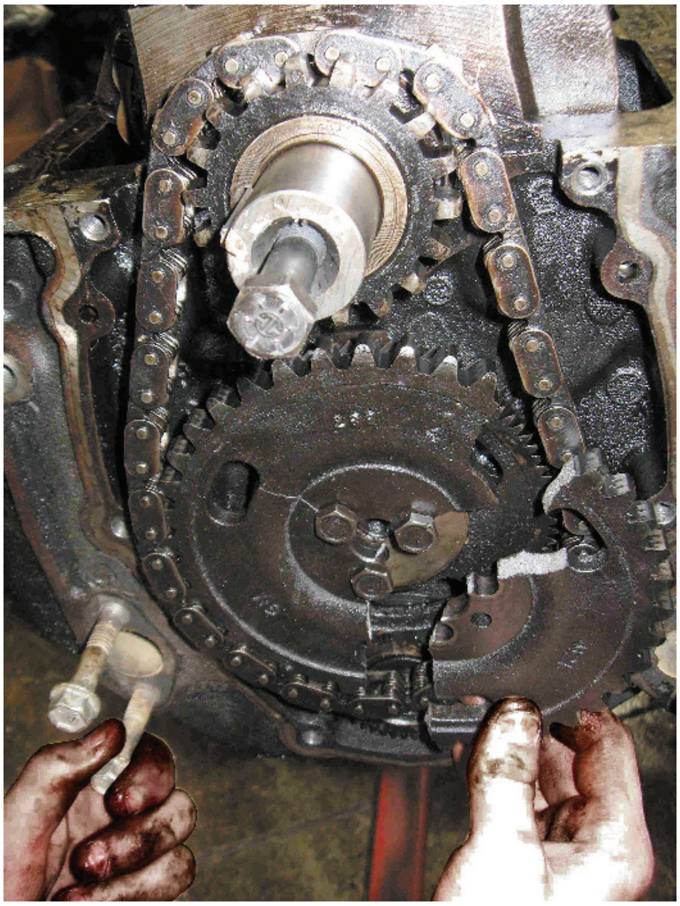


FIGURE 25–13 When the timing chain cover was removed, the broken timing gear explained why this GM 4.3 liter V-6 engine stopped running.

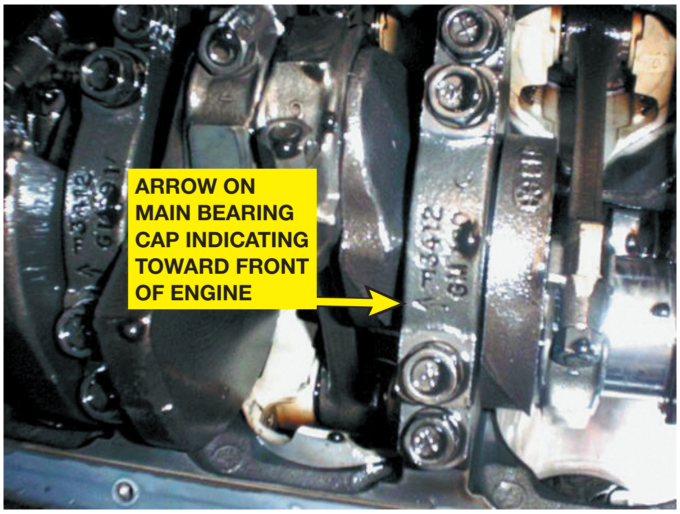


FIGURE 25–14 Most engines, such as this Chevrolet V-8 with four-bolt main bearing caps, have arrows marked on the bearing caps that should point to the front of the engine.

CYLINDER HEAD DISASSEMBLY

OHV ENGINE CYLINDER HEADS After the heads are removed and placed on the bench, the valves can be removed.

CAUTION: Always wear safety glasses when working on a cylinder head. Valve springs can release quickly, causing valve parts to fly.

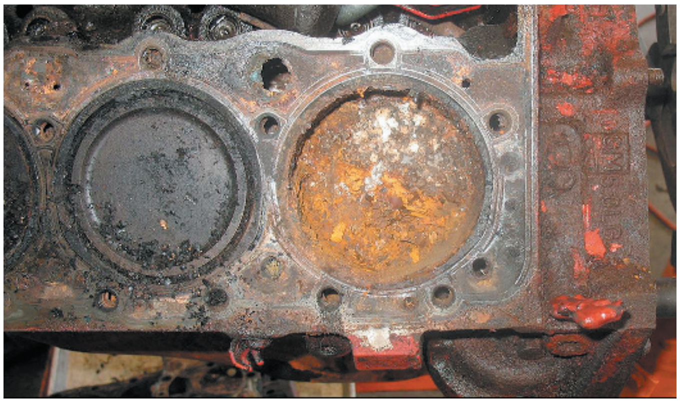


FIGURE 25–15 This small block Chevrolet V-8 had water standing in the cylinders, causing a lot of rust, which was discovered as soon as the head was removed.

TECH TIP

The Wax Trick

Before the engine block can be thoroughly cleaned, all oil gallery plugs must be removed. A popular trick of the trade for plug removal involves heating the plug (not the surrounding metal) with an oxyacetylene torch. The heat tends to expand the plug and make it tighter in the block. Do not overheat.

As the plug is cooling, touch the plug with paraffin wax (beeswax or candle wax may be used). ● **SEE FIGURE 25–16**.

The wax will be drawn down around the threads of the plug by capillary attraction as the plug cools and contracts. After being allowed to cool, the plug is easily removed.

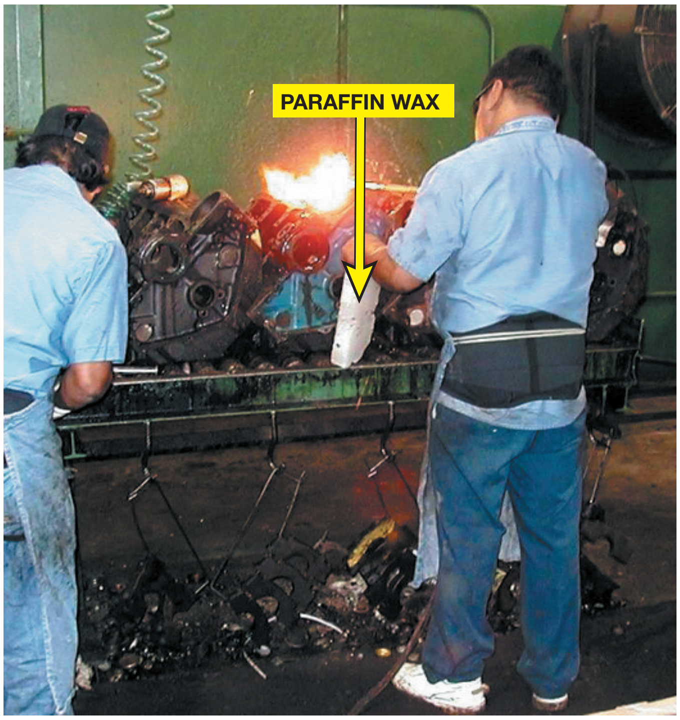


FIGURE 25–16 A torch is used to heat gallery plugs. Paraffin wax is then applied and allowed to flow around the threads. This procedure results in easier removal of the plugs and other threaded fasteners that cannot otherwise be loosened.

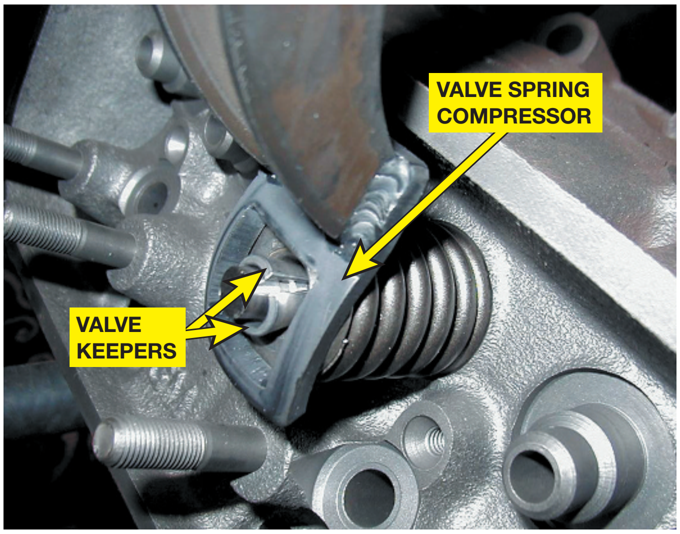


FIGURE 25–17 A valve spring compressor is used to compress the valve spring before removing the keepers (locks).

To disassemble a cylinder head, perform the following steps:

STEP 1 Tap the valve spring retainer with a brass hammer, hitting the retainer on an angle to "break the taper" of the valve keepers (locks).

STEP 2 Using a valve spring compressor, compress the valve spring far enough to expose the keepers. ● **SEE FIGURE 25–17**.

STEP 3 Remove the two keepers using a magnet.

STEP 4 After the valve keepers have been removed, slowly release the compressor to remove and to free the valve retainer and spring.

STEP 5 The valve tip edge and keeper (lock) area should be lightly filed or stoned to remove any burrs *before* sliding the valve from the head. Burrs will scratch the valve guide.

STEP 6 Remove all valve stem seals and the metal spring seats that are used on aluminum heads.

STEP 7 When all valves are removed following the same procedure, carefully inspect the valve springs, retainers, keepers (locks), guides, and seats.

OHC ENGINE CYLINDER HEADS After the heads are removed and placed on the bench, the valves can be removed after the camshaft is removed. Often a special valve spring compressor is required to reach the valve retainers. Always read, understand, and follow all vehicle manufacturer's instructions.

TECH TIP

Mark It to Be Safe

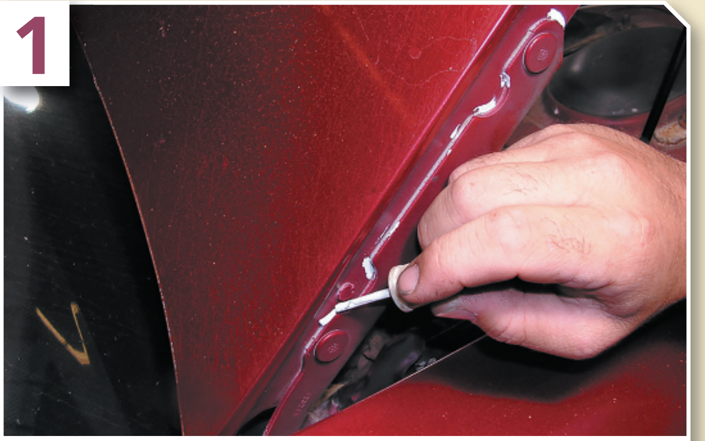
Whenever you disassemble anything, it is always wise to mark the location of parts, bolts, hoses, and other items that could be incorrectly assembled. Remember, the first part removed will be the last part that is assembled. If you think you will remember where everything goes—forget it! It just does not happen in the real world.

One popular trick is to use correction fluid to mark the location of parts before they are removed. Most of these products are alcohol or water-based, dry quickly, and usually contain a brush in the cap for easy use.

ENGINE REMOVAL

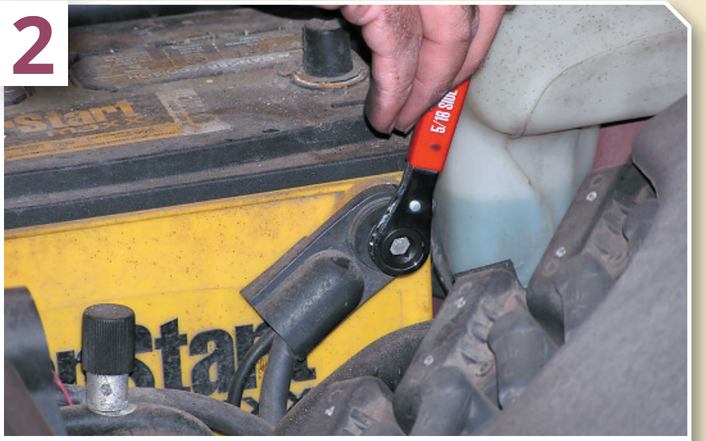
STEP BY STEP

1



Before beginning work on removing the engine, mark and remove the hood and place it in a safe location.

2

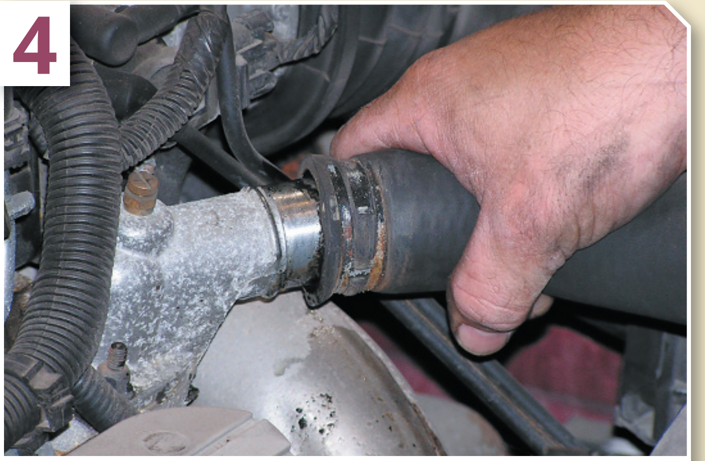


For safety, remove the negative battery cable to avoid any possible electrical problems from occurring.

3

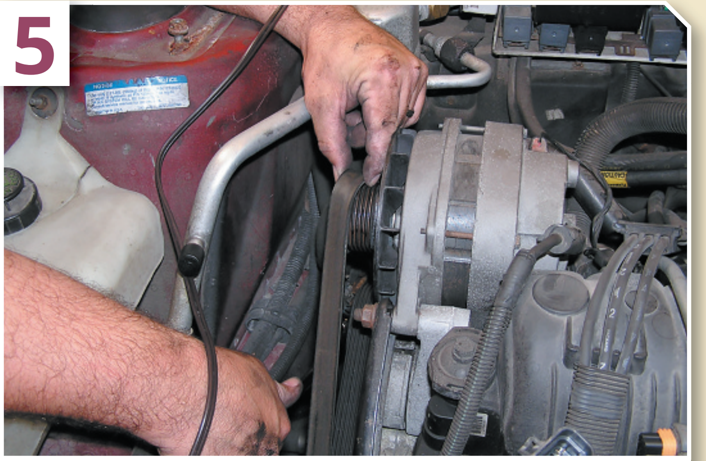
Drain the coolant and dispose of properly.

4



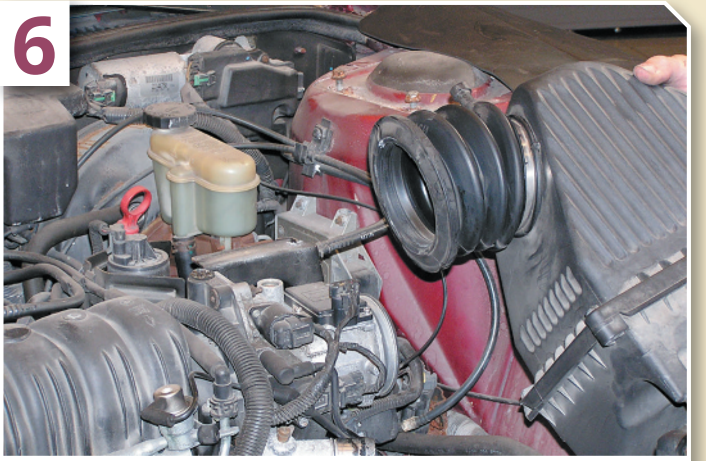
Disconnect all cooling system and heater hoses and remove the radiator.

5



Remove the accessory drive belt(s) and set the alternator, power steering pump, and air-conditioning compressor aside.

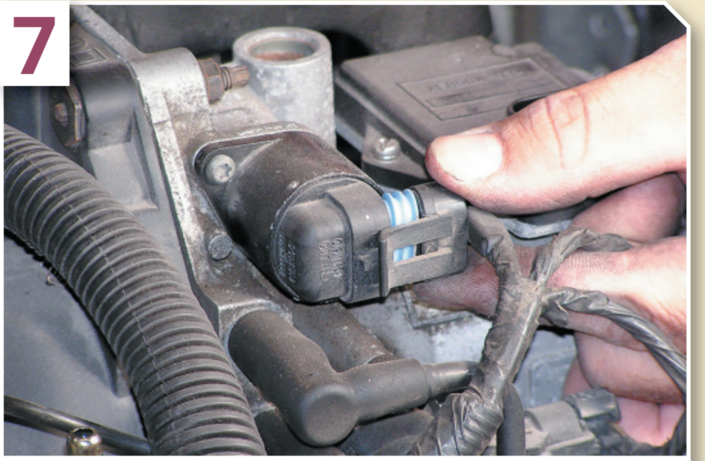
6



Remove the air intake system, including the air filter housing, as needed.

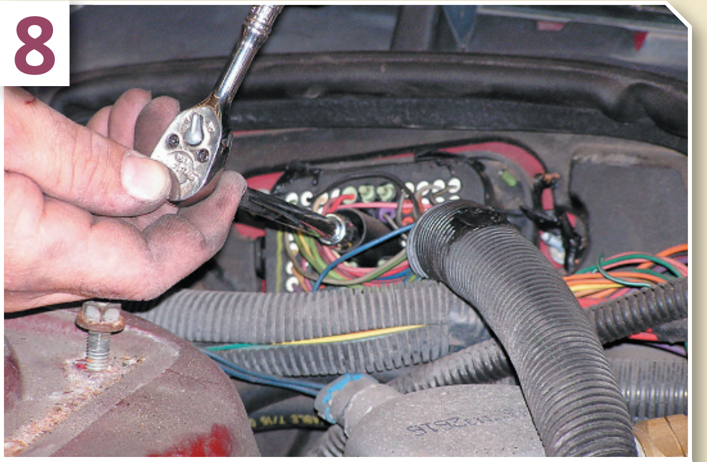
ENGINE REMOVAL

7



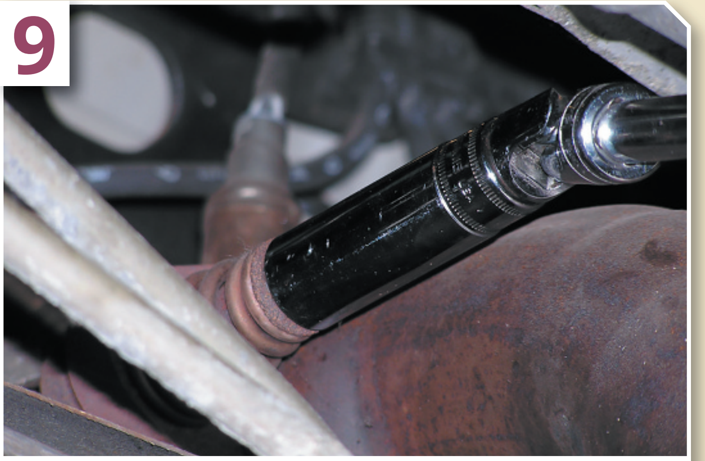
Remove the electrical connector from all sensors and label.

8



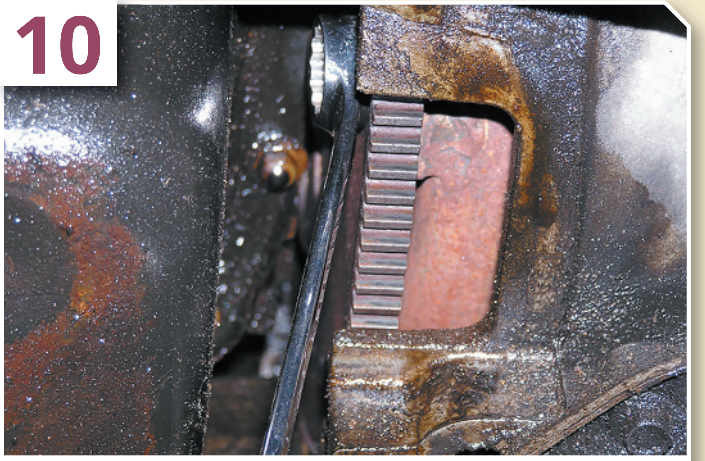
Disconnect the engine wiring harness connector at the bulkhead.

9



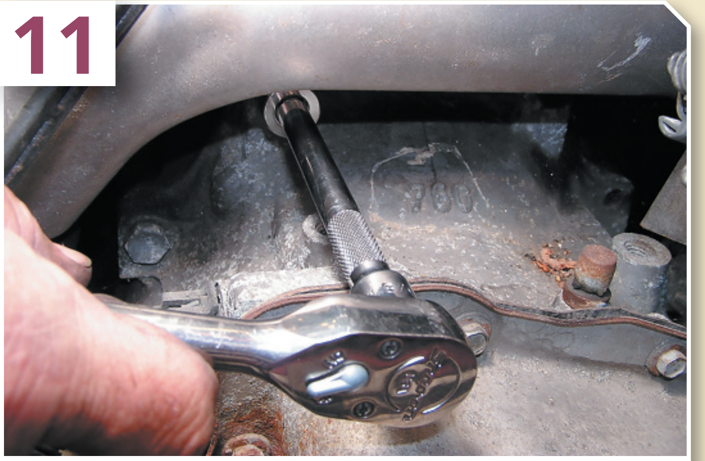
Safely hoist the vehicle and disconnect the exhaust system from the exhaust manifolds.

10



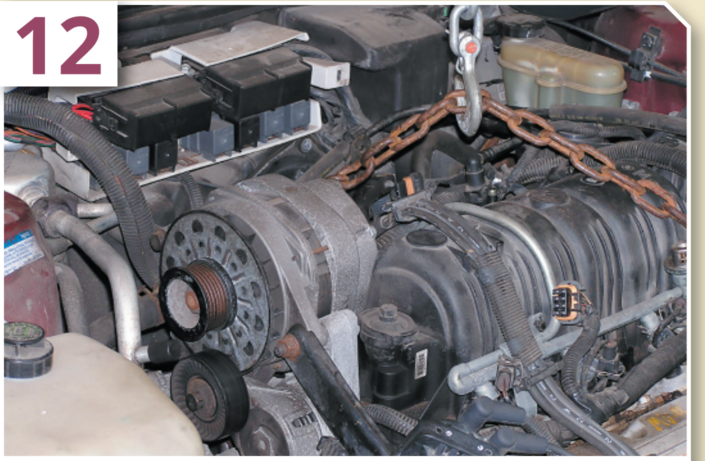
Mark and then remove the fasteners connecting the flex plate to the torque converter.

11



Lower the vehicle and remove the engine mount bolts and transaxle bell housing fasteners.

12



Secure the lifting chain to the engine hooks and carefully remove the engine from the vehicle.

REVIEW QUESTIONS

1. What are the differences between a minor and a major overhaul?
2. When should the factory-installed lifting hooks be used?
3. Why should the cylinder bore be measured before continuing with an engine disassembly?
4. Why should the ridge that sometimes forms at the top of the cylinder be removed?
5. Why should the burrs often seen at the top of the valve stem be removed before removing the valves from the head?

CHAPTER QUIZ

1. A short block includes the _____________.
   - **a.** block
   - **b.** crankshaft and main bearings
   - **c.** pistons, rods, and rod bearings
   - **d.** All of the above
2. Technician A says that a minor overhaul can often be done with the engine remaining in the vehicle. Technician B says that a core is required for most remanufactured engines. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. When removing the engine only from a vehicle equipped with an automatic transmission, the torque converter normally _____________.
   - **a.** stays mounted on the transmission
   - **b.** is removed and stays attached to the engine
   - **c.** must be drained
   - **d.** remains connected to the flexplate
4. When removing cylinder heads, the fasteners should be removed in which order?
   - **a.** The reverse order of tightening
   - **b.** The same order as the specified tightening sequence
   - **c.** Any order
   - **d.** Loosened slightly in the same order as the tightening sequence and then removed in any order
5. With the rocker cover (valve cover) removed, the technician can inspect all items *except* _____________.
   - **a.** combustion chamber deposits
   - **b.** rocker arms and valve spring
   - **c.** camshaft (overhead camshaft engine only)
   - **d.** valve stems and pushrods (overhead valve engines only)
6. What needs to be removed before the valves can be removed from the cylinder head?
   - **a.** The valve keepers
   - **b.** The camshaft if OHV engine
   - **c.** The cylinder head from the block
   - **d.** Both a and c
7. After the oil pan is removed, the technician should inspect _____________.
   - **a.** the oil pump and pickup screen
   - **b.** to make certain that all rod and main bearings are numbered or marked
   - **c.** the valve lifters (tappets) for wear
   - **d.** Both a and b
8. The ridge at the top of the cylinder _____________.
   - **a.** is caused by the rings that do not travel all the way to top of the cylinder
   - **b.** represents a failure of the top piston ring to correctly seal against the cylinder wall
   - **c.** should not be removed before removing pistons except when reboring the cylinders
   - **d.** means that a crankshaft with an incorrect stroke was installed in the engine
9. Before the timing chain can be inspected and removed, the _____________ must be removed.
   - **a.** valve cover
   - **b.** vibration damper
   - **c.** cylinder head(s)
   - **d.** intake manifold (V-type engines only)
10. Before the valves are removed from the cylinder head, what operations need to be completed?
    - **a.** Remove valve keepers (locks)
    - **b.** Remove cylinder head(s) from the engine
    - **c.** Remove burrs from the stem of the valve(s)
    - **d.** All of the above

Chapter

26

ENGINE CLEANING AND CRACK DETECTION

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the mechanical cleaning procedure of engines.
- Discuss chemical cleaners.
- Describe spray and steam washing.
- Describe thermal cleaning.
- Describe tank and vapor cleaning.
- Describe ultrasonic and vibratory cleaning.
- Explain crack detection.
- Explain crack repair.

KEY TERMS:

Acid materials 276 • Agitation 277 • Aqueous-based solutions 276 • Caustic materials 276 • Dye-penetrant testing 279 • Fusible link 277 • Hydroseal 277 • pH 276 • Putty knife 274 • Pyrolytic 277 • Ultrasonic cleaning 278 • Zyglo 279

MECHANICAL CLEANING

After an engine has been disassembled and before it can be overhauled or repaired, the engine and engine parts should go through two important operations.

1. All parts, including fasteners, must be thoroughly cleaned.
2. All components and parts must be inspected to ensure that they are serviceable and free from faults such as cracks.

PRINCIPLES Heavy deposits should be removed by mechanical cleaning before using other cleaning methods. Mechanical cleaning involves the following methods:

- Scraping
- Abrasive brushing
- Abrasive blasting

SCRAPING The scraper most frequently used is a **putty knife**, or a plastic card. The broad blade of the putty knife helps avoid scratching the surface as it is used to clean the parts. A plastic card such as an old gift, credit, or other similar card can be used to clean aluminum parts such as cylinder head gasket surfaces without causing any damage.

TECH TIP

The Ice Scraper Trick

Using a steel scraper can damage aluminum heads or block deck surfaces. To prevent damage, try using a file to sharpen a plastic ice scraper and then use this to scrape gaskets from aluminum engine parts. This method works very well.

ABRASIVE PADS OR DISCS An abrasive pad or disc can be used on *disassembled* parts only. After an abrasive pad or disc has been used, the part *must* be thoroughly cleaned to remove the particles from the plastic bristles or pad. The abrasive aluminum oxide particles from the bristles can get into the engine and cause major damage.

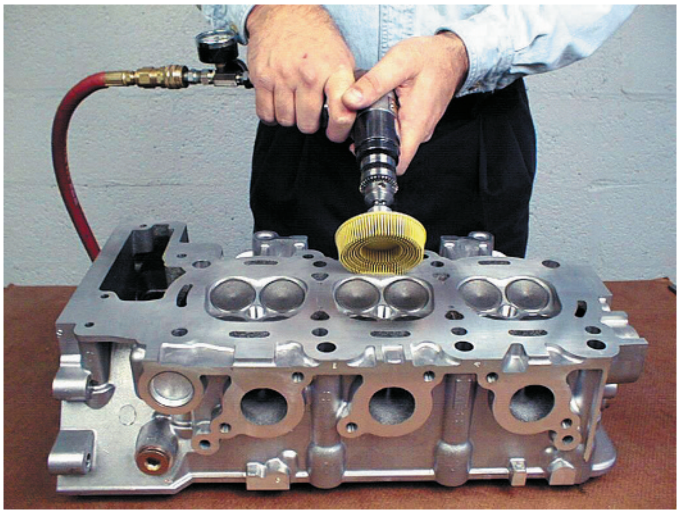


FIGURE 26–1 An air-powered grinder attached to a bristle pad being used to clean the gasket surface of a cylinder head. This type of cleaning pad should not be used on the engine block where the grit could get into the engine oil and cause harm when the engine is started and run after the repair.

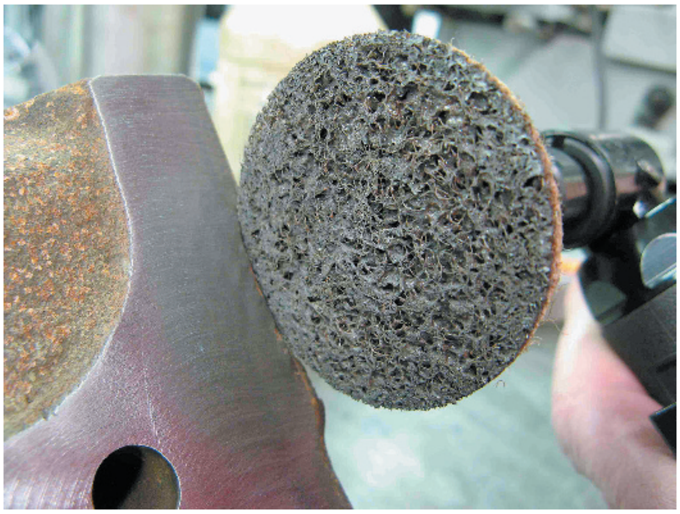


FIGURE 26–2 An abrasive disc commonly called by its trade name, Scotch Brite™ pad.

There are three colors of rotary discs, and each is made from a different grit size of abrasive. The three colors of bristle discs and their applications include

- **White.** Has the finest grit size and is used for cleaning aluminum parts
- **Yellow.** Has a coarse grit and can be used on aluminum
- **Green.** For use on cast-iron components only

● **SEE FIGURES 26–1 AND 26–2.**

CAUTION: Do not use steel wire brushes on aluminum parts! Steel is harder than aluminum and will remove some of the aluminum from the surface during cleaning.

MEDIA BLASTING Media blasting with baking soda is the cleaning method of choice for most shops. Baking soda (bicarbonate of soda) works well because it is

- Nontoxic
- Nonflammable
- Nonhazardous
- Environmentally safe

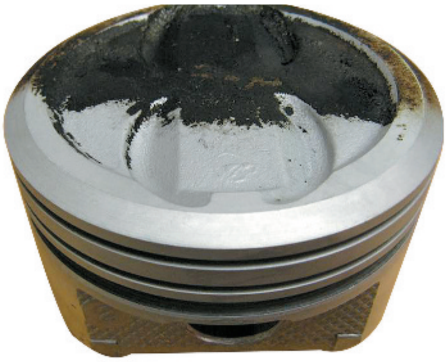


FIGURE 26–3 Using baking soda is the recommended way to clean engine parts because any soda that is left on or in the part is dissolved in oil or water, unlike either sand or glass beads, which can be engine damaging.

A soda blasting machine uses compressed air to deliver the baking soda media onto the part being cleaned. ● **SEE FIGURE 26–3.**

Cleaning cast-iron or aluminum engine parts with solvents or heat usually requires another operation to achieve a uniform surface finish. Blasting the parts with steel, cast-iron, aluminum, or stainless steel shot, baking soda, or glass beads is a simple way to achieve a matte or satin surface finish on the engine parts. To keep the shot or beads from sticking to the parts, they must be dry, without a trace of oil or grease, prior to blasting. This means that blasting is the second cleaning method after the part has been precleaned in a tank, spray washer, or oven. Some blasting is done automatically in an airless shot-blasting machine. Another method is to hard-blast parts in a sealed cabinet. ● **SEE FIGURE 26–4.**

CAUTION: Glass beads often remain in internal passages of engine parts, where they can come loose and travel through the cylinders when the engine is started. Among

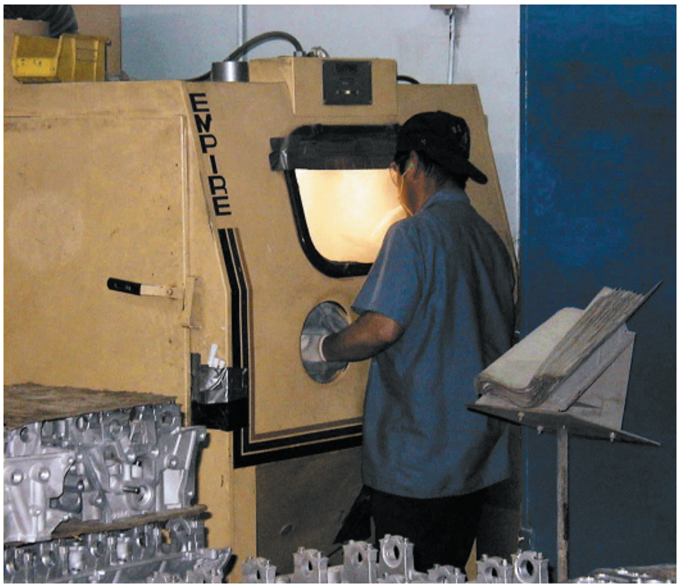


FIGURE 26–4 Small engine parts can be blasted clean in a sealed cabinet.

other places, these small but destructive beads can easily be trapped under the oil baffles of rocker covers and in oil pans and piston ring grooves. To help prevent the glass beads from sticking, be sure the parts being cleaned are free of grease and dirt, and completely *dry*.

CHEMICAL CLEANERS

pH Most chemical cleaners used for cleaning carbon-type deposits are strong soaps called **caustic materials**. **pH** value, measured on a scale from 1 to 14, indicates the amount of chemical activity in the soap. The term *pH* is from the French *pouvoir hydrogine,* meaning "hydrogen power." Pure water is neutral; on the pH scale, water is pH 7. Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the caustic action will be. **Acid materials** have pH numbers from 1 through 6. The lower the number, the stronger the acid action will be. Caustic materials and acid materials neutralize each other. This is what happens when baking soda (a caustic) is used to clean the outside of the battery (an acid surface). The caustic baking soda neutralizes any sulfuric acid that has been spilled or splashed on the outside of the battery.

CAUTION: Whenever working with chemicals, you must use eye protection.

SOLVENT-BASED CLEANING Cleaning chemicals applied to engine parts will mix with and dissolve deposits. The chemicals loosen the deposits so that they can be brushed or rinsed from the surface. A deposit is said to be *soluble* when it can be dissolved with a chemical or solvent. Chemical cleaning can involve a spray washer or a soak in a cold or hot tank. The cleaning solution is usually solvent based, with a medium pH rating of between 10 and 12. Most chemical solutions also contain silicates to protect the metal (aluminum) against corrosion.

Strong caustics do an excellent job on cast-iron items but are often too corrosive for aluminum parts. Aluminum cleaners include mineral spirit solvents as well as alkaline detergents.

CAUTION: When cleaning aluminum cylinder heads, blocks, or other engine components, make sure that the chemicals used are "aluminum safe." Many chemicals that are not aluminum safe may turn the aluminum metal black. Try to explain that to a customer!

WATER-BASED CHEMICAL CLEANING Because of environmental concerns, most chemical cleaning is now performed using water-based solutions (also called **aqueous-based solutions**). Most aqueous-type chemicals are silicate based and are mixed with water. Aqueous-based solutions can be used in one of the following two ways:

- Sprayed on
- Used in a tank for soaking parts

Aluminum heads and blocks usually require overnight soaking in a solution kept at about 190°F (90°C). For best results, the cleaning solution should be agitated.

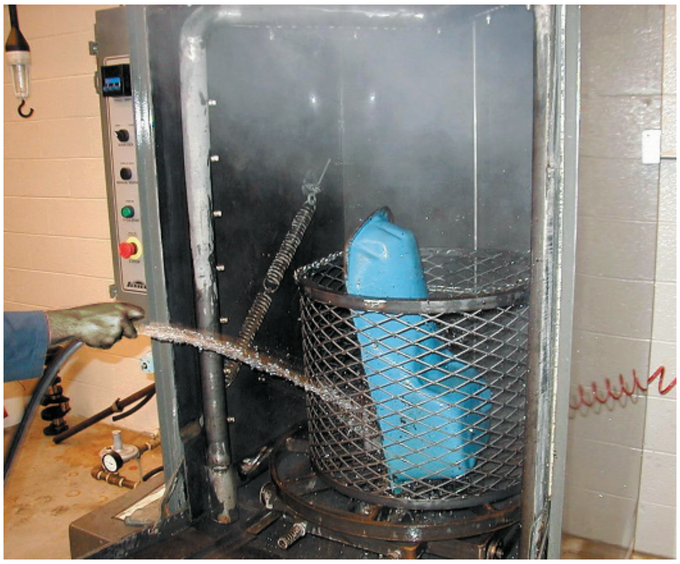


FIGURE 26–5 A pressure jet washer is similar to a large industrial-sized dishwasher. Each part is then rinsed with water to remove chemicals or debris that may remain there while it is still in the tank.

SPRAY AND STEAM WASHING

SPRAY WASHING A spray washer directs streams of liquid through numerous high-pressure nozzles to dislodge dirt and grime on an engine surface. The force of the liquid hitting the surface, combined with the chemical action of the cleaning solution, produces a clean surface. Spray washing is typically performed in an enclosed washer (like a dishwasher), where parts are rotated on a washer turntable. ● **SEE FIGURE 26–5**.

Spray washing is faster than soaking. A typical washer cycle is less than 30 minutes per load, compared to eight or more hours for soaking. Most spray washers use an aqueous-based cleaning solution heated to 160°F to 180°F (70°C to 80°C) with foam suppressants. High-volume remanufacturers use industrial dishwashing machines to clean the disassembled engine component parts.

STEAM CLEANING Steam vapor is mixed with high-pressure water and sprayed on the parts. The heat of the steam plus the force of the high-pressure water perform the actual cleaning. Steam cleaning must be used with extreme care. Usually, a caustic cleaner is added to the steam and water to aid in the cleaning. This mixture is so active that it will damage and even remove paint, so painted surfaces must be protected from the spray. Engines are often steam cleaned before they are removed from the vehicle.

THERMAL CLEANING

TEMPERATURES INVOLVED Thermal cleaning uses heat to vaporize and change dirt, oil, and grease into a dry, powdery ash. Thermal cleaning is best suited for cleaning cast iron, where temperatures as high as 800°F (425°C) are used, whereas aluminum should not be heated to over 600°F (315°C).

ADVANTAGES The major advantages of thermal cleaning include the following:

1. This process cleans the inside as well as the outside of the casting or part.
2. The waste generated is nonhazardous and is easy to dispose of. However, the heat in the oven usually discolors the metal, leaving it looking dull.

MICROBIAL CLEANING Microbial cleaning uses microbes that are living organisms (single-celled bacteria) that literally "eat" the hydrocarbons (grease and oils) off of the parts being cleaned. The typical microbial cleaning system includes three parts:

- A liquid assists the microbes by breaking the hydrocarbons to a smaller (molecular) size.
- The microbes, stored in a dormant phase until ready for use, give an indefinite shelf life to the product. Once the microbes come into contact with the liquid, they wake up from the dormant state and begin to feed.
- A third part is a blend of nutrients to ensure that the microbes start to multiply in the shortest amount of time to help speed the cleaning time needed.

Microbial cleaning is environment friendly, but is slower to clean parts. ● **SEE FIGURE 26–6**.

PYROLYTIC OVEN A **pyrolytic** (high-temperature) oven cleans engine parts by decomposing dirt, grease, and gaskets with heat in a manner similar to that of a self-cleaning oven. This method of engine parts cleaning is the least hazardous method and is becoming the most popular because there is no hazardous waste associated with it. Labor costs are also reduced because the operator does not need to be present during the actual cleaning operation. ● **SEE FIGURE 26–7**.

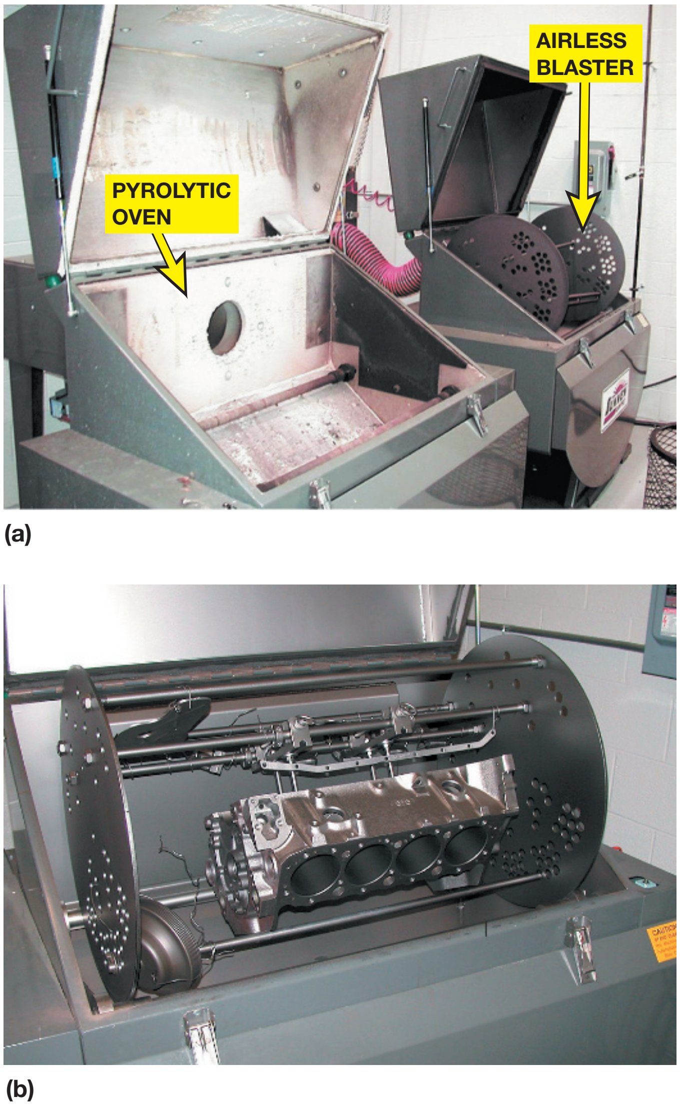


FIGURE 26–7 (a) A pyrolytic (high-temperature) oven cleans by baking the engine parts. After the parts have been cleaned, they are then placed into an airless blaster. This unit uses a paddle to scoop stainless steel shot from a reservoir and forces it against the engine part. The parts must be free of grease and oil to function correctly. (b) This cleaned engine block has been baked and shot blasted.

TANK AND VAPOR CLEANING

COLD TANK CLEANING The cold soak tank is used to remove grease and carbon. The disassembled parts are placed in the tank so that they are *completely* covered with the chemical cleaning solution. After a soaking period, the parts are removed and rinsed until the milky appearance of the emulsion is gone. The parts are then dried with compressed air. The clean, dry parts are then usually given a very light coating of clean oil to prevent rusting. Carburetor cleaner, purchased with a basket in a bucket, is one of the most common types of cold soak agents in the automotive shop. Usually, there will be a layer of water over the chemical to prevent evaporation of the chemical. This water layer is called a **hydroseal**.

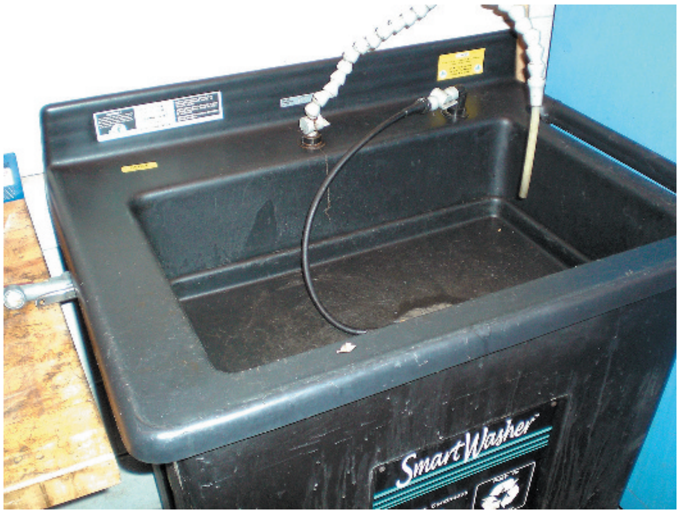


FIGURE 26–6 A microbial cleaning tank uses microbes to clean grease and oil from parts.

Parts washers are often used in place of soaking tanks. This equipment can move parts back and forth through the cleaning solution or pumps the cleaning solution over the parts. This movement, called **agitation**, keeps fresh cleaning solution moving past the soil to help it loosen. The parts washer is usually equipped with a safety cover held open by a low-temperature **fusible link**. If a fire occurs, the fusible link will melt and the cover will drop closed to snuff the fire out.

HOT TANK CLEANING The hot soak tank is used for cleaning heavy organic deposits and rust from iron and steel parts. The caustic cleaning solution used in the hot soak tank is heated to near 200°F (93°C) for rapid cleaning action. The solution must

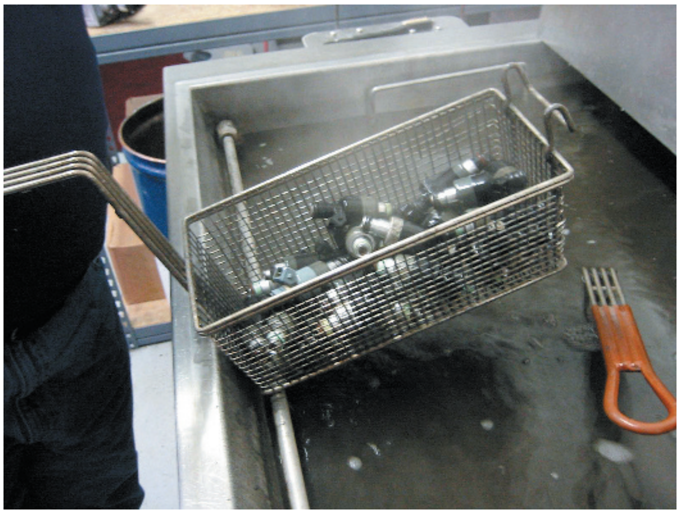


FIGURE 26–8 An ultrasonic cleaner is used to clean fuel injectors.

be inhibited when aluminum is to be cleaned. After the deposits have been loosened, the parts are removed from the tank and rinsed with hot water or steam cleaned, which dries them rapidly. They must then be given a light coating of oil to prevent rusting.

HINT: Fogging oil from a spray can does an excellent job of coating metal parts to keep them from rusting.

VAPOR CLEANING

Vapor cleaning is popular in some automotive service shops. The parts to be cleaned are suspended in hot vapors above a perchloroethylene solution. The vapors of the solution loosen the soil from the metal so that it can be blown, wiped, or rinsed from the surface.

ULTRASONIC AND VIBRATORY CLEANING

ULTRASONIC CLEANING

Ultrasonic cleaning is used to clean small parts that must be absolutely clean, such as hydraulic lifters and diesel injectors. The disassembled parts are placed in a tank of cleaning solution that is then vibrated at ultrasonic speeds to loosen all the soil from the parts. The soil goes into the solution or falls to the bottom of the tank. ● **SEE FIGURE 26–8**.

VIBRATORY CLEANING

The vibratory method of cleaning is best suited for small parts. Parts are loaded into a vibrating bin with small odd-shaped ceramic or steel pieces, called media, with a cleaning solution of mineral spirits or water-based detergents that usually contain a lubricant additive to help the media pieces slide around more freely. The movement of the vibrating solution and the scrubbing action of the media do an excellent job of cleaning metal.

CRACK DETECTION

VISUAL INSPECTION

After the parts have been thoroughly cleaned, they should be reexamined for defects. A magnifying glass is helpful in finding defects. Internal parts such as pistons, connecting rods, and crankshafts that have cracks should be replaced. Cracks in the block and heads, however, can often be repaired.

MAGNETIC CRACK DETECTION

The process of detecting cracks using a magnetic field is commonly referred to by the brand name Magnafluxing. Cracks in engine blocks, cylinder heads, crankshafts, and other engine components are sometimes difficult to find during a normal visual inspection, which is why all remanufacturers and most engine builders use a crack detection procedure on critical engine parts.

Magnetic flux testing is the method most often used on steel and iron components. A metal engine part (such as a cast-iron cylinder head) is connected to a large electromagnet. Magnetic lines of force are easily conducted through the iron part and concentrate on the edges of a crack. A fine iron powder is then applied to the part being tested, and the powder will be attracted to the strong magnetic concentration around the crack. ● **SEE FIGURES 26–9 THROUGH 26–11**.

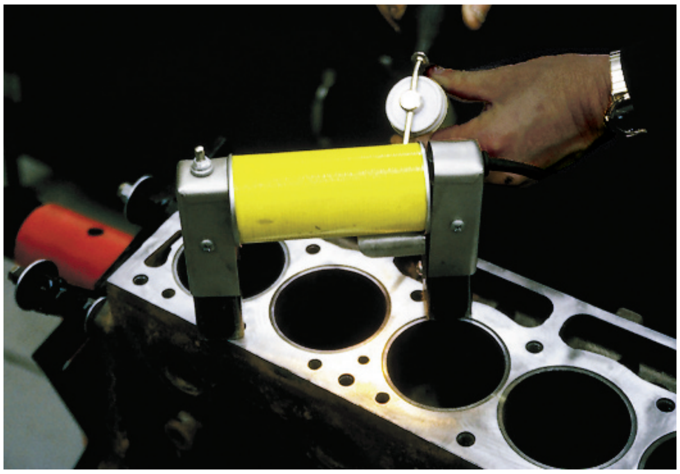


FIGURE 26–9 The top deck surface of a block is being tested using magnetic crack inspection equipment.

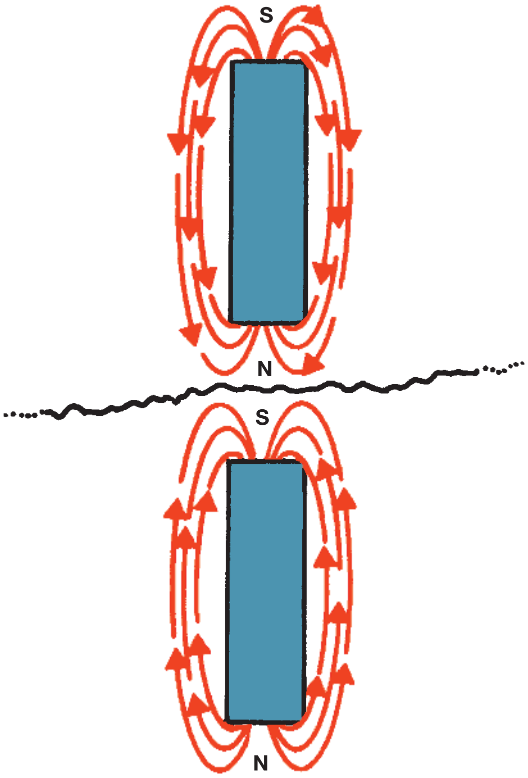


FIGURE 26–10 If the lines of force are interrupted by a break (crack) in the casting, two magnetic fields are created and the powder will lodge in the crack.

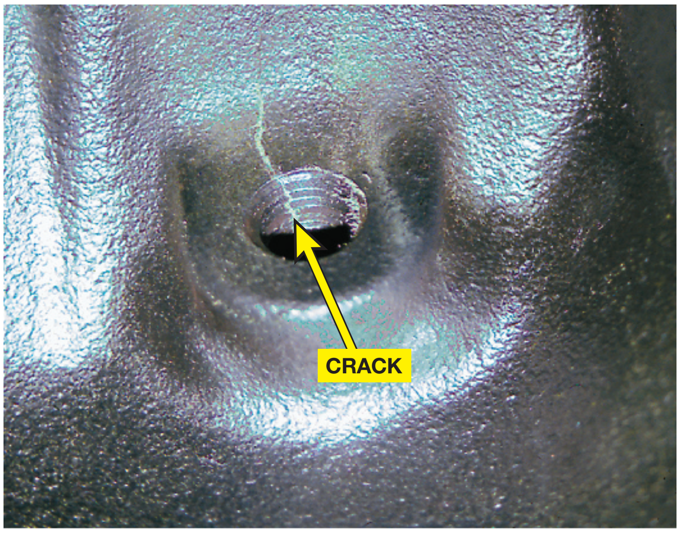


FIGURE 26–11 This crack in a vintage Ford 289, V-8 block was likely caused by the technician using excessive force trying to remove the plug from the block. The technician should have used heat and wax, not only to make the job easier, but also to prevent damaging the block.

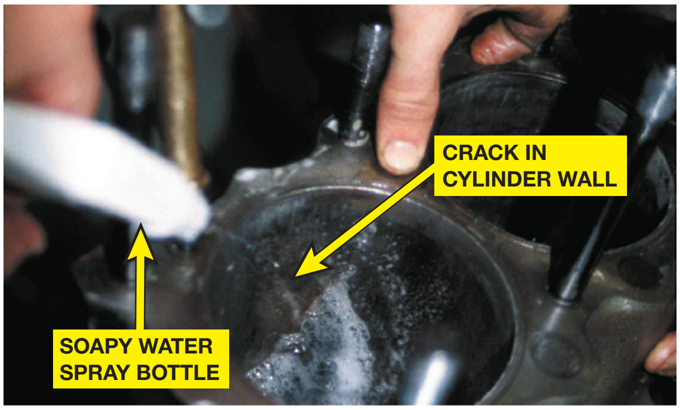


FIGURE 26–12 To make sure that the mark observed in the cylinder wall was a crack, compressed air was forced into the water jacket while soapy water was sprayed on the cylinder wall. Bubbles confirmed that the mark was indeed a crack.

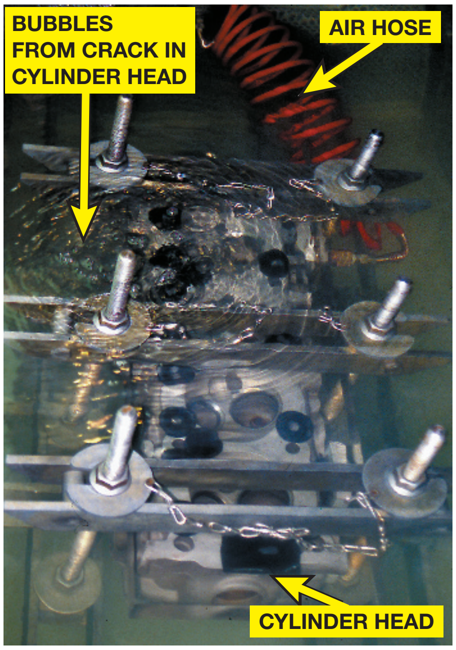


FIGURE 26–13 A cylinder head is under water and being pressure tested using compressed air. Note that the air bubbles indicate a crack.

DYE-PENETRANT TESTING

Dye-penetrant testing is often used on pistons and other parts constructed of aluminum or other nonmagnetic material. A dark red-penetrating chemical is first sprayed on the component being tested. After cleaning, a white powder is sprayed over the test area. If a crack is present, the red dye will stain the white powder. Even though this method will also work on iron and steel (magnetic) parts, it is often used only on nonmagnetic parts because magnetic methods do not work on these parts.

FLUORESCENT-PENETRANT TESTING

To be seen, fluorescent penetrant requires a black light. It can be used on iron, steel, or aluminum parts. Cracks show up as bright lines when viewed with a black light. The method is commonly called **Zyglo**, a trademark of the Magnaflux Corporation.

PRESSURE TESTING

Cylinder heads and blocks are often pressure tested with air and checked for leaks. All coolant passages are blocked with rubber plugs or gaskets, and compressed air is applied to the water jacket(s). The head or block is then lowered into water, where air bubbles indicate a leak. For more accurate results, the water should be heated because the hot water expands the casting by about the same amount as an operating engine would. An alternative method involves running heated water with a dye through the cylinder or block. Any leaks revealed by the dyed water indicate a crack. ● **SEE FIGURES 26–12 AND 26–13**.

CRACK REPAIR

CRACK CONCERNS

Most components that have cracks are often replaced. Cracks in the engine block can cause coolant to flow into the oil or oil into the coolant. A cracked block can also cause coolant to leak externally from a crack that goes through to a coolant passage. Cracks in the head will allow coolant to leak into the engine, or they will allow combustion gases to leak into the coolant. Cracks across the valve seat cause hot spots on the valve, which will burn the valve face. A head with a crack will either have to be replaced or the crack will have to be repaired.

STOP DRILLING

A hole can be drilled at each end of the crack to keep it from extending further, a step sometimes called *stop drilling.* Cracks that do not cross oil passages, bolt holes, or seal surfaces can sometimes be left alone if stopped.

CRACK-WELDING CAST IRON

It takes a great deal of skill to weld cast iron. The cast iron does not puddle or flow as steel does when it is heated. Heavy cast parts, such as the head and block, conduct heat away from the weld so fast that it is difficult to get the part hot enough to melt the iron for welding. When it does melt, a crack will often develop next to the edge of the weld bead. Welding can be done satisfactorily when the entire cast part is heated red-hot.

An effective technique involves flame welding using a special torch. ● **SEE FIGURE 26–14**.

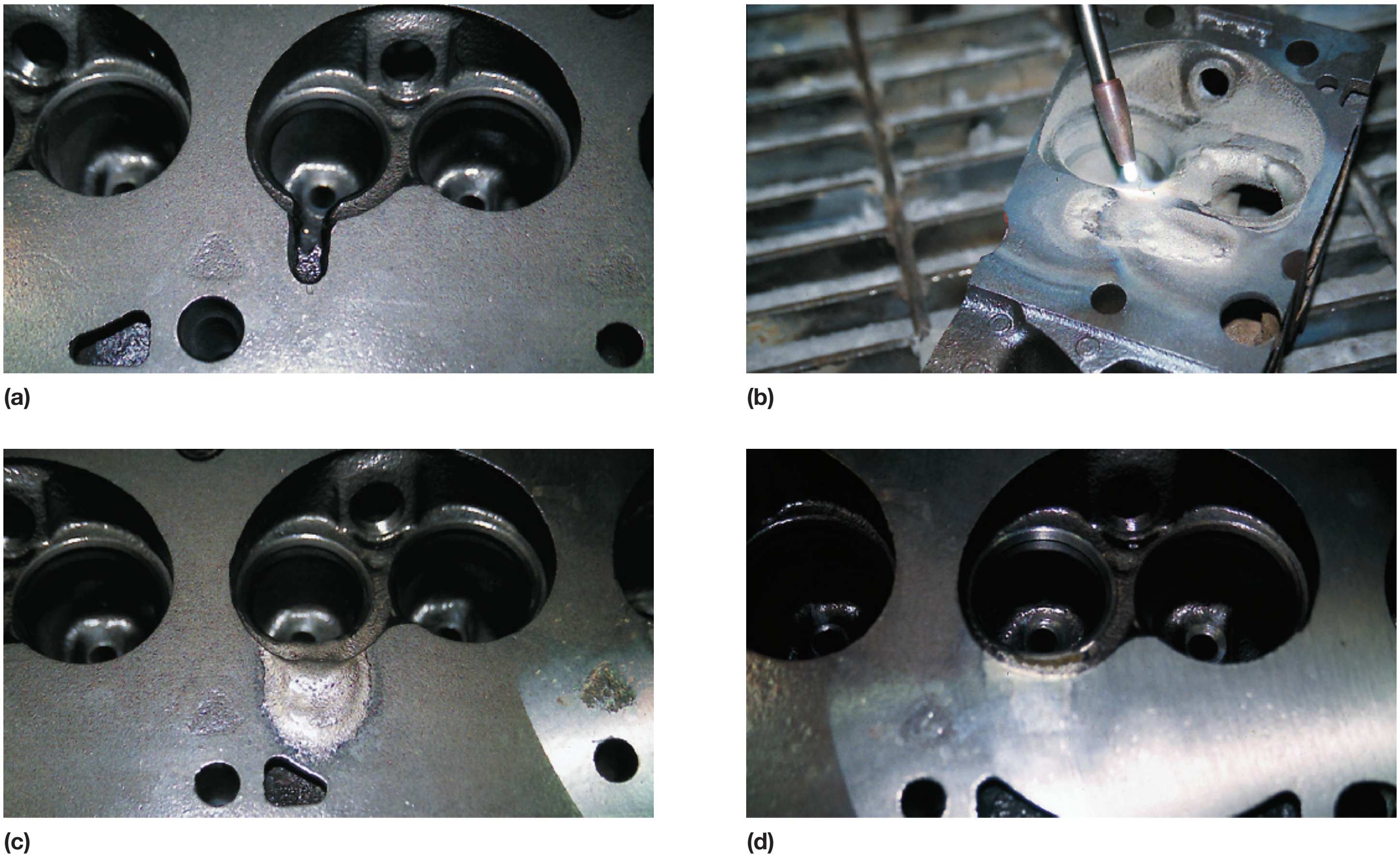

(a)
(b)
(c)
(d)

FIGURE 26–14 (a) Before welding, the crack is ground out using a carbide grinder. (b) Here the technician is practicing using the special cast-iron welding torch before welding the cracked cylinder head. (c) This is the finished welded crack before final machining. (d) Note the finished cylinder head after the crack has been repaired using welding.

CRACK-WELDING ALUMINUM Cracks in aluminum can be welded using a Heli-arc® or similar welder that is specially designed to weld aluminum. The crack should be cut or burned out before welding begins. The old valve-seat insert should be removed if the crack is in or near the combustion chamber.

CRACK PLUGGING In the process of crack plugging, a crack is closed using interlocking tapered plugs. This procedure can be performed to repair cracks in both aluminum and cast-iron engine components. The ends of the crack are center punched and drilled with the proper size of tap drill for the plugs. The hole is reamed with a tapered reamer (● **FIGURE 26–15**) and is then tapped with a special tap to give full threads (● **FIGURE 26–16**).

The plug is coated with sealer; then it is tightened into the hole (● **FIGURE 26–17**), sawed about one-fourth of the way through, and broken off.

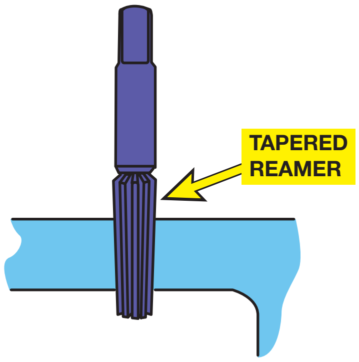


FIGURE 26–15 Reaming a hole for a tapered plug.

The saw slot controls the breaking point. ● **SEE FIGURE 26–18.**

If the plug should break below the surface, it will have to be drilled out and a new plug installed. The plug should go to the full depth or thickness of the cast metal. After the first plug is installed on each end, a new hole is drilled with the tap drill so

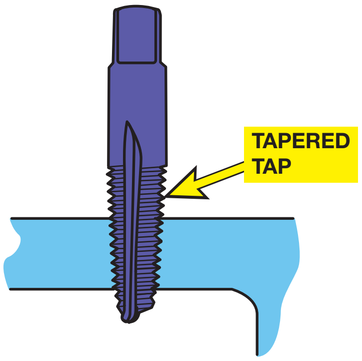


FIGURE 26–16 Tapping a tapered hole for a plug.

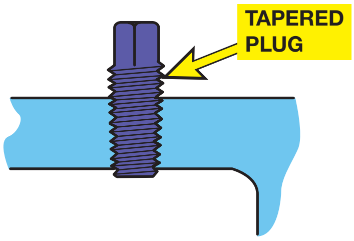


FIGURE 26–17 Screwing a tapered plug in the hole.

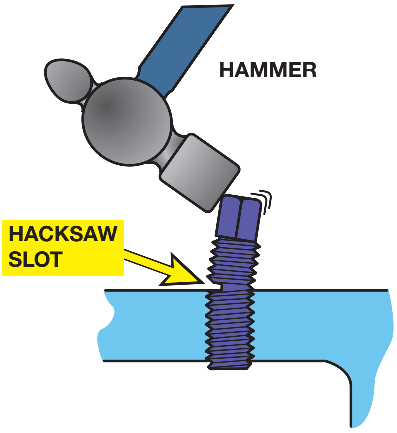


FIGURE 26–18 Cutting the plug with a hacksaw.

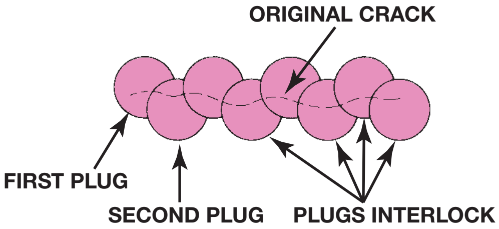


FIGURE 26–19 Interlocking plugs.

that it cuts into the edge of the first plug. This new hole is reamed and tapped, and a plug is inserted as before. The plug should fit about one-fourth of the way into the first plug to lock it into place. ● **SEE FIGURE 26–19**.

Interlocking plugs are placed along the entire crack, alternating slightly from side to side. The exposed ends of the plugs are peened over with a hammer to help secure them in place. The surface of the plugs is then ground or filed down nearly to the gasket surface. In the combustion chamber and at the ports, the plugs are ground down to the original surface using a hand grinder. The gasket surface of the head must be resurfaced after the crack has been repaired. ● **SEE FIGURE 26–20** for an example of a cylinder head repair using plugs.

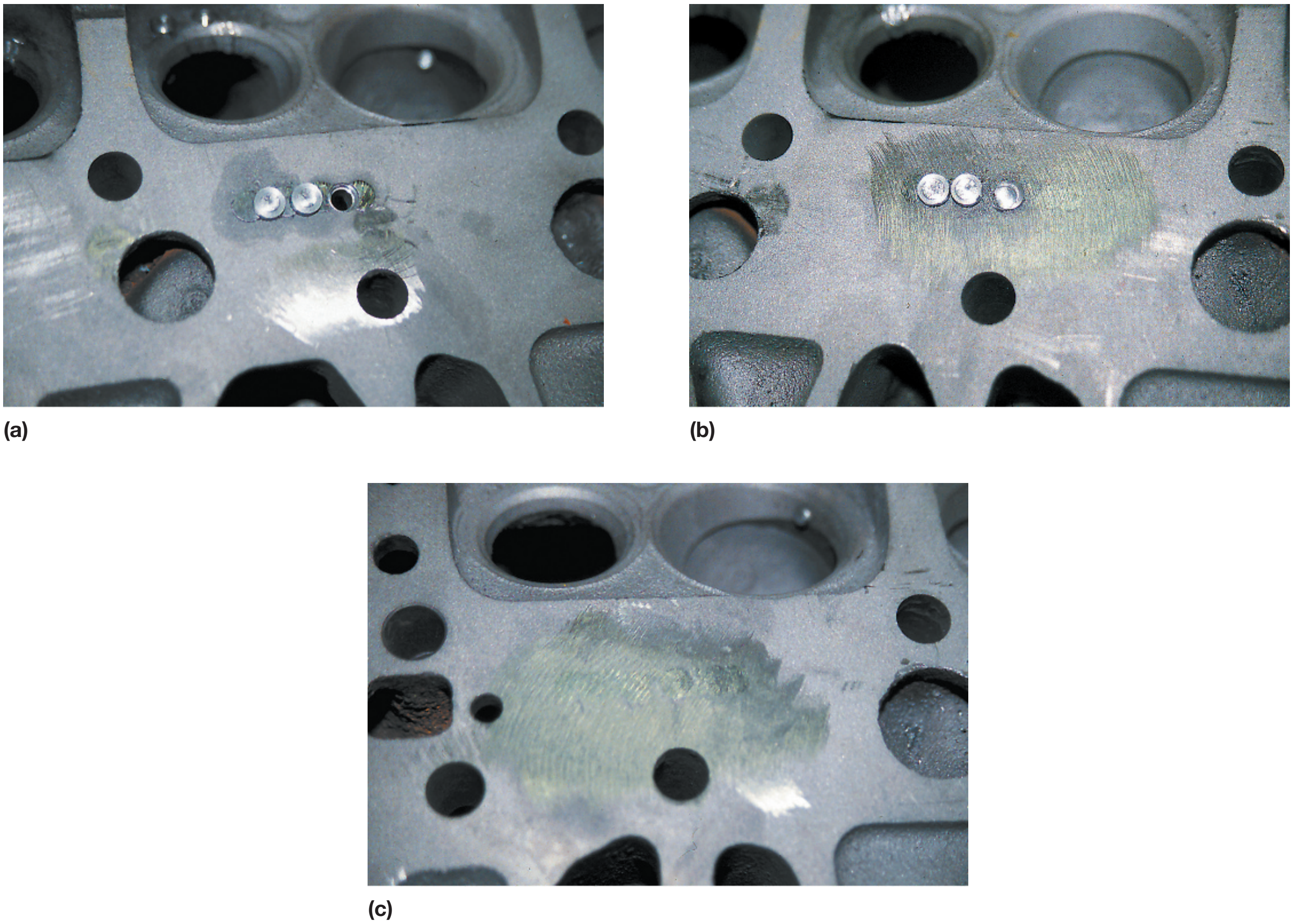


FIGURE 26–20 (a) A hole is drilled and tapped for the plugs. (b) The plugs are installed. (c) After final machining, the cylinder head can be returned to useful service.

REVIEW QUESTIONS

1. What are five methods that could be used to clean engines or engine parts?
2. How do magnetic crack inspection, dye-penetrant testing, and fluorescent-penetrant testing methods work and where can each be used?
3. How can engine block and cylinder heads be repaired if cracked?
4. What precautions need to be followed when cleaning aluminum parts using mechanical methods?
5. What is the purpose of stop drilling?

CHAPTER QUIZ

1. Abrasive pads or discs should be used _____________.
   - **a.** on disassembled engine parts only
   - **b.** according to the specified grit size for the material being cleaned
   - **c.** but clean the part thoroughly to wash away the abrasive material
   - **d.** All of the above
2. What actually does the cleaning when using steam?
   - **a.** Heat from the steam
   - **b.** Pressure behind the steam
   - **c.** Abrasives used
   - **d.** Both a and b
3. Aqueous-based cleaning means _____________.
   - **a.** water based
   - **b.** abrasive based
   - **c.** strong chemical based
   - **d.** All of the above
4. A pyrolytic oven is used to clean parts; however, caution should be used to limit the temperature, to prevent damaging engine parts. What are the maximum recommended temperatures?
   - **a.** 300°F (150°C) for all engine parts
   - **b.** 600°F (315°C) for aluminum parts
   - **c.** 800°F (425°C) for cast iron
   - **d.** Both b and c
5. Which media is best to use for cleaning parts as it does not need to be thoroughly cleaned after using?
   - **a.** Baking soda
   - **b.** Stainless steel shot
   - **c.** Glass beads
   - **d.** Aluminum shot
6. Cleaning chemicals are usually either a caustic material or an acid material. Which of the following statements is true?
   - **a.** Both caustics and acids have a pH of 7 if rated according to distilled water.
   - **b.** An acid is lower than 7 and a caustic is higher than 7 on the pH scale.
   - **c.** An acid is higher than 7 and a caustic is lower than 7 on the pH scale.
   - **d.** Pure water is a 1 and a strong acid is a 14 on the pH scale.
7. Many cleaning methods involve chemicals that are hazardous to use. The least hazardous method is generally considered to be the _____________.
   - **a.** pyrolytic oven
   - **b.** hot vapor tank
   - **c.** hot soak tank
   - **d.** cold soak tank
8. Magnetic crack inspection _____________.
   - **a.** uses a red dye to detect cracks in aluminum
   - **b.** uses a black light to detect cracks in iron parts
   - **c.** uses a fine iron powder to detect cracks in iron parts
   - **d.** uses a magnet to remove cracks from iron parts
9. Technician A says that engine parts should be cleaned before a thorough test can be done to detect cracks. Technician B says that pressure testing can be used to find cracks in blocks or cylinder heads. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. Plugging can be used to repair cracks _____________.
    - **a.** in cast-iron cylinder heads
    - **b.** in aluminum cylinder heads
    - **c.** in both cast-iron and aluminum cylinder heads
    - **d.** only in cast-iron blocks

Chapter

27

CYLINDER HEAD INSPECTION AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the design and construction of cylinder heads.
- Explain the design and construction of intake and exhaust ports.
- Discuss cylinder head passages.
- Describe cylinder head disassembly and inspection.
- Describe cylinder head resurfacing.
- Discuss valve guides.
- Describe valve guide replacement.
- Discuss intake and exhaust valves.
- Discuss valve seats.
- Discuss valve springs.
- Discuss valve seat reconditioning.
- Discuss valve stem height and installed height.
- Explain valve stem seals.
- Describe the procedure of installing valves.

KEY TERMS:

Arithmetic average roughness height 288 • Bend 287 • Concentric 289 • Distortion 287 • Free rotators 295 • Insert seat 293 • Installed height 296 • Integral seat 293 • Locks 291 • Poppet valve 291 • Port 285 • Porting (relieving) 285 • Positive rotators 295 • Quench area 283 • Retainer 291 • RMS 288 • Squish area 283 • Stellite® 292 • Twist 287 • Valve duration 284 • Valve face 291 • Valve guide 289 • Valve seat 291 • Valve seat inserts 289 • Valve spring 291 • Valve spring inserts (VSI) 296 • Valve spring surge 294 • Valve stem height 296 • Variable rate springs 294 • Warpage 287

CYLINDER HEADS

CONSTRUCTION Cylinder heads support the valves and valve train, and contain passages for the flow of intake, exhaust gases, coolant, and sometimes engine oil. In an overhead camshaft design engine, the cylinder head also supports all of the valve train components, including the camshaft, rocker arms, or followers, as well as the intake and exhaust valves and valve guides. ● **SEE FIGURE 27–1**.

DESIGN FEATURES Most cylinder head designs incorporate the following design factors to achieve fast burning of the air–fuel mixture and to reduce exhaust emissions.

These factors include:

- **Squish area**. This is an area of the combustion chamber where the piston nearly contacts the cylinder head. When the piston is moving upward toward the cylinder head, the air–fuel mixture is rapidly pushed out of the squish area, causing turbulence. Turbulence helps mix the air and fuel, thereby ensuring a more uniform and complete combustion. ● **SEE FIGURE 27–2**.
- **Quench area**. The squish area can also be the quench area where the air–fuel mixture is cooled by the cylinder head. The quench area is the flat area of the combustion chamber that is above the flat area of the piston. As the piston moves upward on the compression stroke, the air–fuel mixture is forced from this area as the piston gets near the top. The quench area operates at lower temperatures than the rest of the combustion chamber and can cause the gasoline vapors to condense on these cooler surfaces, thereby helping to reduce detonation caused by the autoignition of these gases in the combustion chamber.
- **Spark plug placement.** The best spark plug placement is at the center of the combustion chamber. ● **SEE FIGURE 27–3**.

The closer to the center, the shorter the flames travel to all edges of the combustion chamber, which also reduces abnormal combustion (ping or spark knock). While it is best to have the spark plug in the center, some combustion chamber designs do not allow this, due to valve size, combustion chamber design, and valve placement. Some engines use two spark plugs per cylinder

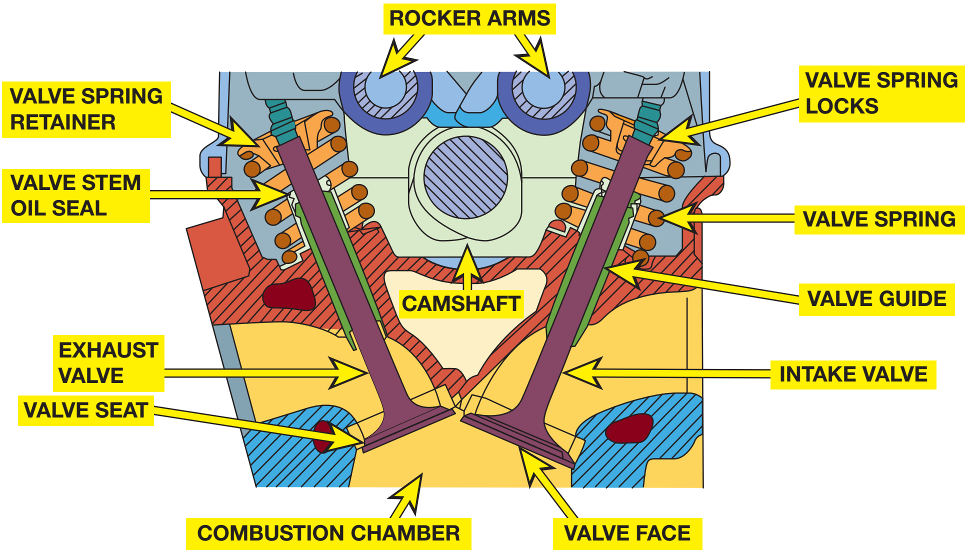

ROCKER ARMS
VALVE SPRING RETAINER
VALVE SPRING LOCKS
VALVE STEM OIL SEAL
VALVE SPRING
CAMSHAFT
VALVE GUIDE
EXHAUST VALVE
INTAKE VALVE
VALVE SEAT
COMBUSTION CHAMBER
VALVE FACE

FIGURE 27–1 The seats and guides for the valves are in the cylinder head, as well as the camshaft and the entire valve train if it is an overhead camshaft design.

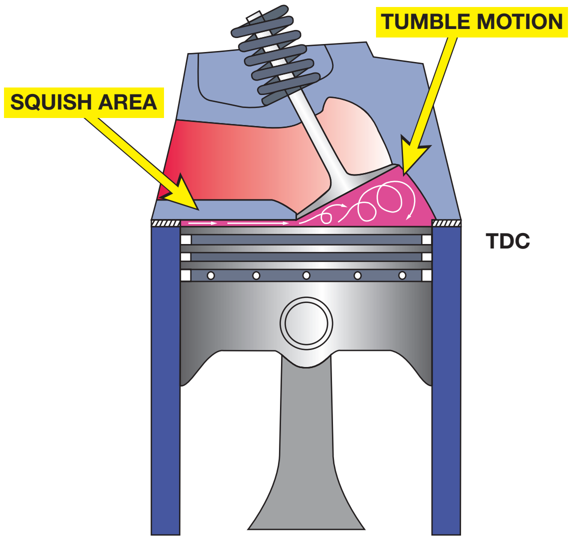

TUMBLE MOTION
SQUISH AREA
TDC

FIGURE 27–2 A wedge-shaped combustion chamber showing the squish area where the air–fuel mixture is squeezed, causing turbulence that pushes the mixture toward the spark plug.

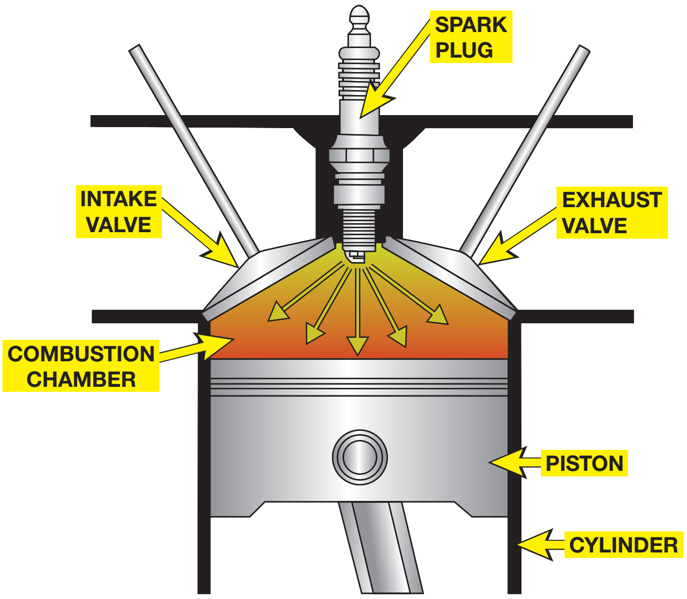

SPARK PLUG
INTAKE VALVE
EXHAUST VALVE
COMBUSTION CHAMBER
PISTON
CYLINDER

FIGURE 27–3 Locating the spark plug in the center of the combustion chamber reduces the distance the flame front must travel.

to achieve rapid combustion needed to meet exhaust emissions standards. ● **SEE FIGURE 27–4** for an example of a two-spark plug combustion chamber used in a hemispherical (Hemi) cylinder head design.

COMBUSTION CHAMBER DESIGNS Combustion chamber shape has an effect on engine power and efficiency. The combustion chamber is created as two parts.

- The upper part consists of the cylinder head and cylinder walls.
- The lower part is the top of the piston.

The most commonly used combustion chamber shapes include the following:

- **Wedge.** Commonly found on many two-valve pushrod engines (cam-in-block) designs
- **Pentroof.** Commonly found on many four-valve overhead camshaft design engines
- **Hemispherical (hemi).** Found on both cam-in-block and overhead camshaft design engines

FOUR-VALVE CYLINDER HEADS Adding more than two valves per cylinder permits more air to flow into and out of the engine with greater velocity without excessive valve duration. **Valve duration** is the number of degrees by which the crankshaft rotates when the valve is off the valve seat. Increased valve duration increases valve overlap. The valve overlap occurs when both valves are open at the same time at the end of the exhaust stroke and at the beginning of the intake stroke. At lower engine speeds, the gases can move back and forth between the open valves. Therefore, the greater valve duration hurts low engine speed performance and driveability, but it allows for more air–fuel mixture to enter the engine for better high-speed power.

VALVE SIZE AND LIFT The maximum amount of gas moving through the opening area of a valve depends on the distance around the valve and the degree to which it lifts open. ● **SEE FIGURE 27–5.**

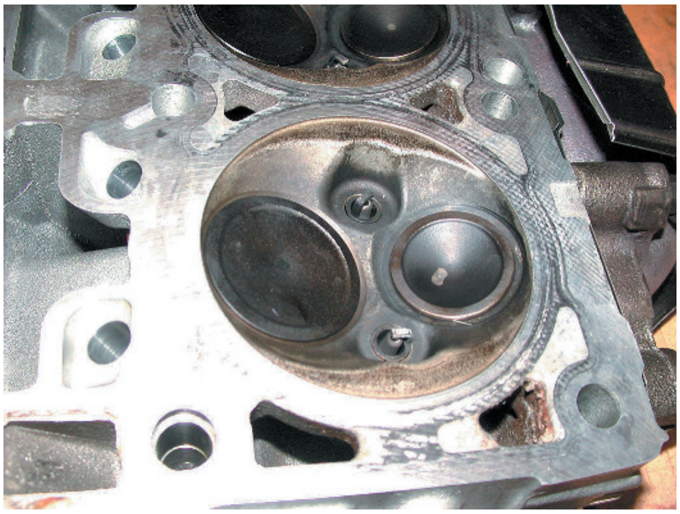


FIGURE 27–4 The combustion chamber of the 5.7 liter Chrysler Hemi cylinder head shows the two spark plugs used to ensure rapid burn for best power and economy with the lowest possible exhaust emissions.

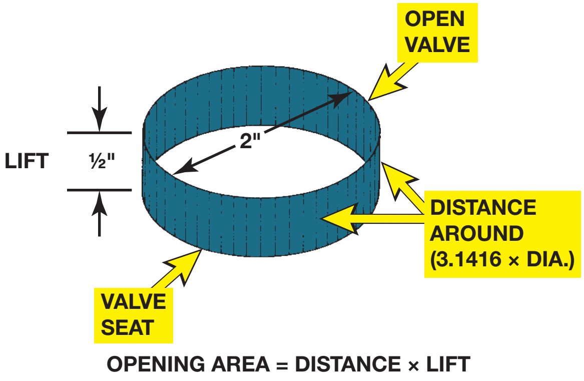

OPEN VALVE
LIFT
½"
2"
DISTANCE AROUND (3.1416 × DIA.)
VALVE SEAT
OPENING AREA = DISTANCE × LIFT

FIGURE 27–5 Method for measuring the valve opening space.

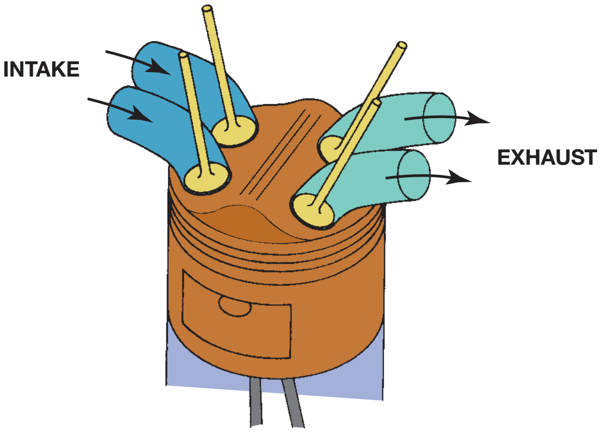


FIGURE 27–6 Four valves in a pentroof combustion chamber.

When four valves are used, either the combustion chamber has a pentroof design, with each pair of valves in line, or it is hemispherical, with each valve on its own axis. ● **SEE FIGURE 27–6**.

Four valves on the pentroof design will be operated with dual overhead camshafts or with single overhead camshafts and rocker arms. When four valves are used, it is possible to place the spark plug at the center of the combustion chamber.

INTAKE AND EXHAUST PORTS

PURPOSE AND FUNCTION The part of the intake or exhaust system passage that is cast in the cylinder head is called a **port**. Ports lead from the manifolds to the valves. The most desirable port shape is not always possible because of space requirements in the head. Space is required for the head bolt bosses, valve guides, cooling passages, and pushrod openings. Inline engines may have both intake and exhaust ports located on the same side of the engine. On some older engines, two cylinders share the same port because of the restricted space available.

Larger ports and better breathing are possible in engines that have the intake port on one side of the head and the exhaust port on the opposite side. Sometimes a restricting hump within a port may actually increase the airflow capacity of the port.

It does this by redirecting the flow to an area of the port that is large enough to handle the flow. Modifications in the field, such as **porting** or **relieving**, would result in restricting the flow of such a carefully designed port.

INTAKE PORTS The intake port in a cylinder head designed for use with a carburetor or throttle-body-type fuel injection is relatively long, whereas the exhaust port is short. On engines designed for use with port fuel injection, the cylinder head ports are designed to help promote swirl in the combustion chamber, as shown in ● **FIGURE 27–7**.

EXHAUST PORTS Like the intake ports, exhaust ports are designed to allow the free flow of exhaust gases from the engine. The length of the exhaust ports is shorter than the intake ports to help reduce the amount of heat transferred to the coolant. ● **SEE FIGURE 27–8**.

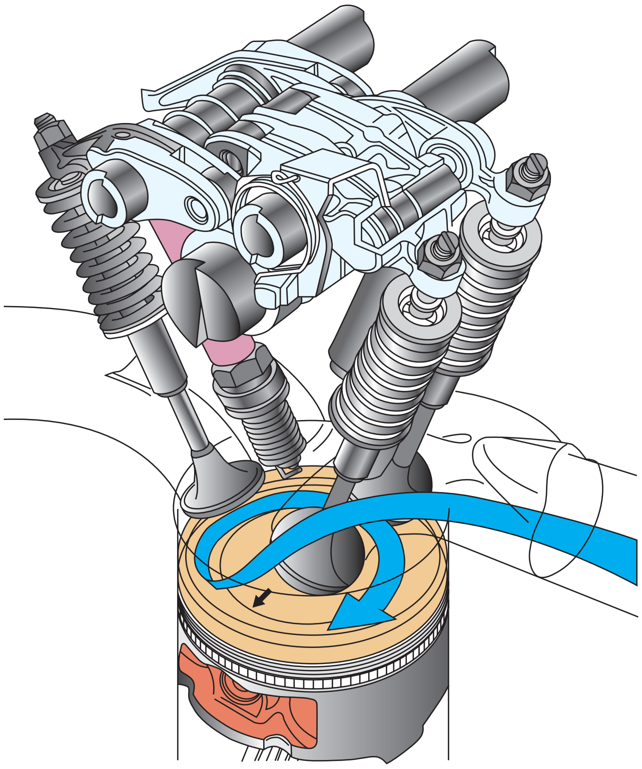


FIGURE 27–7 The intake manifold design and combustion chamber design both work together to cause the air–fuel mixture to swirl as it enters the combustion chamber.

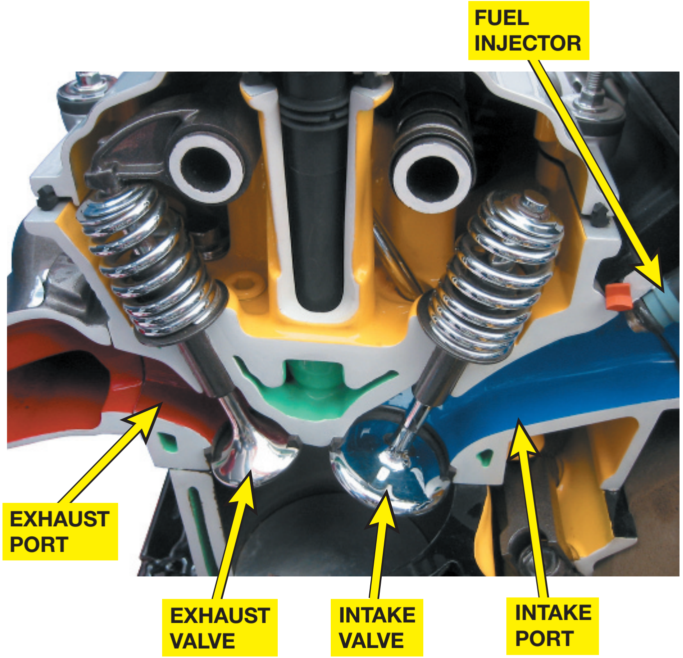


FIGURE 27–8 A port-injected engine showing the straight free-flowing intake and exhaust ports.

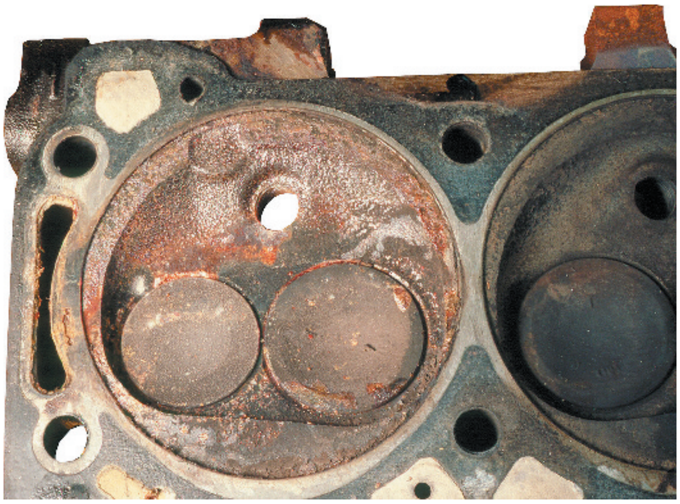


FIGURE 27–10 Coolant flows through the cylinder head, and the passages are sealed by the head gasket. In this case the head gasket has failed, allowing coolant to enter the cylinder on the left.

CYLINDER HEAD PASSAGES

COOLANT FLOW PASSAGES The engine is designed so that coolant will flow from the coolest portion of the engine to the warmest portion. The water pump takes the coolant from the radiator. The coolant is circulated through the block, where it is directed all around the cylinders. The coolant then flows upward through the gasket to the cooling passages cast into the cylinder head. The heated coolant is collected at a common point and returned to the radiator to be cooled and recirculated.

Typical coolant passages in a head are shown in ● **FIGURE 27–9**.

HEAD GASKET HOLES There are relatively large holes in the gasket surface of the head leading to the head cooling passages. The openings between the head and the block are usually too large for the correct coolant flow. When the openings are too large, the head gasket performs an important coolant flow function. Special-size and smaller holes are made in the gasket. These holes correct the coolant flow rate at each opening. Therefore, it is important that the head gasket be installed correctly for proper engine cooling. ● **SEE FIGURE 27–10**.

LUBRICATING OIL PASSAGES Lubricating oil is delivered to the overhead valve mechanism, either through the valve pushrods or through drilled passages in the head and block casting. There are special openings in the head gasket to allow the oil to pass between the block and head without leaking. After the oil passes through the valve mechanisms, it returns to the oil pan through oil return passages, usually called "drainback holes." Some engines have drilled oil return holes, but most engines have large cast holes that allow the oil to return freely to the engine oil pan. The cast holes are large and do not easily become plugged.

NOTE: Many aluminum cylinder heads have smaller-than-normal drainback holes. If an engine has excessive oil consumption, check the drain holes before removing the engine.

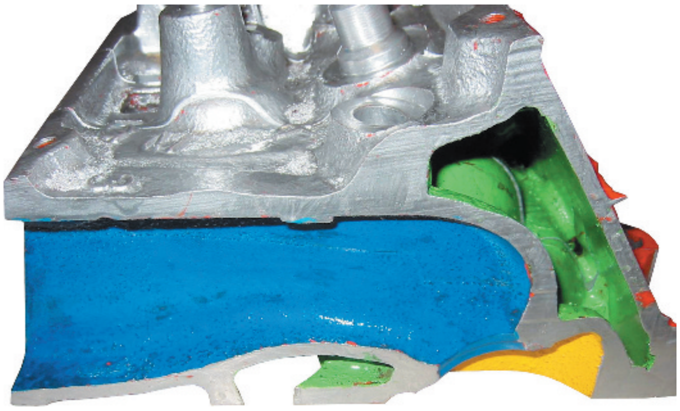


FIGURE 27–9 A cutaway head showing the coolant passages in green.

CYLINDER HEAD DISASSEMBLY AND INSPECTION

DISASSEMBLING OVERHEAD CAMSHAFT HEAD The overhead camshaft will have either one-piece bearings in a solid bearing support or split bearings and a bearing cap. When one-piece bearings are used, the valve springs will have to be compressed with a fixture or the finger follower will have to be removed before the camshaft can be pulled out endwise. When bearing caps are used, they should be loosened alternately so that bending loads are not placed on either the cam or bearing caps. ● **SEE FIGURES 27–11 AND 27–12**.

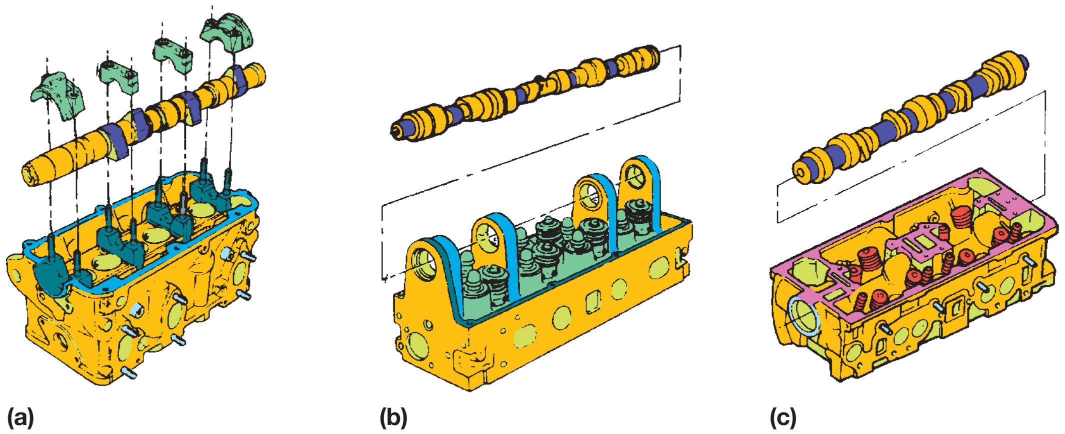


FIGURE 27–11 Overhead camshafts may be (a) held in place with bearing caps, (b) supported by towers, or (c) fitted into bearing bores machined directly into the head.

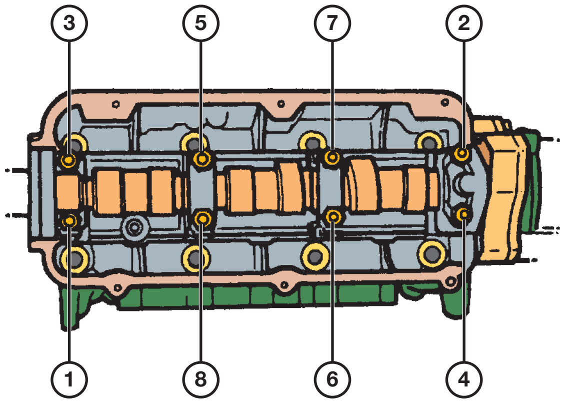


FIGURE 27–12 Always follow the specified loosening sequence to prevent valve spring tension from bending the camshaft.

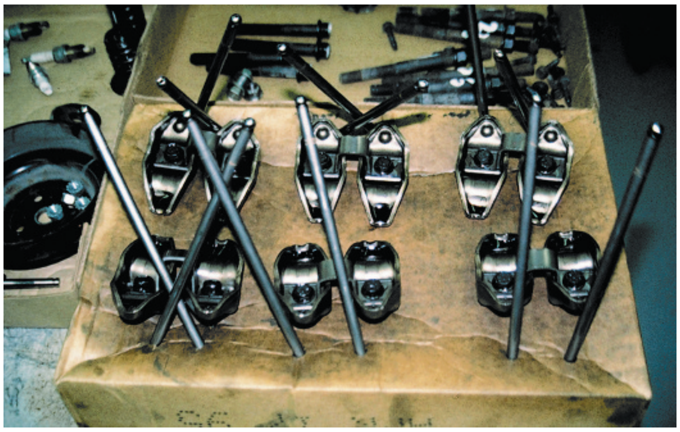


FIGURE 27–13 Pushrods can be kept labeled if stuck through a cardboard box. Individual parts become worn together. Using cardboard is a crude but effective material to keep all valve train parts together and labeled exactly as they came from the engine.

VALVE TRAIN DISASSEMBLY Disassemble the cylinder head as discussed in Chapter 25. All valve train components that are to be reused must be kept together. As wear occurs, parts are worn together.

- Be sure to keep the top part of the pushrod at the top.
- Keep the rocker arms with the same pushrods as they wear together. ● **SEE FIGURE 27–13**.
- Intake and exhaust valve springs can be different and must be kept with the correct valve.

CYLINDER HEAD INSPECTION The surface must be thoroughly cleaned and inspected as follows:

STEP 1 After removing the old gasket material, use a file and draw it across the surface of the head to remove any small burrs.

STEP 2 The head should be checked in five planes. Checking the cylinder head gasket surface with a precision straightedge in five planes checks the head for **warpage**, **distortion**, **bend**, and **twist**. ● **SEE FIGURE 27–14**.

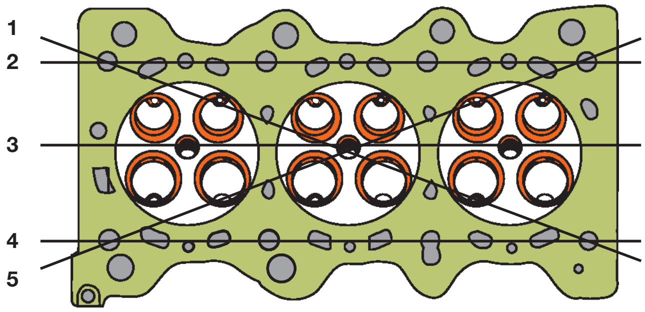


FIGURE 27–14 Cylinder heads should be checked in five planes for warpage, distortion, bend, and twist.

These defects are determined by trying to slide a 0.004 inch (0.1 mm) feeler gauge under a precision straightedge held against the head surface. The clearance between the cylinder head and the straightedge should not vary by over 0.002 inch (0.05 mm) in any 6 inch (15 cm) length, or by more than 0.004 inch overall. Always check the manufacturer's recommended specifications. ● **SEE FIGURE 27–15**.

NOTE: Always check the cylinder head thickness and specifications to be sure that material can be safely removed from the surface. Some manufacturers do not recommend any machining, but rather require cylinder head replacement if cylinder head surface flatness is not within specifications.

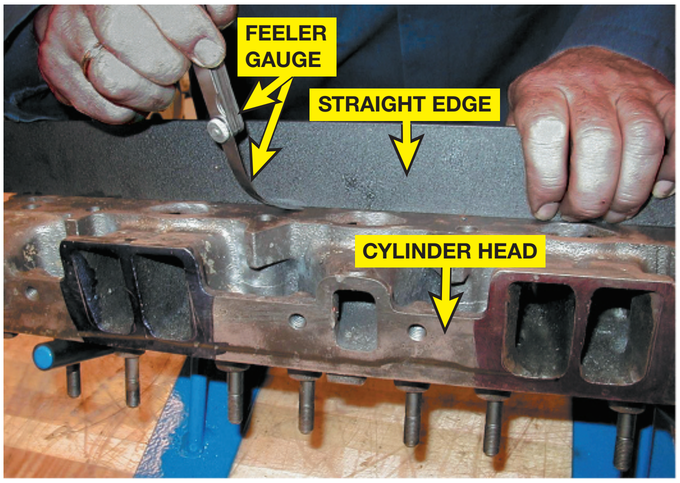


FIGURE 27–15 A precision ground straightedge and a feeler gauge are used to check the cylinder head for flatness.

CYLINDER HEAD RESURFACING

REFINISHING METHODS The cylinder head surface that mates with the top deck of the block is often called the "fire deck." Machine shops can use milling (broaching) or grinding to resurface the cylinder head.

Resurfacing the cylinder head changes the compression ratio of the engine by about 1/10 point per 0.01 inch of removed material. For example, the compression ratio would be increased from 9.0:1 to 9.2:1 if 0.02 inch were removed from a typical cylinder head.

SURFACE FINISH The surface finish of a reconditioned part is as important as the size of the part. Surface finish is measured in units called microinches (abbreviated "μ in."). The symbol in front of the inch abbreviation is the Greek letter *mu*. One microinch equals 0.000001 inch, or 0.025 micrometer (μm). The finish classification in microinches gives the distance between the highest peak and the deepest valley. The usual method of expressing surface finish is by the **arithmetic average roughness height** (RA), that is, the average of the distances of all peaks and valleys from the mean (average) line. Surface finish is measured using a machine with a diamond stylus. ● **SEE FIGURE 27–16.**

Another classification of surface finish, which is becoming obsolete, is called the **root-mean-square (RMS)**. The RMS is a slightly higher number and can be obtained by multiplying RA × 1.11.

Typical surface finish roughness recommendations for cast-iron and aluminum cylinder heads and blocks include the following:

Cast Iron

Maximum: 110 RA (125 RMS) (Rough surfaces can limit gasket movement and conformity.)

Minimum: 30 RA (33 RMS) (Smoother surfaces increase the tendency of the gasket to flow and *reduce* gasket sealing ability.)

Recommended range: 60 to 100 RA (65 to 110 RMS)

Aluminum

Maximum: 60 RA (65 RMS)

Minimum: 30 RA (33 RMS)

Recommended range: 50 to 60 RA (55 to 65 RMS)

The rougher the surface is, the higher the microinch finish measurement will be.

Typical preferred microinch finish standards for other engine components include the following:

Crank and rod journal:	10 to 14 RA (12 to 15 RMS)
Honed cylinder:	18 to 32 RA (20 to 35 RMS)
Connecting rod big end:	45 to 72 RA (50 to 80 RMS)

INTAKE MANIFOLD ALIGNMENT

PURPOSE The intake manifold of a V-type engine may no longer fit correctly after the gasket surfaces of the heads are ground. The ports and the assembly bolt holes may no longer match. The intake manifold surface must be resurfaced to remove enough metal to rematch the ports and bolt holes. The amount of metal that must be removed depends on the angle between the head gasket surface and the intake manifold gasket surface. ● **SEE FIGURE 27–17.**

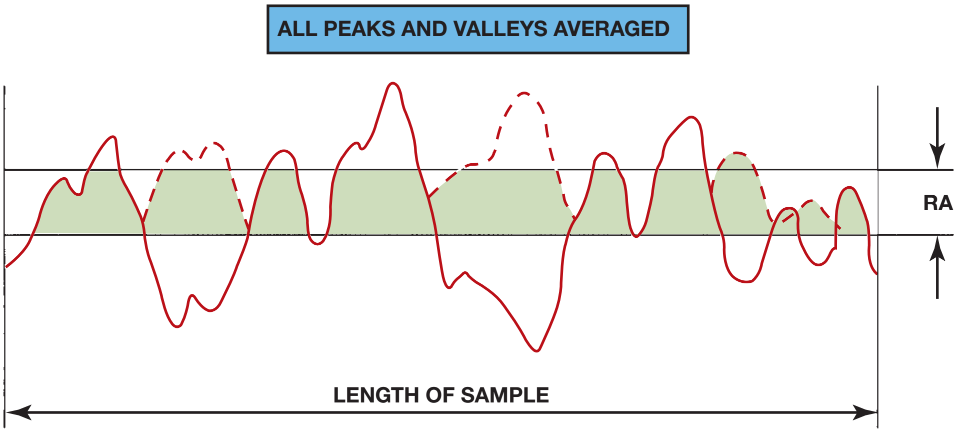
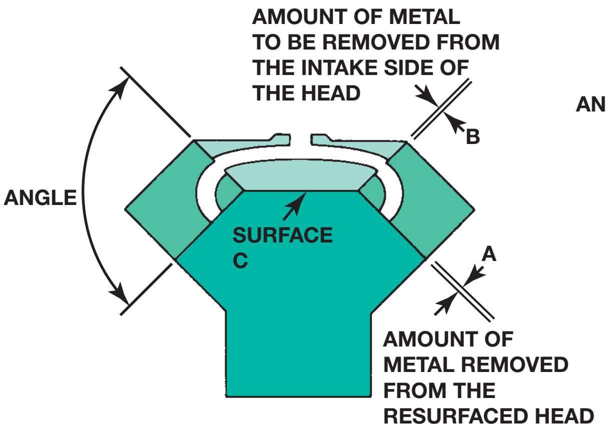


FIGURE 27–16 A graph showing a typical rough surface as would be viewed through a magnifying glass. RA is an abbreviation indicating the average height of all peaks and valleys.


AMOUNT OF METAL TO BE REMOVED FROM THE INTAKE SIDE OF THE HEAD
B
ANGLE
SURFACE C
A
AMOUNT OF METAL REMOVED FROM THE RESURFACED HEAD

ANGLE	AMOUNT TO BE REMOVED FROM B
90°	A × 1.000
85°	A × 1.100
80°	A × 1.233
75°	A × 1.414
70°	A × 1.673
65°	A × 2.067
60°	A × 2.733

THE AMOUNT REMOVED FROM SURFACE C IS 1.4 × A

FIGURE 27–17 The material that must be removed for a good manifold fit.

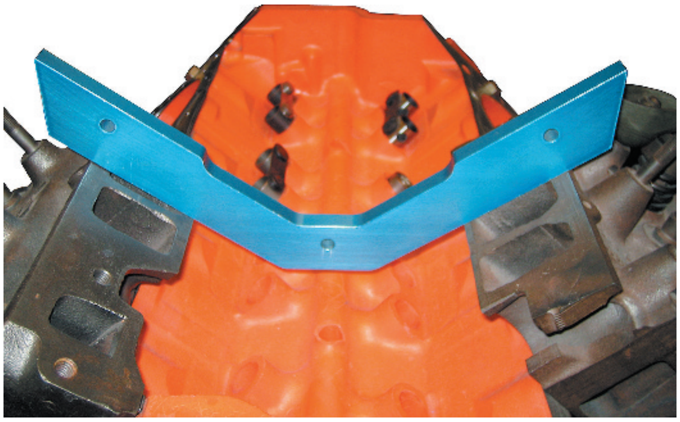


FIGURE 27–18 Using an intake manifold template to check for the proper angles after the cylinder heads have been machined.

PROCEDURE Automotive machine shops that perform head resurfacing have tables that specify the exact amount of metal to be removed. It is usually necessary to also remove some metal from both the front and the back gasket surfaces of closed-type intake manifolds used on V-type engines. This is necessary to provide a good gasket seal that will prevent oil leakage from the lifter valley. ● **SEE FIGURE 27–18**.

CAUTION: Do not remove any more material than is necessary to restore a flat cylinder head-to-block surface. Some manufacturers limit total material that can be removed from the block deck and cylinder head to 0.008 inch (0.2 mm). Removal of material from the cylinder head of an overhead camshaft engine shortens the distance between the camshaft and the crankshaft. This causes the valve timing to be retarded unless a special copper spacer shim is placed between the block deck and the gasket to restore proper crankshaft-to-camshaft centerline dimension.

VALVE GUIDES

TYPES The valve guide supports the valve stem so that the valve face will remain perfectly centered, or **concentric**, with the valve seat. The valve guide is generally integral with the head casting in cast-iron heads for better heat transfer and for lower manufacturing costs. ● **SEE FIGURE 27–19**.

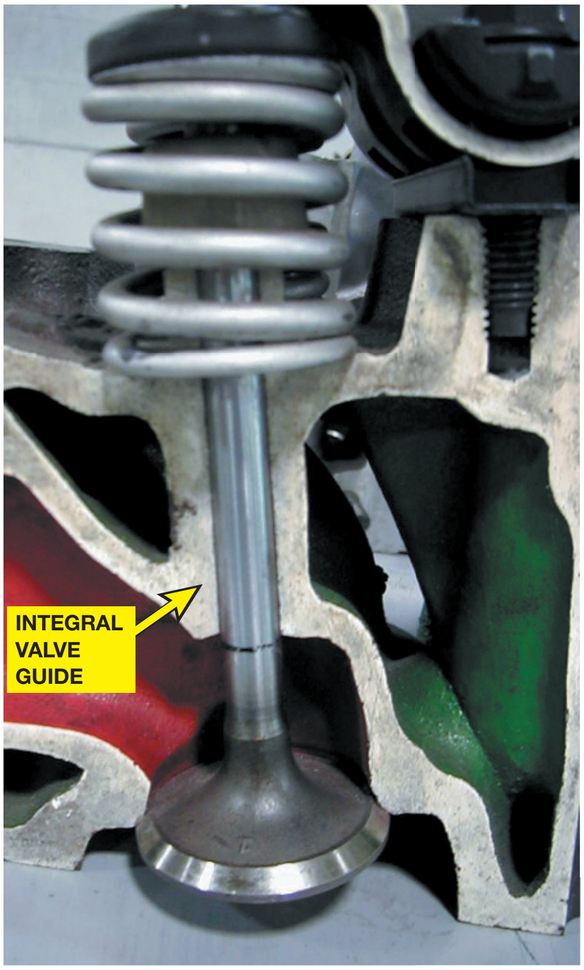


FIGURE 27–19 An integral valve guide is simply a guide that has been drilled into the cast-iron cylinder head.

Removable or pressed-in **valve guides** and **valve seat inserts** are always used in aluminum heads. ● **SEE FIGURE 27–20**.

No matter how good the valves or seats are, they cannot operate properly if the valve guide is not accurate. In use, the valve opening mechanism pushes the valve tip sideways. This is the major cause of valve stem and guide wear. The movement of the valve causes both the top and bottom ends of the guide to wear until the guide has bell-mouth shapes at both ends. ● **SEE FIGURE 27–21**.

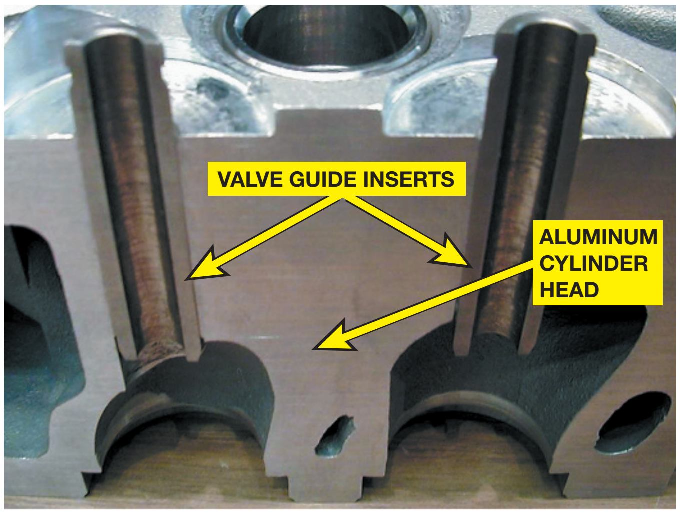


FIGURE 27–20 All aluminum cylinder heads use valve guide inserts.

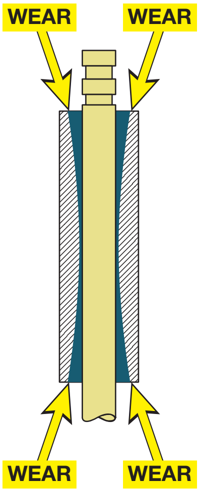


FIGURE 27–21 Valve guides often wear to a bell-mouth shape to both ends due to the forces exerted on the valve by the valve train components.

VALVE STEM-TO-GUIDE CLEARANCE

Engine manufacturers usually recommend the following valve stem-to-guide clearances:

- Intake valve: 0.001 to 0.003 inch (0.025 to 0.076 mm)
- Exhaust valve: 0.002 to 0.004 inch (0.05 to 0.1 mm)

Be sure to check the exact specifications for the engine being serviced. The exhaust valve clearance is greater than the intake valve clearance because the exhaust valve runs hotter and, therefore, expands more than the intake valve.

Excessive valve stem-to-guide clearance can cause excessive oil consumption. The intake valve guide is exposed to manifold vacuum that can draw oil from the top of the cylinder head down into the combustion chamber. In this situation, valves can also run hotter than usual because much of the heat in the valve is transferred to the cylinder head through the valve guide.

NOTE: A human hair is about 0.002 inch (0.05 mm) in diameter. Therefore, the typical clearance between a valve stem and the valve guide is only the thickness of a human hair.

MEASURING VALVE GUIDES

Valves should be measured for stem wear before valve guides are measured. The valve guide is measured in the middle with a small-hole gauge. The gauge size is checked with a micrometer. The guide is then checked at each end.

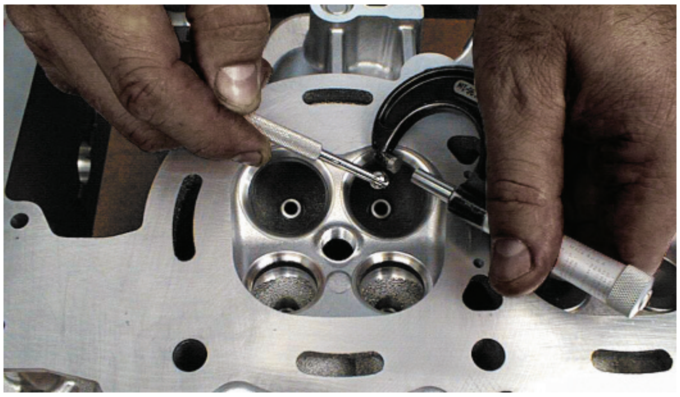


FIGURE 27–22 A small-hole gauge and a micrometer are being used to measure the valve guide. The guide should be measured in three places: at the top, middle, and bottom.

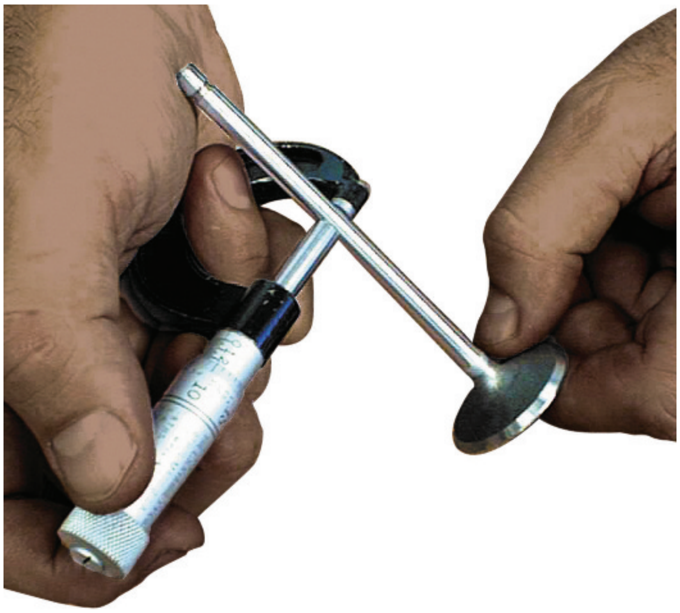


FIGURE 27–23 The diameter of the valve stem is being measured using a micrometer. The difference between the inside diameter of the valve guide and the diameter of the valve stem is the valve guide-to-stem clearance.

The expanded part of the ball should be placed crosswise to the engine where the greatest amount of valve guide wear exists. The dimension of the valve stem diameter is subtracted from the dimension of the valve guide diameter. If the clearance exceeds the specified clearance, the valve guide will have to be reconditioned. ● **SEE FIGURES 27–22 AND 27–23**.

Valve stem-to-guide clearance can also be checked using a dial indicator (gauge) to measure the amount of movement of the valve when lifted off the valve seat. ● **SEE FIGURE 27–24**.

OVERSIZE STEM VALVES

Some domestic vehicle manufacturers that have integral valve guides in their engines recommend reaming worn valve guides and installing new valves with **oversize (OS) stems**. When a valve guide is worn, the valve stem is also likely to be worn. In this case, new valves are required. If new valves are used, they can just as well have oversize stems as standard stems. Typically, available sizes include 0.003, 0.005, 0.015, and 0.03 inch OS. The valve guide is reamed or honed to the correct size to fit the oversize stem of the new valve.

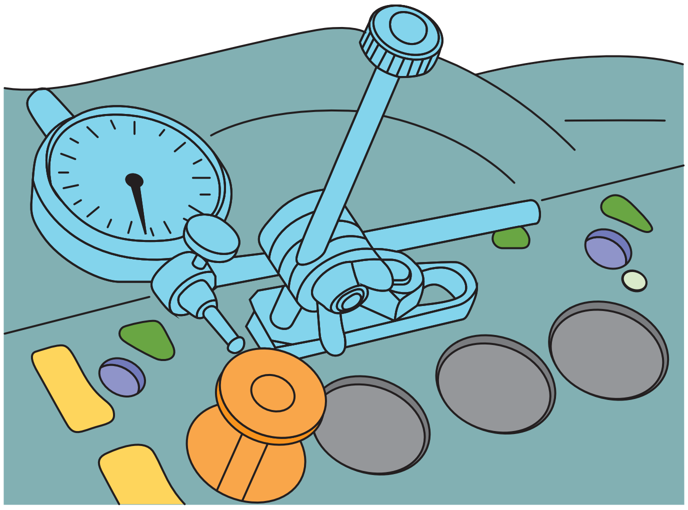


FIGURE 27–24 Measuring valve guide-to-stem clearance with a dial indicator while rocking the stem in the direction of normal thrust. The reading on the dial indicator should be compared to specifications because it does not give the guide-to-stem clearance directly. The valve is usually held open to its maximum operating lift.

The resulting clearance of the valve stem in the guide is the same as the original clearance. The oil clearance and the heat transfer properties of the original valve and guide are not changed when new valves with oversize stems are installed.

NOTE: Many remanufacturers of cylinder heads use oversize valve stems to simplify production.

VALVE GUIDE REPLACEMENT

PURPOSE When an engine is designed with replaceable valve guides, their replacement is always recommended when the cylinder head is being reconditioned.

VALVE GUIDE REPLACEMENT METHODS The automotive machine shop will use one of several methods to restore the valve guides. These could include one of the following depending on the engine and the machine shop preference.

Valve guide inserts are used when the integral valve guide is badly worn. This repair method is usually preferred in heavy-duty and high-speed engines. Two types of guide inserts are commonly used for guide repair.

- Thin-walled bronze alloy sleeve bushing
- Spiral bronze alloy bushing

INTAKE AND EXHAUST VALVES

TERMINOLOGY Automotive engine valves are of a **poppet valve** design. The term *poppet* refers to the shape of the valve and their operation in automotive engines. The valve is opened by means of a valve train that is operated by a cam. The cam is timed to the piston position and crankshaft cycle. The valve is closed by one or more springs.

A typical valve is shown in ● **FIGURE 27–25**.

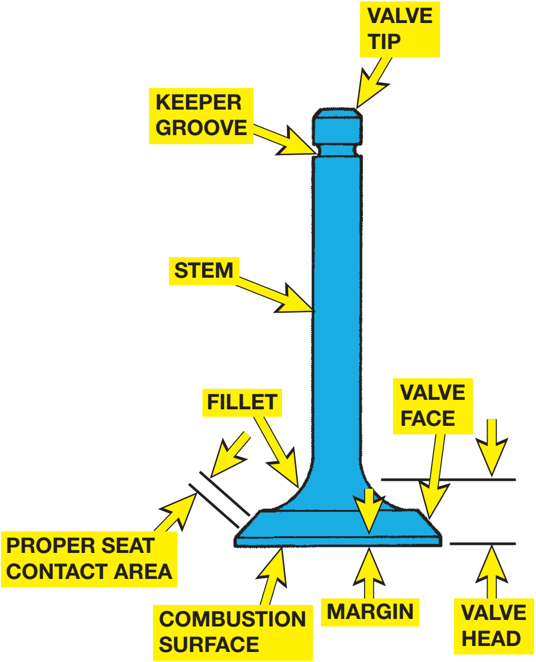


FIGURE 27–25 Identification of the parts of a valve.

Intake valves control the inlet of cool, low-pressure induction charges. Exhaust valves handle hot, high-pressure exhaust gases. This means that exhaust valves are exposed to more severe operating conditions. They are, therefore, made from much higher quality materials than the intake valves, which makes them more expensive.

The valve is held in place and is positioned in the head by the **valve guide**. The portion of the valve that seals against the **valve seat** in the cylinder head is called the **valve face**. The face and seat will have an angle of either 30 or 45 degrees, which are the nominal angles; actual service angles may vary. Most engines use a nominal 45-degree valve and seat angle.

PARTS INVOLVED

- A **valve spring** holds the valve against the seat.
- The valve *keepers* (also called **locks**) secure the spring **retainer** to the stem of the valve.

For valve removal, it is necessary to compress the spring and remove the valve keepers. Then the spring, valve seals, and valve can be removed from the head. A typical valve assembly is shown in ● **FIGURE 27–26**.

VALVE SIZE RELATIONSHIPS Extensive testing has shown that a normal relationship exists between the different dimensions of valves.

- **Intake valves.** Engines with cylinder bores that measure from 3 to 8 inches (80 to 200 mm) will have intake valve head diameters that measure approximately 45% of the bore size. The intake valve must be larger than the exhaust valve to handle the same mass of gas. The larger intake valve controls low-velocity, low-density gases. The distance the valve opens is close to 25% of the valve head diameter.
- **Exhaust valves.** The exhaust valve head diameter is approximately 38% of the cylinder bore size. Exhaust valve heads are, therefore, approximately 85% of the size of intake valve heads. The exhaust valve, however, controls high-velocity, high-pressure gases. These gases can be handled by a smaller valve. ● **SEE FIGURE 27–27**.

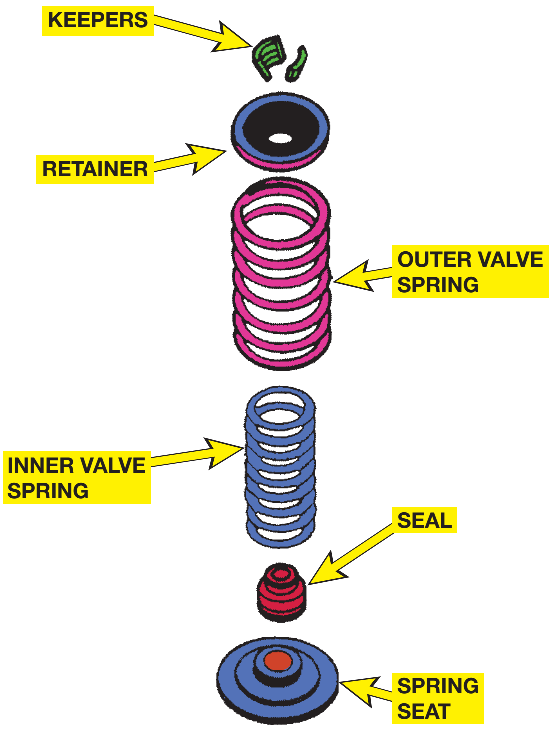


FIGURE 27–26 Typical valve spring and related components. Dual valve springs are used to reduce valve train vibrations and a spring seat is used to protect aluminum heads.

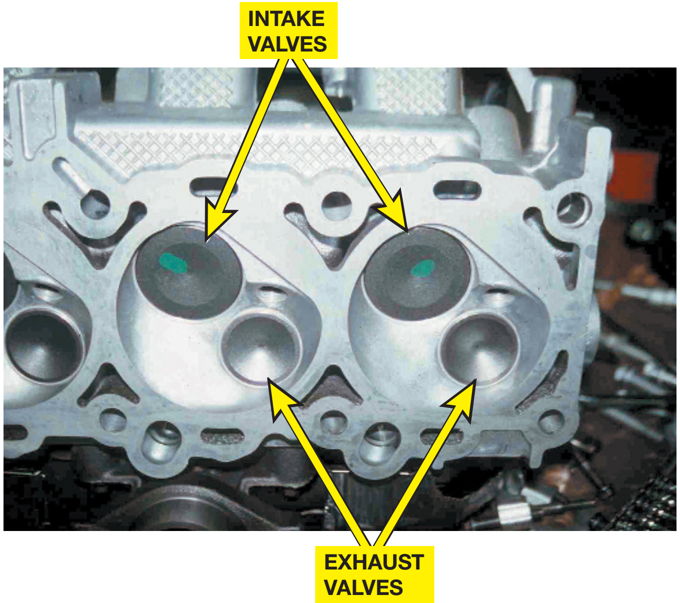


FIGURE 27–27 The intake valve is larger than the exhaust valve because the intake charge is being drawn into the combustion chamber at a low speed due to differences in pressure between atmospheric pressure and the pressure (vacuum) inside the cylinder. The exhaust is actually pushed out by the piston and, therefore, the size of the valve does not need to be as large, leaving more room in the cylinder head for the larger intake valve.

VALVE MATERIALS

- **Alloy steel.** Alloys used in exhaust valve materials are largely of chromium for oxidation resistance, with small amounts of nickel, manganese, and nitrogen added. Heat-treating is used whenever it is necessary to produce special valve properties.
- **Stellite®.** An alloy of nickel, chromium, and tungsten, **Stellite®** is nonmagnetic. Some valves use this product only on the tip of the valve to help reduce wear in places where the rocker arm contacts the valve stem on engines that do not use a roller rocker arm. Stellite® is also used on some valve faces.
- **Inconal®.** A type of alloy containing nickel, chrome, and iron and is used mostly in racing engines.
- **Titanium.** About half the weight of conventional valves, titanium reduces the tension on valve springs resulting in higher RPM engine operation. The valve stems are often moly coated to help prevent sticking in the valve guide.
- **Stainless steel.** Used in many heavy-duty applications, stainless steel often uses chrome-plated valve stems and Stellite tips to improve long-term durability.
- **Aluminized.** The valve is aluminized where corrosion may be a problem. Aluminized valve facing reduces valve recession when unleaded gasoline is used. Aluminum oxide forms to separate the valve steel from the cast-iron seat to keep the face metal from sticking.

SODIUM-FILLED VALVES Some heavy-duty applications use hollow stem exhaust valves that are partially filled with metallic sodium. The sodium in the valve becomes a liquid at operating temperatures. As it splashes back and forth in the valve stem, the sodium transfers heat from the valve head to the valve stem. The heat goes through the valve guide into the coolant. In general, a one piece valve design using properly selected materials will provide satisfactory service for automotive engines. ● **SEE FIGURE 27–28.**

WARNING

If a sodium-filled valve is damaged and the sodium leaks out, it can cause a fire if exposed to water. Sodium reacts violently when exposed to water and burns uncontrollably.

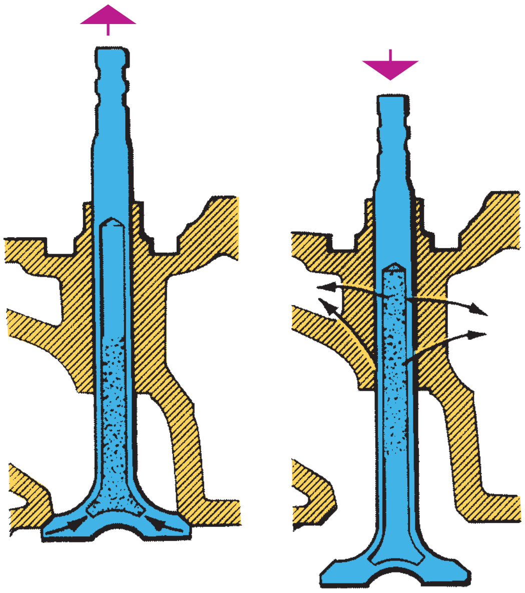


FIGURE 27–28 A sodium-filled valve uses a hollow stem, which is partially filled with metallic sodium (a liquid when hot) to conduct heat away from the head of the valve.

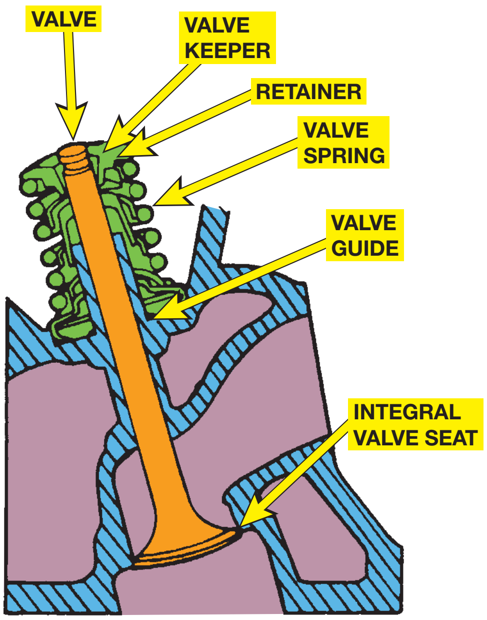


FIGURE 27–29 Integral valve seats are machined directly into the cast-iron cylinder head and are induction hardened to prevent wear.

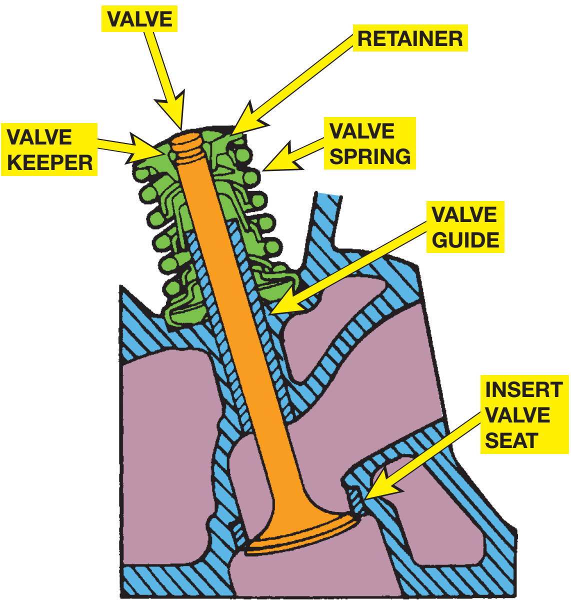


FIGURE 27–30 Insert valve seats are a separate part that is interference fitted to a counterbore in the cylinder head.

VALVE SEATS

INTEGRAL SEATS The valve face closes against a valve seat to seal the combustion chamber. The seat is generally formed as part of the cast-iron head of automotive engines, called an **integral seat**. ● **SEE FIGURE 27–29**.

The seats are usually induction hardened so that unleaded gasoline can be used. This minimizes valve recession as the engine operates. Valve recession is the wearing away of the seat, so that the valve sits further into the head.

INSERT SEATS An **insert seat** fits into a machined recess in the steel or aluminum cylinder head. Insert seats are used in *all* aluminum head engines and in applications for which corrosion and wear resistance are critical. Aluminum heads also include insert valve guides.

The exhaust valve seat runs as much as 180°F (82°C) *cooler* in aluminum heads than in cast-iron heads, because aluminum conducts heat faster than cast iron. Insert seats are also used to recondition integral valve seats that have been badly damaged. ● **SEE FIGURE 27–30**.

VALVE SPRINGS

PURPOSE AND FUNCTION A valve spring holds the valve against the seat when the valve is not being opened. One end of the valve spring is seated against the head. The other end of the spring is attached under compression to the valve stem through a valve spring retainer and a valve spring keeper (lock). ● **SEE FIGURE 27–31**.

SPRING MATERIALS AND DESIGN Valves usually have a single inexpensive valve spring. The springs are generally made of chromium vanadium alloy steel. When one spring cannot control the valve, another spring or damper is added. Some valve springs use a flat coiled damper inside the spring. The damper helps to reduce valve seat wear. This eliminates spring surge and adds some valve spring tension. The normal valve spring winds up as it is compressed. This causes a small, but important, turning motion as the valve closes on the seat. The turning motion helps to keep the wear even around the valve face. ● **SEE FIGURE 27–32**.

- Multiple valve springs are used where large camshaft lobe lifts are required and a single spring does not have enough strength to control the valve.

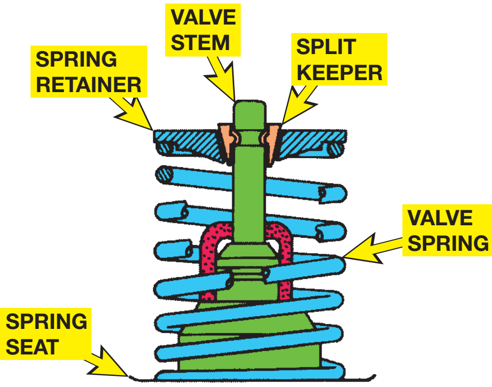


FIGURE 27–31 A retainer and two split keepers hold the spring in place on the valve. A separate metal washer is used on aluminum heads. Otherwise, the spring seat is a machined area in the head.

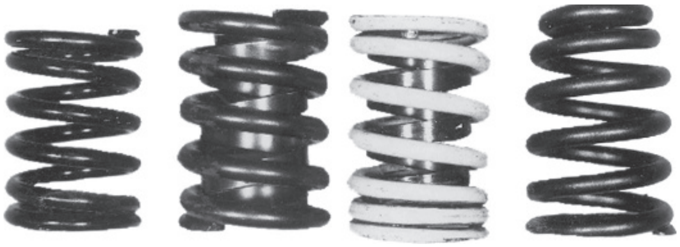


FIGURE 27–32 Valve spring types (left to right): coil spring with equally spaced coils; spring with damper inside spring coil; closely spaced spring with a damper; taper wound coil spring.

- If dual coil springs are wrapped in the same direction, they are used for extra tension.
- If the inner spring or flat damper is wrapped in the opposite direction, it is used as a damper to control spring oscillations. This is done to control valve spring surge and to prevent excessive valve rotation. These are sometimes called *surge dampers.*

Valve spring surge is the tendency of a valve spring to vibrate.

VARIABLE RATE SPRINGS **Variable rate springs**, also called *progressive rate* or *variable pitch springs,* have uneven spacing between the coils. Where nonprogressive rate (linear) valve springs provide the same rate, through all heights, a variable rate valve spring has a different spring rate, depending on how much it is compressed. One advantage of using a variable rate spring is that it provides a low seat pressure and still provides the rate needed for high-lift camshaft designs. This type of spring is used to help control valve surge.

VALVE SPRING INSPECTION Valve springs close the valves after they have been opened by the cam. They must close squarely to form a tight seal and to prevent valve stem and guide wear. It is necessary, therefore, that the springs be square and have the proper amount of closing force. The valve springs are checked for squareness by rotating them on a flat surface with a square held against the side. They should be within 1/16 inch (1.6 mm) of being square. Out-of-square springs will have to be replaced. ● **SEE FIGURE 27–33**.

Only the springs that are square should be checked to determine their compressed force. The surge damper is often specified to be *removed* from the valve spring when the spring force is being checked. Check service information for the exact procedure to follow for the engine being checked. A valve spring scale is used to measure the valve spring force at a specific height measurement. ● **SEE FIGURE 27–34**.

Another type uses a torque wrench on a lever system to measure the valve spring force. Valve springs are checked for the following:

1. Free height (or length) without being compressed, should be within 1/16 (0.06) inch of specifications
2. Pressure with valve closed and height as per specifications
3. Pressure with valve open and height as per specifications

Most specifications allow for variations of plus or minus 10% from the published figures.

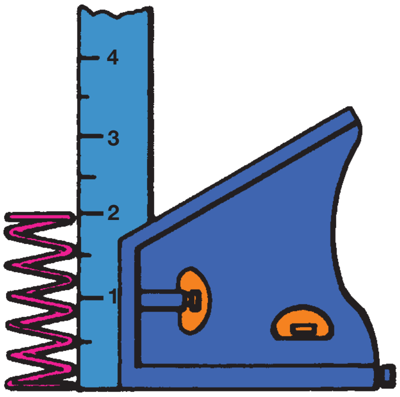


FIGURE 27–33 All valve springs should be checked for squareness by using a square on a flat surface and rotating the spring while checking. The spring should be replaced if more than 1/16 inch (1.6 mm) is measured between the top of the spring and the square.

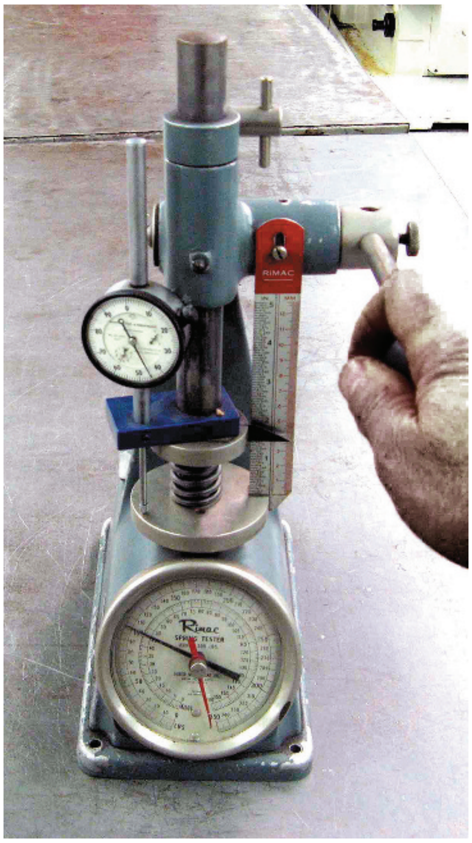


FIGURE 27–34 One popular type of valve spring tester used to measure the compressed force of valve springs. Specifications usually include (1) free height (height without being compressed), (2) pressure at installed height with the valve closed, and (3) pressure with the valve open to the height specified.

VALVE KEEPERS AND ROTATORS

VALVE KEEPERS Valve keepers (locks) are used on the end of the valve stem to retain the spring. The inside surfaces of the keeper use a variety of grooves or beads. The design depends on the holding requirements. The outside of the keeper fits into a cone-shaped seat in the center of the valve spring retainer. ● **SEE FIGURE 27–35**.

VALVE ROTATORS Some valve spring retainers have built-in devices called valve rotators. They cause the valve to rotate in a controlled manner as it is opened. The purposes and functions of valve rotators include the following:

- Help prevent carbon buildup from forming by providing a "wiping" action of the valve face
- Reduce hot spots on the valves by constantly turning them
- Help to even out the wear on the valve face and seat
- Improve valve guide lubrication

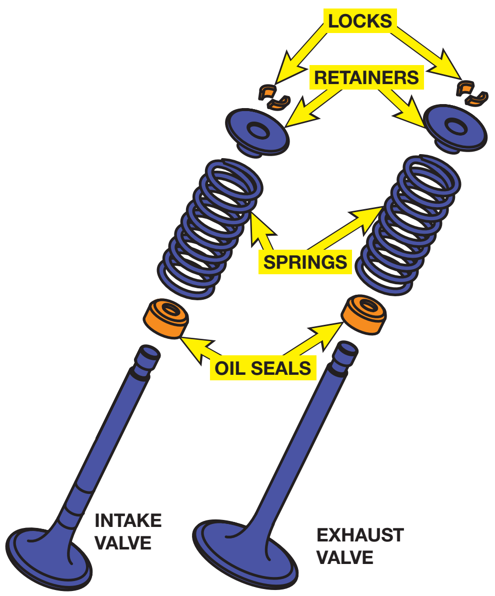


FIGURE 27–35 Valve keepers (also called locks) are tapered so they wedge into a tapered hole in the retainer.

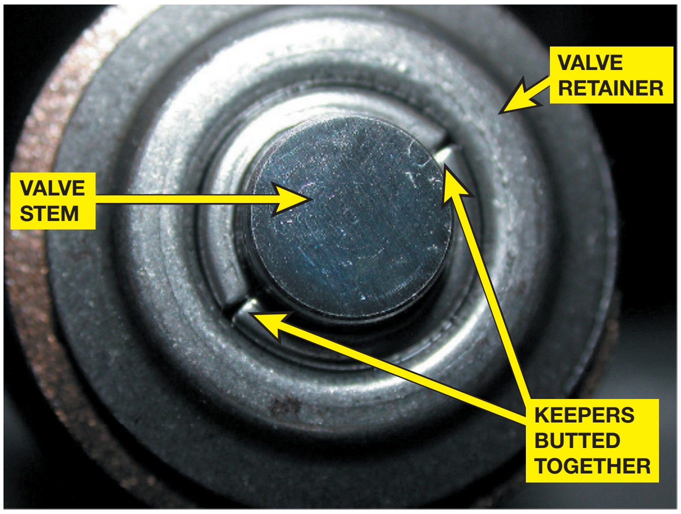


FIGURE 27–36 Notice that there is no gap between the two keepers (ends butted together). As a result, the valve is free to rotate because the retainer applies a force, holding the keepers in place, but not tight, against the stem of the valve. Most engines, however, do not use free rotators and, therefore, have a gap between the keepers.

The two types of valve rotators are free and positive.

- **Free rotators** simply take the pressure off the valve to allow engine vibration to rotate the valve. ● **SEE FIGURE 27–36**.
- **Positive rotators** use the force of the valve opening to rotate the valve. One type uses small steel balls and a slight ramp to cause the valve to rotate. Each ball moves down its ramp to turn the rotator sections as the valve opens. A second type uses a coil spring. The spring lies down as the valve opens. This action turns the rotator body in relation to the collar. Valve rotators are only used when it is desirable to increase the valve service life, because rotors cost more than plain retainers. ● **SEE FIGURE 27–37**.

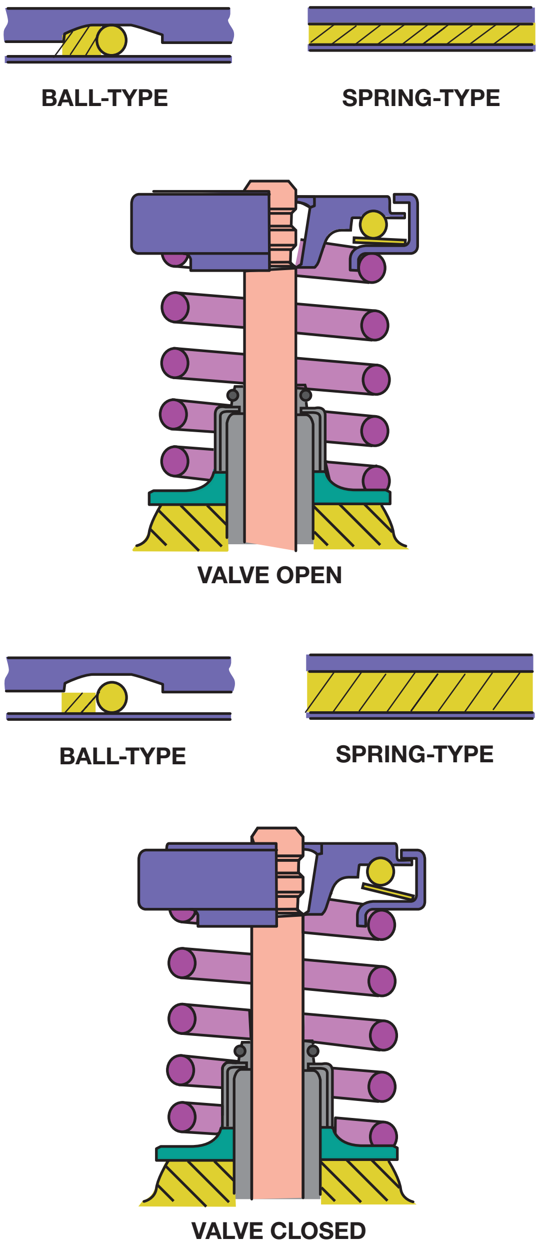


FIGURE 27–37 Type of valve rotator operation. Ball-type operation is on the left and spring-type operation is on the right.

VALVE SEAT RECONDITIONING

VALVE SEAT RECONDITIONING The machine shop will recondition the valve seats at the following times:

- After the cylinder head has been properly cleaned, resurfaced, and the valve guides have been resized or reconditioned
- When the valve guides have been replaced

The final valve seat width and position are checked with the valve that is to be used on the seat being reconditioned.

VALVE SEAT ANGLES Valve seats will have a normal seat angle of either 45 or 30 degrees.

- **45 degrees.** This is the most used, and the narrow 45-degree valve seats will crush carbon deposits to prevent buildup of deposits on the seat. The valve heat will transfer to the seat and cylinder head.

- **30 degrees.** Usually used on intake valves only. The 30-degree valve seat is more likely to burn than a 45-degree seat because some deposits can build up to keep the valve from seating properly. The 30-degree valve seat will, however, allow more gas flow than a 45-degree valve seat when both are opened to the same amount of lift.

INTERFERENCE ANGLE Ideally, the valve face and valve seat should have exactly the same angle. This is impossible, especially on exhaust valves, because the valve head becomes much hotter than the seat, so the valve expands more than the seat. This expansion causes the hot valve to contact the seat in a different place on the valve than it did when it was cold. As a result of its shape, the valve does not expand evenly when heated. This uneven expansion also affects the way in which the hot valve contacts the seat. In valve and valve seat reconditioning, the valve is often ground with a face angle 1 degree less than the seat angle to compensate for the change in hot seating. This angle is called an interference angle. It makes a positive seal at the combustion chamber edge of the seat when the engine is first started after a valve job.

As the engine operates, the valve will peen itself on the seat. In a short time, it will make a matched seal. After a few thousand miles, the valve will have formed its own seat.

VALVE STEM HEIGHT

DEFINITION **Valve stem height** is the distance the valve stem is above the spring seat. Valve stem height is a different measurement from installed height. ● **SEE FIGURE 27–38**.

- Valve stem height is important to maintain for all engines, but especially for overhead camshaft engines.
- When the valve seat and the valve face are ground, the valve stem extends deeper into the combustion chamber and extends higher or farther into the cylinder head.
- The valve is put in the head, and the length from the tip to the valve spring seat is measured.
- The tip is ground to shorten the valve stem length to compensate for the valve face and seat grinding.

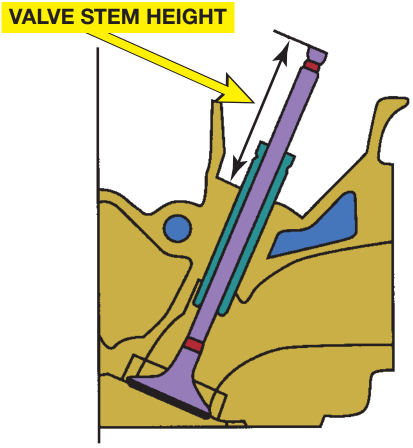


FIGURE 27–38 Valve stem height is measured from the spring seat to the tip of the valve after the valve seat and valve face have been refinished. If the valve stem height is too high, up to 0.02 inch (0.5 mm) can be ground from the tips of most valves.

- The valve will not close if the valve tip extends too far from the valve guide on engines that have hydraulic lifters and nonadjustable rocker arms.
- If the valve is too long, the tip may be ground by as much as 0.020 inch (0.5 mm) to reduce its length. If more grinding is required, the valve must be replaced. If it is too short, the valve face or seat may be reground, within limits, to allow the valve to seat deeper.
- Where excessive valve face and seat grinding has been done, shims can be placed under the rocker shaft on some engines as a repair to provide correct hydraulic lifter plunger centering. These shims must have the required lubrication holes to allow oil to enter the shaft.

INSTALLED HEIGHT

DEFINITION **Installed height** is the distance between the valve spring seat and the underside of the valve spring retainer. When the valves and/or valve seats have been machined, the valve projects farther than before on the rocker arm side of the head. The valve face is slightly recessed into the combustion chamber side of the head. The valve spring tension is, therefore, reduced because the spring is not as compressed as it was originally.

CORRECTING INSTALLED HEIGHT To restore original valve spring tension, special valve spring spacers, inserts, or shims are installed under the valve springs. These shims are usually called **valve spring inserts (VSI)**. Valve spring inserts are generally available in three different thicknesses.

- **0.015 inch (0.38 mm).** Used for balancing valve spring pressure
- **0.030 inch (0.75 mm).** Generally used for new springs on cylinder heads that have had the valve seats ground and valves refaced
- **0.060 inch (1.5 mm).** Necessary to bring assembled height to specifications (These thicker inserts may be required if the seats have been resurfaced more than once.)

STEP 1 To determine the exact thickness of insert to install, measure the valve spring installed height. ● **SEE FIGURE 27–39**.

STEP 2 If the installed height is greater than specifications, select the valve spring insert (shim) that brings the installed

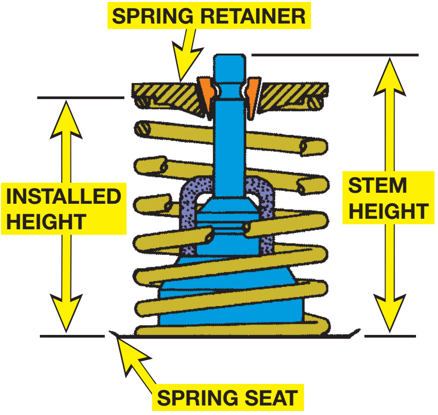


FIGURE 27–39 Installed height is determined by measuring the distance from the spring seat to the bottom of the valve spring retainer.

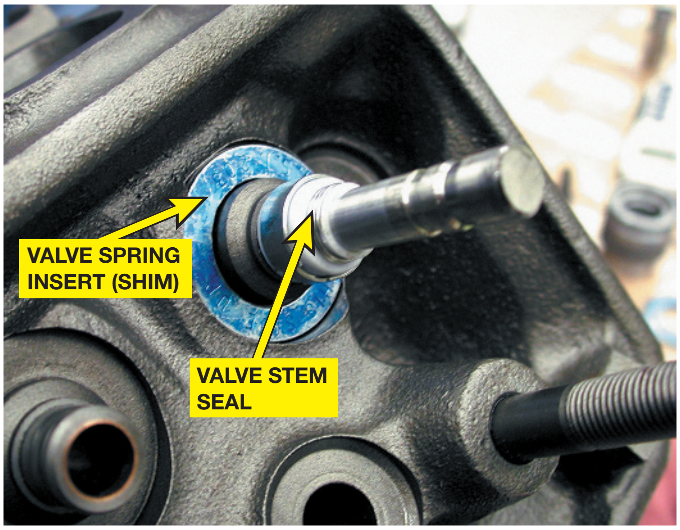


FIGURE 27–40 Valve spring inserts are used to restore proper installed height.

height to within specifications. Be sure to install the valve spring inserts with the grooves facing toward the cylinder head. These are used to allow air to flow between the cylinder and the insert to help insulate the valve springs. Most inserts are labeled with the message, "This Side Up," which means toward the valve spring. ● **SEE FIGURE 27–40**.

CAUTION: Do not use more than one valve spring insert. If the correct installed height cannot be achieved using one insert, replace the valve seat to restore the proper installed height.

VALVE STEM SEALS

PURPOSE AND FUNCTION Leakage past the valve guides is a major oil consumption problem in any overhead valve or overhead cam engine. A high vacuum exists in the intake port, as shown in ● **FIGURE 27–41**.

Most engine manufacturers use valve stem seals on the exhaust valve, because a weak vacuum in the exhaust port area can draw oil into the exhaust stream, as illustrated in ● **FIGURE 27–42**.

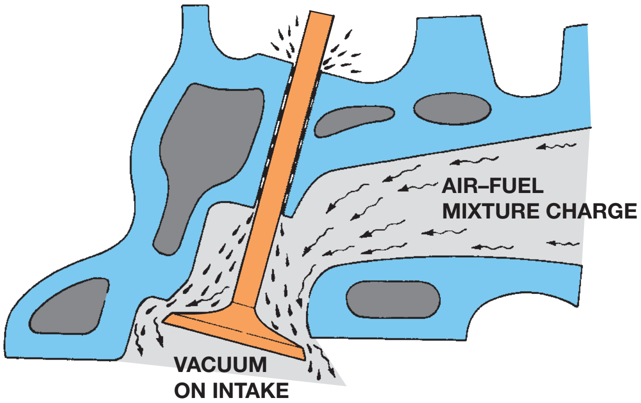


FIGURE 27–41 Engine vacuum can draw oil past the valve guides and into the combustion chamber. The use of valve stem seals limits the amount of oil that is drawn into the engine. If the seals are defective, excessive blue (oil) smoke is most often observed during engine start-up.

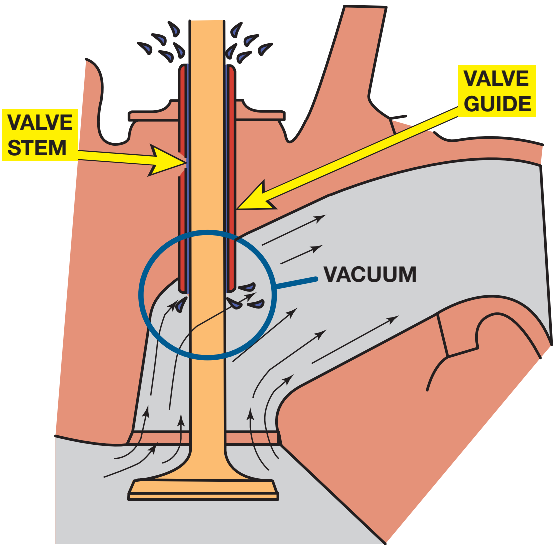


FIGURE 27–42 Engine oil can also be drawn past the exhaust valve guide because of a small vacuum created by the flow of exhaust gases. Any oil drawn past the guide would simply be forced out through the exhaust system and not enter the engine. Some engine manufacturers do not use valve stem seals on the exhaust valves.

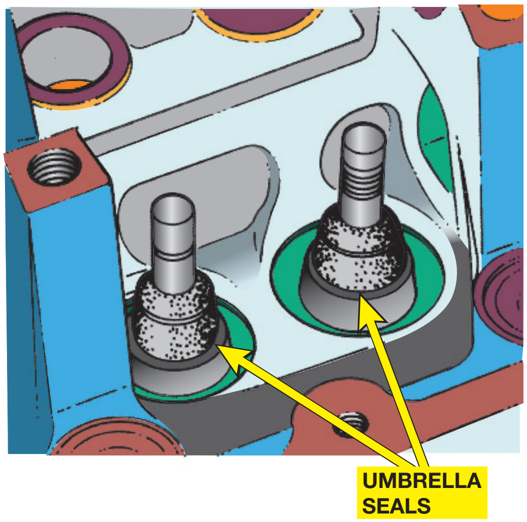
Valve stem seals are used on overhead valve engines to control the amount of oil used to lubricate the valve stem as it moves in the guide. The stem and guide will scuff if they do not have enough oil. Too much oil will cause excessive oil consumption and will cause heavy carbon deposits to build up on the spark plug nose and on the valves.

TYPES OF VALVE STEM SEALS The types of valve stem seals include the following:

- The *umbrella valve stem seal* holds tightly on the valve stem and moves up and down with the valve. Any oil that spills off the rocker arms is deflected out over the valve guide, much as water is deflected over an umbrella. As a result, umbrella valve stem seals are often called *deflector valve stem seals*. ● **SEE FIGURE 27–43**.
- The *O-ring valve stem seal* used on Chevrolet engines keeps oil from leaking between the valve stem and valve spring retainer. The oil is deflected over the retainer and shield. The assembly controls oil like an umbrella-type oil seal. Both types of valve stem seals allow only the correct amount of oil to reach the valve guide to lubricate the valve stem. The rest of the oil flows back to the oil pan. ● **SEE FIGURE 27–44**.
- *Positive valve stem seals* hold tightly around the valve guide, and the valve stem moves through the seal. The Teflon® wiping ring wipes the excess oil from the valve stem. ● **SEE FIGURES 27–45 AND 27–46**.

VALVE SEAL MATERIALS Valve stem seals are made from many different types of materials. They may be made from nylon or Teflon, but most valve stem seals are made from synthetic rubber. Three types of synthetic rubbers are in common use.

- Nitrile (Nitril)
- Polyacrylate
- Viton


UMBRELLA SEALS

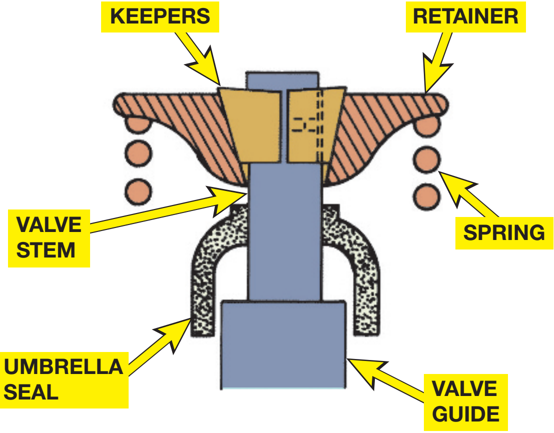

KEEPERS
RETAINER
VALVE STEM
SPRING
UMBRELLA SEAL
VALVE GUIDE

FIGURE 27–43 Umbrella seals install over the valve stems and cover the guide.

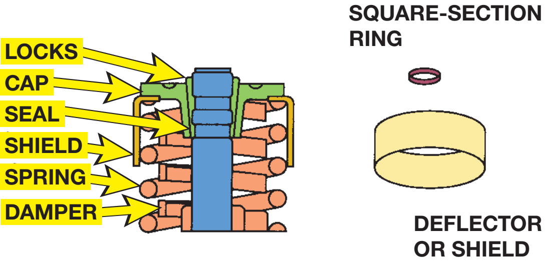
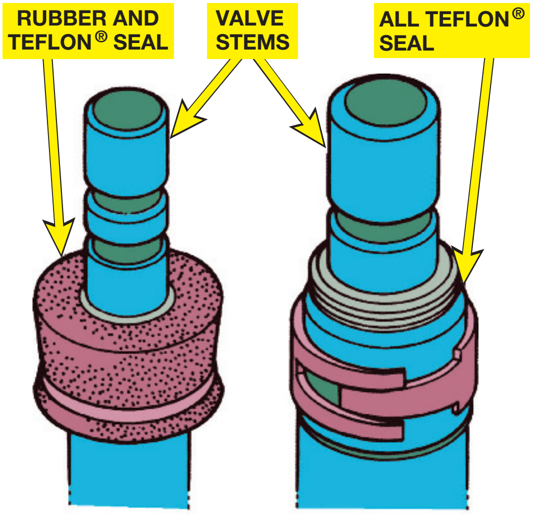

LOCKS
CAP
SEAL
SHIELD
SPRING
DAMPER
SQUARE-SECTION RING
DEFLECTOR OR SHIELD

FIGURE 27–44 A small square cut O-ring is installed under the retainer in a groove in the valve under the groove(s) used for the keepers (locks).

Nitrile is the oldest valve stem seal material. It has a low cost and a low useful temperature. Engine temperatures have increased with increased emission controls and improved efficiencies, which make it necessary to use premium polyacrylate, even with its higher cost. In many cases, it is being retrofit to the older engines because it will last much longer than Nitrile. Diesel engines and engines used for racing, heavy trucks, and trailer towing, along with turbocharging, operate at still higher temperatures. These engines may require expensive Viton valve stem seals that operate at higher temperatures. ● **SEE FIGURE 27–47**.


RUBBER AND TEFLON® SEAL
VALVE STEMS
ALL TEFLON® SEAL

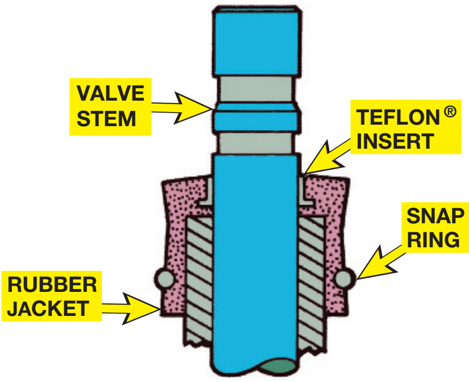

VALVE STEM
TEFLON® INSERT
SNAP RING
RUBBER JACKET

FIGURE 27–45 Positive valve stem seals are the most effective type because they remain stationary on the valve guide and wipe the oil from the stem as the valve moves up and down.

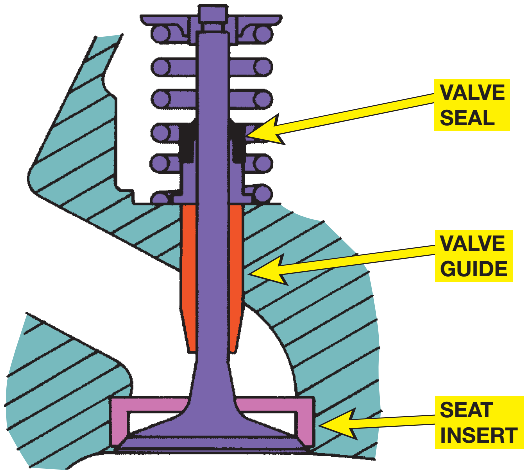

VALVE SEAL
VALVE GUIDE
SEAT INSERT

FIGURE 27–46 The positive valve stem seal is installed on the valve guide.

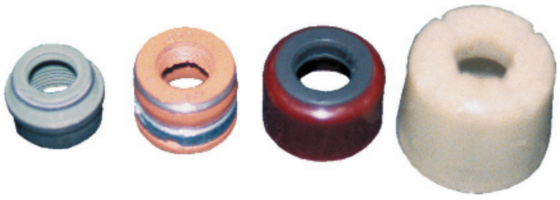


FIGURE 27–47 An assortment of shapes, colors, and materials of positive valve stem seals.

TECH TIP

Purchase Engine Parts from a Known Manufacturer

It is interesting to note that an automotive service technician cannot tell the difference between these synthetic rubber valve stem seals if they have come out of the same mold for the same engine. Often suppliers that package gasket sets for sale at a low price will include low-temperature Nitrile, even when the engine needs higher-temperature polyacrylate. The best chances of getting the correct valve stem seal material for an engine is to purchase gaskets and seals packaged by a major brand gasket company.

TECH TIP

Check before Bolting It On

Using new assembled cylinder heads, whether aluminum or cast iron, is a popular engine buildup option. However, experience has shown that metal shavings and casting sand are often found inside the passages.

Before bolting on these “ready to install” heads, disassemble them and clean all passages. Often machine shavings are found under the valves. If this debris were to get into the engine, the results would be extreme wear or damage to the pistons, rings, block, and bearings. This cleaning may take several hours, but how much is your engine worth?

INSTALLING THE VALVES

PROCEDURE Assembling a cylinder head includes the following steps:

STEP 1 Clean the reconditioned cylinder head thoroughly with soap and water to wash away any remaining grit and metal shavings from the valve grinding operation.

STEP 2 Valves are assembled in the head, one at a time. The valve guide and stem are given a liberal coating of engine oil, and the valve is installed in its guide. Install the valve spring seat if assembling an aluminum head. ● **SEE FIGURE 27–48**.

STEP 3 Umbrella or positive valve stem seals are installed. Push umbrella seals down until they touch the valve guide. Use a plastic sleeve over the tip of the valve when installing positive seals to prevent damage to the seal lip. Make sure that the positive seal is fully seated on the valve guide and that it is square.

STEP 4 Hold the valve against the seat as the valve spring seat or insert, valve spring, valve seal, and retainer are placed over the valve stem. One end of the valve spring compressor pushes on the retainer to compress the spring.

STEP 5 The O-ring type of valve stem seal, if used, is installed in the lower groove. The valve keepers are installed while the valve spring is compressed. Using grease helps to keep them attached to the valve stem as the valve spring compressor is released.

STEP 6 Release the valve spring compressor slowly and carefully while making sure that the valve keepers seat properly between the valve stem grooves and the retainer. ● **SEE FIGURE 27–49**.

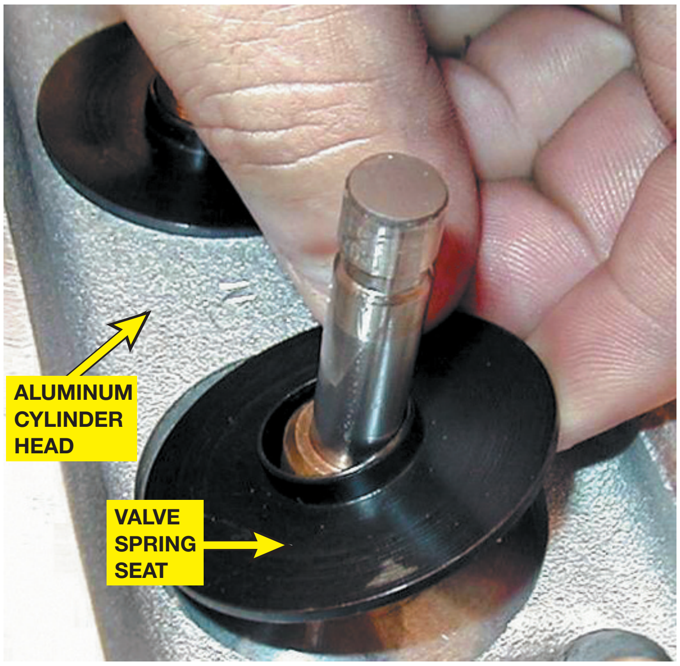


FIGURE 27–48 A metal valve spring seat must be used between the valve spring and the aluminum cylinder head. Many Chrysler aluminum cylinder heads use a combination valve spring seat and valve stem seal.

TECH TIP

Use a Brass Mallet to Check Valve Installation

As a final quality control check, use a copper or brass mallet and lightly tap each valve spring retainer after final assembly to make sure the keepers were correctly seated and installed. If they were not, the mallet would cause them to “fly off.” Best to check now rather than when the engine is started.

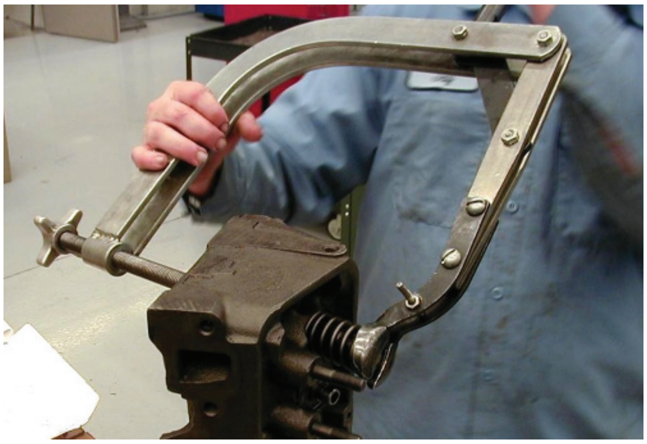


FIGURE 27–49 A valve spring compressor is used to compress the spring and retainer so the keepers can be installed.

REVIEW QUESTIONS

1. What is the purpose of valve springs ?
2. What are the advantages of using four valves per cylinder?
3. How is valve stem-to-guide clearance measured?
4. What is an interference angle between the valve and the sea?
5. How are the correct valve spring inserts (shims) selected and why are they used?

CHAPTER QUIZ

1. Cylinder heads with four valves flow more air than those with two valves because they _________.
   - **a.** have a greater open area
   - **b.** use a higher lift camshaft
   - **c.** increase the velocity of the air
   - **d.** Both a and c
2. Two technicians are discussing cylinder heads. Technician A says that valve guides should be replaced if worn beyond specifications. Technician B says cam bearing cap bolts should be loosened in a specific sequence. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Technician A says that cylinder heads have passages for coolant to flow. Technician B says cylinder heads have passages for refrigerant to flow. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. The gasket surface of a cylinder head, as measured with a precision straightedge, should have a maximum variation of _________.
   - **a.** 0.002 inch in any 6-inch length, or 0.004 inch overall
   - **b.** 0.001 inch in any 6-inch length, or 0.004 inch overall
   - **c.** 0.020 inch in any 10-inch length, or 0.02 inch overall
   - **d.** 0.004 inch in any 10-inch length, or 0.008 inch overall
5. Which of the following statements is true about valve seats?
   - **a.** Insert seats are used only in cast-iron heads.
   - **b.** Insert seats fit into a machined recess under the valve spring.
   - **c.** Exhaust valve seats run cooler in aluminum heads than in cast-iron heads.
   - **d.** Integral exhaust valve seats operate at hotter temperatures than do insert seats.
6. Typical valve stem-to-guide clearance is _________.
   - **a.** 0.03 to 0.045 inch (0.8 to 1 mm)
   - **b.** 0.015 to 0.02 inch (0.4 to 0.5 mm)
   - **c.** 0.005 to 0.01 inch (0.13 to 0.25 mm)
   - **d.** 0.001 to 0.004 inch (0.03 to 0.05 mm)
7. Which statement is true about surface finish?
   - **a.** Cast-iron surfaces should be smoother than aluminum surfaces.
   - **b.** The rougher the surface, the higher the microinch finish measurement.
   - **c.** The smoother the surface, the higher the microinch finish measurement.
   - **d.** A cylinder head should be much smoother than a crankshaft journal.
8. Dampers (damper springs) are used inside some valve springs to _________.
   - **a.** prevent valve spring surge
   - **b.** keep the valve spring attached to the valve
   - **c.** decrease valve spring pressure
   - **d.** retain valve stem seals
9. Valve spring inserts (shims) are designed to _________.
   - **a.** increase installed height of the valve
   - **b.** decrease installed height of the valve
   - **c.** adjust the correct valve spring installed height
   - **d.** decrease valve spring pressure to compensate for decreased installed height
10. Umbrella-type valve stem seals _________.
    - **a.** fit tightly onto the valve guide
    - **b.** fit on the valve face to prevent combustion leaks
    - **c.** fit tightly onto the valve stem
    - **d.** lock under the valve retainer

Chapter

28

CAMSHAFTS AND VALVE TRAINS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the purpose and function of the camshaft.
- Describe camshaft design.
- Discuss camshaft drives.
- Discuss camshaft movement.
- Discuss rocker arms.
- Discuss pushrods.
- Discuss tappets.
- Explain overhead camshaft valve trains.
- Explain valve train lubrication.
- Explain valve train problem diagnosis.
- Explain camshaft specifications.
- Explain how to remove a camshaft.
- Explain how to measure a camshaft.

KEY TERMS:

Aerated 314 • Asymmetrical 308 • Bucket 313 • Cam chucking 305 • Cam follower 313 • Cam-in-block 302 • Camshaft bearings 302 • Camshaft duration 315 • Composite camshaft 302 • Double roller chain 304 • Dual overhead camshaft (DOHC) 302 • Finger follower 313 • Flat-link type 304 • Freewheeling engine 305 • Hydraulic lash adjusters (HLA) 313 • Hydraulic valve lifter 311 • Interference engine 305 • Lobe 301 • Lobe centers 315 • Lobe displacement angle (LDA) 315 • Lobe lift 306 • Lobe separation 315 • Lobe spread 315 • Morse type 304 • Overhead camshaft (OHC) 302 • Overhead valve (OHV) 302 • Pump-up 312 • Ramp 311 • Roller chain type 304 • Silent chain type 304 • Single overhead camshaft (SOHC) 302 • Solid valve lifter 311 • Symmetrical 308 • Thrust plate 305 • Total indicator runout (TIR) 316 • Valve (camshaft) overlap 315 • Valve float 312 • Valve lash 311

CAMSHAFT

PURPOSE AND FUNCTION The major function of a camshaft is to open the valves. Camshafts have eccentric shapes called **lobes** that open the valve against the force of the valve springs. The valve spring closes the valve when the camshaft rotates off of the lobe. The camshaft lobe changes rotary motion (camshaft) to linear motion (valves). Cam shape or contour is the major factor in determining the operating characteristics of the engine.

OPERATION The camshaft is driven by

- Timing gears
- Timing chains
- Timing belts

The gear or sprocket on the camshaft has twice as many teeth, or notches, as the one on the crankshaft. This results in two crankshaft revolutions for each revolution of the camshaft. *The camshaft turns at one-half the crankshaft speed in all four-stroke cycle engines.*

Cam lobe shape has more control over engine performance characteristics than any other single engine part. Engines identical in every way except cam lobe shape may have completely different operating characteristics and performance. ● **SEE FIGURE 28–1**.

The camshaft may also operate the following:

- Mechanical fuel pump (carburetor-equipped engines)
- Oil pump
- Distributor (if equipped)

  ● **SEE FIGURE 28–2**.
- High-pressure fuel pump (gasoline direct-injected engines)

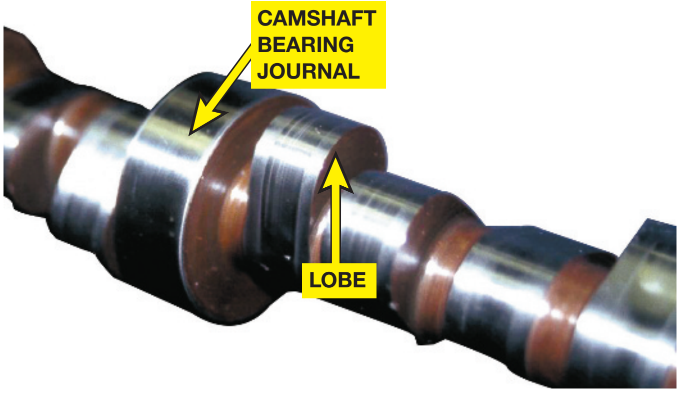


FIGURE 28–1 This high-performance camshaft has a lobe that opens the valve quickly and keeps it open for a long time.

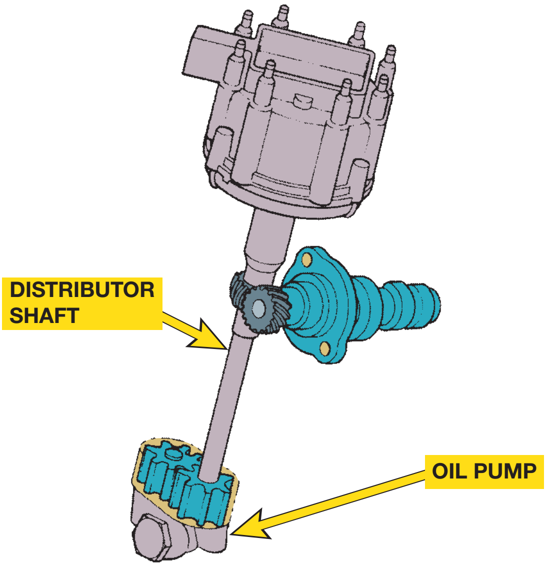


FIGURE 28–2 The camshaft drives the distributor and the oil pump through a shaft from the end of the distributor.

CAMSHAFT LOCATION There are two basic areas where the camshaft can be located in an engine.

- **In the engine block.** This design is called the **cam-in-block** design. The camshaft is supported in the block by **camshaft bearings** and driven by the crankshaft with a gear or sprocket and chain drive. Engines with the cam located in the block are called pushrod or **overhead valve (OHV)** engines. ● **SEE FIGURE 28–3**.
- **Overhead.** Overhead camshafts are either belt or chain driven from the crankshaft and are located in the cylinder head(s). This arrangement is called **overhead camshaft (OHC)** design. If there is a single overhead camshaft for *each bank* of cylinders, the engine is classified as a **single overhead camshaft (SOHC)** engine design. If an engine uses two overhead camshafts per bank of cylinders, this type of engine design is called a **dual overhead camshaft (DOHC)**.

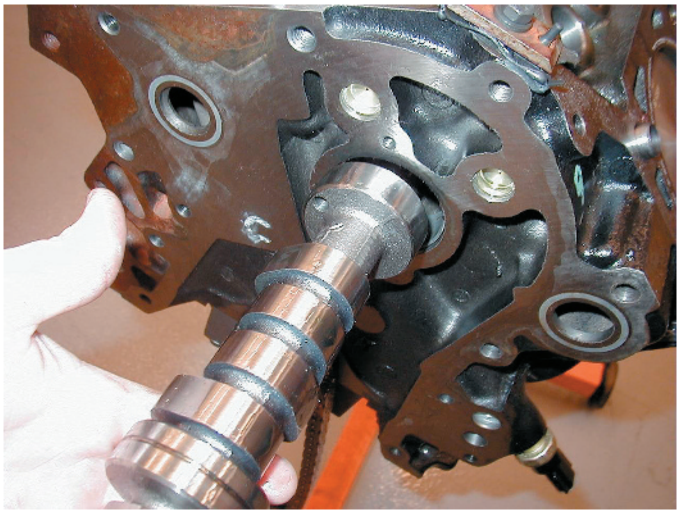


FIGURE 28–3 The camshaft rides on bearings inside the engine block above the crankshaft on a typical cam-in-block engine.

CAMSHAFT DESIGN

CONSTRUCTION The camshaft is usually a one-piece casting from chilled cast iron for many production engines that includes

- Lobes
- Bearing journals
- Accessory drive gear

● **SEE FIGURE 28–4**.

Other types of camshaft construction include

- **Forged steel** (often used in diesel engines)
- **Steel** machined from a solid billet
- **Composite camshafts**, which use a lightweight tubular shaft with hardened steel lobes press-fitted over the shaft. (The actual production of these camshafts involves placing the lobes over the tube shaft in the correct position.) A steel ball is then drawn through the hollow steel tube, expanding the tube and securely locking the cam lobes in position. ● **SEE FIGURE 28–5**.

CAMSHAFT-BEARING JOURNALS On pushrod engines, camshaft-bearing journals must be larger than the cam lobe so that the camshaft can be installed in the engine through the cam bearings. Some overhead cam engines have bearing caps on the cam bearings. These cams can have large cam lobes with small bearing journals. Cam bearings on some engines are progressively smaller from the front journal to the rear. Other engines use the same size of camshaft bearing on all the journals.

HARDNESS Older automotive camshafts were used with flat or convex-faced lifters and made from hardened alloy cast iron. It resists wear and provides the required strength. The very hardness of the camshaft causes it to be susceptible to chipping as the result of edge loading or careless handling.

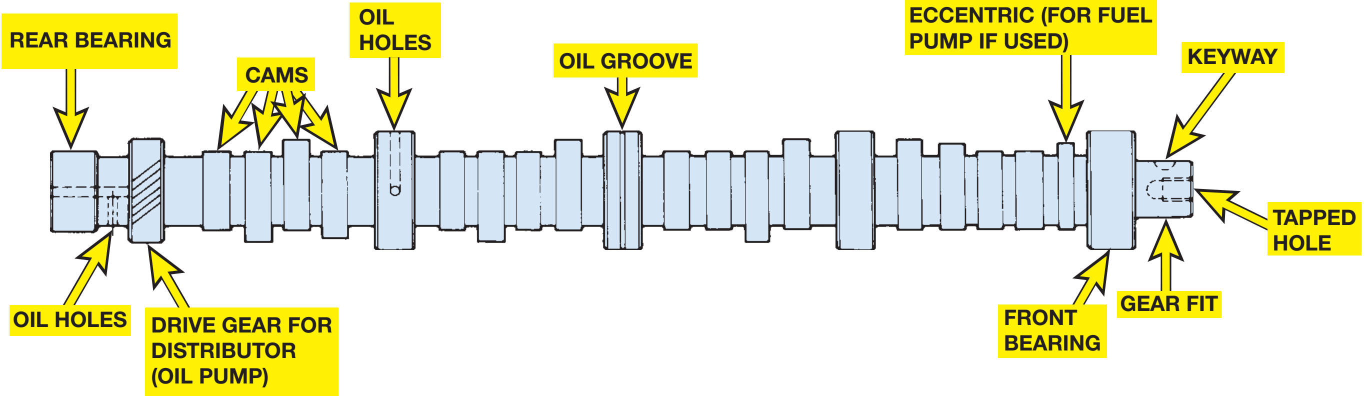

REAR BEARING
CAMS
OIL HOLES
OIL GROOVE
ECCENTRIC (FOR FUEL PUMP IF USED)
KEYWAY
TAPPED HOLE
GEAR FIT
FRONT BEARING
OIL HOLES
DRIVE GEAR FOR DISTRIBUTOR (OIL PUMP)

FIGURE 28–4 Parts of a cam and camshaft terms (nomenclature).

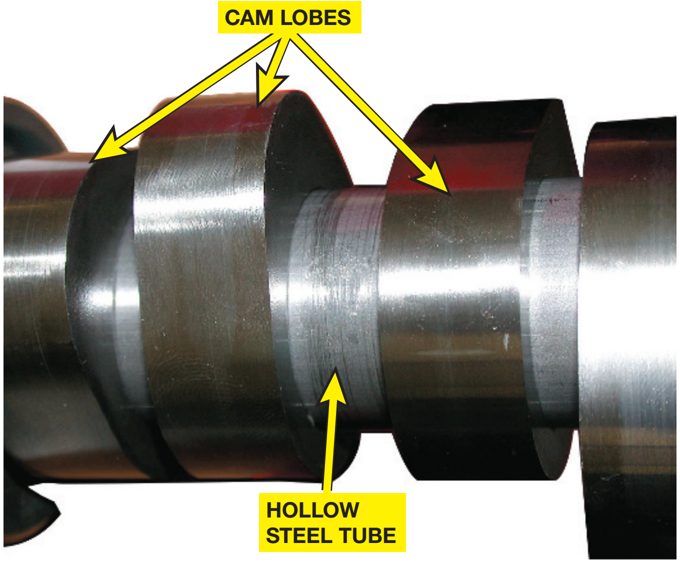

CAM LOBES
HOLLOW STEEL TUBE

FIGURE 28–5 A composite camshaft is lightweight and yet flexible because the hollow tube can absorb twisting forces and the lobes are hard enough to withstand the forces involved in opening valves.

Steel camshafts are usually constructed from SAE 4160 or 4180 steel and are usually induction hardened. Induction hardening involves heating the camshaft to cherry red in an electric field (heating occurs by electrical induction). The heated camshaft is then dropped into oil. The rapid cooling hardens the surface. Camshafts can also be hardened by using the following methods:

- Liquid nitriding, which hardens to 0.001 to 0.0015 inch thick
- Gas nitriding, which hardens to 0.004 to 0.006 inch thick

Typical camshaft hardness should be 42 to 60 on the Rockwell "c" scale.

NOTE: Rockwell is a type of hardness test, and the *c* represents the scale used. The higher the number, the harder the surface. The abbreviation *Rc60*, therefore, indicates Rockwell hardness of 60 as measured on the "c" scale.

If this outer hardness wears off, the lobes of the camshaft are easily worn until they are almost completely rounded. ● **SEE FIGURE 28–6**.

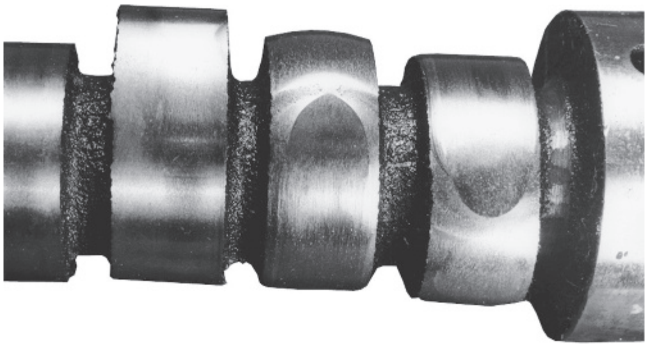


FIGURE 28–6 Worn camshaft with two lobes worn to the point of being almost round.

CAMSHAFT LUBRICATION Some engines transfer lubricating oil from the main oil gallery to the crankshaft around the camshaft journal or around the outside of the camshaft bearing. Cam bearing clearance is critical in these engines. If the clearance is too great, oil leaks out and the crankshaft bearings do not get enough oil. Other engines use drilled holes in the camshaft bearing journals to meter lubricating oil to the overhead rocker arm. Oil goes to the rocker arm each time the holes line up between the bearing oil gallery passage and the outlet passage to the rocker arm.

FUEL PUMP ECCENTRICS On engines equipped with gasoline direct injection (GDI), the cam has an eccentric cam lobe to drive the high-pressure fuel pump. ● **SEE FIGURE 28–7**.

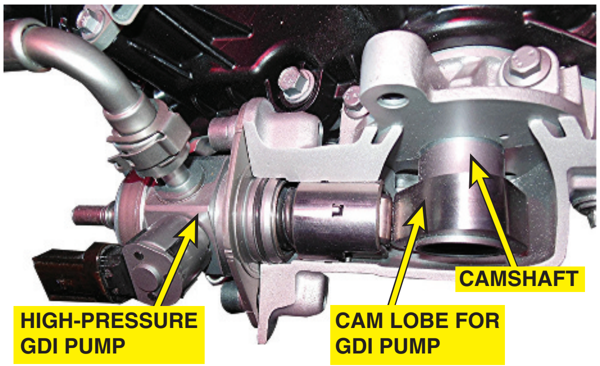

CAMSHAFT
HIGH-PRESSURE GDI PUMP
CAM LOBE FOR GDI PUMP

FIGURE 28–7 The camshaft powers the high-pressure fuel pump on engines equipped with gasoline direct injection (GDI).

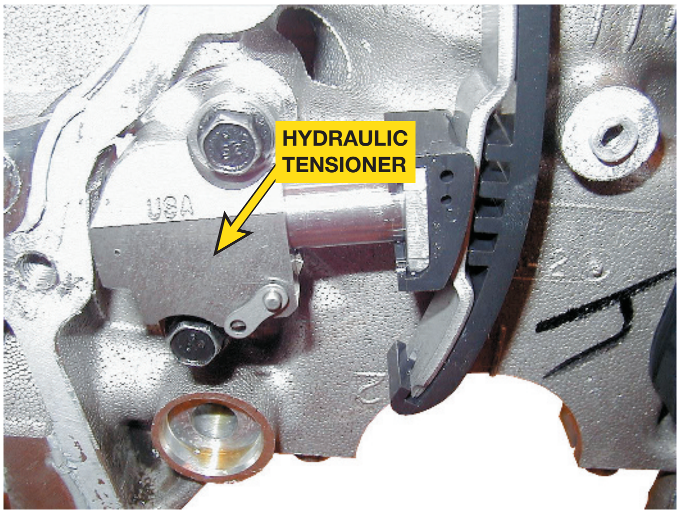


FIGURE 28–8 A timing chain hydraulic tensioner.

CAMSHAFT DRIVES

PURPOSE AND FUNCTION The crankshaft drives the camshaft with one of the following:

- Timing gears
- Sprockets and chains
- Sprockets and timing belts

Timing chains often have tensioners (dampers) pressing on the unloaded side of the chain. The tensioner pad is a Nylatron molding that is filled with molybdenum disulfide to give it low friction. The tensioner is held against the chain by either a spring or hydraulic oil pressure. ● **SEE FIGURE 28–8**.

The gears or sprockets are keyed to their shafts so that they can be installed in only one position. The gears and sprockets are then indexed together by marks on the gear teeth or chain links. However, some engines use a tolerance ring that locks the drive sprocket to the camshaft, such as the Ford modular V-8s. In these engines, the drive sprocket should *not* be removed from the camshaft unless the specified procedures are followed. When the crankshaft and camshaft timing marks are properly lined up, the cam lobes are indexed to the crankshaft throws of each cylinder so that the valves open and close correctly in relation to the piston position.

CAMSHAFT CHAIN DRIVES The crankshaft gear or sprocket that drives the camshaft is usually made of sintered iron. When gears are used on the camshaft, the teeth must be made from a soft material to help reduce noise. Usually, the whole gear is made of aluminum or fiber, especially in older engines.

When a chain and sprocket are used, the camshaft sprocket may be made of iron or it may have an aluminum hub with nylon teeth for noise reduction.

Two types of timing chains are used.

1. The **silent chain type** (also known as a **flat-link type**, or **Morse type** for its original manufacturer) operates quietly but tends to stretch with use. The metal links themselves do not "stretch" but, instead, the pin bushings at each joint wear, which causes the chain to become longer. ● **SEE FIGURES 28–9 AND 28–10**.
2. The **roller chain type** is noisier, but operates with less friction and stretches less than the silent type of chain. If two chains are used side by side, this type of chain is called a **double roller chain**. ● **SEE FIGURES 28–11 AND 28–12**.

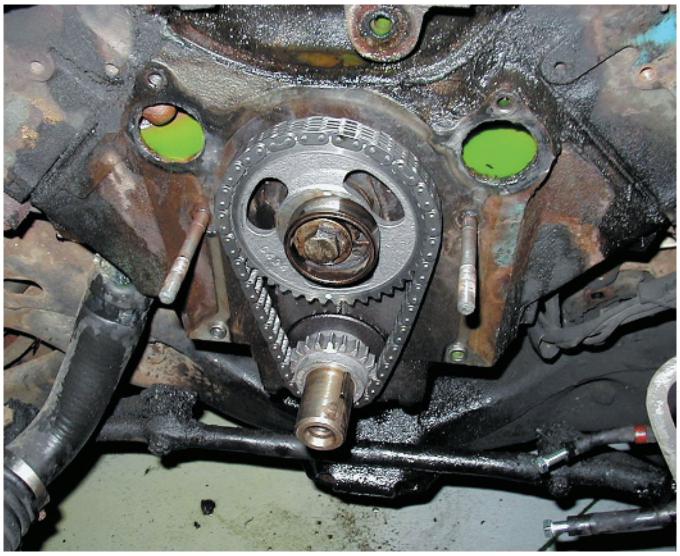


FIGURE 28–9 A replacement silent chain and sprockets. The original camshaft sprocket was aluminum with nylon teeth to help control noise. This replacement set is not noticeably louder than the original and should give the owner many thousands of miles of useful service.

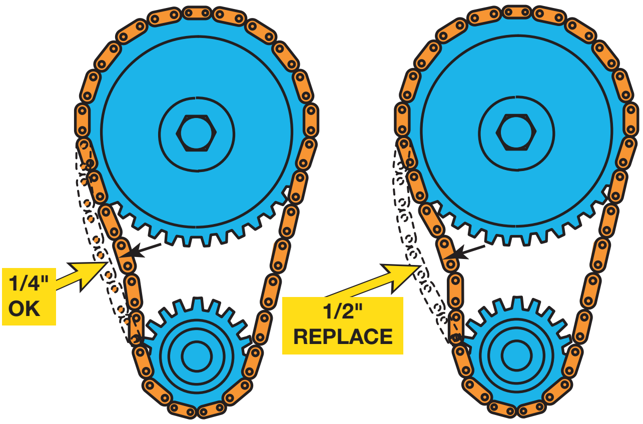


FIGURE 28–10 The industry standard for when to replace a timing chain and gears is when a 1/2 inch (13 mm) or more of slack is measured in the chain. However, it is best to replace the timing chain and gear anytime the camshaft is replaced or the engine is disassembled for repair or overhaul.

NOTE: When the timing chain stretches, the valve timing is retarded and the engine lacks low-speed power. In some instances, the chain can wear through the timing chain cover and create an oil leak.

Some four-cam engines use a two-stage camshaft drive system:

- Primary, from crankshaft to camshaft
- Secondary, from one camshaft to another

● **SEE FIGURE 28–13**.

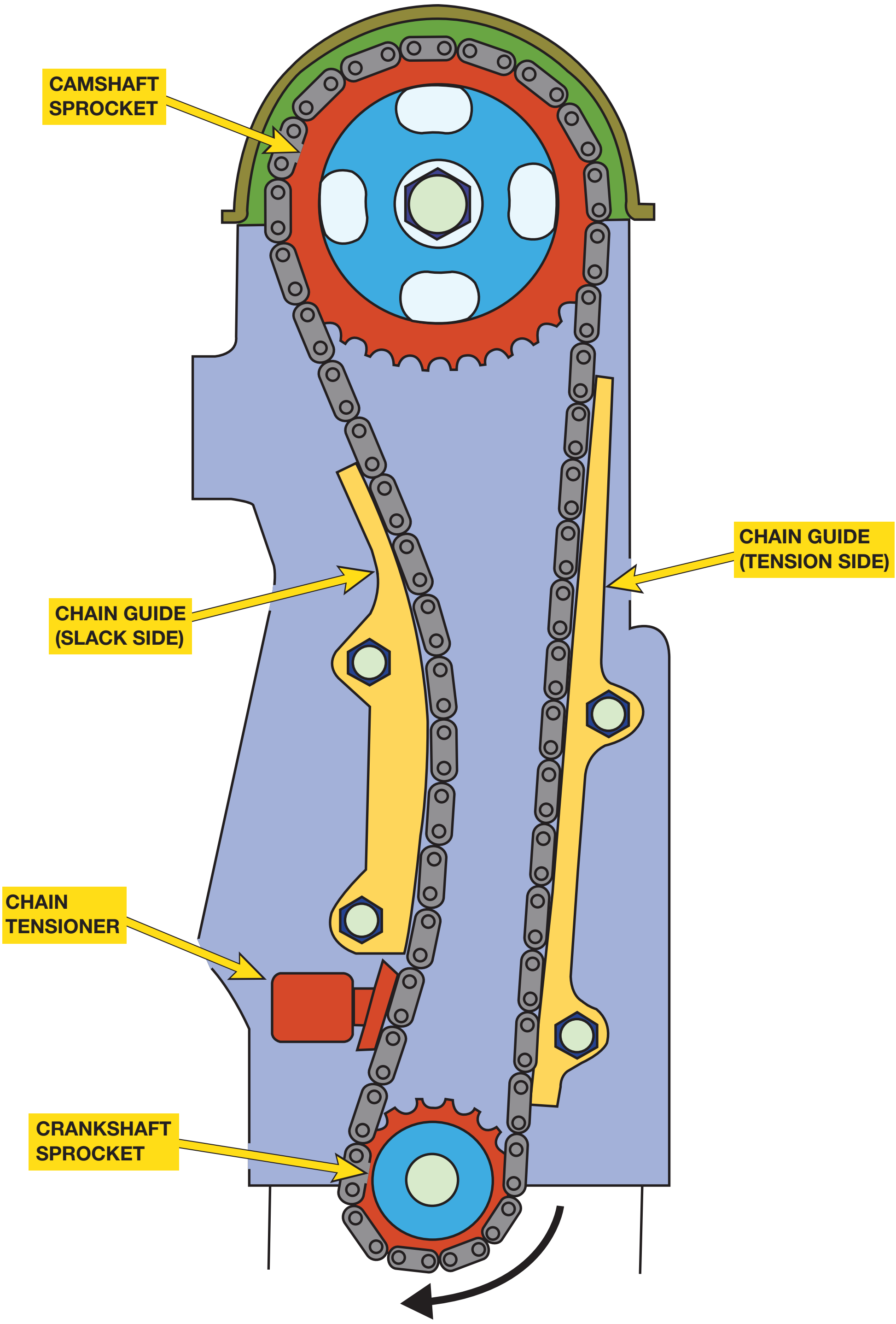


FIGURE 28–11 A typical overhead camshaft timing chain on an overhead camshaft (OHC) engine. Because the engine rotates clockwise as viewed from the front, this creates a tension side and a slack side for the timing chain. The tensioner is used on the slack side of the chain.

CAMSHAFT BELT DRIVES Many overhead camshaft engines use a timing belt rather than a chain. Cam drive belts are made from rubber and fabric and are often reinforced with fiberglass or Kevlar. The belt sprocket teeth are square-cut or cogged. Drive belts and sprockets reduce weight compared to a chain drive and require no lubrication with reduced noise. However, the belt requires periodic replacement, usually every 60,000 miles (100,000 km) or longer in some vehicles. ● **SEE FIGURES 28–14 AND 28–15**.

Unless the engine is freewheeling, the pistons can hit the valves if the belt breaks. A **freewheeling engine** is one that causes no internal damage if the camshaft drive belt breaks when the engine is running. An **interference engine**, however, causes some of the valves that are open to hit the pistons, causing major engine damage. ● **SEE FIGURES 28–16 AND 28–17**.

CAMSHAFT MOVEMENT

REASONS CAMSHAFTS MOVE **Cam chucking** is the movement of the camshaft *lengthwise in the engine during operation.* Each camshaft must have some means to control the shaft end thrust. One method is to use a **thrust plate** between the camshaft drive gear or sprocket and a flange on the camshaft.

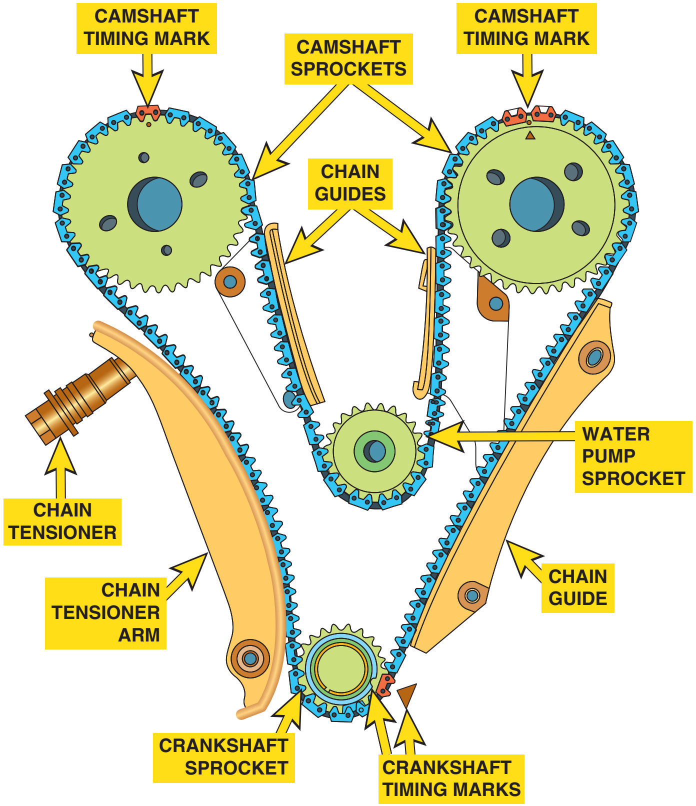

CAMSHAFT TIMING MARK
CAMSHAFT SPROCKETS
CAMSHAFT TIMING MARK
CHAIN GUIDES
WATER PUMP SPROCKET
CHAIN TENSIONER
CHAIN TENSIONER ARM
CHAIN GUIDE
CRANKSHAFT SPROCKET
CRANKSHAFT TIMING MARKS

FIGURE 28–12 A typical overhead camshaft engine showing the location of the tensioner, water pump, and chain guide as well as the timing marks.

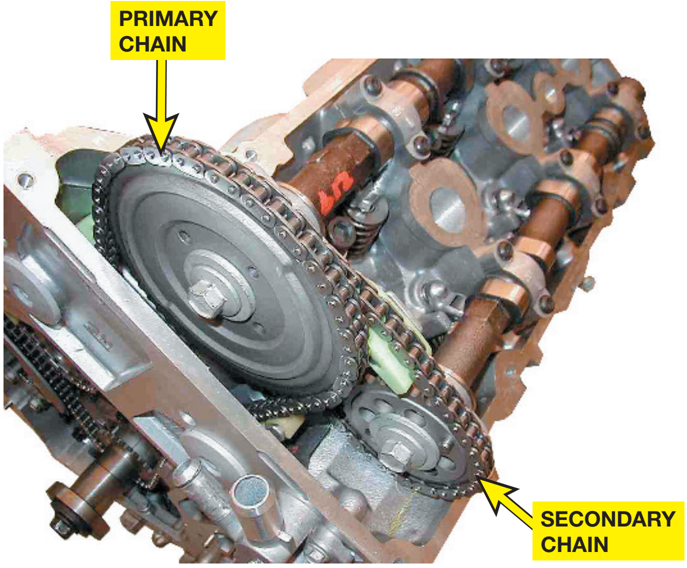

PRIMARY CHAIN
SECONDARY CHAIN

FIGURE 28–13 This dual overhead camshaft (DOHC) engine uses one chain from the crankshaft to the intake cam and a secondary chain to rotate the exhaust camshaft.

A thrust plate is attached to the engine block with cap screws. In a few camshafts, a button, spring, or retainer that contacts the timing cover limits forward motion of the camshaft.

CAMSHAFT LOBE LIFT The **lobe lift** of the cam is usually expressed in decimal inches and represents the distance that the valve lifter or follower is moved. The amount that the valve is

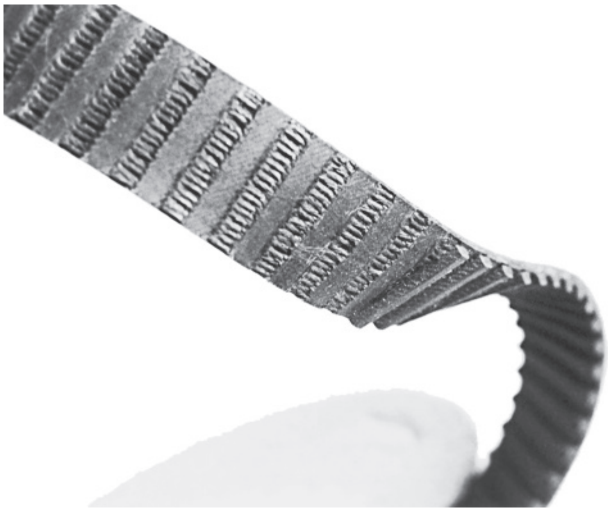


FIGURE 28–14 A timing belt failed when the teeth were sheared off. This belt failed at 88,000 miles because the owner failed to replace it at the recommended interval of 60,000 miles.

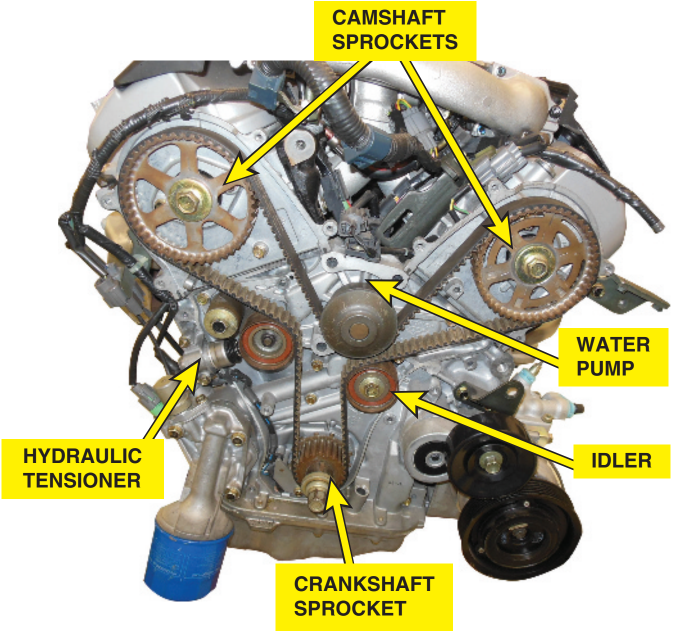

CAMSHAFT SPROCKETS
WATER PUMP
HYDRAULIC TENSIONER
IDLER
CRANKSHAFT SPROCKET

FIGURE 28–15 A typical overhead camshaft engine showing how the timing belt is also used to operate the water pump.

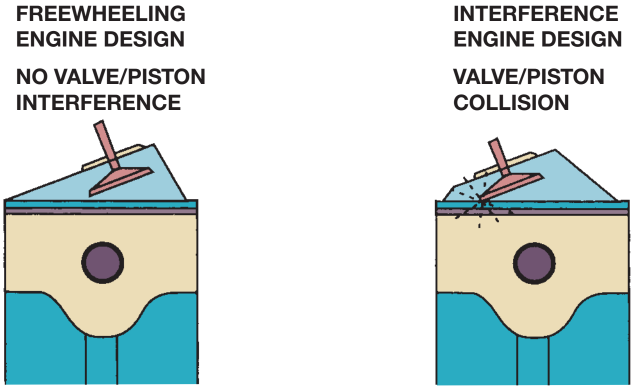

FREEWHEELING ENGINE DESIGN
NO VALVE/PISTON INTERFERENCE
INTERFERENCE ENGINE DESIGN
VALVE/PISTON COLLISION

FIGURE 28–16 Many engines are of the interference design. If the timing belt (or chain) breaks, the piston still moves up and down in the cylinder, while the valves remain stationary. With a freewheeling design, nothing is damaged, but in an interference engine, the valves are often bent.

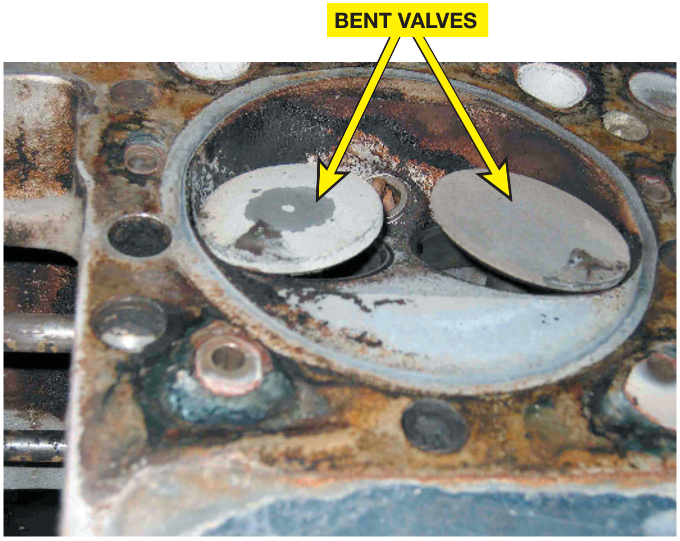


FIGURE 28–17 A head from a Mercedes showing bent valves when the timing chain stretched and skipped over the crankshaft sprocket. When this happened, the piston kept moving and bent the valves.

CASE STUDY

The Case of the Ford Fiesta 1.6L

The owner of a Ford Fiesta complained of a check engine light, yet the engine seemed to run fine. The service technician retrieved a P0017 (cam and crank correlation error) diagnostic trouble code (DTC). The technician removed the timing belt cover and determined that the timing belt had jumped one tooth, likely due to a stretched belt or a worn tensioner. Because this engine is an interference-type engine where the valves hit the piston if the timing belt breaks when the engine is running, the technician recommended replacing the timing belt using a kit available from many suppliers that include the following:

- timing belt
- timing belt tensioner
- water pump

The customer approved the repair and the new timing belt corrected the crank/cam correlation error code.

Summary:

Complaint—Check engine light on.
Cause—A diagnostic trouble code (DTC) P0017 cam and crank correlation error was retrieved which was caused by the timing belt that had jumped one tooth.
Correction—Replace timing belt along with the timing belt tensioner and the water pump. The DTC was cleared and road tested to confirm the check engine light nor any diagnostic trouble codes were set. ● **SEE FIGURE 28–18**.

FIGURE 28–18 A timing belt was replaced which corrected the crankshaft/camshaft correlation error diagnostic trouble code.

FREQUENTLY ASKED QUESTION

Why Do Flat-Bottom Lifters Rotate?

Valve trains that use flat-bottom lifters use a spherical (curved) lifter face that slides against the cam lobe. This produces a surface on the lifter face that is slightly convex, by about 0.002 inch. The lifter also contacts the lobe at a point that is slightly off center. This produces a small turning force on the lifter to cause some lifter rotation for even wear. In operation, there is a wide line of contact between the lifter and the high point of the cam lobe. ● **SEE FIGURE 28–19**.

These are the highest loads that are produced in an engine. This surface is the most critical lubrication point in an engine.

lifted is determined by the lobe lift times the ratio of the rocker arm. ● **SEE FIGURES 28–20 AND 28–21**.

The higher the lift of the camshaft lobe, the greater the amount of air and fuel that can enter the engine. The more air

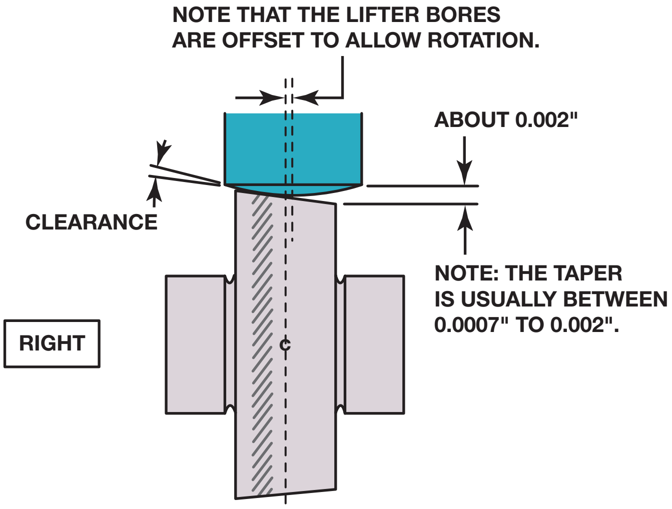

NOTE THAT THE LIFTER BORES ARE OFFSET TO ALLOW ROTATION.
ABOUT 0.002"
CLEARANCE
NOTE: THE TAPER IS USUALLY BETWEEN 0.0007" TO 0.002".
RIGHT

FIGURE 28–19 The slight angle and the curve on the bottom of a flat-bottom lifter cause the lifter and the pushrod to rotate during normal operation.

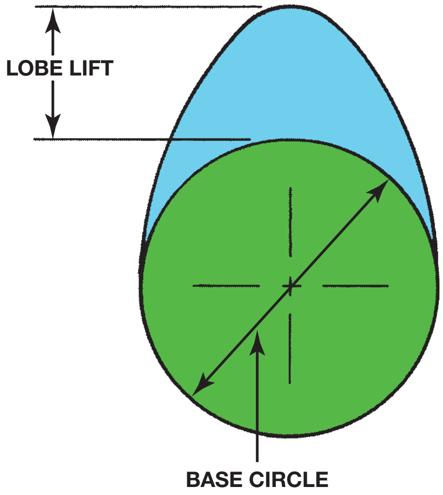


FIGURE 28–20 The lobe lift is the amount the cam lobe lifts the lifter. The green circle is called the base circle. Rocker arm ratio increases the total valve lift.

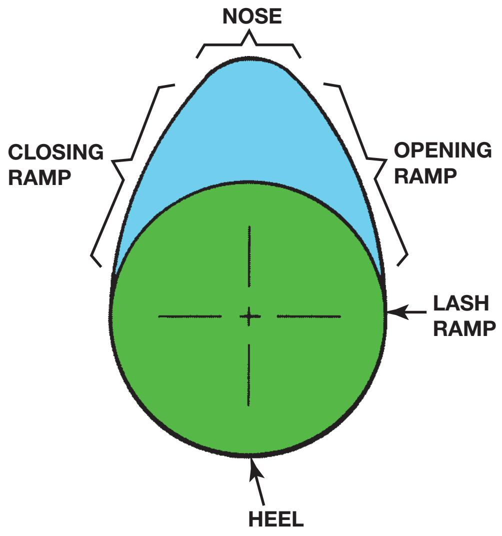


FIGURE 28–21 The ramps on the cam lobe allow the valves to be opened and closed quickly, yet under control, to avoid damaging valve train components, especially at high engine speeds.

and fuel burned in an engine, the greater the power potential of the engine. The amount of lift of a camshaft is often different for the intake and exhaust valves.

- If the specifications vary, the camshaft is called **asymmetrical**.
- If the lift is the same, the cam is called **symmetrical**.

However, when the amount of lift increases, so do the forces on the camshaft and the rest of the valve train. Generally, a camshaft with a lift of over 0.5 inch (1.3 cm) is unsuitable for street operation, except for use in engines that are over 400 cu. in. (6 liters).

ROCKER ARMS

PURPOSE AND FUNCTION A rocker arm reverses the upward movement of the pushrod to produce a downward movement on the tip of the valve. Engine designers make good use of the rocker arm. It is designed to reduce the travel of the cam follower or lifter and pushrod while maintaining the required valve lift. This is done by using a rocker arm ratio usually of 1.5:1.

For a given amount of lift on the pushrod, the valve opens to 1.5 times the cam lobe lift. This ratio allows the camshaft to be smaller, so the engine can be smaller. ● **SEE FIGURE 28–22**.

TECH TIP

Best to Warn the Customer

A technician replaced a timing chain and gears on a high mileage Chevrolet V-8. The repair was accomplished correctly, yet after starting, the engine burned an excessive amount of oil. Before the timing chain replacement, oil consumption was minimal. The replacement timing chain restored proper operation of the engine by restoring the proper cam and valve timing, which increased engine vacuum. Increased vacuum can draw oil from the crankcase past worn piston rings and through worn valve guides during the intake stroke. Similar increased oil consumption problems occur if a valve job is performed on a high-mileage engine with worn piston rings and/or cylinders.

To satisfy the owner of the vehicle, the technician had to disassemble and refinish the cylinders and replace the piston rings. Therefore, all technicians should warn customers that increased oil usage might result from almost any engine repair to a high-mileage engine.

CAUTION: Using rocker arms with a higher ratio than stock can also cause the valve spring to compress too much and actually bind. Valve spring bind (coil bind) occurs when the valve spring is compressed to the point where there is no clearance in the spring. (It is completely compressed.) When coil bind occurs in a running engine, bent pushrods, broken rocker arms, or other valve train damage can result. ● SEE FIGURE 28–23.

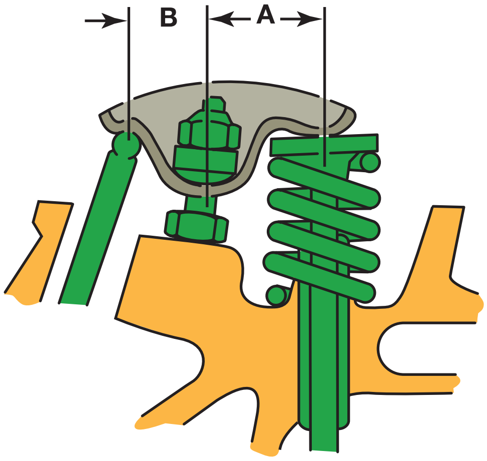


FIGURE 28–22 A 1.5:1 ratio rocker arm means that dimension A is 1.5 times the length of dimension B. Therefore, if the pushrod is moved up 0.4 inch by the camshaft lobe, the valve is pushed down (opened) 0.4 inch × 1.5, or 0.6 inch.

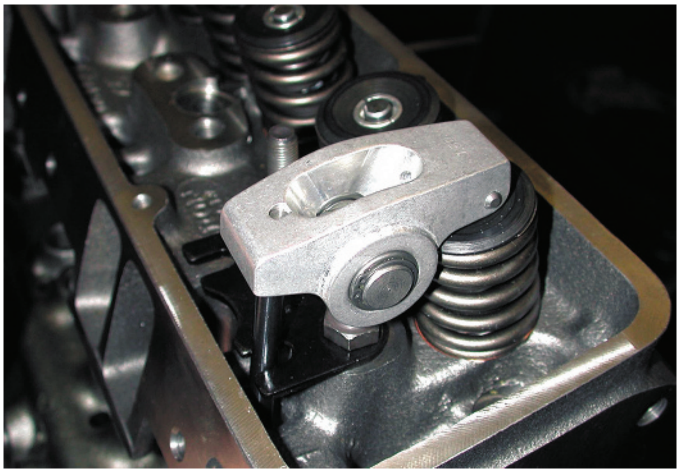


FIGURE 28–23 A high-performance aluminum roller rocker arm. Both the pivot and the tip that contacts the stem of the valve are equipped with rollers to help reduce friction for more power and better fuel economy.

Rocker arms may be

- Cast
- Forged
- Stamped steel

Forged rocker arms are the strongest, but they require expensive manufacturing operations. Rocker arms may have bushings or bearings installed to reduce friction and increase durability. Cast rocker arms cost less to make and do not usually use bushings, but they do require several machining operations. They are not as strong as forged rocker arms, but are satisfactory for passenger vehicle service. Stamped steel rocker arms are lightweight and cost effective.

SHAFT-MOUNTED ROCKER ARMS On some overhead valve and most single overhead camshaft engines, the rocker arms are mounted on a shaft that runs the full length of the cylinder head. ● **SEE FIGURE 28–24**.

Because the shaft provides a strong and stable platform for the rocker arms, shaft-mounted rocker arms work well, especially at high engine speeds. While most overhead camshaft engines that use rocker arm shafts do use an adjustable rocker arm, most OHV engines using rocker arm shafts have no provision for adjustment. Shaft-mounted rocker arms are lubricated through oil passages that travel from the block through the head and into the shaft, and then to the rocker arms.

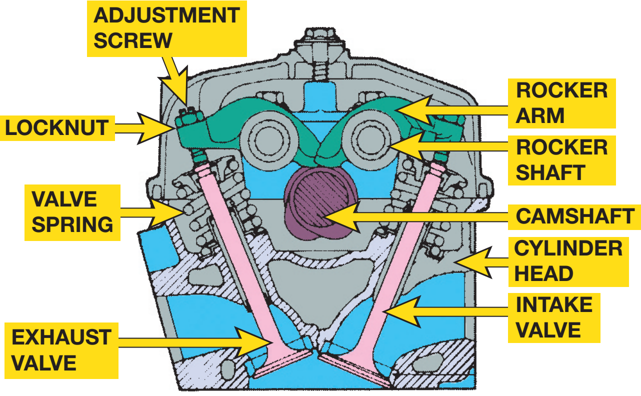


FIGURE 28–24 Some engines today use rocker shafts to support rocker arms, such as the V-6 engine with a single overhead camshaft located in the center of the cylinder head.

FREQUENTLY ASKED QUESTION

Are the Valves Adjustable?

If the stud has the same diameter for its whole length, the rockers are *adjustable* and the nut is the “interference” type (lock-type nut). If the stud has a shoulder of a different diameter, the rockers are *nonadjustable* and the nut does not have interference threads.

TECH TIP

Rocker Arm Shafts Can Cause Sticking Valves

As oil oxidizes, it forms a varnish. Varnish buildup is particularly common on hot upper portions of the engine, such as rocker arm shafts. The varnish restricts clean oil from getting into and lubricating the rocker arms. The cam lobe can easily *force* the valves open, but the valve springs often do not exert enough force to fully close the valves. The result is an engine miss, which may be intermittent. Worn valve guides and/or weak valve springs can also cause occasional rough idle, uneven running, or an engine misfire.

STUD-MOUNTED ROCKER ARMS Stud-mounted rockers are only found on OHV engines and each rocker arm is attached to a stud that is pressed or threaded into the cylinder head. A ball on top of the rocker arm provides the bearing surface as the rocker arm pivots and is held in place and adjusted for valve clearance by a nut. While this design looks less stable than a shaft-mounted rocker, this design has proved to be reliable and is inexpensive to manufacture. The rocker arms receive lubricating oil under pressure through hollow pushrods. ● **SEE FIGURE 28–25**.

Some engines use pushrod guide plates fastened to the head. ● **SEE FIGURE 28–26**.

PEDESTAL-MOUNTED ROCKER ARMS Pedestal-mounted rocker arms are similar to stud-mounted rocker arms, but do not use a stud and are used only in OHV engines. Two rocker arms are attached to and pivot on a pedestal attached to the cylinder

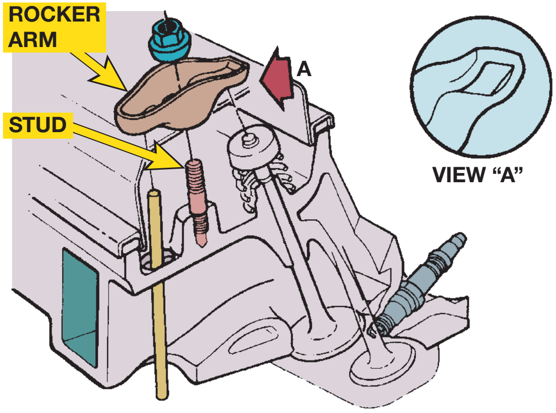


FIGURE 28–25 A typical stud-mounted rocker arm.

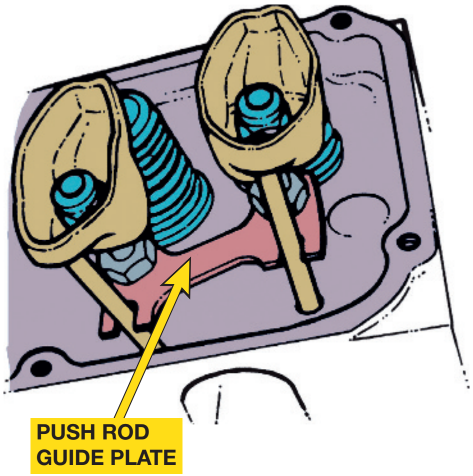


FIGURE 28–26 Pushrod guide plates are bolted to the head and help stabilize the valve train, especially at high engine speeds.

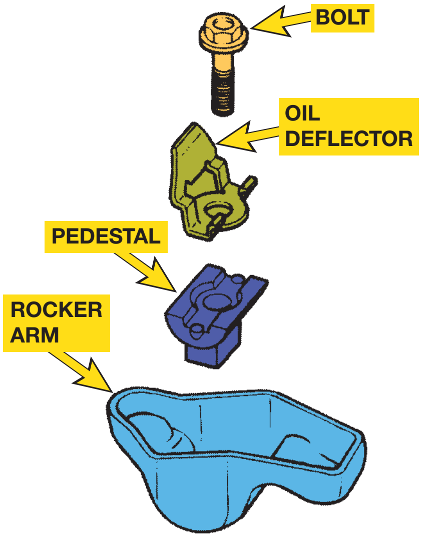


FIGURE 28–27 A pedestal-type rocker arm design that uses one bolt for each rocker arm and is nonadjustable. If valve lash needs to be adjusted, different length pushrod(s) must be used.

head with one or two bolts. The pedestal is usually made from aluminum and the rocker arms are usually stamped steel, which is lightweight and nonadjustable. ● **SEE FIGURE 28–27**.

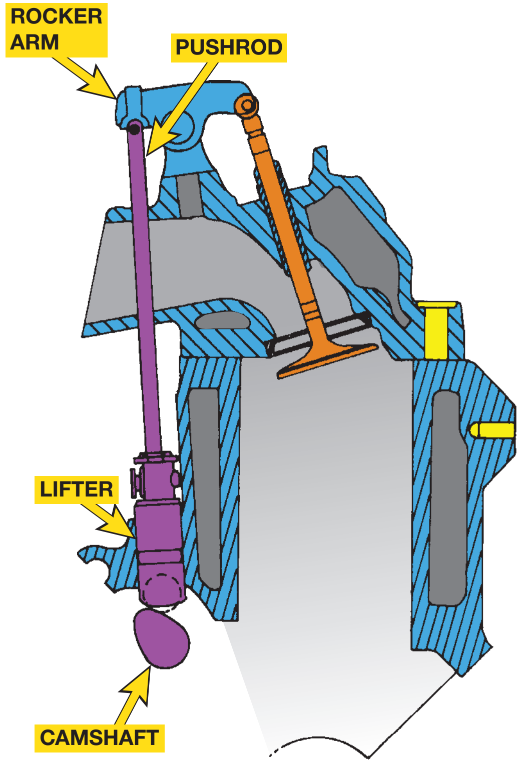


FIGURE 28–28 Overhead valve engines are also known as pushrod engines because of the long pushrod that extends from the lifter to the rocker arm.

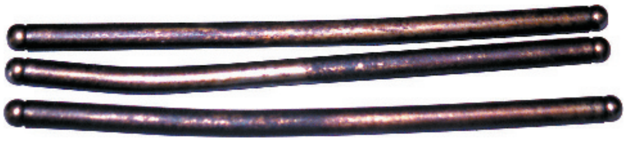


FIGURE 28–29 When the timing chain broke, the valves stopped moving up and down, but the pistons kept moving and hit the valves, causing the pushrods to bend.

PUSHRODS

FUNCTION Pushrods are used on OHV (cam-in-block) engines and transfer the lifting motion of the valve train from the cam lobe and lifters to the rocker arms. ● **SEE FIGURE 28–28**.

TYPES OF PUSHRODS Pushrods are designed to be as light as possible and still maintain their strength. They may be either solid or hollow. If they are to be used as passages for oil to lubricate rocker arms, they *must* be hollow. Pushrods use a convex ball on the lower end that seats in the lifter. The rocker arm end is also a convex ball, unless there is an adjustment screw in the pushrod end of the rocker arm. In this case, the rocker arm end of the pushrod has a concave socket. It mates with the convex ball on the adjustment screw in the rocker arm.

All pushrods should be rolled on a flat surface to check for straightness. ● **SEE FIGURE 28–29**.

The tolerance in the valve train allows for some machining of engine parts without the need to change pushrod length.

However, if one or more of the following changes have been made to an engine, a different pushrod length may be necessary:

- Block deck height machined
- Cylinder head deck height machined

TECH TIP

The Scratch Test

All pushrods used with guide plates *must* be hardened on the sides and on the tips. To easily determine if a pushrod is hardened, simply use a sharp pocketknife to scrape the wall of the pushrod. A heat-treated pushrod does not scratch. ● **SEE FIGURE 28–30**.

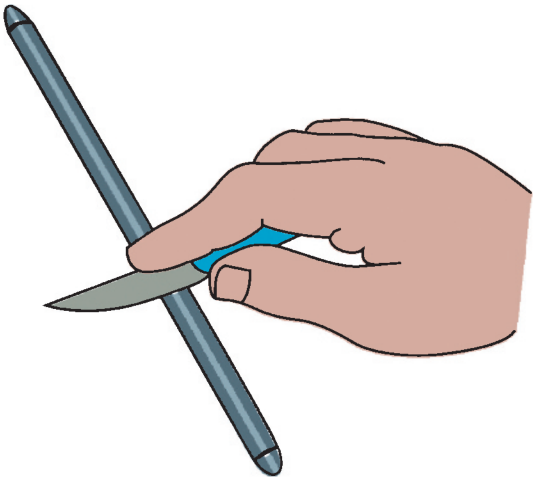


FIGURE 28–30 Hardened pushrods should be used in any engine that uses pushrod guides (plates). To determine if the pushrod is hardened, simply try to scratch the side of the pushrod with a pocketknife.

- Camshaft base circle size reduced
- Valve length increased
- Lifter design changed

HOLLOW PUSHROD DIRT Many engine rebuilders and remanufacturers do not reuse old hollow pushrods. Dirt, carbon, and other debris are difficult to thoroughly clean from inside a hollow pushrod. When an engine is run with used pushrods, the trapped particles can be dislodged and ruin new bearings and other new engine parts. Therefore, for best results, consider purchasing new hollow pushrods instead of trying to clean and reuse the originals.

LIFTERS/TAPPETS

PURPOSE AND FUNCTION Valve lifters or tappets follow the contour or shape of the camshaft lobe. This arrangement changes the rotary cam motion to a reciprocating motion in the valve train. Older-style lifters have a relatively flat surface that slides on the cam.

Most lifters, however, are designed with a roller to follow the cam contour. Roller lifters are used primarily in production engines to reduce valve train friction (by up to 8%). This friction reduction can increase fuel economy and help to offset the greater manufacturing cost. ● **SEE FIGURE 28–31**.

All roller lifters must use a retainer or a guide plate to prevent lifter rotation. The retainer ensures that the roller is kept in line with the cam. ● **SEE FIGURE 28–32**.

VALVE LASH Valve train clearance is also called **valve lash**, which is needed to help compensate for thermal expansion and wear. Valve train clearance must not be excessive, or it causes noise or results in premature failure. Two methods are commonly used to make the necessary valve clearance adjustments:

- One involves a **solid valve lifter**, which can be adjusted mechanically at the rocker arm or by changing shims on certain overhead camshaft engines.
- The other involves a lifter with an automatic hydraulic adjustment built into the lifter body, called a **hydraulic valve lifter**.

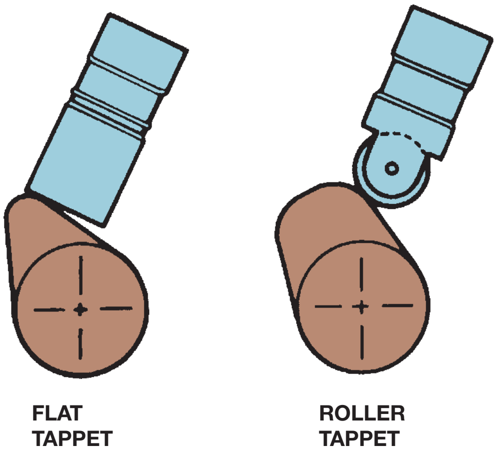


FIGURE 28–31 Older engines used flat-bottom lifters, whereas all engines since the 1990s use roller lifters.

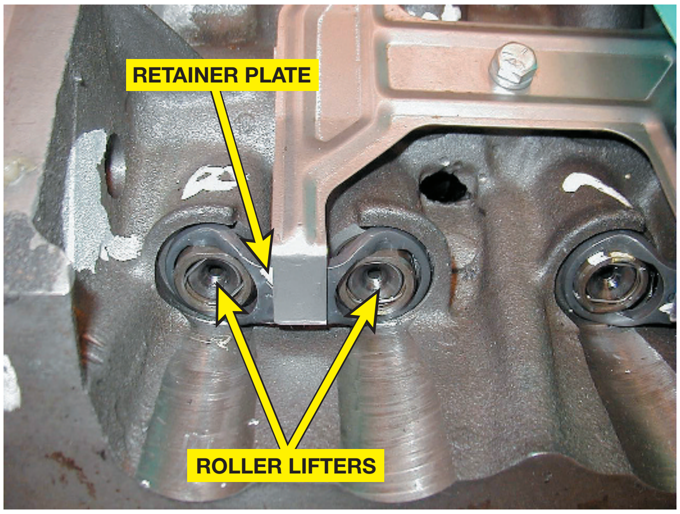


FIGURE 28–32 All roller lifters must use some method to keep the lifter straight and not rotating.

SOLID LIFTERS Overhead valve engines with mechanical lifters have an adjustment screw at the pushrod end of the rocker arm or an adjustment nut at the ball pivot. Adjustable pushrods are available for specific applications.

Valve trains using solid lifters must run with some clearance to ensure positive valve closure, regardless of the engine temperature. This clearance is matched by a gradual rise in the cam contour, called a **ramp**. (Hydraulic lifter camshafts do not have this ramp.) The ramp takes up the clearance before the valve begins to open. The camshaft lobe also has a closing ramp to ensure quiet operation.

A lifter is solid in the sense that it transfers motion directly from the cam to the pushrod or valve. Its physical construction is that of a lightweight cylinder, either hollow or with a small-diameter center section and full-diameter ends. In some types that transfer oil through the pushrod, the external appearance is the same as for hydraulic lifters. ● **SEE FIGURE 28–33**.

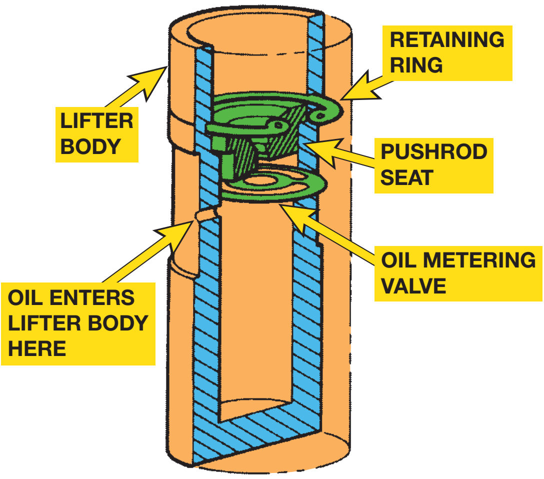


FIGURE 28–33 A cutaway of a flat-bottom solid lifter. Because this type of lifter contains a retaining ring and oil holes, it is sometimes confused with a hydraulic lifter that also contains additional parts. The holes in this lifter are designed to supply oil to the rocker arms through a hollow pushrod.

HYDRAULIC LIFTERS A hydraulic lifter consists primarily of a hollow cylinder body enclosing a closely fit hollow plunger, a check valve, and a pushrod cup. Lifters that feed oil up through the pushrod have a metering disc or restrictor valve located under the pushrod cup. Engine oil under pressure is fed through an engine passage to the exterior lifter body. An undercut portion allows the oil under pressure to surround the lifter body. Oil under pressure goes through holes in the undercut section into the center of the plunger. From there, it goes down through the check valve to a clearance space between the bottom of the plunger and the interior bottom of the lifter body. It fills this space with oil at engine pressure. Slight leakage allowance is designed into the lifter so that the air can bleed out and the lifter can leak down if it should become overfilled.

The pushrod fits into a cup in the top, open end of the lifter plunger. Holes in the pushrod cup, pushrod end, and hollow pushrod allow oil to transfer from the lifter piston center, past a metering disc or restrictor valve, and up through the pushrod to the rocker arm. Oil leaving the rocker arm lubricates the rocker arm assembly.

As the cam starts to push the lifter against the valve train, the oil below the lifter plunger is squeezed and tries to return to the lifter plunger center. A lifter check valve, either ball or disc type, traps the oil below the lifter plunger. This hydraulically locks the operating length of the lifter. The hydraulic lifter opens the engine valve as would a solid lifter. When the lifter returns to the base circle of the cam, engine oil pressure again works to replace any oil that may have leaked out of the lifter. ● **SEE FIGURE 28–34**.

The job of the hydraulic lifter is to take up all clearance in the valve train. Occasionally, engines are run at excessive speeds. This tends to throw the valve open, causing **valve float**. During valve float, clearance exists in the valve train. The hydraulic lifter takes up this clearance as it is designed to do. When this occurs, it keeps the valve from closing on the seat, a process called **pump-up**. Pump-up does not occur when the engine is operated in the speed range for which it is designed.

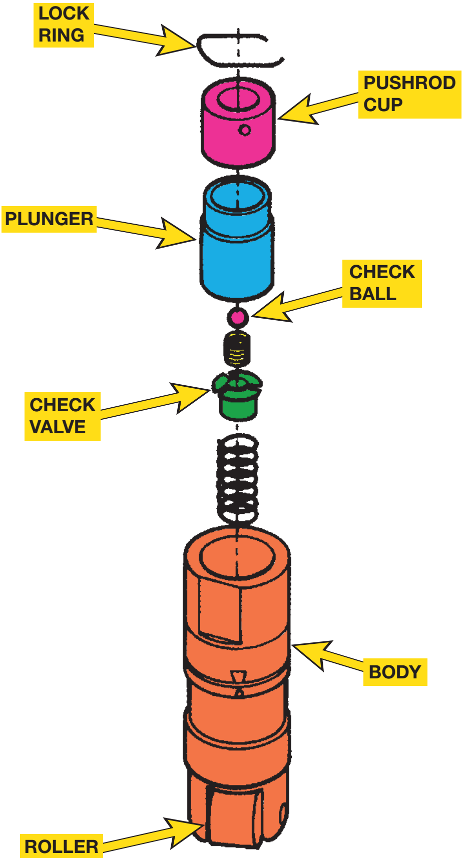


FIGURE 28–34 An exploded view of a hydraulic roller lifter.

CASE STUDY

The Case of the Worn Hemi Camshaft

A customer complained that the engine of their Ram truck (5.7-liter Hemi V8) was making a "ticking" sound and the "check engine" light was on. A P0300 (random misfire) diagnostic trouble code (DTC) was retrieved and the ticking sound was confirmed by the service technician. Because the ticking sound usually is associated with the valve train problem, the valve covers were removed for a visual inspection. It was apparent that one pushrod was not moving with the engine running. Apparently, the valve lifter anti-rotation retainer broke allowing the lifter to turn sideways, which then caused excessive wear to the camshaft lobe. ● **SEE FIGURE 28–35**.

The customer approved of the repair of a replacement camshaft and lifters which corrected the misfire and the engine noise concerns.

Summary:

Complaint—The owner of a Ram truck complained of a ticking sound from the engine and a check engine light on in the dash.

Cause—A valve lifter had broken free of the retainer plate which allowed the roller lifter to turn sideways wearing the camshaft lobe This wear caused the engine noise and a random misfire.

Correction—The camshaft and lifters were replaced and the diagnostic trouble code was cleared. These actions corrected the customer concern.

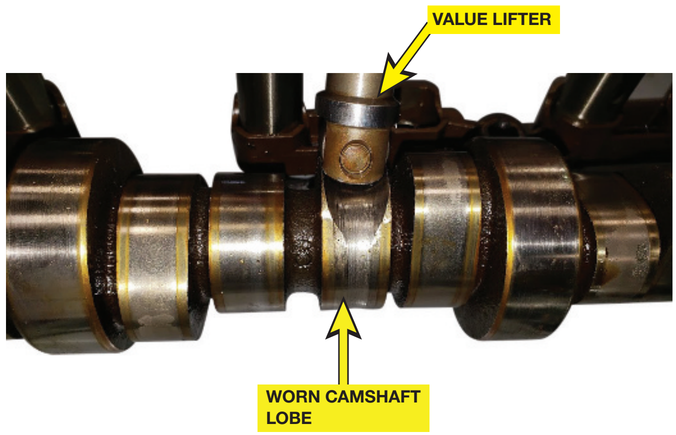

VALUE LIFTER
WORN CAMSHAFT LOBE

FIGURE 28–35 The extremely worn cam lobe caused by the valve lifter rotating sideways.

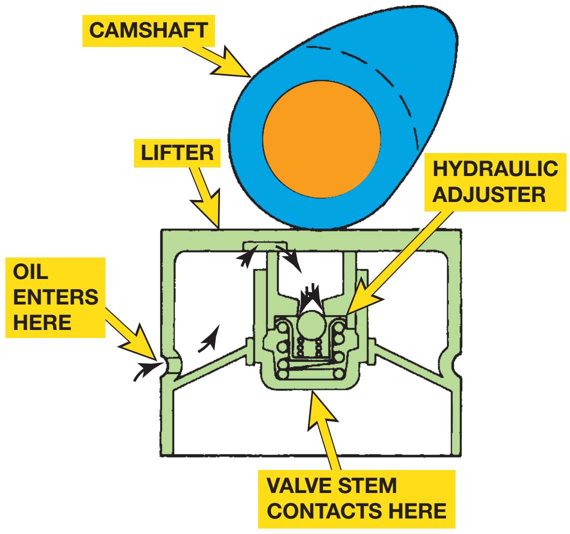

CAMSHAFT
LIFTER
HYDRAULIC ADJUSTER
OIL ENTERS HERE
VALVE STEM CONTACTS HERE

FIGURE 28–36 Hydraulic lifters may be built into bucket type lifters on some overhead camshaft engines.

OVERHEAD CAMSHAFT VALVE TRAINS

TERMINOLOGY Overhead camshaft engines use several different types of valve opening designs.

1. One type opens the valves directly with a **bucket**. ● **SEE FIGURE 28–36**.
2. The second type uses a **cam follower**, also called a **finger follower**, that provides an opening ratio similar to that of a rocker arm. Finger followers open the valves by approximately 1 1/2 times the cam lift. The pivot point of the finger follower may have a mechanical adjustment or it may have an automatic hydraulic adjustment. ● **SEE FIGURE 28–37**.
3. A third type moves the rocker arm directly through a hydraulic lifter.
4. In the fourth design, some newer engines have the hydraulic adjustment in the rocker arm and are commonly called **hydraulic lash adjusters (HLA)**. ● **SEE FIGURE 28–38**.

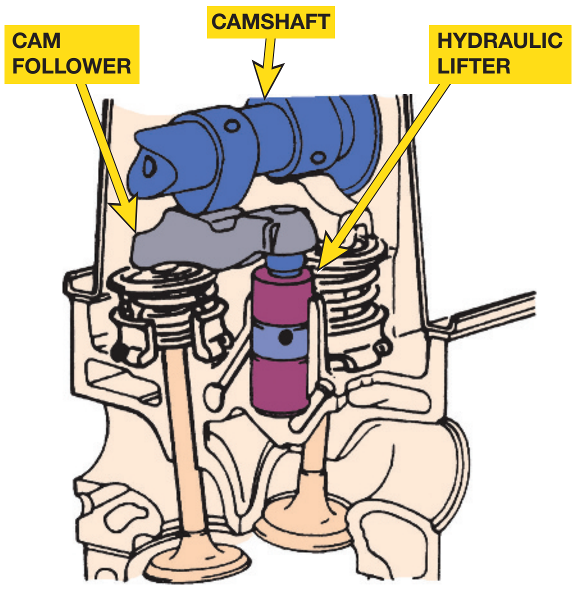

CAM FOLLOWER
CAMSHAFT
HYDRAULIC LIFTER

FIGURE 28–37 The use of cam followers allows the use of hydraulic lifters with an overhead camshaft design.

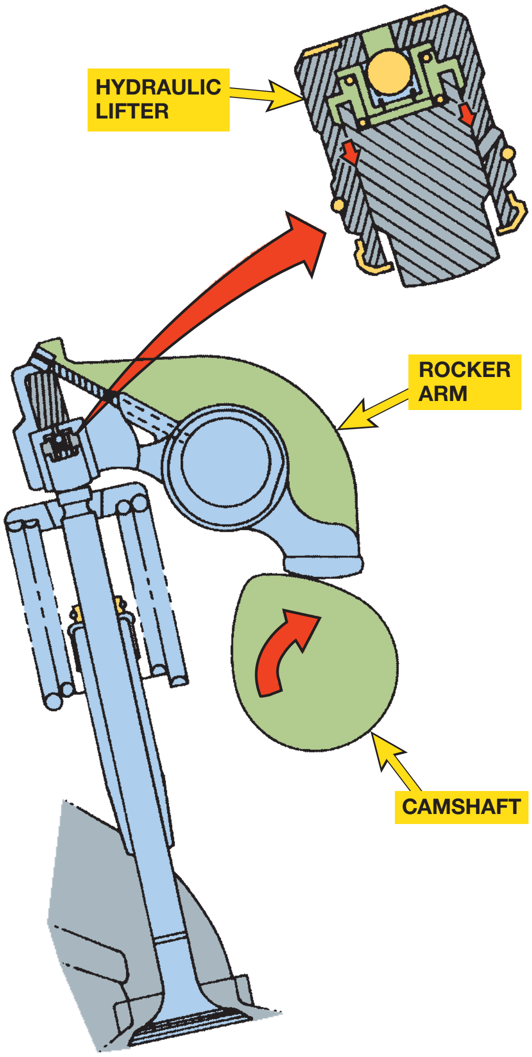

HYDRAULIC LIFTER
ROCKER ARM
CAMSHAFT

FIGURE 28–38 Hydraulic lash adjusters (HLA) are built into the rocker arm on some OHC engines. Sometimes HLAs may not bleed down properly if the wrong viscosity (SAE rating) oil is used.

VALVE TRAIN LUBRICATION

The lifters in an OHV engine are lubricated through oil passages drilled through the block. The engine oil flows through the lifter, and up through the hollow pushrod where the oil flows to lubricate and cool the rocker arm, valve, and valve spring.

NOTE: The Chrysler 5.7 liter Hemi engine is opposite because the oil is first sent to the rocker arm through passages in the block and head and then *down* through the hollow pushrod to the lifters. In all other engine designs, the oil flows through the lifter and *up* to the rocker arm through the hollow pushrod.

CAMSHAFT LUBRICATION The camshaft in OHV engines is lubricated by splash oil thrown up by the movement of the crankshaft counterweights and connecting rods. At low engine speed, there is less splash lubrication than occurs at higher engine speeds. This is the major reason why an engine equipped with flat-bottom lifters should be operated at a fast idle of about 2,500 RPM during the first 10 minutes of engine operation. The high idle speed helps ensure that there is enough splash oil to properly lubricate and break in a new camshaft and lifters.

VALVE TRAIN PROBLEM DIAGNOSIS

SYMPTOMS A camshaft with a partially worn lobe is often difficult to diagnose. Sometimes a valve "tick, tick, tick" noise is heard if the cam lobe is worn. The ticking noise can be intermittent, which makes it harder to determine the cause. If the engine has an OHC, it is usually relatively easy to remove the cam cover and make a visual inspection of all cam lobes and the rest of the valve train. In an OHV engine, the camshaft is in the block, where easy visual inspection is not possible. However, it always pays to perform a visual inspection. ● **SEE FIGURE 28–39**.

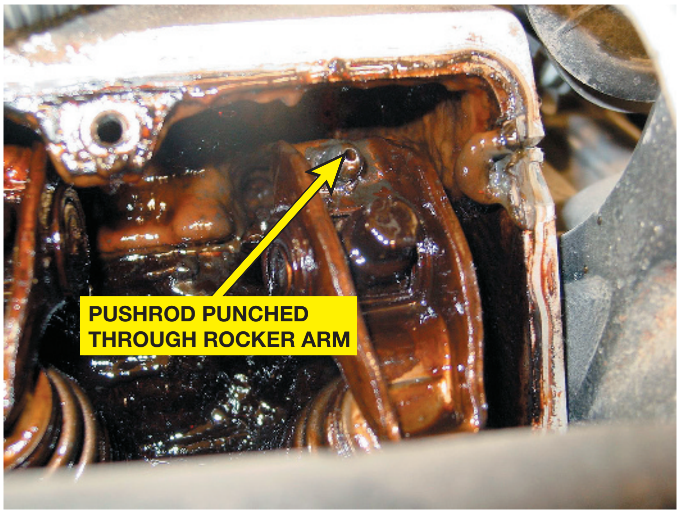


FIGURE 28–39 The cause of a misfire diagnostic trouble code was discovered to be a pushrod that had worn through the rocker arm on a General Motors 3.1 liter V-6 engine.

VALVE NOISE DIAGNOSIS Valve lifters are often noisy, especially at engine start-up. When the engine is off, some valves are open. The valve spring pressure forces the inner plunger to leak down (oil is forced out of the lifter). Therefore, many vehicle manufacturers consider valve ticking at one-half engine speed after start-up to be normal, especially if the engine is quiet after 10 to 30 seconds. Be sure that the engine is equipped with the correct oil filter, and that the filter has an internal check valve. If in doubt, use an original equipment oil filter. If all of the valves are noisy, check the oil level. If low, the oil may have been **aerated** (air mixed with the oil), which would prevent proper operation of the hydraulic lifter. Aeration can be caused by

- Low oil pressure, which can also cause all valves to be noisy
- The oil level being too high, which can also cause noisy valve lifters. (The crankshaft counterweights create foam as they rotate through the oil. This foam can travel through the oiling systems to the lifters. The foam in the lifters prevents normal operation and allows the valves to make noise.)

If the valves are abnormally noisy, remove the valve cover and use a stethoscope to listen or apply pressure to the rocker arms to determine which valves or valve train parts may be causing the noise. Check for all of the following items:

- Valve lash too loose
- Worn camshaft lobe
- Dirty, stuck, or worn lifters
- Worn rocker arm (if the vehicle is so equipped)
- Worn rocker arm shaft (● **SEE FIGURE 28–40**.)
- Worn or bent pushrods (if the vehicle is so equipped)
- Broken or weak valve springs
- Sticking or warped valves

Any of the above can cause the engine to idle roughly, misfire, or even backfire during acceleration.

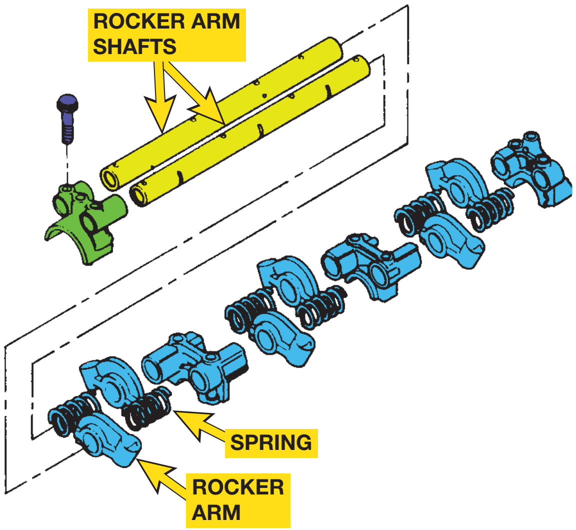


FIGURE 28–40 Shaft-mounted rocker arms are held in position by an assortment of springs, spacers, and washers, which should be removed so that the entire shaft can be inspected for wear.

TECH TIP

The Rotating Pushrod Test

To quickly and easily test whether the camshaft is okay, observe if the pushrods are rotating when the engine is running. This test works on any overhead valve pushrod engine that uses flat-bottom lifters. Due to the slight angle on the cam lobe and lifter offset, the lifter (and pushrod) should rotate whenever the engine is running. To check, simply remove the rocker arm cover and observe the pushrods when the engine is running. If one or more pushrods are *not* rotating, this camshaft and/or the lifter for that particular valve is worn and needs to be replaced.

CASE STUDY

The Noisy Camshaft

The owner of an overhead cam 4-cylinder engine complained of a noisy engine. After taking the vehicle to several technicians and getting high estimates to replace the camshaft and followers, the owner tried to find a less expensive solution. Finally, another technician replaced the serpentine drive belt on the front of the engine and "cured" the "camshaft" noise for a fraction of the previous estimates.

Many engines have been disassembled and/or overhauled because of a noise that was later determined to be from one of the following:

- Loose or defective accessory drive belt(s)
- Loose torque converter-to-flex plate (drive plate) bolts (nuts)
- Defective mechanical fuel pump (if equipped)

Summary:

Complaint—Vehicle owner complained about an noisy engine.
Cause—A defective accessory drive belt was found to be the cause of the noise.
Correction—The accessory drive belt was replaced, which eliminated the noisy engine complaint.

CAMSHAFT SPECIFICATIONS

DURATION **Camshaft duration** is the number of degrees of *crankshaft* (not camshaft) rotation for which a valve is lifted off the seat.

The specification for duration can be expressed by several different methods, which must be considered when comparing one cam with another. The three most commonly used methods include

1. **Duration of valve opening at zero lash (clearance).** If a hydraulic lifter is used, the lash is zero. If a solid lifter is used, this method of expression refers to the duration of the opening of the valve after the specified clearance (lash) between the rocker arm and the valve stem tip has been closed.
2. **Duration at 0.05 inch lifter (tappet) lift.** Because this specification method eliminates all valve lash clearances and compensates for lifter (tappet) styles, it is the preferred method to use when comparing one camshaft with another.

VALVE OVERLAP Another camshaft specification is the number of degrees of overlap. **Valve (camshaft) overlap** is the number of degrees of crankshaft rotation during which both intake and exhaust valves are open. In other words, overlap occurs at the beginning of the intake stroke and at the end of the exhaust stoke. All camshafts provide for some overlap to improve engine performance and efficiency, especially at higher engine speeds. ● **SEE FIGURE 28–41**.

LOBE CENTERS Another camshaft specification that creates some confusion is the angle of the centerlines of the intake and exhaust lobes. This separation between the centerlines of the intake and exhaust lobes is called

- **Lobe center**
- **Lobe separation**
- **Lobe displacement angle (LDA)**
- **Lobe spread**

The lobe center is measured in degrees. ● **SEE FIGURE 28–42**.

The usual method of drawing a camshaft timing diagram is in a circle illustrating two revolutions (720 degrees) of the crankshaft. ● **SEE FIGURE 28–43** for an example of a typical camshaft timing diagram for a camshaft with the same specifications as the one illustrated in ● **FIGURE 28–38**.

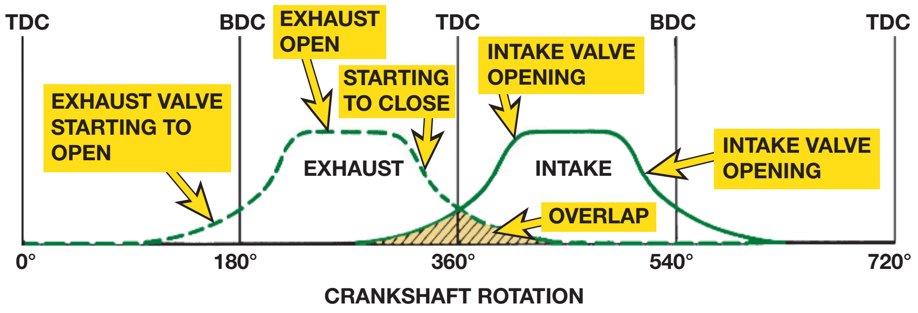


FIGURE 28–41 Graphic representation of a typical camshaft showing the relationship between the intake and exhaust valves. The shaded area represents the overlap period of 100 degrees.

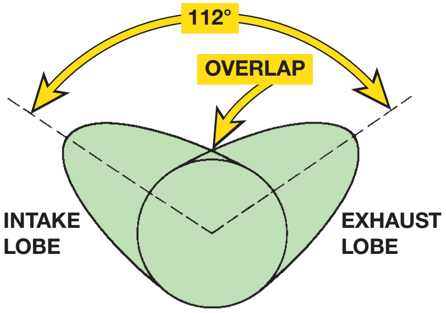

112°
OVERLAP
INTAKE LOBE
EXHAUST LOBE

FIGURE 28–42 As the lobe center angle decreases, the overlap increases, with no other changes in the lobe profile lift and duration.

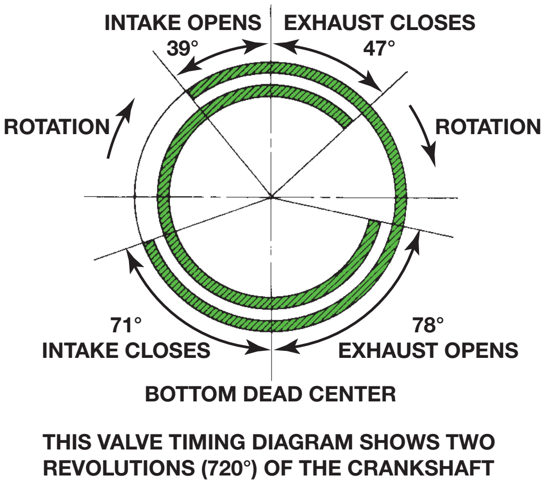

INTAKE OPENS
39°
EXHAUST CLOSES
47°
ROTATION
ROTATION
71°
INTAKE CLOSES
78°
EXHAUST OPENS
BOTTOM DEAD CENTER
THIS VALVE TIMING DIAGRAM SHOWS TWO REVOLUTIONS (720°) OF THE CRANKSHAFT

FIGURE 28–43 Typical camshaft valve timing diagram with the same specifications as those shown in FIGURE 28–36.

CAMSHAFT REMOVAL

CAM-IN-BLOCK ENGINES If the engine is of an OHV design, the camshaft is usually located in the block above the crankshaft. The timing chain and gears (if the vehicle is so equipped) should be removed after the timing chain (gear) cover is removed. Loosen the rocker arms (or rocker arm shaft) and remove the pushrods. Then remove the valve lifters before removing the camshaft from the block.

NOTE: Be sure to keep the pushrods and rocker arms together if they are to be reused.

MEASURING CAMSHAFTS

TOTAL INDICATOR RUNOUT All camshafts should be checked for straightness by placing them on V-blocks and measuring the cam bearings for runout by using a dial indicator. The maximum **total indicator runout (TIR)** (also called total indicated runout) should be less than 0.002 inch (0.05 mm).

CAM LOBE HEIGHT Sometimes the camshaft lobe height needs to be measured to verify the exact camshaft that is installed in the engine. This can be done by attaching a dial indicator and slowly rotating the engine while observing the indicator and comparing the measurement to factory specifications. ● **SEE FIGURE 28–44**.

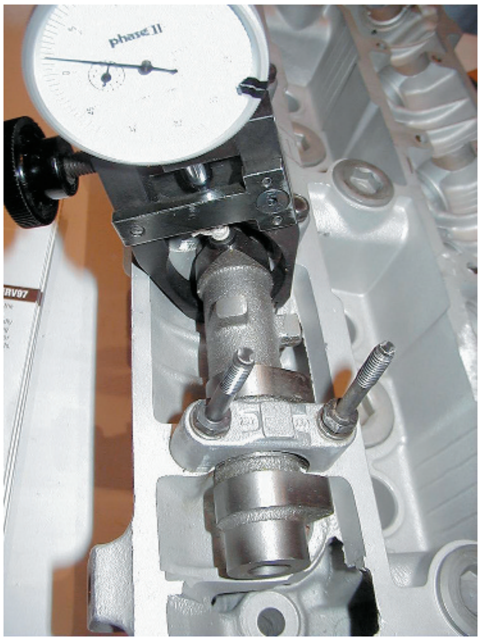


FIGURE 28–44 A dial indicator being used to measure cam lobe height.

REVIEW QUESTIONS

1. How is the camshaft driven by the crankshaft?
2. What drives the high-pressure fuel pump on a GDI engine?
3. How is a composite camshaft constructed?
4. What is meant by an “interference” engine?
5. Why should the pushrods and rocker arms be kept together if they are to be reused?

CHAPTER QUIZ

1. The camshaft makes ______________ for every revolution of the crankshaft.
   - **a.** one-quarter revolution
   - **b.** one-half revolution
   - **c.** one revolution
   - **d.** two revolutions
2. A DOHC V-6 has how many camshafts?
   - **a.** 4
   - **b.** 2
   - **c.** 3
   - **d.** 1

3. Which timing chain type is also called a "silent chain"?
   - **a.** Roller
   - **b.** Morse
   - **c.** Flat link
   - **d.** Both b and c
4. Many technicians always use new pushrods because ______________.
   - **a.** they are less expensive to buy than clean
   - **b.** all of the dirt cannot be cleaned out from the hollow center
   - **c.** they wear at both ends
   - **d.** they shrink in length if removed from an engine
5. Hydraulic valve lifters can make a ticking noise when the engine is running if ______________.
   - **a.** the valve lash is too close
   - **b.** the valve lash is too loose
   - **c.** the lobe centerline is over 110 degrees
   - **d.** Both a and c
6. Hydraulic lifters or hydraulic lash adjusters (HLA) may not bleed down properly and cause an engine to miss if ______________.
   - **a.** the engine oil is one quart low
   - **b.** the wrong API-rated engine oil is used
   - **c.** the wrong SAE-rated engine oil is used
   - **d.** Both a and b
7. If lift and duration remain constant and the lobe center angle decreases, ______________.
   - **a.** the valve overlap decreases
   - **b.** the effective lift increases
   - **c.** the effective duration increases
   - **d.** the valve overlap increases
8. What is the slack side of a timing chain?
   - **a.** The left side as viewed from the front of the engine
   - **b.** The right side as viewed from the front of the engine
   - **c.** Either a or b
   - **d.** Both a and b
9. The maximum total indicator runout (TIR) of a camshaft should be less than ______________.
   - **a.** 0.002 in.
   - **b.** 0.006 in.
   - **c.** 0.004 in.
   - **d.** 0.008 in.
10. What can cause valve train noise?
    - **a.** Valve lash too loose
    - **b.** Dirty, stuck, or worn lifters
    - **c.** Broken or weak valve springs
    - **d.** Any of the above

Chapter 29

VARIABLE VALVE TIMING AND DISPLACEMENT SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and function of variable valve timing (VVT).
- List the steps involved when diagnosing a VVT system.
- Describe how a variable valve timing and lift electronic control (VTEC) system works.
- Explain the operation of variable displacement systems.
- Explain the diagnosis of variable displacement systems.

KEY TERMS:

Variable valve timing and lift electronic control (VTEC) 324 • Oil control valve (OCV) 319 • Spline phaser 320 • Vane phaser 320

VARIABLE VALVE TIMING

PURPOSE OF VARIABLE VALVE TIMING Conventional camshafts are permanently synchronized to the crankshaft so that they operate the valves at a specific point in each combustion cycle. In an engine, the intake valve opens slightly before the piston reaches the top of the cylinder and closes about 60 degrees after the piston reaches the bottom of the stroke on every cycle, regardless of the engine speed or load.

VARIABLE VALVE TIMING SYSTEMS Variable valve timing (VVT) involves the use of electric and hydraulic actuators that are used to change the timing of the camshaft(s) in relation to the crankshaft. Variable valve timing, also called variable cam timing (VCT), allows the valves to be operated at different points in the combustion cycle to improve performance. There are four basic types of VVT used on engines:

- **Exhaust only.** An engine that uses VVT on the exhaust only is used to create an EGR affect, thereby eliminating the need for an exhaust gas recirculation (EGR) valve. In this system, the exhaust valve is retarded when the engine is operating at part throttle. This delays the closing of the exhaust valves, which allows exhaust gases to be trapped in the combustion chamber. ● **SEE FIGURE 29–1**.

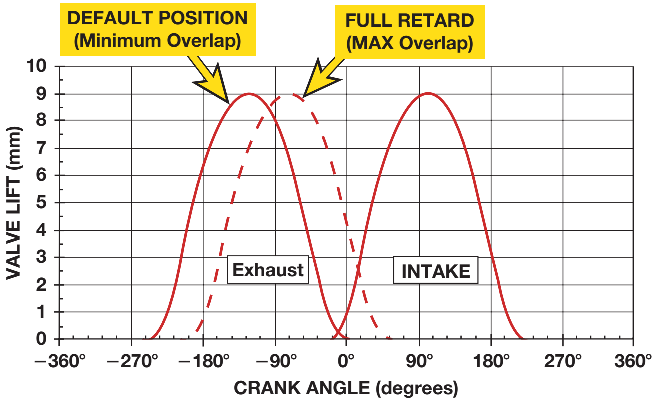


FIGURE 29–1 The exhaust-only variable cam timing systems allow the overlap period where both valves are open to be changed. The at-rest position provides little valve overlap, whereas the maximum overlap allows for internal EGR needed to reduce NO$_x$ exhaust emissions.

- **Intake only.** Changing the intake camshaft timing results in improved engine performance. This is due to commanding the intake valve to close earlier in the compression stroke, resulting in less of the air/fuel charge being pushed back into the intake port (reversions). The result is improved low-speed torque that the engine can produce. On a system that controls the intake camshaft only, the camshaft timing is advanced at low engine speed, closing the intake valves earlier to improve low RPM torque. At high engine speeds, the camshaft is retarded by using engine oil pressure against a helical gear to rotate the camshaft. When the camshaft is retarded, the intake valve closing is delayed, improving cylinder filling at higher engine speeds.

- **Cam-in-block.** Some overhead valve (OHV) engines that use a single camshaft to control the valves are equipped with a phaser that allows the cam to be rotated in relation to the crankshaft to achieve VVT. The powertrain control module (PCM) retards the camshaft to trap exhaust gases so an EGR valve is not needed to meet NO_x exhaust emissions. The camshaft can be changed to create a broad engine torque range and improved fuel economy.
- **Both Intake and Exhaust Cams.** Many double overhead camshaft (DOHC) engines use VVT on both the intake and the exhaust camshafts. By varying both camshafts, the engine torque is increased over a wide engine speed range. This allows the PCM to control the amount of exhaust gases trapped in the combustion chamber to control the formation of oxides of nitrogen (NO_x) emissions. This is achieved by allowing the intake valve(s) to open sooner or the exhaust valve(s) to stay open longer. ● **SEE FIGURE 29–2** and ● **SEE CHART 29–1**.

CAMSHAFT PHASING CHANGED	PURPOSE
Exhaust cam phasing	Reduces NO_x exhaust emissions
Exhaust cam phasing	Increases fuel economy (reduced pumping losses)
Intake cam phasing	Increases low-speed torque
Intake cam phasing	Increases high-speed power

CHART 29–1

By varying the intake camshaft timing, engine performance is improved. By varying the exhaust camshaft timing, the exhaust emissions and fuel consumption are reduced.

PARTS AND OPERATION The camshaft position actuator **oil control valve (OCV)** directs oil from the oil feed in the head to the appropriate camshaft position actuator oil passages. There is one OCV for each camshaft position actuator. The OCV is sealed

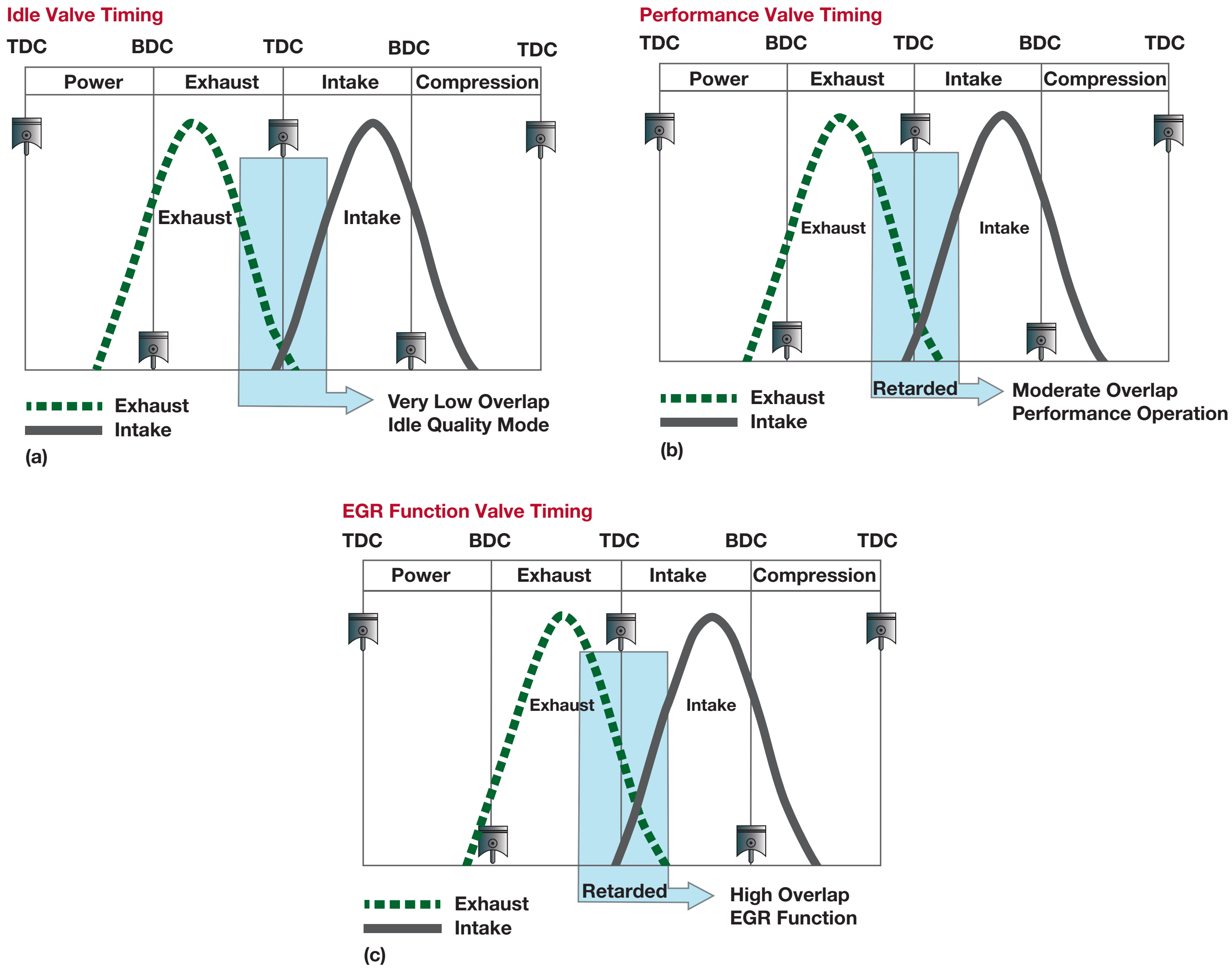

Idle Valve Timing
TDC
BDC
TDC
BDC
TDC
Power
Exhaust
Intake
Compression
Exhaust
Intake
Exhaust
Intake
Very Low Overlap
Idle Quality Mode
(a)
Performance Valve Timing
TDC
BDC
TDC
BDC
TDC
Power
Exhaust
Intake
Compression
Exhaust
Intake
Retarded
Exhaust
Intake
Moderate Overlap
Performance Operation
(b)
EGR Function Valve Timing
TDC
BDC
TDC
BDC
TDC
Power
Exhaust
Intake
Compression
Exhaust
Intake
Retarded
Exhaust
Intake
High Overlap
EGR Function
(c)

FIGURE 29–2 (a) At engine start, the camshaft timing has little valve overlap, which improves idle quality. (b) During acceleration, the valve overlap is increased to improve engine performance. (c) To reduce NO_x emissions, the valve timing is changed to trap some of the exhaust gases in the combustion chamber, thereby eliminating the needs for an EGR valve.

FREQUENTLY ASKED QUESTION

What Are the Various Names Used for Variable Valve Timing Systems?

- **BMW—**VANOS (Variable Nockenwellen Steuerung)
- **Ford—**VVT (Variable Valve Timing)
- **GM—**DCVCP (Double Continuous Variable Cam Phasing), if used for both intake and exhaust camshafts
- **Honda—**VTEC (Variable valve Timing and lift Electronic Control)
- **Hyundai—**MPI CVVT (Multiport Injection Continuously Variable Valve Timing)
- **Mazda—**S-VT (Sequential Valve Timing)
- **Mitsubishi—**MIVECC (Mitsubishi Innovative Valve timing Electronic Control system)
- **Nissan—**N-VCTT (Nissan Variable Control Timing)
- **Nissan—**VVL (Variable Valve Lift)
- **Porsche—**Variocam (Variable camshaft timing)
- **Suzuki—**VVT (Variable Valve Timing)
- **Subaru—**AVCS (Active Valve Control System)
- **Toyota—**VVT-i (Variable Valve Timing-intelligent)
- **Toyota—**VVTL-i (Variable Valve Timing and Lift-intelligent)
- **Volkswagen—**VVT (Variable Valve Timing)
- **Volvo—**VVT (Variable Valve Timing)

and mounted to the front cover. The ported end of the OCV is inserted into the cylinder head with a sliding fit. A filter screen protects each OCV oil port from any contamination in the oil supply. The camshaft position actuator is mounted to the front end of the camshaft. The timing notch in the nose of the camshaft aligns with the dowel pin in the camshaft position actuator to ensure proper cam timing and camshaft position actuator oil hole alignment. ● **SEE FIGURE 29–3**.

CAMSHAFT PHASERS There are two types of cam phasing devices used:

1. **Spline phaser** is used on overhead camshaft (OHC) engines. ● **SEE FIGURE 29–4**.
2. **Vane phaser** is used on overhead camshaft (OHC) and overhead valve (OHV) cam-in-block engines.

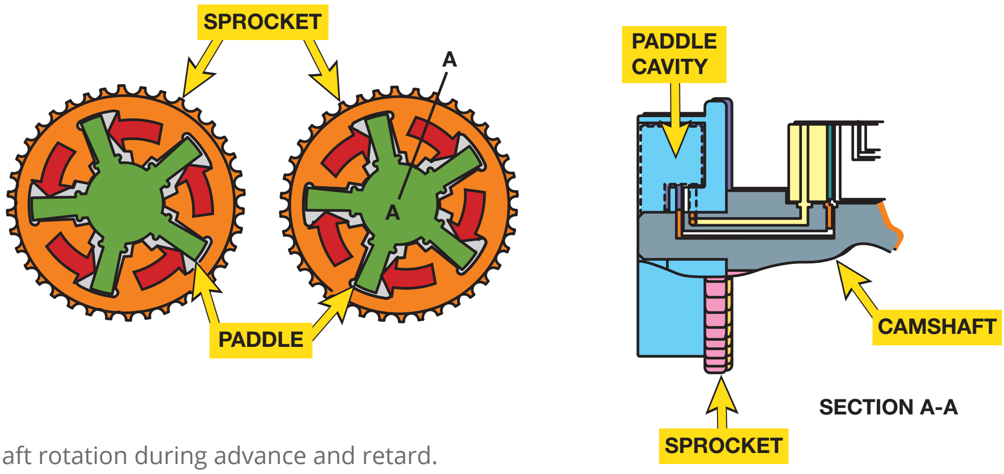


FIGURE 29–3 Camshaft rotation during advance and retard.

SPLINE PHASER SYSTEM OPERATION On a typical OHC engine, the control valve is located on the front passenger side of the cylinder head. The OCV is controlled using a pulse-width modulation (PWM) signal from the PCM. Oil pressure is regulated by the control valve and then directed to the ports in the cylinder head leading to the camshaft and cam phaser position. The cam phaser is located on the exhaust cams and is part of the exhaust cam sprocket. When the ECM commands an increase in oil pressure, the piston is moved inside the cam phaser and rides along the helical splines, which compresses the coil spring. This movement causes the cam phaser gear and the camshaft to move in an opposite direction, thereby retarding the cam timing. ● **SEE FIGURE 29–5**.

VANE PHASER SYSTEM ON AN OVERHEAD CAMSHAFT ENGINE The vane phaser system used on OHC engines uses a camshaft position (CMP) sensor on each camshaft. Each camshaft has its own actuator and its own OCV. Instead of using a piston along a helical spline, the vane phaser uses a rotor with four vanes, which is connected to the end of the camshaft. The rotor is located inside the stator, which is bolted to the cam sprocket. The stator and rotor are not connected. Oil pressure is controlled on both sides of the vanes of the rotor, which creates a hydraulic link between the two parts. The OCV varies the balance of pressure on either side of the vanes and thereby controls the position of the camshaft. A return spring is used under the reluctor of the phaser to help return it to the home or position. ● **SEE FIGURE 29–6**.

MAGNETICALLY CONTROLLED VANE PHASER A magnetically controlled vane phaser is controlled by the PCM by using a 12-volt pulse-width-modulated signal to an electromagnet, which

TECH TIP

Check the Screen on the Control Valve If There Are Problems

If a NO_x emission failure at a state inspection occurs or a diagnostic trouble code is set related to the cam timing, remove the control valve and check for a clogged oil screen. A lack of regular oil changes can cause the screen to become clogged, thereby preventing proper operation. A rough idle is a common complaint because the spring may not be able to return the camshaft to the idle position after a long highway trip. ● **SEE FIGURE 29–7**.

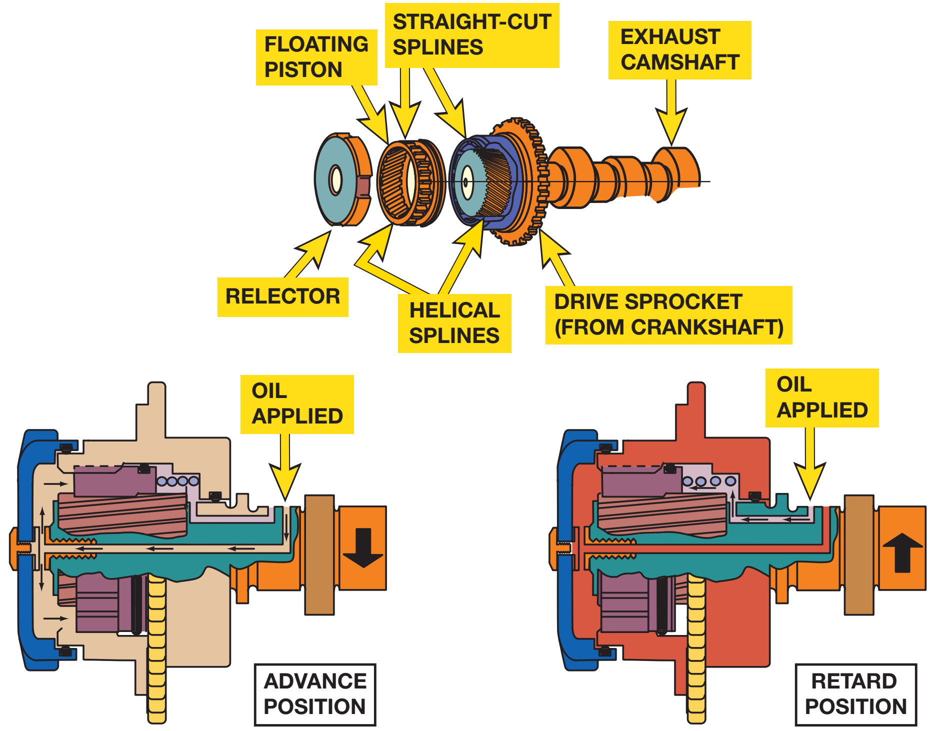

FLOATING PISTON
STRAIGHT-CUT SPLINES
EXHAUST CAMSHAFT
RELECTOR
HELICAL SPLINES
DRIVE SPROCKET (FROM CRANKSHAFT)
OIL APPLIED
OIL APPLIED
ADVANCE POSITION
RETARD POSITION

FIGURE 29–4 Spline cam phaser assembly.

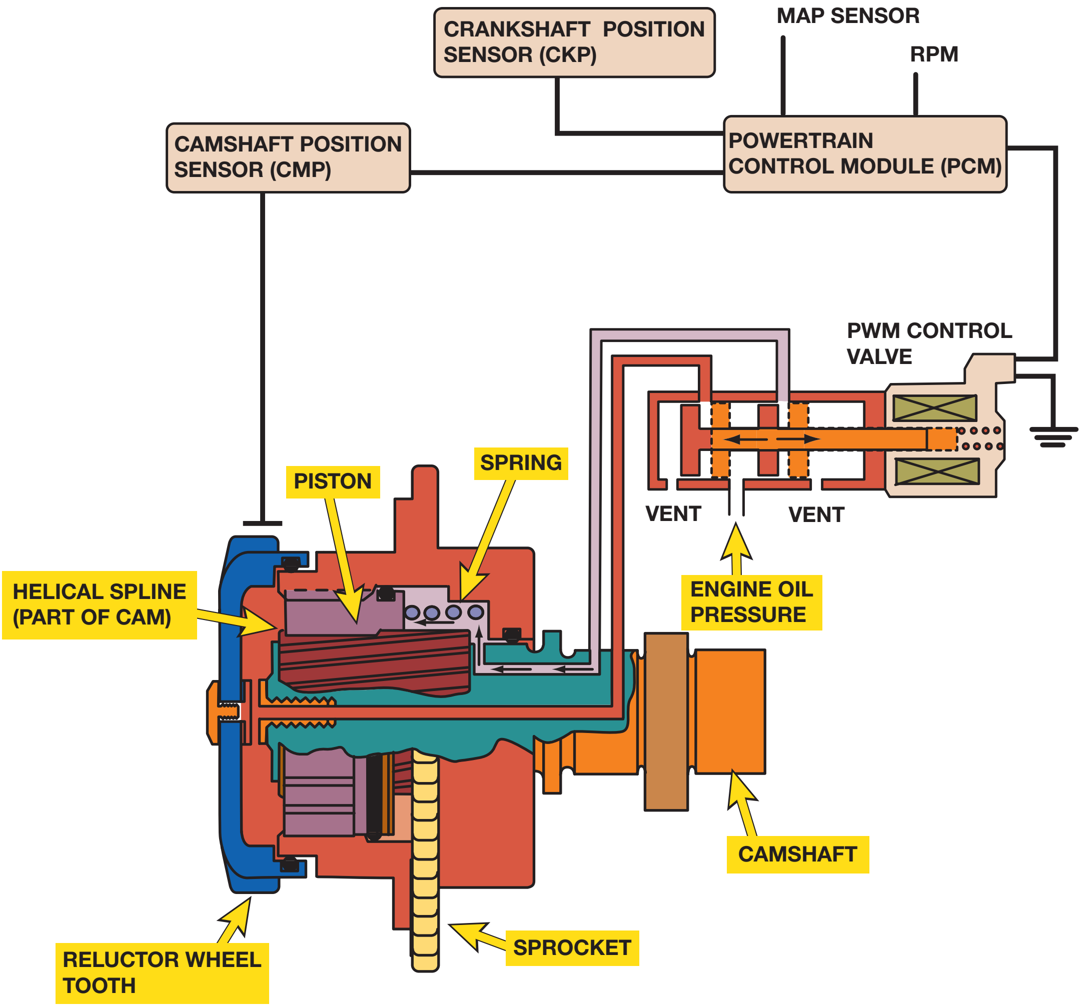

CRANKSHAFT POSITION SENSOR (CKP)
MAP SENSOR
RPM
CAMSHAFT POSITION SENSOR (CMP)
POWERTRAIN CONTROL MODULE (PCM)
PWM CONTROL VALVE
VENT
VENT
ENGINE OIL PRESSURE
PISTON
SPRING
HELICAL SPLINE (PART OF CAM)
CAMSHAFT
SPROCKET
RELUCTOR WHEEL TOOTH

FIGURE 29–5 A spline phaser showing the control valve and how it works internally. Note that the PCM uses the engine speed (RPM), crankshaft position (CKP) sensor, and the camshaft position (CMP) sensor to monitor and command the camshaft for maximum power and lowest possible exhaust emissions.

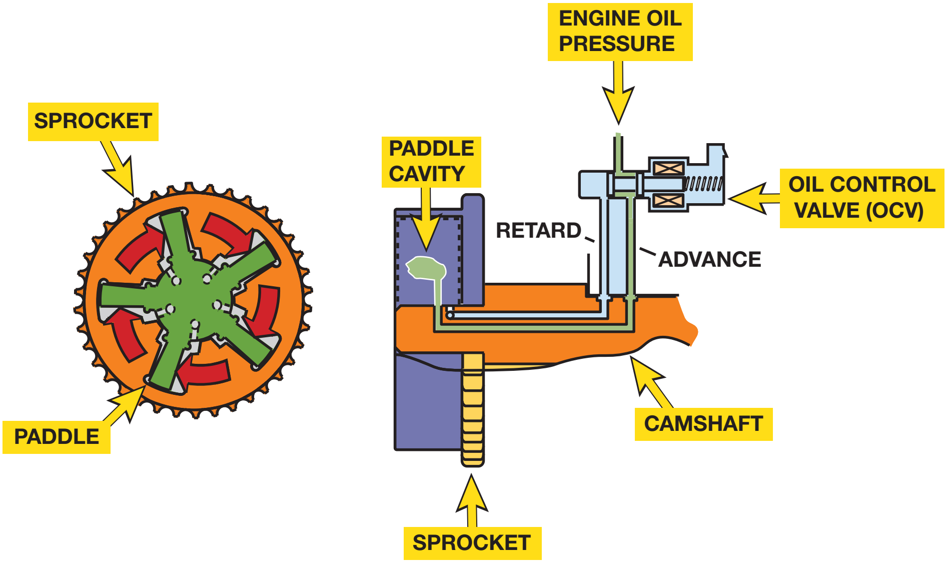

ENGINE OIL PRESSURE
SPROCKET
PADDLE CAVITY
OIL CONTROL VALVE (OCV)
RETARD
ADVANCE
PADDLE
CAMSHAFT
SPROCKET

FIGURE 29–6 A vane phaser is used to move the camshaft using changes of oil pressure from the oil control valve.

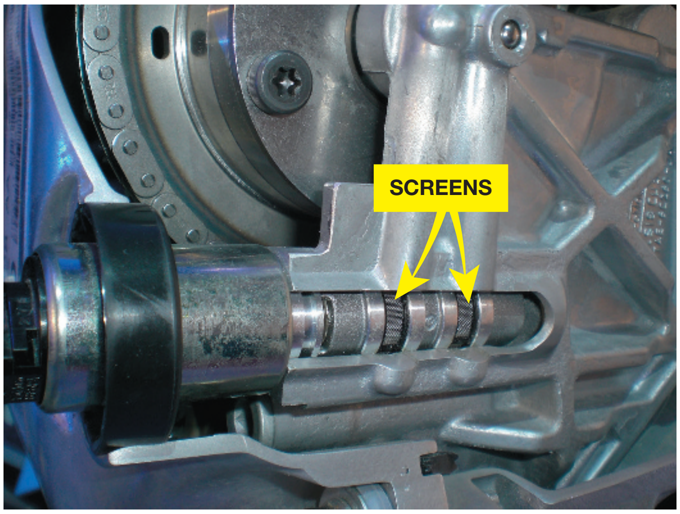


FIGURE 29–7 The screen(s) protects the solenoid valve from dirt and debris that can cause the valve to stick. This fault can set a P0017 diagnostic trouble code (crankshaft position–camshaft position correlation error).

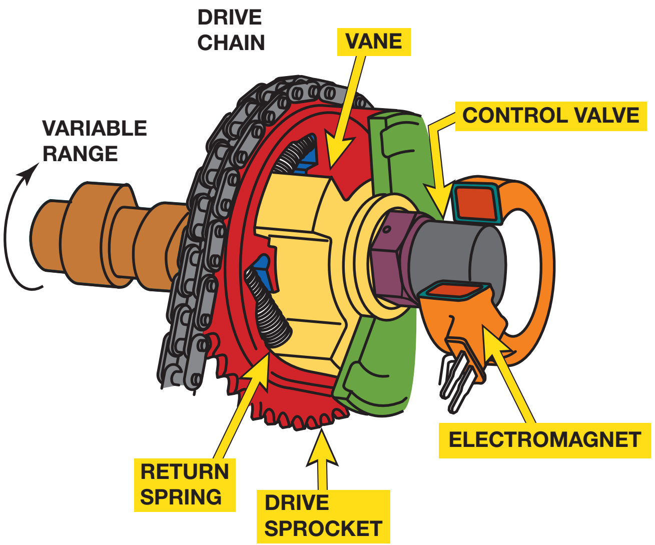

DRIVE CHAIN
VANE
VARIABLE RANGE
CONTROL VALVE
ELECTROMAGNET
RETURN SPRING
DRIVE SPROCKET

FIGURE 29–8 A magnetically controlled vane phaser.

operates the OCV. A magnetically controlled vane phaser is used on many engines that use OHCs on both the intake and exhaust. The OCV directs pressurized engine oil to either advance or retard chambers of the camshaft actuator to change the camshaft position in relation to the crankshaft position. ● **SEE FIGURE 29–8.**

The following occurs when the pulse width is changed:

- **0% pulse width.** The oil is directed to the advance chamber of the exhaust camshaft actuator and the retard chamber of the intake camshaft activator.
- **50% pulse width.** The PCM is holding the cam in the calculated position based on engine RPM and load. At 50% pulse width, the oil flow through the phaser drops to zero. ● **SEE FIGURE 29–9.**
- **100% pulse width.** The oil is directed to the retard chamber of the exhaust camshaft actuator and the advance chamber of the intake camshaft actuator.

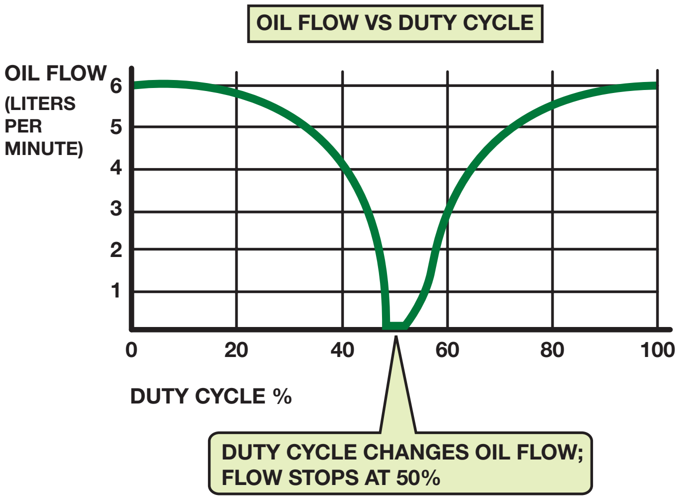


FIGURE 29–9 When the PCM commands 50% duty cycle, the oil flow through the phaser drops to zero.

The cam phasing is continuously variable with a range from 40 for the intake camshaft and 50 for the exhaust camshaft. The PCM uses the following sensors to determine the best position of the camshaft for maximum power and lowest possible exhaust emissions:

- Engine speed (RPM)
- MAP sensor
- Crankshaft position (CKP) sensor
- Camshaft position (CMP) sensor
- Barometric pressure (BARO) sensor

FREQUENTLY ASKED QUESTION

What Happens When the Engine Stops?

When the engine stops, the oil pressure drops to zero and a spring-loaded locking pin is used to keep the camshaft locked to prevent noise at engine start. When the engine starts, oil pressure releases the locking pin.

DIAGNOSIS OF VARIABLE VALVE TIMING SYSTEMS

DIAGNOSTIC STEPS The diagnostic procedure as specified by most vehicle manufacturers usually includes the following steps:

STEP 1 Verify the customer concern. This will usually be a "check engine light" (malfunction indicator light or MIL), as the engine performance effects would be minor under most operating conditions.

STEP 2 Perform a thorough visual inspection including checking the oil for proper level and condition.

STEP 3 Check for stored diagnostic trouble codes (DTCs). Typical VVT-related DTCs include the following:

P0011—Intake cam position is over advanced bank 1
P0012—Intake cam position is over retarded bank 1
P0013—Exhaust camshaft position actuator
P0014—Exhaust camshaft too far advanced
P0021—Intake cam position is over advanced bank 2
P0022—Intake cam position is over retarded bank 2

STEP 4 Use a scan tool and check for duty cycle on the cam phase solenoid while operating the vehicle at a steady road speed. The commanded pulse width should be 50%. If the pulse width is not 50%, the PCM is trying to move the phaser to its commanded position and the phaser has not reacted properly. A PWM signal of higher or lower than 50% usually indicates a stuck phaser assembly.

STEP 5 Check the solenoid for proper resistance. If a scan tool with bidirectional control is available, connect an ammeter and measure the current as the solenoid is being commanded on by the scan tool.

STEP 6 Check for proper engine oil pressure. Low oil pressure or restricted flow to the cam phaser can be the cause of many DTCs.

STEP 7 Determine the root cause of the problem and clear all DTCs.

STEP 8 Road-test the vehicle to verify the fault has been corrected.

CASE STUDY

The Case of the Chevrolet Equinox

The owner of a Chevrolet Equinox complained that the engine was making noise and the "check engine" light on the dash was on. The service technician used a scan tool and retrieved two diagnostic trouble codes:

P0014—Exhaust cam position sensor system performance
P0013—Camshaft position actuator circuit open

The service technician removed the exhaust cam actuator solenoid and found that the filter screen was covered with metal shavings. ● **SEE FIGURE 29–10**.

The technician recommended replacing the engine due to the amount of metal shavings and a new camshaft actuator solenoid. The customer approved the repair, and this solved both the engine noise and eliminated the check engine light after the installation of the replacement engine, and after that the DTCs were cleared.

Summary:

Complaint—The owner complained of a noisy engine and the "check engine" light on the dash was on.

Cause—Major engine wear caused the noise and the wear metal caused the exhaust camshaft actuator solenoid filter screen to become clogged, setting a diagnostic trouble code and lighting the check engine light.

Correction—The engine was replaced and the trouble code cleared.

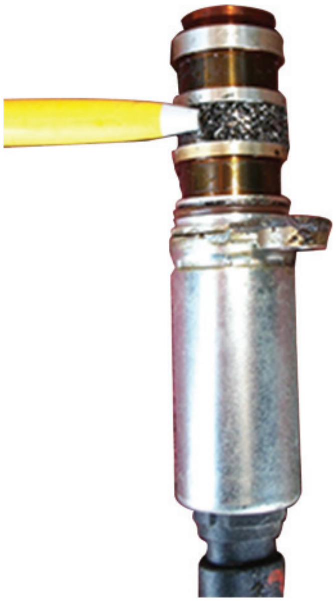


FIGURE 29–10 The exhaust camshaft actuator solenoid taken from a Chevrolet 2.4-liter four-cylinder showing the filter screen clogged with metal shavings.

VARIABLE VALVE TIMING AND LIFT ELECTRONIC CONTROL

OPERATION Variable camshafts such as the system used by Honda/Acura are called **variable valve timing and lift electronic control (VTEC)**. This system uses two different camshafts for low and high RPM. When the engine is operating at idle and speeds below about 4000 RPM, the valves are opened by camshafts that are optimized by maximum torque and fuel economy. When engine speed reaches a predetermined speed, depending on the exact make and model, the computer turns on a solenoid, which opens a spool valve. When the spool valve opens, the engine oil pressure pushes against pins that lock the three intake rocker arms together. With the rocker arms lashed, the valves must follow the profile of the high RPM cam lobe in the center. This process of switching from the low-speed camshaft profile to the high-speed profile takes about 100 milliseconds (0.1 sec). ● **SEE FIGURES 29–11 AND 29–12**.

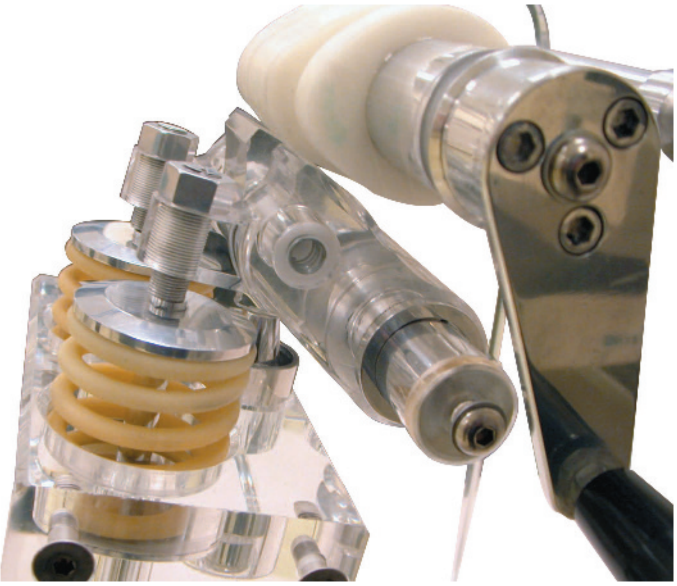


FIGURE 29–11 A plastic mock-up of a Honda VTEC system that uses two different camshaft profiles: one for low-speed engine operation and the other for high-speed operation.

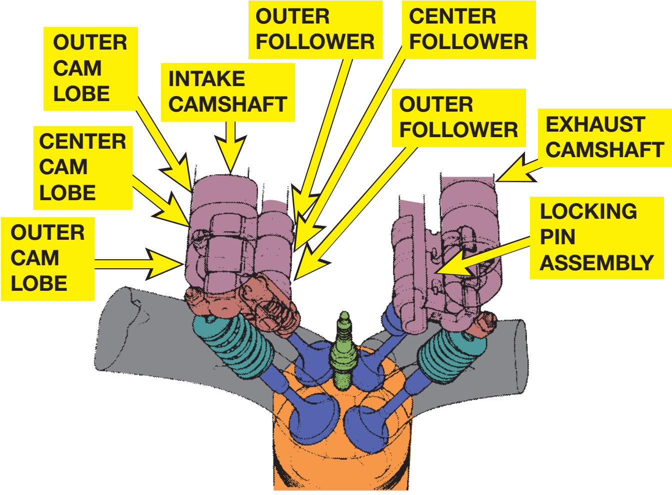


FIGURE 29–12 Engine oil pressure is used to switch cam lobes on a VTEC system.

VARIABLE DISPLACEMENT SYSTEMS

PURPOSE AND FUNCTION Some engines are designed to be operated on four of eight or three of six cylinders during low-load conditions to improve fuel economy. The PCM monitors engine speed, coolant temperature, throttle position, and load. It also determines when to deactivate cylinders. The following list names the systems that can deactivate cylinders:

- Cylinder cutoff system
- Variable displacement system
- Active Fuel Management or Dynamic Fuel Management—General Motors
- Multiple Displacement System (MDS)—Chrysler
- Multiair—Some Chrysler and Fiat brand vehicles

PARTS AND OPERATION The key to this process is the use of two-stage hydraulic valve lifters. In normal operation, the inner and outer lifter sleeves are held together by a pin and operate as an assembly. When the computer determines that the cylinder can be deactivated, oil pressure is delivered to a passage, which depresses the pin and allows the outer portion of the lifter to follow the contour of the cam while the inner portion remains stationary, keeping the valve closed. The electronic operation is achieved through the use of a lifter oil manifold containing solenoids to control the oil flow, which is used to activate or deactivate the cylinders. ● **SEE FIGURES 29–13 AND 29–14**.

When cylinders are deactivated, the fuel injectors are turned off but the spark plugs continue to fire. Keeping the spark plugs firing helps to prevent the spark plugs from cooling, which could lead to fouling. The exhaust valves close trapping exhaust in the deactivated cylinders to help keep the piston rings seated. The PCM usually restores operation for all cylinders after a certain amount of time operating in cylinder deactivation mode. The time varies but often after about 10 minutes it then goes back to deactivating the cylinders in less than a minute to optimize fuel economy and reduce exhaust emissions.

ENABLE CRITERIA Before the engine starts to disable cylinders, the following conditions usually need to be met but can vary with make, model, and year:

- System voltage above the lower threshold and below upper limit threshold (usually 11 to 18 volts)
- Engine speed within the designed parameters (usually between 900 and 3000 RPM)
- Engine oil temperature within normal operating range usually 70°F to 250°F (21°C to 121°C)
- Engine oil pressure within the normal range usually 28 to 75 PSI.

DISABLE CRITERIA The engine is restored to firing on all cylinders if any of the following occurs:

- The intake manifold vacuum reaches a low level indicating a heavy load on the engine.
- The accelerator pedal position (APP) sensor reading is above a threshold or the rate of increase is too high indicating that the driver is requiring more power from the engine.
- The system voltage is outside of the high or low threshold.

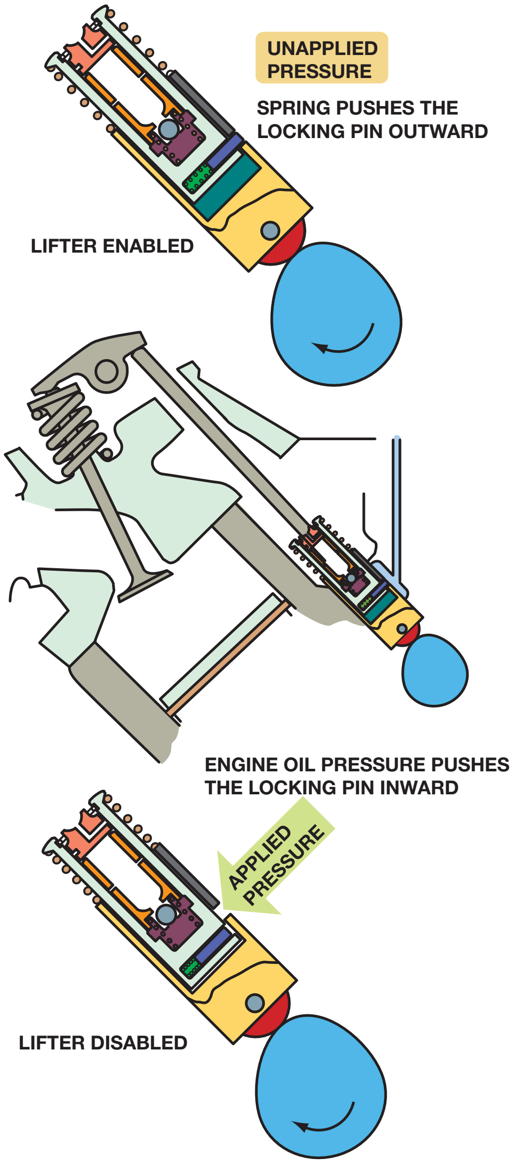

UNAPPLIED PRESSURE
SPRING PUSHES THE LOCKING PIN OUTWARD
LIFTER ENABLED
ENGINE OIL PRESSURE PUSHES THE LOCKING PIN INWARD
APPLIED PRESSURE
LIFTER DISABLED

FIGURE 29–13 Oil pressure applied to the locking pin causes the inside of the lifter to freely move inside the outer shell of the lifter, thereby keeping the valve closed.

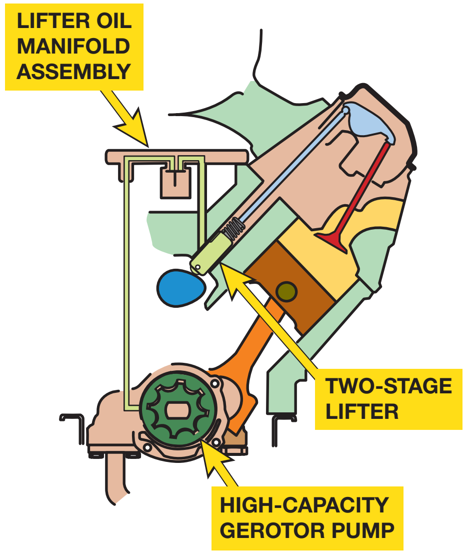


FIGURE 29–14 Active fuel management includes many different components and changes to the oiling system, which makes routine oil changes even more important on engines equipped with this system.

CASE STUDY

The Case of the Wrong Oil

A Dodge Durango was in the shop for routine service, including a tire rotation and an oil change.

Shortly after, the customer returned and stated that the “check engine” light was on. A scan tool was used to retrieve any diagnostic trouble codes. A P0521, “oil pressure not reaching specified value at 1250 RPM” was set. A check of service information showed that this code could be set if the incorrect viscosity engine oil was used. The shop had used SAE 10W-30, but the 5.7-liter Hemi V-8 with multiple displacement system (MDS) required SAE 5W-20 oil. The correct oil was installed and the DTC cleared. A thorough test-drive confirmed that the fault had been corrected and the shop learned that the proper viscosity oil is important to use in all vehicles.

Summary:

Complaint—The check engine light was on after an oil change.

Cause—Incorrect viscosity oil was used.

Correction—The oil was replaced with the specified viscosity and the DTC was cleared.

VARIABLE DISPLACEMENT SYSTEM DIAGNOSIS

DIAGNOSTIC STEPS The diagnosis of the variable displacement system usually starts as a result of a check engine light (malfunction indicator lamp or MIL). The diagnostic procedure specified by the vehicle manufacturer usually includes the following steps:

STEP 1 Verify the customer concern. With a cylinder deactivation system, the customer concern could be lower than expected fuel economy.

STEP 2 Check for any stored DTCs. A fault code set for an emission-related fault could cause the PCM to disable cylinder deactivation.

STEP 3 Perform a thorough visual inspection, including checking the oil level and condition.

STEP 4 Check scan tool data for related parameters to see if any of the sensors are out of the normal range.

STEP 5 Determine the root cause and perform the repair as specified in service information.

STEP 6 Test-drive the vehicle to verify proper operation.

REVIEW QUESTIONS

1. What is the advantage of varying the intake camshaft timing?
2. What is the advantage of varying the exhaust camshaft timing?
3. Why must the engine oil be changed regularly on an engine equipped with variable valve timing (VVT)?
4. What sensors does the powertrain control module (PCM) monitor to determine the best camshaft timing?
5. What diagnostic trouble codes are associated with the variable valve timing (VVT) system?

CHAPTER QUIZ

1. Variable valve timing can be found on which type of engines?
   a. Cam-in-block
   b. SOHC
   c. DOHC
   d. All of the above
2. To reduce oxides of nitrogen (NO_x) exhaust emissions, which camshaft is varied?
   a. Exhaust camshaft only
   b. Intake camshaft only
   c. Both the intake and exhaust camshaft
   d. The exhaust camshaft is advanced and the intake camshaft is advanced.
3. To increase engine performance, which camshaft is varied?
   a. Exhaust camshaft only
   b. Intake camshaft only
   c. Both the intake and exhaust camshaft
   d. The exhaust camshaft is advanced and the intake camshaft is advanced.
4. What is the commanded pulse width of the camshaft phaser that results in zero oil flow?
   a. 0%
   b. 25%
   c. 50%
   d. 100%
5. What sensors are used by the PCM to determine the best position of the camshafts for maximum power and lowest possible exhaust emissions?
   a. Engine speed (RPM)
   b. Crankshaft position (CKP) sensor
   c. Camshaft position (CMP) sensor
   d. All of the above
6. How is the camshaft actuator controlled?
   a. On only when conditions are right
   b. Pulse-width-modulated (PWM) signal
   c. Spring-loaded to the correct position based on engine speed
   d. Vacuum-controlled valve
7. If the engine oil is not changed regularly, what is the most likely fault that can occur to an engine equipped with variable valve timing (VVT)?
   a. Low oil pressure diagnostic trouble code (DTC)
   b. A no-start condition because the camshaft cannot rotate
   c. The filter screens on the actuator control valve become clogged
   d. Any of the above
8. How quickly can the rocker arms be switched from the low-speed camshaft profile to the high-speed camshaft profile on a Honda equipped with a variable valve timing and lift electronic control (VTEC) system?
   a. 50 milliseconds
   b. 100 milliseconds
   c. 250 milliseconds
   d. 500 milliseconds
9. Which diagnostic trouble code (DTC) may be set if there is a problem with the bank 1 intake cam position?
   a. P0300
   b. P0420
   c. P0011 or P0012
   d. P0021 or P0022
10. If the incorrect grade of engine oil is used in an engine equipped with a variable displacement engine, what diagnostic trouble code (DTC) could be set?
   a. P0521
   b. P0300
   c. P0420
   d. P0011

Chapter 30

PISTONS, RINGS, AND CONNECTING RODS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and function of pistons.
- Explain piston construction.
- Discuss piston pins.
- Discuss piston pin retaining methods.
- Explain piston rings.
- Discuss piston ring construction.
- Discuss connecting rods.
- Discuss connecting rod service.
- Explain piston and rod assembly.
- Explain piston ring service.

KEY TERMS:

Back clearance 334 • Balancing bosses (pads) 337 • Barrel face ring 335 • Bleed hole 337 • Blowby 334 • Cam ground 330 • Compression rings 333 • Connecting rod bearing journal 327 • Crankpin 327 • Crank throw 327 • Double knock 332 • Ductile iron 335 • Freewheeling 329 • Full floating 332 • Grooves 328 • Heat dams 330 • Hypereutectic 329 • Interference fit 333 • Lands 328 • Lock ring 332 • Major thrust surface 331 • Oil control ring 333 • Piston 327 • Piston pin 327 • Piston ring expander 341 • Piston rings 327 • Positive twist ring 335 • Reverse twist ring 335 • Ring gap 334 • Scraper ring 335 • Side clearance 334 • Skirt 328 • Slipper skirt 330 • Spit hole 337 • Struts 331 • Taper face ring 334 • Wrist pin 327

PISTONS

PURPOSE AND FUNCTION

All engine power is developed by burning fuel mixed with air in the combustion chamber. Heat from the combustion causes the burned gas to increase in pressure. The force of this pressure is converted into useful work through the piston, connecting rod, and crankshaft. Therefore, the piston serves three purposes:

1. **Transfers force.** The piston transfers the force of combustion to the crankshaft through the connecting rod.
2. **Seals the combustion chamber.** The piston and piston rings seal the compressed air during the compression stroke and the combustion gases on the power stroke.
3. **Conducts heat.** The piston transfers heat from the combustion chamber to the cylinder walls through the piston rings and to the engine oil through the piston.

PARTS INVOLVED

The **piston** forms a movable bottom to the combustion chamber. ● **SEE FIGURE 30–1**.

The piston is attached to the connecting rod with a **piston pin**, also called a **wrist pin**. The piston pin is allowed to have a rocking movement because of a swivel joint at the piston end of the connecting rod. The crankshaft changes the up-and-down (reciprocating) motion of the pistons into rotary motion. The connecting rod is connected to a part of the crankshaft called a **crank throw**, **crankpin**, or **connecting rod bearing journal**.

Piston rings seal the small space between the piston and cylinder wall, keeping the pressure above the piston. When the pressure builds up in the combustion chamber, it pushes on the piston. The piston, in turn, pushes on the piston pin and upper end of the connecting rod. The lower end of the connecting rod pushes on the crank throw. This provides the force to turn the crankshaft. As the crankshaft turns, it develops inertia. *Inertia is the force that causes the crankshaft to continue rotating.* This action will bring the piston back to its original position, where it will be ready for the next power stroke. While the engine is running, the combustion cycle keeps repeating as the piston reciprocates (moves up and down) and the crankshaft rotates.

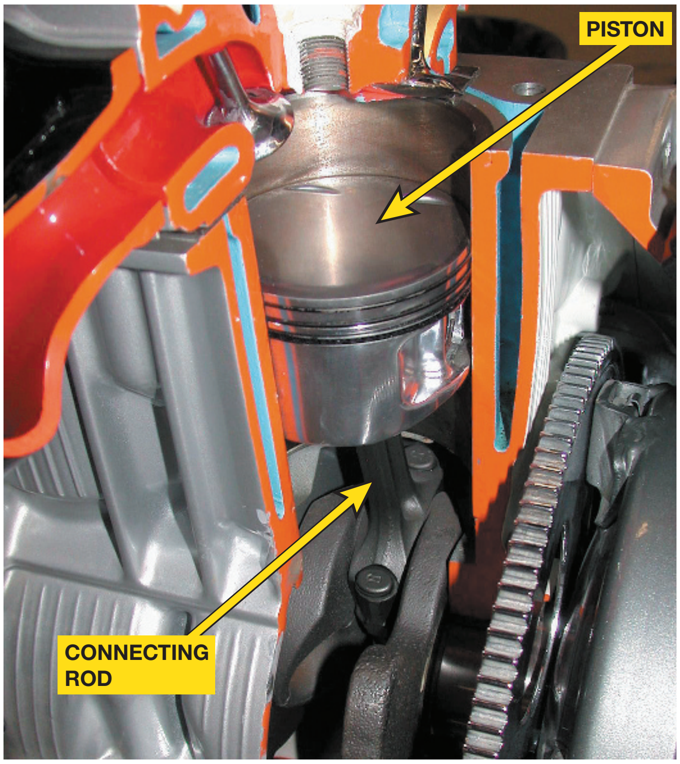


FIGURE 30–1 The piston seals the bottom of the combustion chamber and is attached to a connecting rod.

TECH TIP

Piston Weight Is Important!

All pistons in an engine should weigh the same to help ensure a balanced engine. Piston weight becomes a factor when changing pistons. Most aluminum pistons range in weight from 10 to 30 ounces (280 to 850 grams) (1 oz = 28.35 g). *A typical paper clip weighs 1 g*. If the cylinder has been bored, larger replacement pistons are obviously required. If the replacement pistons weigh more, this puts additional inertia loads on the rod bearings. Therefore, to help prevent rod bearing failure on an overhauled engine, the replacement pistons should not weigh more than the original pistons.

CAUTION: Some less expensive replacement cast pistons or high-performance forged pistons are much heavier than the stock pistons, even in the stock bore size. This means that the crankshaft may need heavy metal added to the counterweights of the crankshaft for the engine to be balanced.

For the same reason, if one piston is being replaced, all pistons should be replaced or at least checked and corrected to ensure the same weight.

PISTON OPERATION When the engine is running, the piston starts at the top of the cylinder. As it moves downward, it accelerates until it reaches a maximum velocity slightly before it is halfway down. The piston comes to a stop at the bottom of the cylinder at 180 degrees of crankshaft rotation. During the next 180 degrees of crankshaft rotation, the piston moves upward. It accelerates to reach a maximum velocity slightly above the halfway point and then comes to a stop at the top of the stroke. Thus, the piston starts, accelerates, and stops twice in each crankshaft revolution.

NOTE: A typical piston in an engine operating at 4000 RPM accelerates from 0 to 60 mph (97 km/h) in about 0.004 second (4 ms) as it travels about halfway down the cylinder.

This reciprocating action of the piston produces large *inertia forces*. Inertia is the force that causes a part that is stopped to stay stopped or a part that is in motion to stay in motion. The lighter the piston can be made, the less inertia force that is developed. Less inertia will allow higher engine operating speeds. For this reason, pistons are made to be as light as possible while still having the strength that is needed.

The piston operates with its top or head exposed to the hot combustion gases, whereas the skirt contacts the relatively cool cylinder wall. This results in a temperature difference of about 275°F (147°C) between the top and bottom of the piston.

PISTON CONSTRUCTION

PISTON RING GROOVES Piston ring **grooves** are located between the piston head and skirt. The width of the grooves, the width of the **lands** between the ring grooves, and the number of rings are major factors in determining minimum piston height. The outside diameter of the lands is about 0.02 to 0.04 inch (0.5 to 1 mm) smaller than the **skirt** diameter. ● **SEE FIGURE 30–2**.

● **SEE FIGURE 30–3** for an example of how to measure the diameter of a piston.

CAST PISTONS Cast aluminum pistons usually are made using *gravity die casting*. In this process, molten aluminum alloy and about 10% silicon are poured into a mold. The silicon is used to increase the strength and help control the expansion of the piston when it gets hot. Other metals used in the aluminum alloy include copper, nickel, manganese, and magnesium. ● **SEE FIGURE 30–4**.

HYPEREUTECTIC PISTONS A standard cast aluminum piston contains about 9% to 12% silicon and is called a *eutectic* piston.

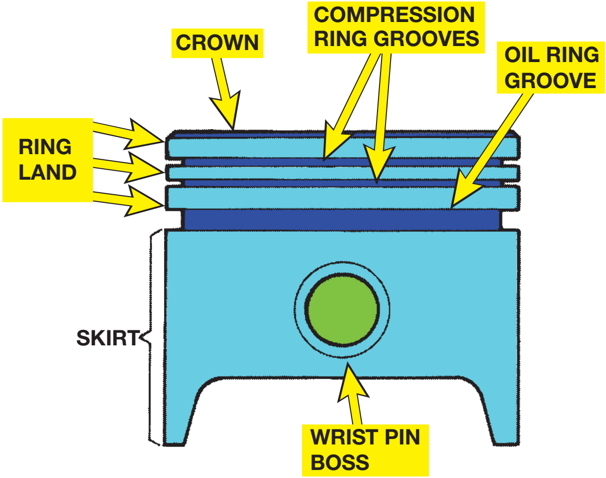


FIGURE 30–2 All pistons share the same parts in common.

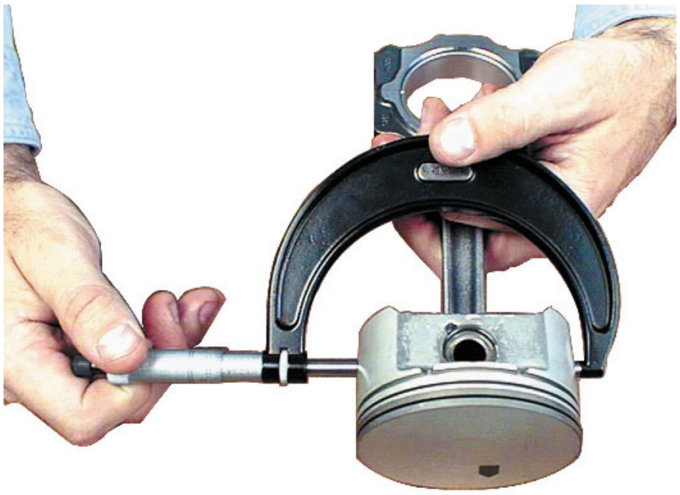


FIGURE 30–3 A piston diameter is measured across the thrust surfaces.

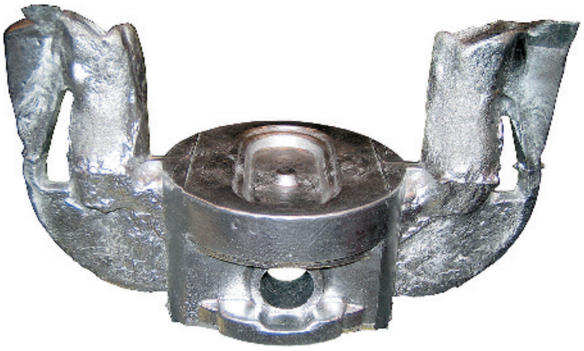


FIGURE 30–4 A cast piston showing the sprues that were used to fill the mold with molten aluminum alloy.

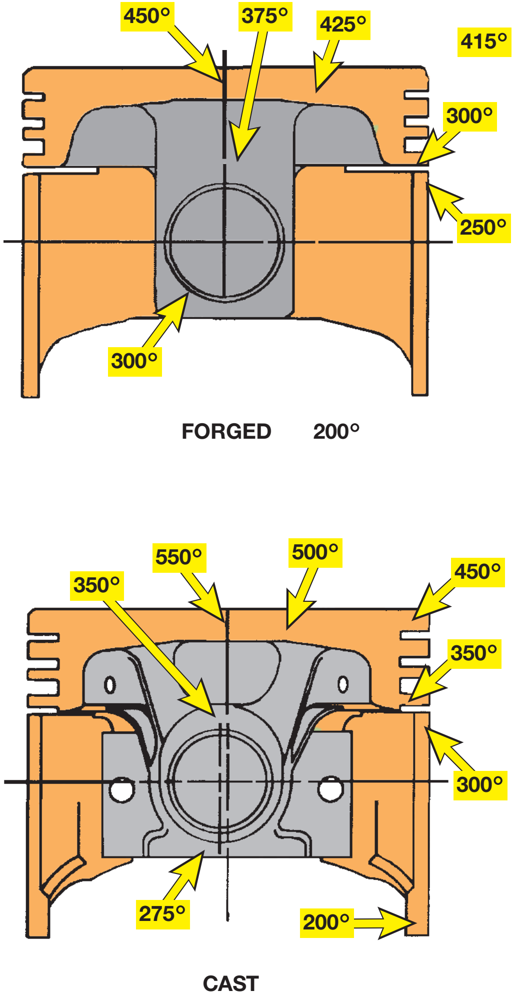


FIGURE 30–5 The top of the piston temperature can be 100°F (38°C) lower on a forged piston compared to a cast piston.

To add strength, the silicon content is increased to about 16%, and the resulting piston is called a **hypereutectic** piston. Other advantages of a hypereutectic piston are its 25% weight reduction and lower expansion rate. The disadvantage of hypereutectic pistons is their higher cost because they are more difficult to cast and machine.

Hypereutectic pistons are commonly used in the aftermarket and as original equipment in many turbocharged and supercharged engines.

FORGED PISTONS High-performance engines need pistons with added strength. Forged pistons have a dense grain structure and are very strong. Forged pistons are often used in turbocharged or supercharged engines. Because forged pistons are less porous than cast pistons, they conduct heat more quickly. Forged pistons generally run about 20% cooler than cast pistons. ● **SEE FIGURE 30–5**.

PISTON HEAD DESIGNS Because the piston head forms a portion of the combustion chamber, its shape is vital to the combustion process. Many newer engines have *flat-top* pistons. Some of these flat-top pistons come so close to the cylinder head that *recesses* are cut in the piston top for valve clearance. Pistons used in high-powered engines may have raised domes or *pop-ups* on the piston heads. These are used to increase the compression ratio. Pistons used in other engines may be provided with a depression or a *dish*. The varying depths of the dish provide different compression ratios required by different engine models.

NOTE: Newer engines do not use valve reliefs because this requires that the thickness of the top of the piston be increased to provide the necessary strength. The thicker the top of the piston, the lower down from the top the top piston ring sits. To reduce unburned hydrocarbon (HC) exhaust emissions, engineers attempt to place the top piston ring as close to the top of the piston as possible to prevent the unburned fuel from being trapped (and not burned) between the top of the piston and the top of the top piston ring.

Recesses machined or cast into the tops of the pistons for valve clearance are commonly called

- Eyebrows
- Valve reliefs
- Valve pockets

The depth of the eyebrows has a major effect on the compression ratio and is necessary to provide clearance for the valves if the timing belt or chain of an overhead camshaft engine should break. Without the eyebrows, the pistons could hit the valves near TDC if the valves are not operating (closing) because of nonrotation of the camshaft. If an engine is designed not to have the pistons hitting the valves, if the timing belt or chain breaks, the engine is called **freewheeling**. ● **SEE FIGURE 30–6**.

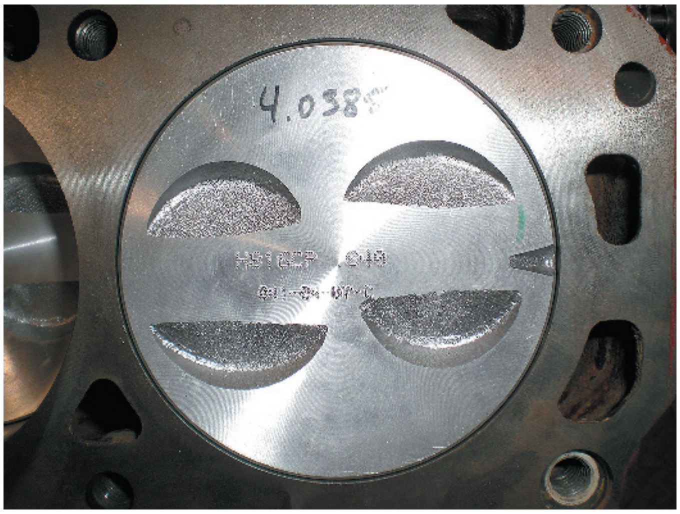


FIGURE 30–6 Valve reliefs are used to provide valve clearance.

SLIPPER SKIRT PISTONS A **slipper skirt** design piston is shorter on the two sides that are not thrust surfaces. Advantages of using a slipper skirt design include

- Lighter weight
- Allows for a shorter overall engine height because the crankshaft counterweights can be closer to the piston when they are at the bottom of the stroke

Most engines today use a slipper skirt piston design.

CAM GROUND PISTONS Aluminum pistons expand when they get hot. A method of expansion control was devised using a **cam ground** piston skirt. With this design, the piston thrust surfaces closely fit the cylinder, and the piston pin boss diameter is fitted loosely. As the cam ground piston is heated, it expands along the piston pin so that it becomes nearly round at its normal operating temperatures. A cam ground piston skirt is illustrated in ● **FIGURE 30–7**.

PISTON FINISH The finish on piston skirts varies with the manufacturer, but all are designed to help reduce scuffing. Scuffing is a condition where the metal of the piston actually contacts the cylinder wall. When the piston stops at the top of the cylinder, welds or transfer of metal from one part to the other can take place. Scuffing can be reduced by coating the piston skirts with tin 0.0005 inch (0.0125 mm) thick or a moly graphite coating. ● **SEE FIGURE 30–8**.

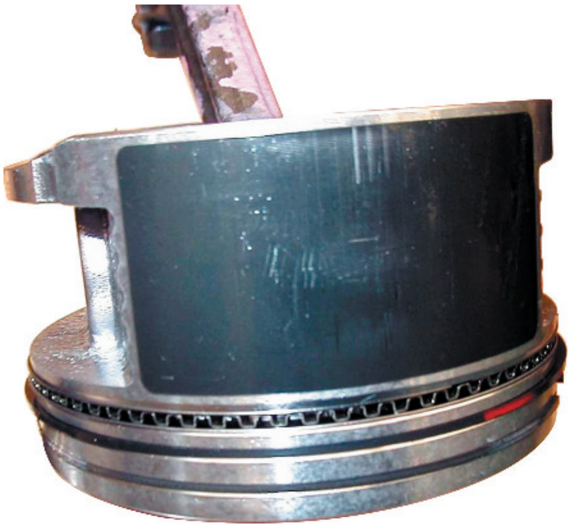


FIGURE 30–8 A moly graphite coating on this piston from a General Motors 3800 V-6 engine helps to prevent piston scuffing.

PISTON HEAD SIZE The top or head of the piston is smaller in diameter than the rest of the piston. The top of the piston is exposed to the most heat and therefore tends to expand more than the rest of the piston. ● **SEE FIGURE 30–9**.

Most pistons have horizontal separation slots that act as **heat dams**. These slots reduce heat transfer from the hot piston head to the lower skirt. This, in turn, keeps the skirt temperature lower to reduce skirt expansion. Because the slot is placed in the oil ring groove, it can be used for oil drainback and expansion control.

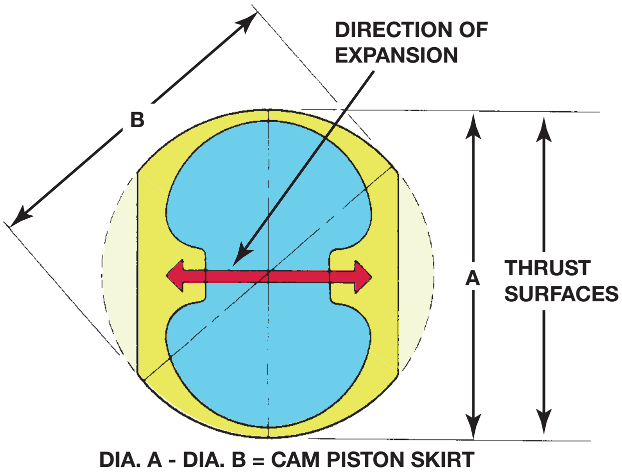

DIRECTION OF EXPANSION
B
A
THRUST SURFACES
DIA. A - DIA. B = CAM PISTON SKIRT

FIGURE 30–7 Piston cam shape. The largest diameter is across the thrust surfaces and perpendicular to the piston pin (labeled A).

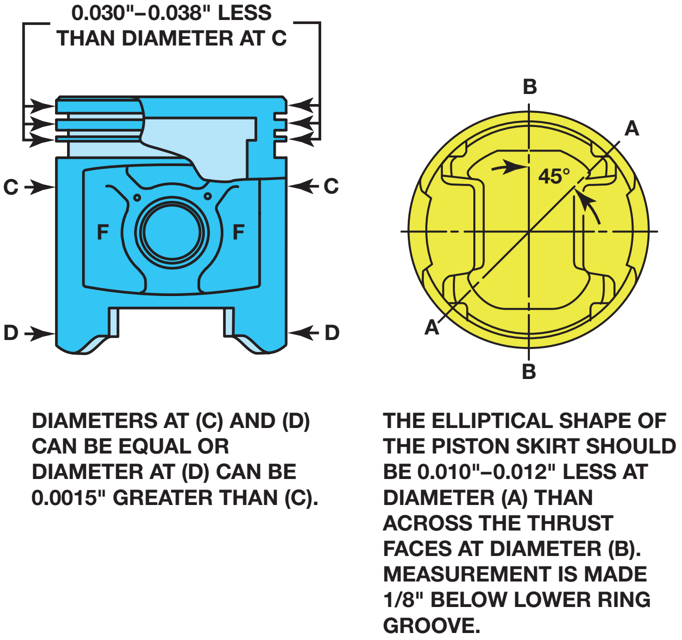

0.030"–0.038" LESS THAN DIAMETER AT C
C
C
F
F
D
D
B
A
45°
A
B
DIAMETERS AT (C) AND (D) CAN BE EQUAL OR DIAMETER AT (D) CAN BE 0.0015" GREATER THAN (C).
THE ELLIPTICAL SHAPE OF THE PISTON SKIRT SHOULD BE 0.010"–0.012" LESS AT DIAMETER (A) THAN ACROSS THE THRUST FACES AT DIAMETER (B). MEASUREMENT IS MADE 1/8" BELOW LOWER RING GROOVE.

FIGURE 30–9 The head of the piston is smaller in diameter than the skirt of the piston to allow it to expand when the engine is running.

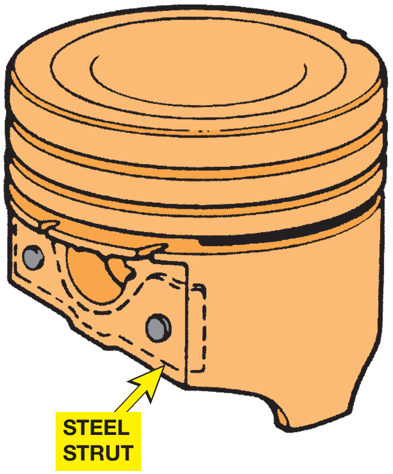


FIGURE 30–10 Steel struts cast inside the piston help control expansion and add strength to the piston pin area.

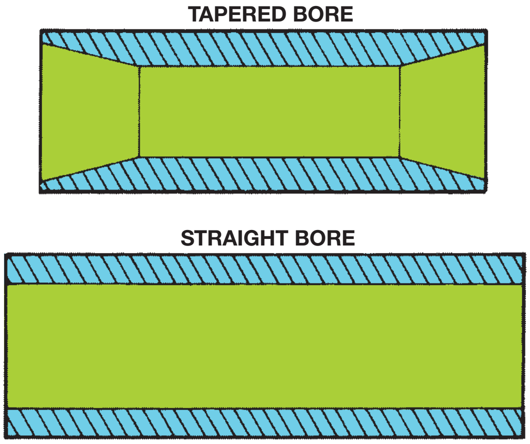


FIGURE 30–11 Most piston pins are hollow to reduce weight and have a straight bore. Some pins have a tapered bore to reinforce the pin.

PISTON STRUT INSERTS A major development in expansion control occurred when the piston aluminum was cast around two stiff steel **struts**.

- The struts add strength to the piston in the piston pin area where additional strength is needed.
- The struts help control thermal expansion.
- Pistons with steel strut inserts allow good piston-to-cylinder wall clearance at normal temperatures. At the same time, they allow the cold operating clearance to be as small as 0.0005 inch (one-half thousandth of an inch) (0.0127 mm). This small clearance will prevent cold piston slap and noise. A typical piston expansion control strut is visible in ● **FIGURE 30–10**.

PISTON PINS

TERMINOLOGY Piston pins are used to attach the piston to the connecting rod. Piston pins are also known as *wrist pins* or *gudgeon pins*, a British term. The piston pin transfers the force produced by combustion chamber pressures and piston inertia to the connecting rod. The piston pin is made from high-quality steel in the shape of a tube to make it both strong and light. Sometimes, the interior hole of the piston pin is tapered, so it is large at the ends and small in the middle of the pin. This gives the pin strength that is proportional to the location of the load placed on it. A double-taper hole such as this is more expensive to manufacture, so it is used only where its weight advantage merits the extra cost. ● **SEE FIGURE 30–11**.

PISTON PIN OFFSET Some piston pin holes are not centered in the piston. They are located toward the **major thrust surface**, approximately 0.062 inch (1.57 mm) from the piston centerline, as shown in ● **FIGURE 30–12**.

Pin offset is designed to reduce piston slap and the noise that can result as the large end of the connecting rod crosses over top dead center.

- **Minor thrust.** The minor thrust side of the piston head has a greater area than the major side. This is caused by the pin offset. As the piston moves up in the cylinder on the compression stroke, it rides against the minor thrust surface. When compression pressure becomes high enough, the greater head area on the minor side causes the piston to cock slightly in the cylinder. This keeps the *top* of the minor thrust surface on the cylinder. It forces the *bottom* of the major thrust surface to contact the cylinder wall. As the piston approaches top center, both thrust surfaces are in contact with the cylinder wall.
- **Major thrust.** When the crankshaft crosses over top center, the force on the connecting rod moves the entire piston toward the major thrust surface. The lower portion of the major thrust surface has already been in contact with the cylinder wall. The rest of the piston skirt slips into full contact just after the crossover point, thereby controlling piston slap. This action is illustrated in ● **FIGURE 30–13**.

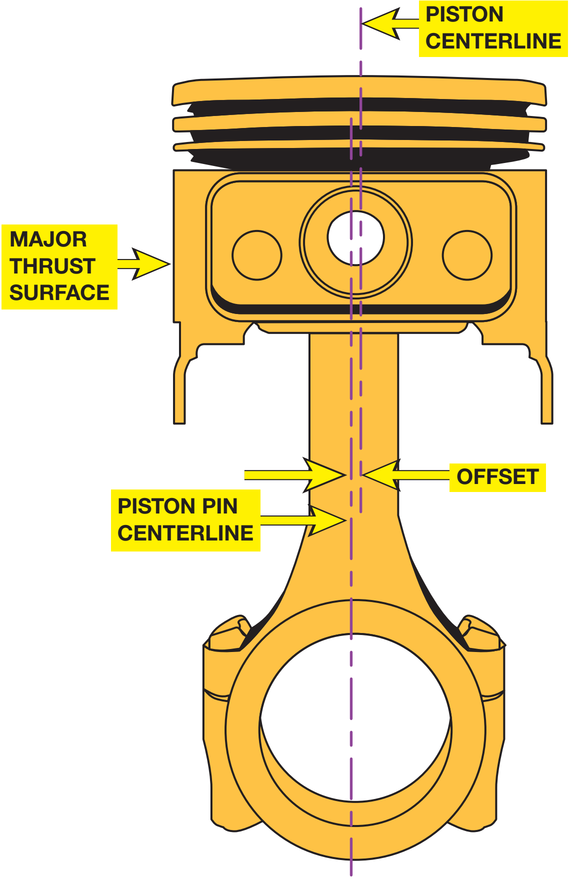


FIGURE 30–12 Piston pin offset toward the major thrust surface.

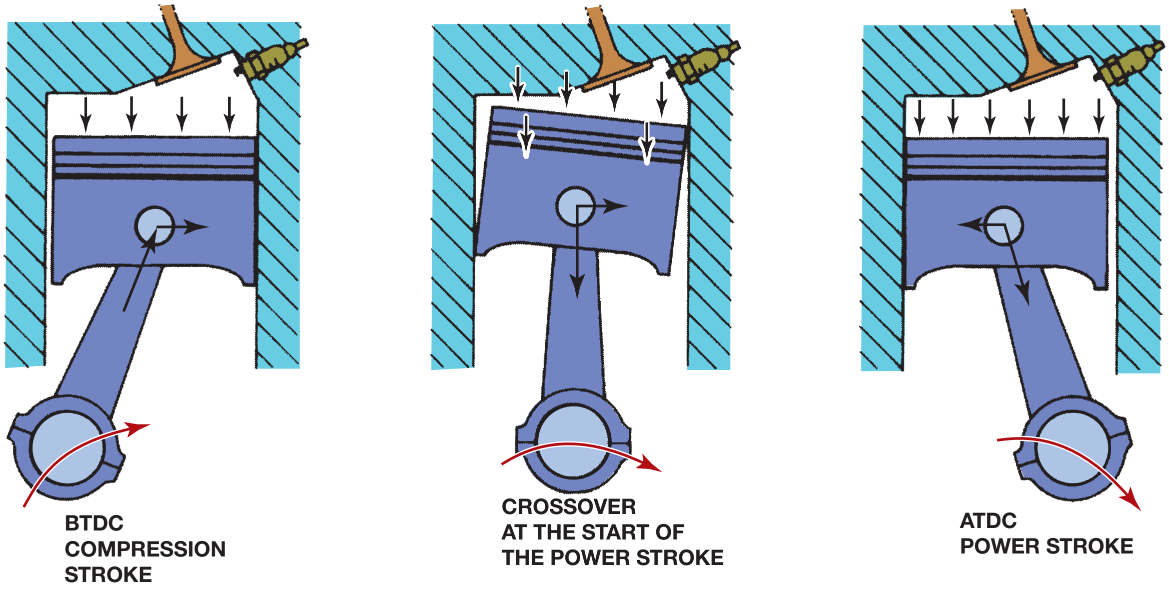


FIGURE 30–13 Engine rotation and rod angle during the power stroke cause the piston to press harder against one side of the cylinder, called the major thrust surface.

FREQUENTLY ASKED QUESTION

Which Side Is the Major Thrust Side?

The thrust side is the side the rod points to when the piston is on the power stroke. Any V-block engine (V-6 or V-8) that rotates clockwise is viewed from the front of the engine. The left bank piston thrust side faces the inside (center) of the engine. The right bank piston thrust side faces the outside of the block. This rule, called the *left-hand rule*, states the following:

- Stand at the rear of the engine and point toward the front of the engine with your left hand.
- Raise your thumb straight up, indicating the top of the engine.
- Point your other fingers toward the right. This represents the major thrust side of the piston.

Always assemble the connecting rods onto the rods so that the notch or "F" on the piston is pointing toward the front of the engine and the oil squirt hole on the connecting rod is pointing toward the major thrust side with your left hand.

NOTE: Not all piston pins are offset. In fact, many engines operate without the offset to help reduce friction and improve power and fuel economy.

PISTON PIN FIT The finish and size of piston pins are closely controlled. Piston pins have a smooth, mirror-like finish. Their size is held to tens of thousandths of an inch so that exact fits can be maintained. If the piston pin is loose in the piston or in the connecting rod, it will make a sound while the engine is running. This is often described as a **double knock**. The noise is created when the piston stops at top dead center and occurs again as it starts to move downward, creating a double knock or rattling sound. If the piston pin is too tight in the piston, it will restrict piston expansion along the pin diameter and lead to piston scuffing. Normal piston pin clearances range from 0.0005 to 0.0007 inch (0.0126 to 0.018 mm).

PISTON PIN RETAINING METHODS

FULL FLOATING **Full-floating** piston pins are free to "float" in the connecting rod and the piston. Often, a bronze bushing is installed in the small end of the connecting rod to support the piston pin. Full-floating pins require a retaining device to keep the piston pin from moving endwise and scrape against the cylinder wall. Most full-floating piston pins use some type of **lock ring** to retain the piston pin. There are two common types of lock rings:

- One is an internal snap ring that fits into a groove in the piston pin bore. These internal snap rings or "circle clips" are commonly called "circlips."
- The other is a "spiral lock" ring, which is a wound flat ring with two or three layers made from hardened steel. The spiral lock is inserted into a groove cut into the piston pin bore by starting with the bottom layer and twisting the spiral ring into place until all layers are in the groove.

Full-floating piston pins are most often used in high-performance modified engines and in diesel engines. ● **SEE FIGURE 30–14**.

Some engines use aluminum or plastic plugs in both ends of the piston pin. These plugs touch the cylinder wall without scoring, to hold the piston pin centered in the piston.

INTERFERENCE FIT Another method of retaining the piston pin in the connecting rod is to make the connecting rod hole slightly smaller than the piston pin. The pin is installed by heating the rod to expand the hole or by pressing the pin into the rod. This retaining method will securely hold the pin. ● **SEE FIGURE 30–15**.

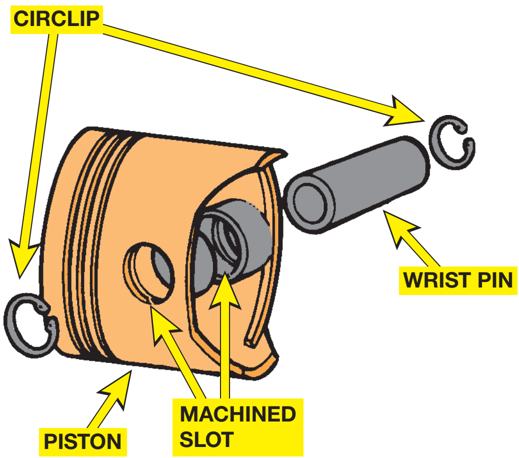


FIGURE 30–14 Circlips hold full-floating piston pins in place.

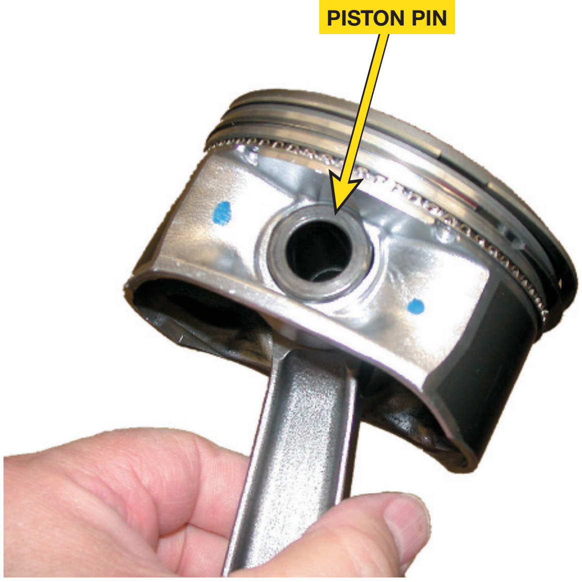


FIGURE 30–15 A typical interference fit piston pin.

This press or shrink fit is called an **interference fit**. Care must be taken to have the correct hole sizes, and the pin must be centered in the connecting rod. Because the interference fit method is the least expensive to use, it is found in the majority of engines.

PISTON RINGS

PURPOSE AND FUNCTION Piston rings serve several major functions in engines.

- They form a sliding combustion chamber seal that prevents the high-pressure combustion gases from leaking past the piston.
- They keep engine oil from getting into the combustion chamber.
- The rings transfer some of the piston heat to the cylinder wall, where it is removed from the engine through the cooling system. ● **SEE FIGURE 30–16**.

CLASSIFICATIONS Piston rings are classified into two types:

1. Two **compression rings**, located toward the top of the piston
2. One **oil control ring**, located below the compression rings

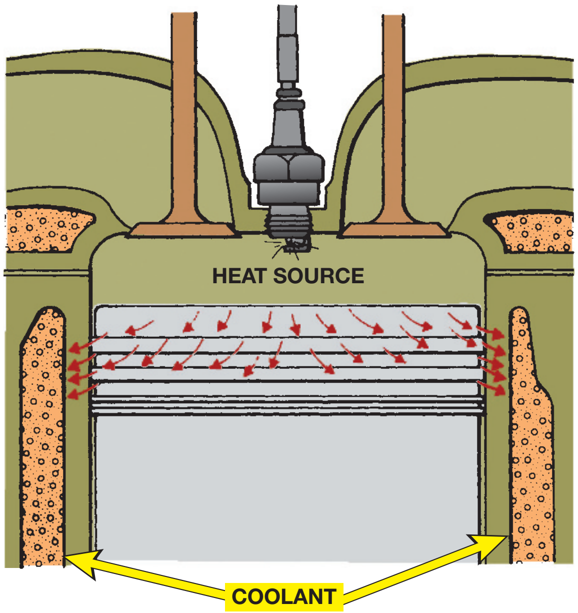


FIGURE 30–16 The rings conduct heat from the piston to the cylinder wall.

CASE STUDY

Big Problem, No Noise

Sometimes the piston pin can “walk” off the center of the piston and score the cylinder wall. This scoring is often not noticed because this type of wear does not create noise. Because the piston pin is below the piston rings, little combustion pressure is lost past the rings until the groove worn by the piston pin has worn the piston rings.

Troubleshooting the exact cause of the increased oil consumption is difficult because the damage done to the oil control rings by the groove usually affects only one cylinder.

Often, compression tests indicate good compression because of the cylinder seals, especially at the top. More than one technician has been surprised to see the cylinder gouged by a piston pin when the cylinder head has been removed for service. In such a case, the cost of the engine repair immediately increases far beyond that of normal cylinder head service.

Summary:

Complaint—Engine was burning oil yet the compression was good leading the technician to remove the head.

Cause—A piston pin had moved and scored the cylinder wall.

Correction—The engine was replaced to correct the oil burning concern.

NOTE: Some engines, such as Honda high-fuel economy engines, use pistons with only two rings: one compression ring and one oil control ring.

COMPRESSION RINGS A compression ring is designed to form a seal between the moving piston and the cylinder wall. This is

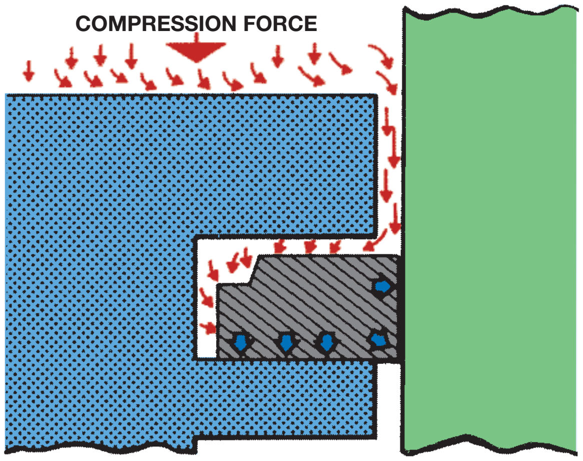


FIGURE 30–17 Combustion chamber pressure forces the ring against the cylinder wall and the bottom of the ring groove to effectively seal the cylinder.

necessary to get maximum power from the combustion pressure. At the same time, the compression ring must keep friction at a minimum. This is made possible by providing only enough static or built-in mechanical tension to hold the ring in contact with the cylinder wall during the intake stroke. Combustion chamber pressure during the compression, power, and exhaust strokes is applied to the top and back of the ring. This pressure will add extra force on the ring that is required to seal the combustion chamber during these strokes. ● **FIGURE 30–17** illustrates how the combustion chamber pressure adds force to the ring.

The space in the ring groove above the ring is called the **side clearance**, and the space behind the ring is called the **back clearance**. ● **SEE FIGURE 30–18**.

OIL CONTROL RINGS The scraping action of the oil control ring allows oil to return through the expander and openings in the piston.

Steel spring expanders were placed in the ring groove behind the ring to improve static radial tension. They forced the ring to conform to the cylinder wall. Many expander designs are used. On the three-piece ring, a spacer expander lies between the top and bottom rails. The spacer expander keeps the rails separated and pushes them out against the cylinder wall. ● **SEE FIGURE 30–19**.

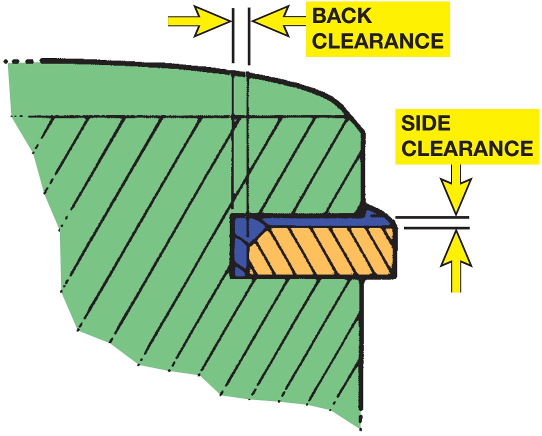


FIGURE 30–18 The side and back clearances must be correct for the compression rings to seal properly.

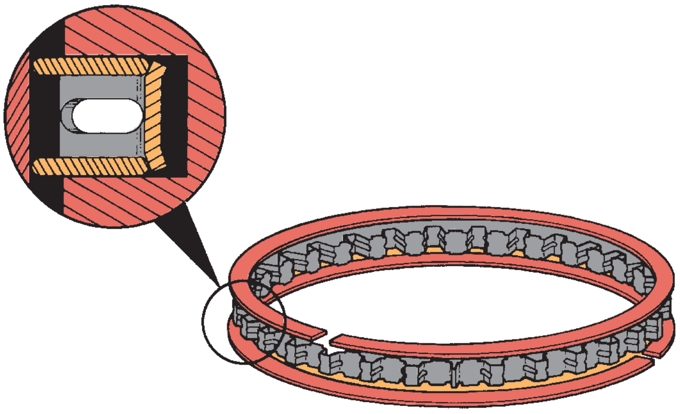


FIGURE 30–19 This typical three-piece oil control ring uses a hump-type stainless steel spacer-expander. The expander separates the two steel rails and presses them against the cylinder wall.

RING GAP The piston **ring gap** will allow some leakage past the top compression ring. This leakage is useful in providing pressure on the second ring to develop a dynamic sealing force. The amount of piston ring gap is critical.

- **Too much gap.** A ring gap that is too great will allow excessive **blowby**. Blowby is the leakage of combustion gases past the rings. Blowby will blow oil from the cylinder wall. This oil loss is followed by piston ring scuffing.
- **Too little gap.** A ring gap that is too little will allow the piston ring ends to touch together when the engine is hot. Ring end touching increases the mechanical force against the cylinder wall, causing excessive wear and possible engine failure.

A butt-type piston ring gap is the most common type used in automotive engines. Some low-speed industrial engines and some diesel engines use a more expensive tapered or seal-cut ring gap. These gaps are necessary to reduce losses of the high-pressure combustion gases. At low speeds, the gases have more time to leak through the gap. Typical ring gaps are illustrated in ● **FIGURE 30–20**.

PISTON RING SHAPES As engine speeds have increased, inertia forces on the piston rings have also increased. As a result, engine manufacturers have found it desirable to reduce inertia forces on the rings by reducing their weight. This has been done by reducing the thickness of the piston ring from 1/4 inch (6 mm) to as little as 1/16 inch (1.6 mm). There are several types of piston rings:

- **Taper face ring** will contact the cylinder wall at the lower edge of the piston ring. ● **SEE FIGURE 30–21**.

When either a chamfer or counterbore relief is made on the *upper inside* corner of the piston ring, the ring cross section is unbalanced, causing the ring to twist in the groove in a positive direction.

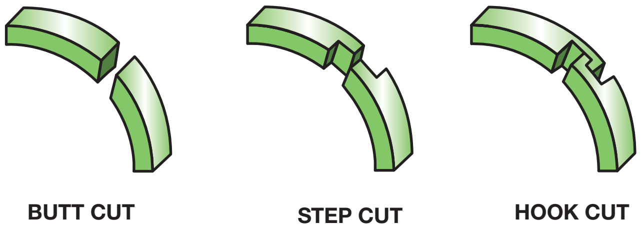


FIGURE 30–20 Typical piston ring gaps.

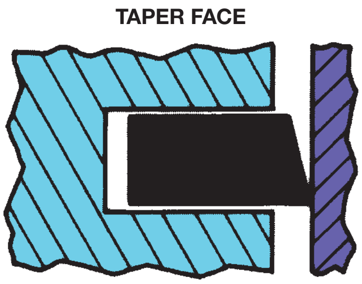


FIGURE 30–21 The taper face ring provides oil control by scraping the cylinder wall. This style of ring must be installed right side up or the ring will not seal and oil will be drawn into the combustion chamber.

- **Positive twist ring** will give the same wall contact as the taper face ring. It will also provide a line contact seal on the bottom side of the groove. Sometimes, twist and a taper face are used on the same compression ring.

Some second rings are notched on the *outer lower* corner. This, too, provides a positive ring twist. The sharp, lower outer corner becomes a scraper that helps in oil control, but this type of ring has less compression control than the preceding types.

- **Reverse twist ring** is produced by chamfering the ring's *lower inner* corner. This seals the lower outer section of the ring and piston ring groove, thus improving oil control. Reverse twist rings require a greater taper face or barrel face to maintain the desired ring face-to-cylinder wall contact. ● **SEE FIGURE 30–22**.

Another style of positive twist ring has a counterbore at the lower outside edge. ● **SEE FIGURE 30–23**.

- **Scraper ring** does a good job of oil control and is usually recommended for use at the second compression ring.
- **Barrel face ring** can replace the outer ring taper on some rings. The barrel is 0.0003 inch per 0.1 inch (0.0076 mm per 0.254 mm) of piston ring width. Barrel faces are found on rectangular rings and on torsionally twisted rings. ● **SEE FIGURE 30–24**.

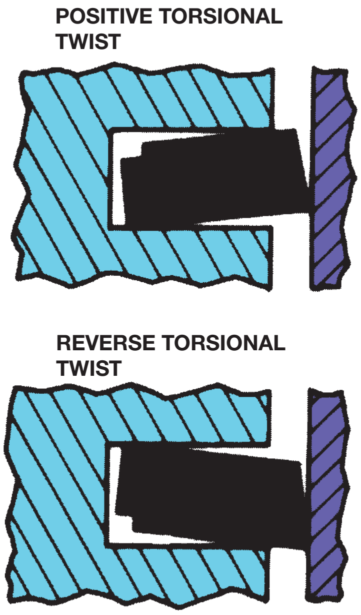


FIGURE 30–22 Torsional twist rings provide better compression sealing and oil control than regular taper rings.

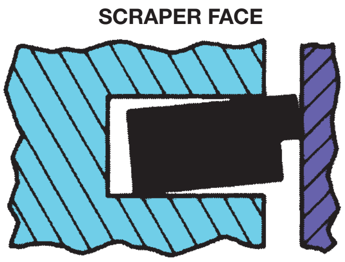


FIGURE 30–23 Scraper-type rings provide improved oil control.

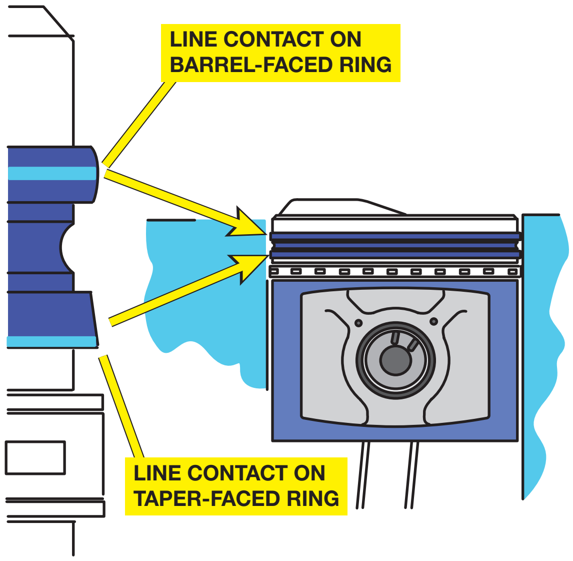

LINE CONTACT ON BARREL-FACED RING
LINE CONTACT ON TAPER-FACED RING

FIGURE 30–24 The upper barrel face ring has a line showing contact with the cylinder wall. The second taper face ring shows contact along the lower edge of the ring.

PISTON RING CONSTRUCTION

PISTON RING MATERIALS Piston ring materials can include

- Plain cast iron
- Pearlitic cast iron
- Nodular cast iron
- Steel
- **Ductile iron** (This is also used as a piston ring material in some automotive engines, which is very flexible and can be twisted without breaking.)

CHROMIUM PISTON RINGS A chromium facing on cast iron rings greatly increases piston ring life, especially where abrasive materials are present in the air. During manufacture, the chromium-plated ring is slightly chamfered at the outer corners. About 0.004 inch (0.01 mm) of chrome is plated on the ring face. Chromium-faced rings are prelapped or honed before they are packaged and shipped to the customer. The finished chromium facing is shown in a sectional view in ● **FIGURE 30–25**.

MOLYBDENUM PISTON RINGS Most molybdenum face piston rings have a groove that is 0.004 to 0.008 inch (0.1 to 0.2 mm) deep cut into the ring face. This groove is filled with molybdenum, using a metallic (or plasma) spray method, so that there is a cast iron edge above and below the molybdenum. This edge may be

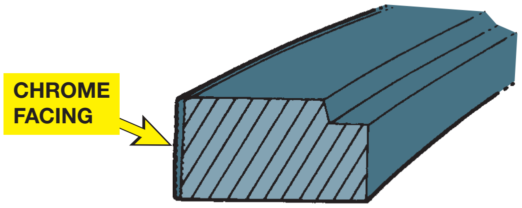


FIGURE 30–25 The chrome facing on this compression ring is about 0.004 inch (0.10 mm) thick.

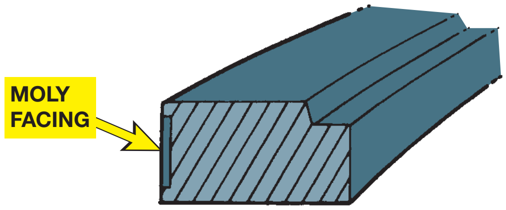


FIGURE 30–26 The moly facing on this compression ring is about 0.005 inch (0.13 mm) thick.

chamfered in some applications. A sectional view of a molybdenum face ring is shown in ● **FIGURE 30–26**.

MOLY-CHROME-CARBIDE RINGS Rings with moly-chrome-carbide coating are also used in some original equipment (OE) and replacement applications. The coating has properties that include the hardness of the chrome and carbide combined with the heat resistance of molybdenum.

CERAMIC-COATED RINGS The ceramic-coated ring surface is created by applying a ceramic coating to the ring using a process called *physical vapor deposition (PVD).* Ceramic-coated rings are also being used where additional heat resistance is needed, such as in some heavy-duty, turbocharged, or supercharged engines. For example, the General Motors Duramax 6.6 liter diesel engine uses ceramic-coated rings.

CONNECTING RODS

PURPOSE AND FUNCTION The connecting rod transfers the force and reciprocating motion of the piston to the crankshaft. The small end of the connecting rod reciprocates with the piston. The large end rotates with the crankpin. ● **SEE FIGURE 30–27**.

These dynamic motions make it desirable to keep the connecting rod as light as possible while still having a rigid beam section. ● **SEE FIGURE 30–29**.

Connecting rods are manufactured by casting, forging, and powdered (sintered) metal processes.

FREQUENTLY ASKED QUESTION

How Much Heat Do the Piston Rings Transfer?

Piston rings are in continuous contact with the cylinder wall, and the amount of heat varies according to the position, with the upper ring transferring up to 45% of the combustion chamber heat. ● **SEE FIGURE 30–28**.

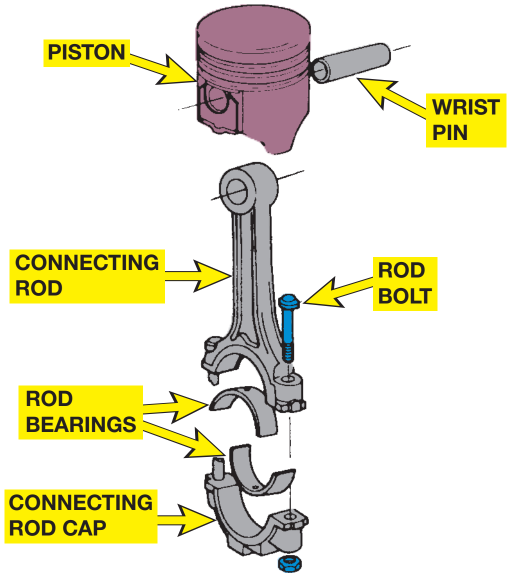


FIGURE 30–27 The connecting rod is the most highly stressed part of any engine because combustion pressure tries to compress it and piston inertia tries to pull it apart.

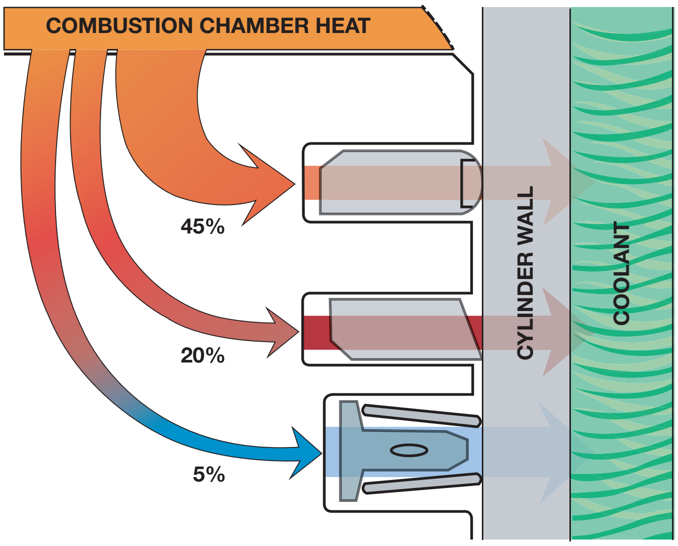


FIGURE 30–28 Piston rings transfer about 70% of the combustion chamber heat from the piston to the cylinder wall.

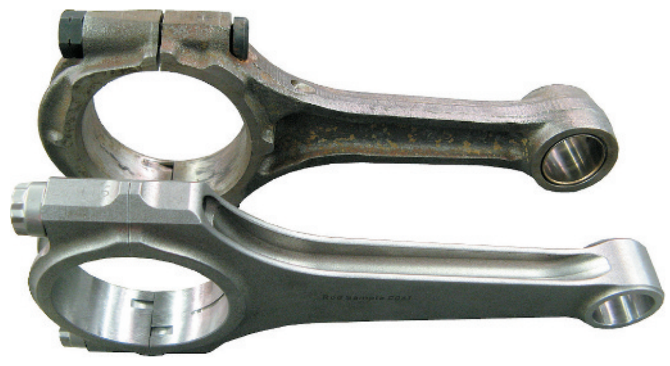


FIGURE 30–29 The I-beam shape is the most common (top connecting rod), but the H-beam shape is common in high-performance and racing engine applications.

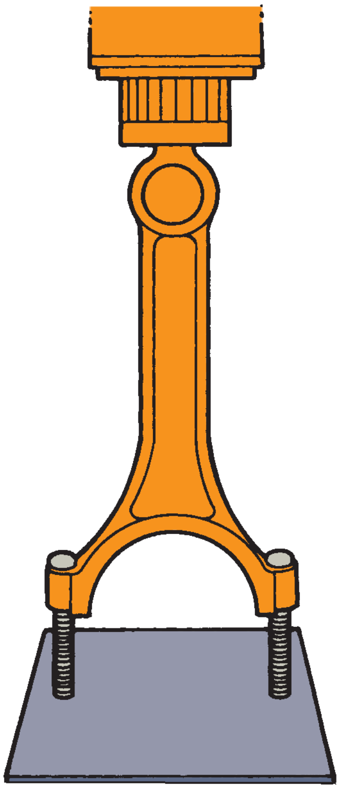


FIGURE 30–30 Rod bolts are quickly removed using a press.

CONNECTING ROD DESIGN The big end of the connecting rod must be a perfect circle. Once a rod and cap are initially machined, they must remain a "matched set" due to the precise machining required to obtain a perfect circle. Therefore, the rod caps must not be interchanged. Assembly bolt holes are closely reamed in both the cap and connecting rod to ensure alignment. The connecting rod bolts have *piloting surfaces* that closely fit these reamed holes. The fit of the connecting rod bolts is so tight that a press must be used to remove the bolts when they are to be replaced, as shown in ● **FIGURE 30–30**.

Many connecting rods are made with **balancing bosses (pads)** so that their weight can be adjusted to specifications. Some have balancing bosses only on the rod cap. Others also have a balancing boss at the small end. Some manufacturers put balancing bosses on the side of the rod, near the center of gravity of the connecting rod. Typical balancing bosses can be seen in ● **FIGURE 30–31**.

Balancing is done on automatic balancing machines as the final machining operation before the rod is installed in an engine.

Some connecting rods have a **spit hole** that bleeds some of the oil from the connecting rod journal. ● **SEE FIGURES 30–32 AND 30–33**.

On inline engines, oil is thrown up from the spit hole into the cylinder in which the rod is located. On V-type engines, it is often thrown into a cylinder in the opposite bank. The oil that is spit from the rod is aimed so that it will splash into the interior of the piston to help lubricate the piston pin. A hole similar to the spit holes may be used, called a **bleed hole**, to control the oil flow through the bearing.

CAST CONNECTING RODS Casting materials and processes have been improved so that they are used in most vehicle engines with high production standards. Cast connecting rods can be identified by their *narrow parting line*. A typical rough connecting rod casting is shown in ● **FIGURE 30–34**.

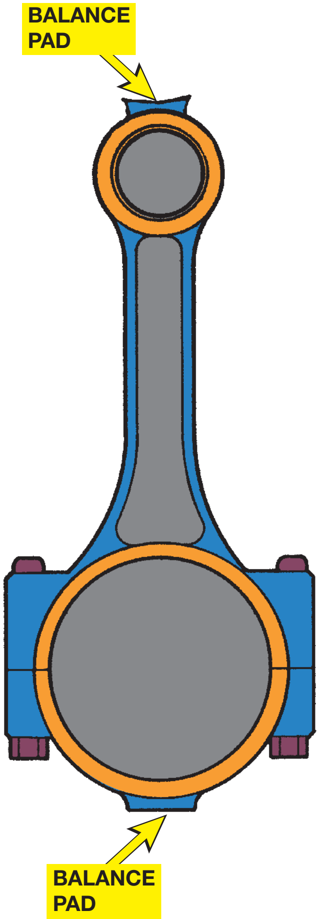


FIGURE 30–31 Some rods have balancing pads on each end of the connecting rod.

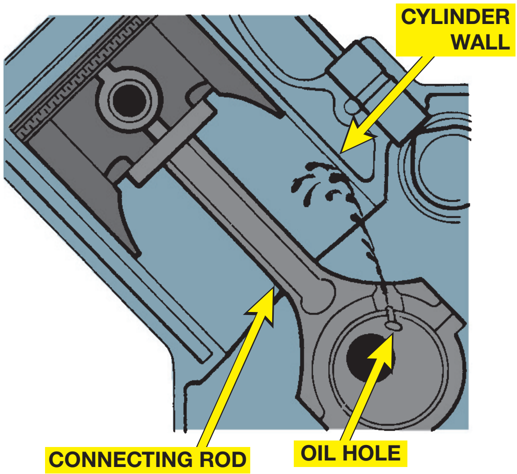


FIGURE 30–32 Some connecting rods have spit holes to help lubricate the cylinder wall or piston pin.

FORGED CONNECTING RODS Forged connecting rods have been used for years. They are generally used in heavy-duty and high-performance engines. Generally, the forging method produces lighter weight and stronger but more expensive connecting rods. Forged connecting rods can be identified by their *wide parting line*. Many high-performance connecting rods use a bronze bushing in the small end as shown in ● **FIGURE 30–35**.

POWDERED METAL CONNECTING RODS Many manufacturers of current model engines use powered metal (PM) connecting rods.

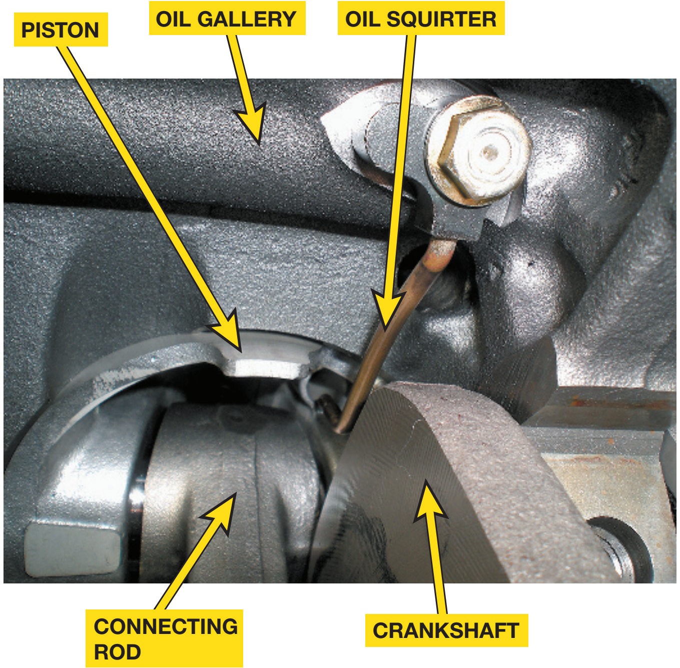


FIGURE 30–33 Some engines are equipped with oil squirters that spray or stream oil toward the underneath side of the piston head to cool the piston and to lubricate the small end of the connecting rod.

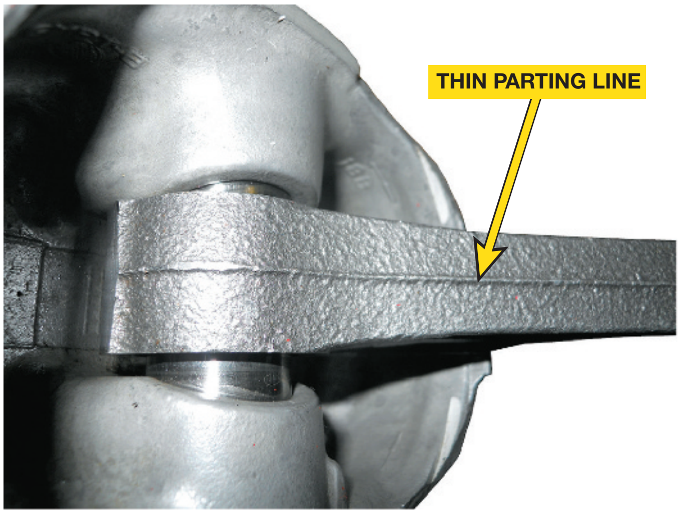


FIGURE 30–34 A cast connecting rod is found on many stock engines and can be identified by the thin parting line.

Powdered metal connecting rods have many advantages over conventional cast or forged rods including precise weight control. Each rod is created using a measured amount of material so that rod balancing, and therefore engine balancing, is now achieved without extra weighting and machining operations.

- Powdered metal connecting rods start as powdered metal, which includes iron, copper, carbon, and other alloying agents.
- This powder is then placed in a die and compacted (forged) under a pressure of 30 to 50 tons per square inch.
- After the part is shaped in the die, it is taken through a sintering operation where the part is heated, without melting, to about 2,000°F (760°C). During the sintering process, the ingredients are transformed into metallurgical bonds, giving the part strength.
- Machining is very limited and includes boring the small and big end and drilling the holes for the rod bearing cap retaining bolts.
- The big end is then fractured using a large press. The uneven parting line helps ensure a perfect match when the pieces are assembled. ● **SEE FIGURE 30–36**.

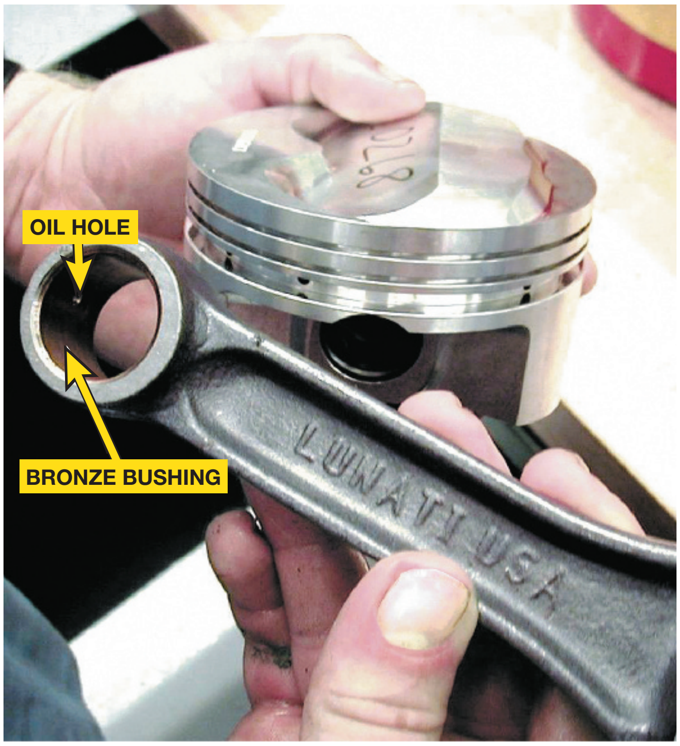


FIGURE 30–35 This high-performance connecting rod uses a bronze bushing in the small end of the rod and oil hole to allow oil to reach the full-floating piston pin.

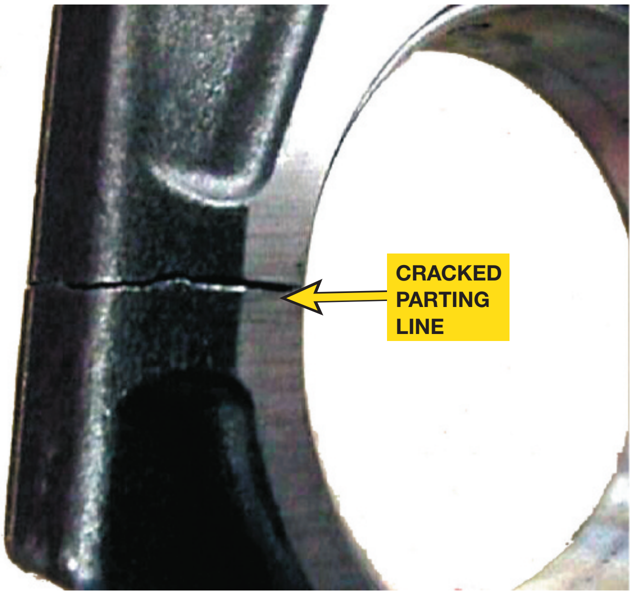


FIGURE 30–36 Powdered metal connecting rods feature a fractured parting line at the big end of the rod.

CONNECTING ROD SERVICE

REMOVING PISTONS FROM RODS The pistons are removed from the rods using a special fixture shown in ● **FIGURE 30–37**.

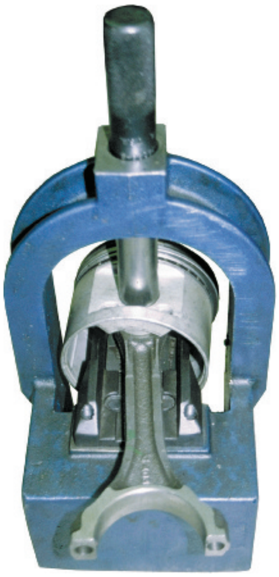


FIGURE 30–37 A press used to remove the connecting rod from the piston.

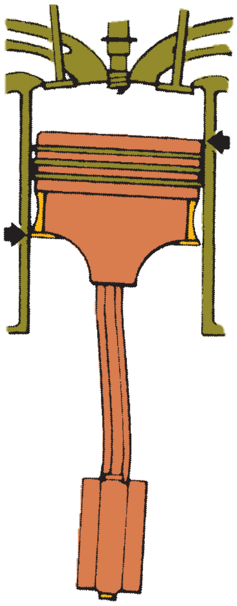


FIGURE 30–38 If the rod is twisted, it will cause diagonal-type wear on the piston skirt.

INSPECTION

Before connecting rod reconditioning, the rod should be checked for twist. ● **SEE FIGURE 30–38**.

In other words, the hole at the small end and the hole at the big end of the connecting rod should be parallel. No more than a 0.002 inch (0.05 mm) twist is acceptable. ● **SEE FIGURE 30–39** for the fixture used to check connecting rods for twist.

If measured rod twist is excessive, some specialty shops can remove the twist by bending the rod cold. Both cast and forged rods can be straightened. However, many engine builders replace the connecting rod if it is twisted.

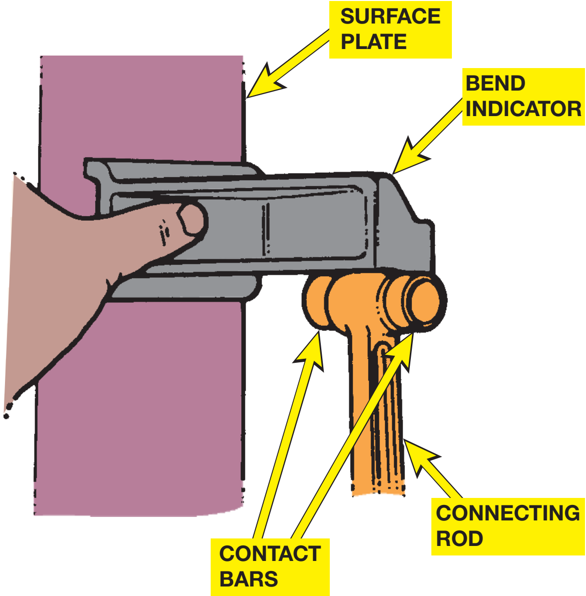


FIGURE 30–39 A rod alignment fixture is used to check a connecting rod for bends or twists.

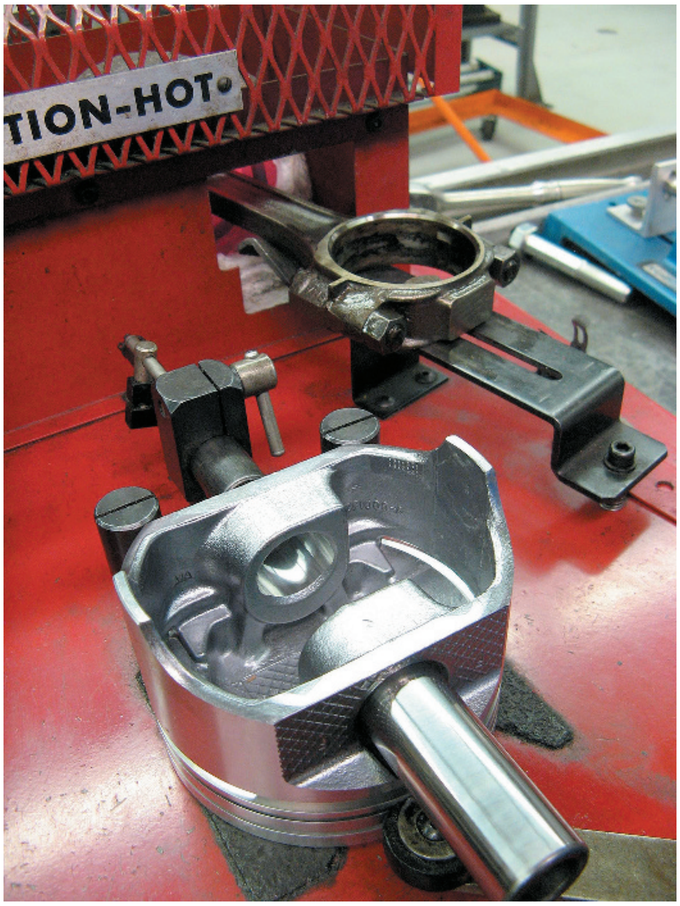


FIGURE 30–40 The small end of the rod is being heated in an electric heater and the piston is positioned properly so the piston pin can be installed as soon as the rod is removed from the heater.

PISTON AND ROD ASSEMBLY

INTERFERENCE FIT RODS

To assemble the piston and rod, the piston pin is put in one side of the piston. The small end of the connecting rod should be checked for proper size.

The small eye of the connecting rod is heated before the pin is installed. ● **SEE FIGURE 30–40**.

This causes the rod eye to expand so that the pin can be pushed into place with little force. The pin must be rapidly pushed into the correct center position. There is only one chance to get it in the right place because the rod will quickly seize on the pin as the rod eye is cooled by the pin.

FULL-FLOATING RODS Full-floating piston pins operate in a bushing in the small eye of the connecting rod. The bushing can be replaced. The bushing and the piston are honed to the same diameter. This allows the piston pin to slide freely through both. The full-floating piston pin is held in place with a lock ring at each end of the piston pin. The lock ring expands into a small groove in the pin hole of the piston.

NOTE: The original lock rings should always be replaced with new rings.

PISTON RING SERVICE

STEPS Each piston ring, one at a time, should be placed backward in the groove in which it is to be run.

STEP 1 **Check side clearance.** As the piston goes rapidly up and down in the cylinder, it tosses the rings to the top and to the bottom of the ring grooves.

The pounding of each ring in its groove gradually increases the piston ring side clearance. Material is worn from both the ring and the groove. Replace the piston if the ring groove is larger than factory specifications. The side clearance in the groove should be checked with a feeler gauge, as shown in ● **FIGURE 30–41**.

STEP 2 **Check ring gap.** After the block and cylinder bores have been reconditioned, invert the piston and push each ring into the lower quarter of the cylinder; then measure the ring gap. ● **SEE FIGURE 30–42**.

The usual ring gap should be approximately 0.004 inch for each inch of bore diameter (0.004 mm for each centimeter of bore diameter). The second ring also needs to have a similar or even larger end gap.

- If excessive ring gap is present, the blowby gases can enter the crankcase. Replace the ring(s) if the gap is too large.

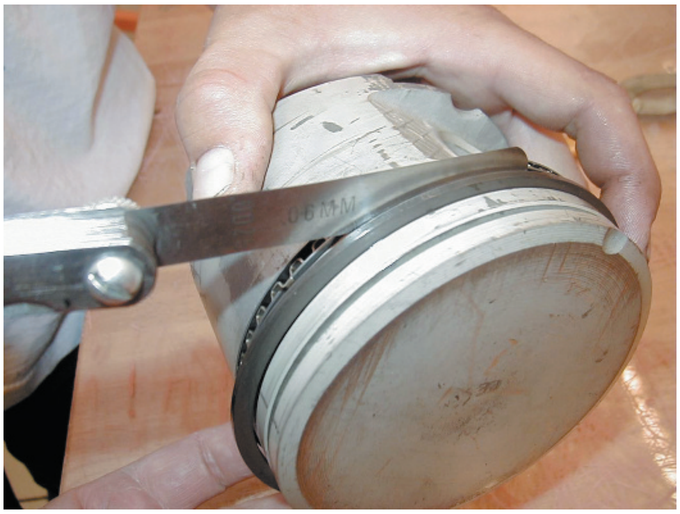


FIGURE 30–41 The side clearance of the piston ring is checked with a feeler gauge.

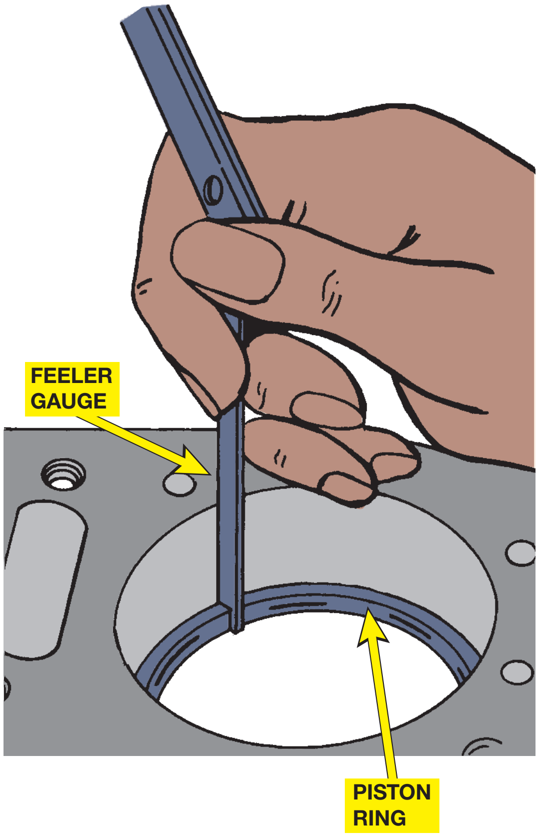


FIGURE 30–42 The ring gap is measured using a feeler gauge.

TECH TIP

Second Ring Gap

Most vehicle manufacturers recommend the ring gap of the second ring should be greater than the gap used in the top ring. If the second ring end gap is small, combustion gases can become trapped between the top and the second ring. This pressure can cause the top ring to be lifted up and off the piston land and cause blowby. The top ring seals in two positions:

- The ring seals against the cylinder wall.
- The ring seals against the piston ring groove land.

By increasing the second piston ring end gap, combustion gases are not allowed to build up enough to cause the top ring to be lifted up off its seal on the piston land. Always follow the vehicle manufacture's recommended instructions and specifications.

- If the gap is too narrow, use a file or hand-operated piston ring grinder to achieve the necessary ring gap. ● **SEE FIGURE 30–43**.

STEP 3 **Installing the oil control ring.** The oil rings are installed first. The expander-spacer of the oil ring is placed in the lower ring groove. One oil ring rail is carefully placed above the expander-spacer by winding it into the groove. The other rail is placed below the expander-spacer. The ring should be rotated in the

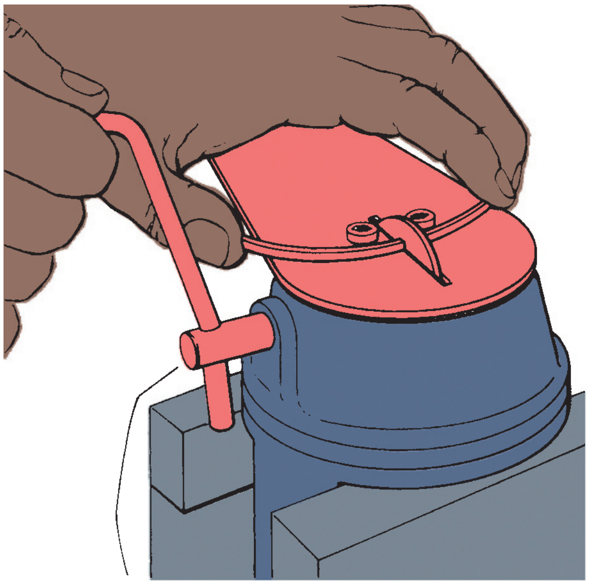


FIGURE 30–43 A hand-operated piston ring end gap grinder being used to increase the end gap of a piston ring so that it is within factory specifications.

groove to ensure that the expander-spacer ends have not overlapped. If they have, the ring must be removed and reassembled correctly.

STEP 4 **Installing the compression rings.** Installing the compression rings requires the use of a **piston ring expander** tool that will only open the ring gap enough to slip the ring on the piston. ● **SEE FIGURE 30–44**.

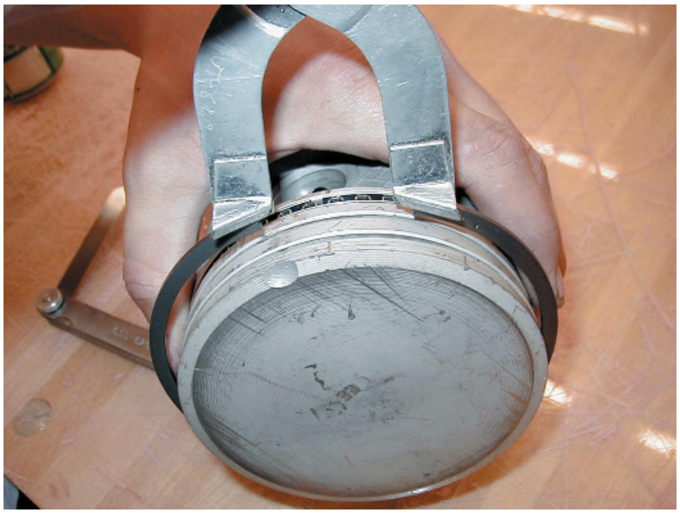


FIGURE 30–44 A typical ring expander being used to install a piston ring on a piston.

Be careful to install the ring with the correct side up. The top of the compression ring is marked with one of the following:

- One dot
- The letter *T*
- The word *top* ● **SEE FIGURE 30–45**.

STEP 5 **Double-check everything.** After the rings are installed, they should be rotated in the groove to ensure that they move freely and checked to ensure that they will go fully into the groove so that the ring face is flush with the surface of the piston ring lands. Usually, the rings are placed on all pistons before any pistons are installed in the cylinders.

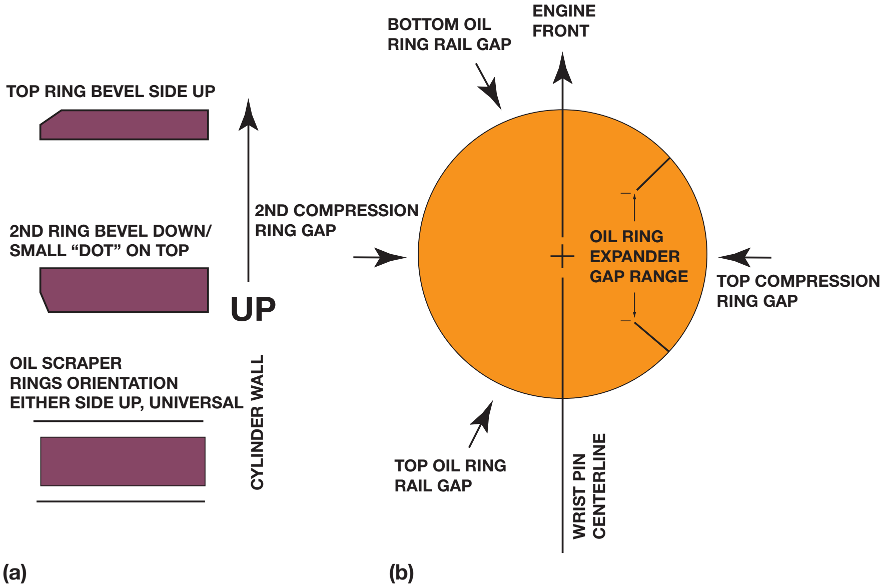

TOP RING BEVEL SIDE UP
2ND RING BEVEL DOWN/ SMALL "DOT" ON TOP
UP
OIL SCRAPER RINGS ORIENTATION EITHER SIDE UP, UNIVERSAL
CYLINDER WALL
(a)
BOTTOM OIL RING RAIL GAP
ENGINE FRONT
2ND COMPRESSION RING GAP
OIL RING EXPANDER GAP RANGE
TOP COMPRESSION RING GAP
TOP OIL RING RAIL GAP
WRIST PIN CENTERLINE
(b)

FIGURE 30–45 (a) Identification marks used to indicate the side of the piston ring to be placed toward the head of the piston. (b) Preferred location of the ring gaps.

REVIEW QUESTIONS

1. What are the method used to control heat expansion?
2. Why are some piston skirts tin plated?
3. How does piston pin offset control piston slap?
4. Why are forged pistons recommended for use in high-performance engines?
5. What causes the piston ring groove clearance to widen in service?

CHAPTER QUIZ

1. A hypereutectic piston _____________.
   - **a.** uses about 16% silicon
   - **b.** is a cast piston
   - **c.** is a forged piston
   - **d.** Both a and b
2. Many aluminum piston skirts are plated with _____________.
   - **a.** tin or moly graphite
   - **b.** lead
   - **c.** antimony
   - **d.** terneplate
3. A hypereutectic piston has a higher _____________.
   - **a.** weight than an aluminum piston
   - **b.** silicon content
   - **c.** tin content
   - **d.** nickel content
4. The purpose of casting steel struts into an aluminum piston is to _____________.
   - **a.** provide increased strength
   - **b.** provide increased weight at the top part of the piston where it is needed for stability
   - **c.** control thermal expansion
   - **d.** Both a and c
5. Full-floating piston pins are retained by _____________.
   - **a.** lock rings
   - **b.** a drilled hole with roll pin
   - **c.** an interference fit between rod and piston pin
   - **d.** an interference fit between piston and piston pin
6. The space behind the ring is called _____________.
   - **a.** side clearance
   - **b.** forward clearance
   - **c.** back clearance
   - **d.** piston ring clearance
7. A misaligned connecting rod causes what type of engine wear?
   - **a.** Cylinder taper
   - **b.** Barrel shape cylinders
   - **c.** Ridge wear
   - **d.** Diagonal wear on the piston skirt
8. Side clearance is a measure taken between the _____________ and the _____________.
   - **a.** piston (side skirt); cylinder wall
   - **b.** piston pin; piston pin retainer (clip)
   - **c.** piston ring; piston ring groove
   - **d.** compression ring; oil control ring
9. Piston ring gap should only be measured after _____________.
   - **a.** all cylinder work has been performed
   - **b.** installing the piston in the cylinder
   - **c.** installing the rings on the piston
   - **d.** Both a and c
10. Which type of connecting rod needs to be heated to install the piston pin?
    - **a.** Forged
    - **b.** Interference fit
    - **c.** Floating
    - **d.** PM rods

Chapter

31

ENGINE BLOCKS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the construction of engine blocks.
- Explain the procedure for engine block service.
- Explain block preparation for assembly.

KEY TERMS:

Bedplate 345 • Block deck 345 • Bores 343 • Compacted graphite iron (CGI) 344 • Cooling jacket 346 • Core plugs 344 • Crosshatch finish 352 • Decking the block 350 • Dry cylinder sleeve 345 • Fiber-reinforced matrix (FRM) 346 • Freeze plugs 344 • Frost plugs 344 • Girdle 347 • Monoblock 343 • Oil gallery 346 • Oil gallery plugs 346 • Plateau honing 351 • Saddles 348 • Wet cylinder sleeve 345

ENGINE BLOCKS

CONSTRUCTION The engine block, which is the supporting structure for the entire engine, is made from one of the following:

- Gray cast iron
- Cast aluminum
- Die-cast aluminum alloy

Cast iron contains about 3% carbon (graphite), which makes it gray in color. Steel is iron with most of the carbon removed. The carbon in cast iron makes it hard but brittle. Cast iron is used to make engine blocks and cylinder heads for the following reasons:

- The carbon in the cast iron allows for easy machining, often without coolant.
- The graphite in the cast iron also has lubricating properties.
- Cast iron is strong for its weight and usually is magnetic.

The liquid cast iron is poured into a mold made from either sand or Styrofoam. All other engine parts are mounted on or in the block. This large casting supports the crankshaft and camshaft (on OHV engines) and holds all the parts in alignment. Newer blocks use thinner walls to reduce weight. Blocks are often of the **monoblock** design, which means that the cylinder, water jacket, main bearing supports (saddles), and oil passages are all cast as one structure for strength and quietness. Large-diameter holes in the block casting form the cylinders to guide the pistons. The cylinder holes are called **bores** because they are made by a machining process called boring. ● **SEE FIGURE 31–1**.

Combustion pressure loads are carried from the head to the crankshaft bearings through the block structure. The block has webs, walls, and drilled passages to contain the coolant and lubricating oil and to keep them separated from each other.

Mounting pads or lugs on the block transfer the engine torque reaction to the vehicle frame through attached engine mounts. A large mounting surface at the rear of the engine block is used for fastening a bell housing or transmission.

The cylinder head(s) and other components attach to the block. The joints between the components are sealed using gaskets or sealants. Gaskets or sealants are used in the joints to take up differences that are created by machining irregularities and that result from different pressures and temperatures.

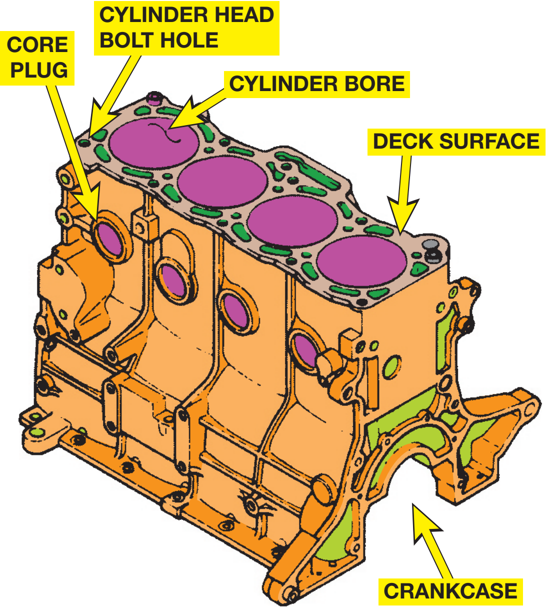


FIGURE 31–1 The cylinder block usually extends from the oil pan rails at the bottom to the deck surface at the top.

BLOCK MANUFACTURING

Cast-iron cylinder block sand casting technology continues to be improved. The trend is to make blocks with larger cores, using fewer individual pieces. Oil-sand cores are forms that shape the internal openings and passages in the engine block. Before casting, the cores are supported within a core box. The core box also has a liner to shape the outside of the block. Special alloy cast iron is poured into the box. It flows between the cores and the core box liner. As the cast iron cools, the core breaks up. When the cast iron has hardened, it is removed from the core box, and the pieces of sand core are removed through the openings in the block by vigorously shaking the casting. These openings in the block are plugged with **core plugs**. Core plugs are also called **freeze plugs** or **frost plugs**. Although the name seems to mean that the plugs would be pushed outward if the coolant in the passages were to freeze, they seldom work this way. ● **SEE FIGURE 31–2**.

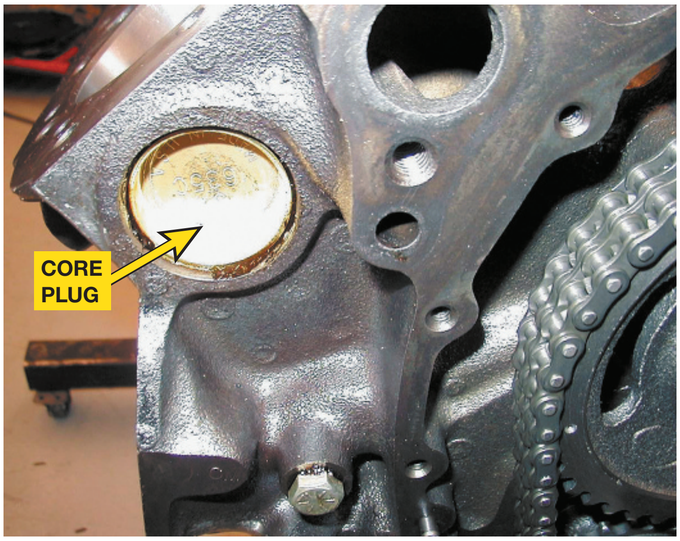


FIGURE 31–2 An expansion (core) plug is used to block the opening in the cylinder head or block the holes where the core sand was removed after the part was cast.

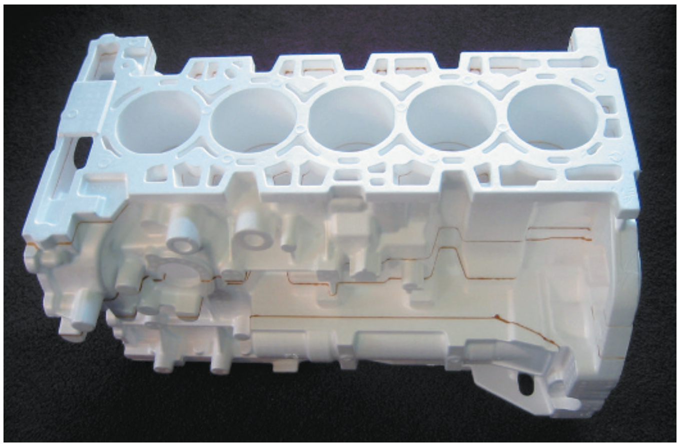


FIGURE 31–3 A Styrofoam casting mold used to make the five cylinder engine blocks for the Chevrolet Colorado. The brown lines are glue used to hold the various parts together. Sand is packed around the mold and molten aluminum is poured into the sand which instantly vaporizes the Styrofoam. The aluminum then flows and fills the area of the mold.

One way to keep the engine weight as low as possible is to make the block with minimum wall thickness. The cast iron used with thin-wall casting techniques has higher nickel content and is harder than the cast iron previously used. Engine designers have used foundry techniques to make engines lightweight by making the cast-iron block walls and bulkheads only as heavy as necessary to support their required loads.

ALUMINUM BLOCKS

Aluminum is used for some cylinder blocks and is nonmagnetic and lightweight. Styrofoam is often used as a core when casting an aluminum block. The Styrofoam vaporizes as soon as the molten aluminum comes in contact with the foam, leaving behind a cavity where the aluminum flows. ● **SEE FIGURE 31–3**.

Aluminum block engines usually require cast-iron cylinder walls for proper wear and longevity. Aluminum blocks may have one of several different types of cylinder walls.

- Most cast-aluminum blocks have cast-iron cylinder sleeves (liners) such as Saturn, Northstar, and Ford modular V-8s

FREQUENTLY ASKED QUESTION

What Is Compacted Graphite Iron?

Compacted graphite iron (CGI) has increased strength, ductility, toughness, and stiffness compared to gray iron. If no magnesium is added, the iron will form gray iron when cooled, with the graphite present in flake form. If a very small amount of magnesium is added, more and more of the sulfur and oxygen form in the molten solution, and the shape of the graphite begins to change to compacted graphite forms. Compacted graphite iron is used for bedplates and many diesel engine blocks. It has higher strength, stiffness, and toughness than gray iron. The enhanced strength has been shown to permit reduced weight while still reducing noise vibration and harshness. Compacted graphite iron is commonly used in the blocks of diesel and some high-performance engines.

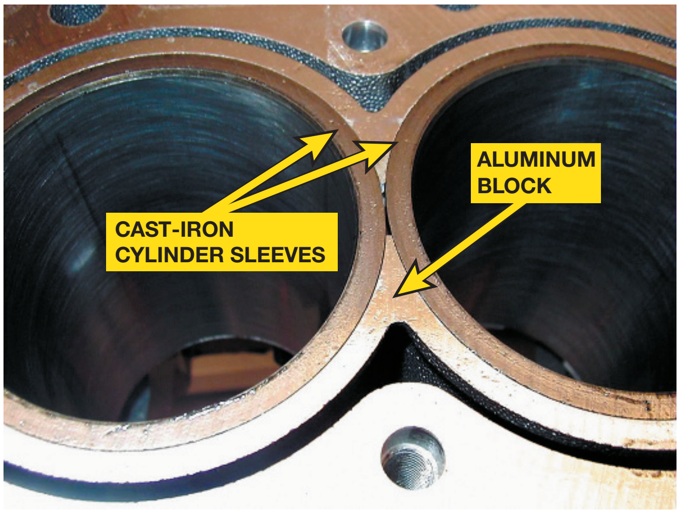


FIGURE 31–4 Cast-iron dry sleeves are used in aluminum blocks to provide a hard surface for the rings.

and V-6s. The cast-iron cylinder sleeves are either cast into the aluminum block during manufacturing or pressed into the aluminum block. These sleeves are not in contact with the coolant passages and are called **dry cylinder sleeves**. ● **SEE FIGURE 31–4**.

- Another aluminum block design has the block die cast from silicon-aluminum alloy with no cylinder liners. Pistons with zinc-copper-hard iron coatings are used in these aluminum bores (in some Porsche engines).
- Some engines have die-cast aluminum blocks with replaceable cast-iron cylinder sleeves. The sleeves are sealed at the block deck and at their base. Coolant flows around the cylinder sleeve, so this type of sleeve is called a **wet cylinder sleeve** (in Cadillac 4.1, 4.5, and 4.9 liter V-8 engines). ● **SEE FIGURE 31–5**.

Cast-iron main bearing caps are used with aluminum blocks to give the required strength.

BEDPLATE DESIGN BLOCKS

A **bedplate** is a structural member that attaches to the bottom of the block and supports the crankshaft. The oil pan is mounted under the bedplate, which in most cases is also part of the structure and support for the block assembly. ● **SEE FIGURE 31–6**.

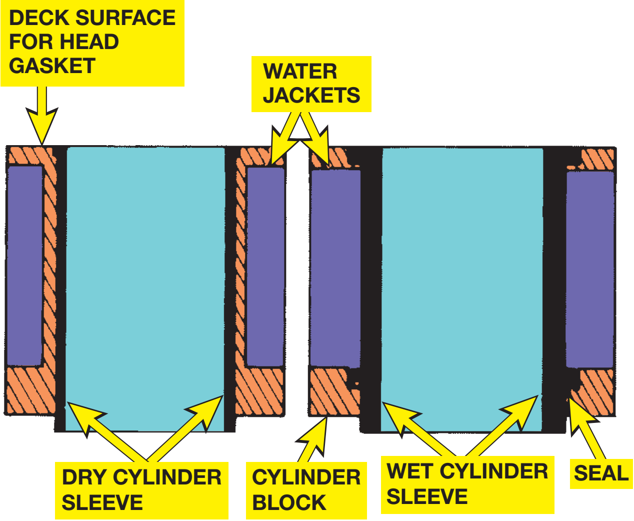


FIGURE 31–5 A dry sleeve is supported by the surrounding cylinder block. A wet sleeve must be thicker to be able to withstand combustion pressures without total support from the block.

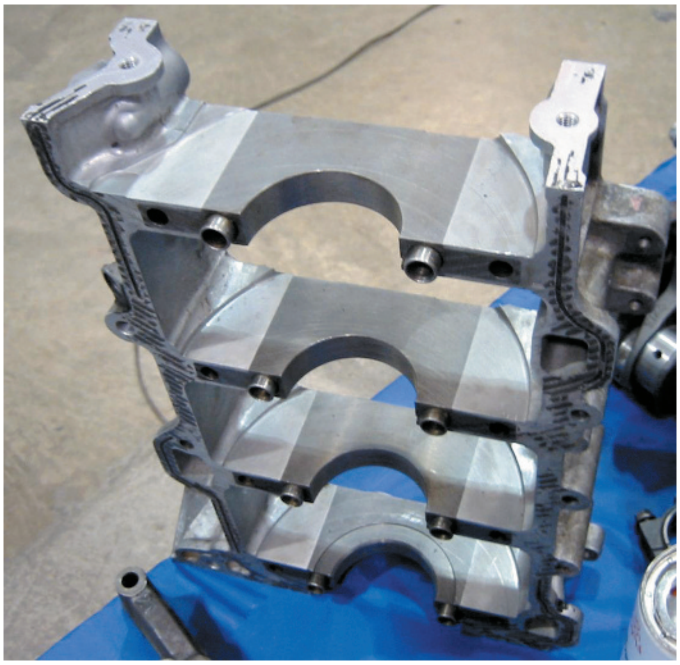


FIGURE 31–6 A bedplate is a structural part of the engine that is attached between the block and the oil pan and supports the crankshaft.

CASTING NUMBERS

Whenever an engine part such as a block is cast, a number is put into the mold to identify the casting. These **casting numbers** can be used to check dimensions, such as the cubic inch displacement, and other information, such as year of manufacture. Sometimes changes are made to the mold, yet the casting number is not changed. Most often the casting number is the best piece of identifying information that the service technician can use. ● **SEE FIGURE 31–7**.

BLOCK DECK

The cylinder head is fastened to the top surface of the block. This surface is called the **block deck**. The deck has a smooth surface to seal *against* the head gasket. Bolt holes are

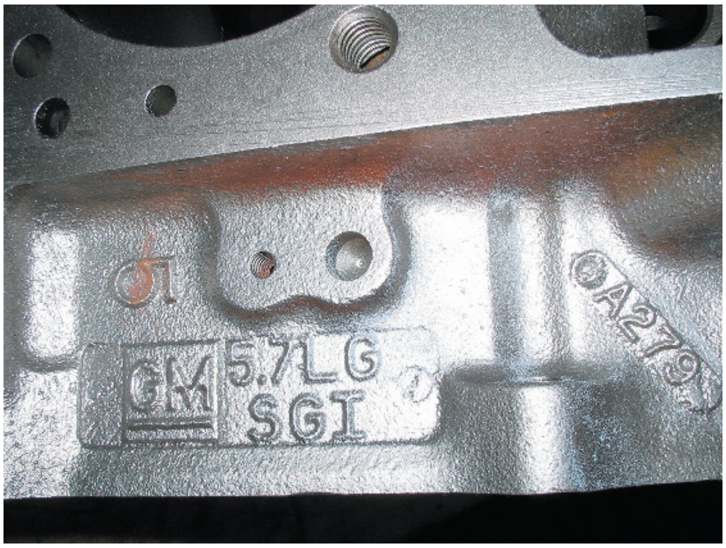


FIGURE 31–7 Casting numbers identify the block.

FREQUENTLY ASKED QUESTION

What Are FRM-Lined Cylinders?

Fiber-reinforced matrix (FRM) is used to strengthen cylinder walls in some Honda/Acura engines. FRM is a ceramic material similar to that used to construct the insulators of spark plugs. The lightweight material has excellent wear resistance and good heat transfer properties, making it ideal for use as a cylinder material. FRM inserts are placed in the mold and the engine block is cast over them. The inserts are rough and can easily adhere to the engine block. The inserts are then bored and honed to form the finished cylinders. FRM blocks were first used in a production engine on the Honda S2000 and are also used on the turbocharged Acura RDX sport utility vehicle.

positioned around the cylinders to form an even holding pattern. Four, five, or six head bolts are used around each cylinder in automotive engines. These bolt holes go into reinforced areas within the block that carry the combustion pressure load to the main bearing bulkheads. Additional holes in the block are used to transfer coolant and oil, as seen in ● **FIGURE 31–8**.

COOLING PASSAGES Cylinders are surrounded by cooling passages. These coolant passages around the cylinders are often called the **cooling jacket**. In most cylinder designs, the cooling passages extend nearly to the bottom of the cylinder. In some engine blocks where the block ends at the centerline of the crankshaft, the cooling passages are limited to the upper portion of the cylinder.

Some engines are built so that the cylinder walls are cast together without a water jacket (passage) between the cylinders. While this design improves the strength of the block and adds stability to the cylinder bores, it can reduce the cooling around the cylinders. ● **FIGURE 31–9** is a typical V-8 engine cutaway that shows the coolant jackets and some of the lubrication holes.

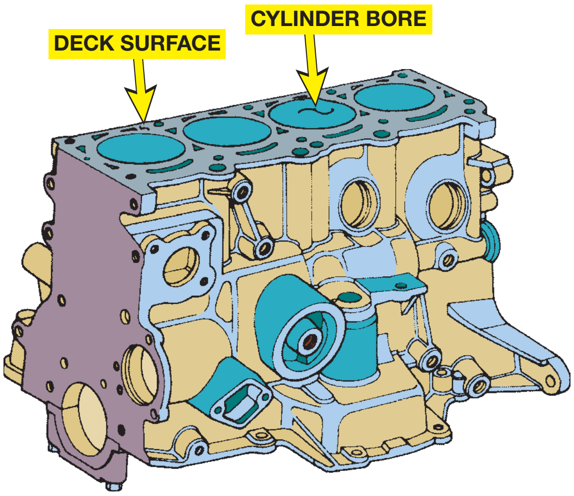


FIGURE 31–8 The deck is the machined top surface of the block.

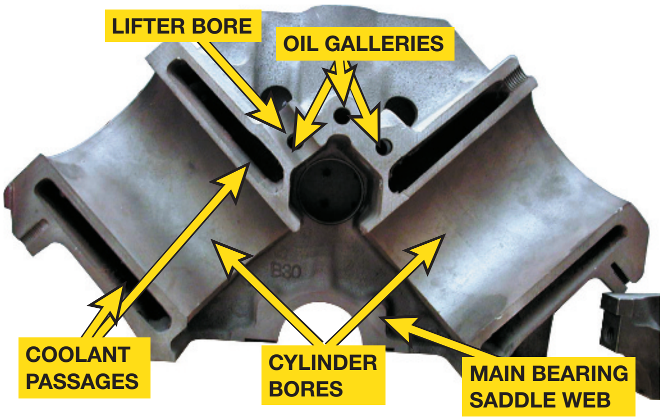


FIGURE 31–9 Cutaway of a Chevrolet V-8 block showing all of the internal passages.

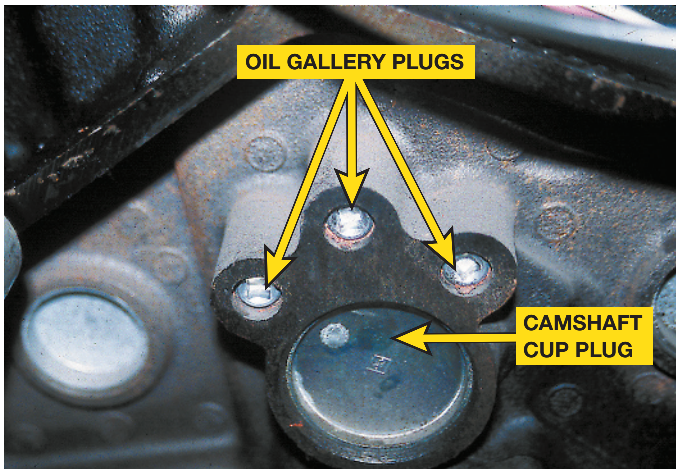


FIGURE 31–10 Typical oil gallery plugs on the rear of a Chevrolet small block V-8 engine.

LUBRICATING PASSAGES An engine block has many oil holes that carry lubricating oil to the required locations. During manufacture, all oil holes, called the **oil gallery**, are drilled from outside the block. When a curved passage is needed, intersecting straight drilled holes are used. In some engines, plugs are placed in the oil holes to direct oil to another point before it comes back to the original hole, on the opposite side of the plug. After oil holes are drilled, the unneeded open ends may be capped by pipe plugs, steel balls, or cup-type soft plugs, often called **oil gallery plugs**. These end plugs in the oil passages can be a source of oil leakage in operating engines. ● **SEE FIGURE 31–10**.

MAIN BEARING CAPS The main bearing caps are cast or manufactured from sintered or billeted materials, separately from the block.

- They are machined and then installed on the block for a final bore finishing operation.
- With caps installed, the main bearing bores and cam bearing bores (on OHV engines) are machined to the correct size and alignment. On some engines, these bores are honed to a very fine finish and exact size.
- Main bearing caps are not interchangeable or reversible because they are individually finished in place.

TECH TIP

What Does LHD Mean?

The abbreviation LHD means *left-hand dipstick,* which is commonly used by rebuilders and remanufacturers in their literature in describing Chevrolet small block V-8 engines. Before about 1980, most small block Chevrolet V-8s used an oil dipstick pad on the left side (driver's side) of the engine block. Starting in about 1980, when oxygen sensors were first used on this engine, the dipstick was relocated to the right side of the block.

Therefore, to be assured of ordering or delivering the correct engine, knowing the dipstick location is critical. An LHD block cannot be used with the exhaust manifold setup that includes the oxygen sensor without major refitting or the installing of a different style of oil pan that includes a provision for an oil dipstick. Engine blocks with the dipstick pad cast on the right side are, therefore, coded as right-hand dipstick (RHD) engines.

NOTE: Some blocks cast around the year 1980 are cast with both right- and left-hand oil dipstick pads, but only one is drilled for the dipstick tube. ● SEE FIGURE 31–11.

- Main bearing caps may have cast numbers indicating their position on the block. If not, they should be marked with numbers and arrows pointing toward the front of the engine.

Standard production engines usually use two bolts to hold the main bearing cap in place. ● **SEE FIGURE 31–12**.

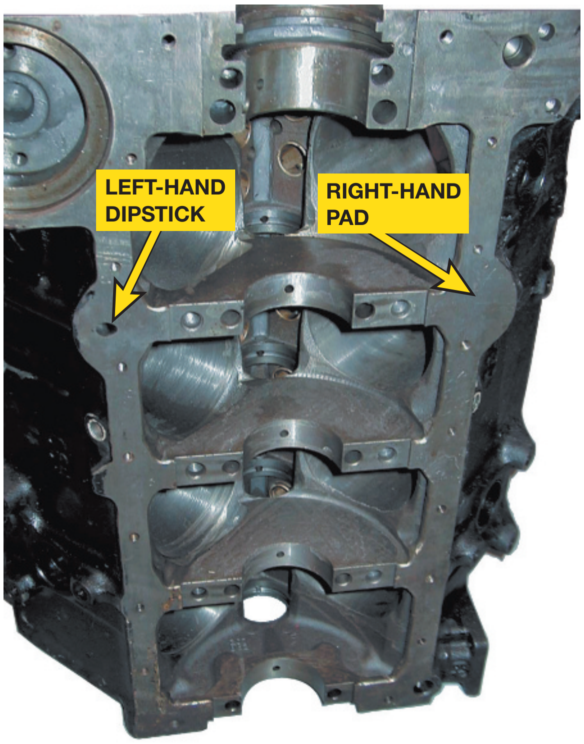


FIGURE 31–11 Small block Chevrolet block. Note the left-hand dipstick hole and a pad cast for a right-hand dipstick.

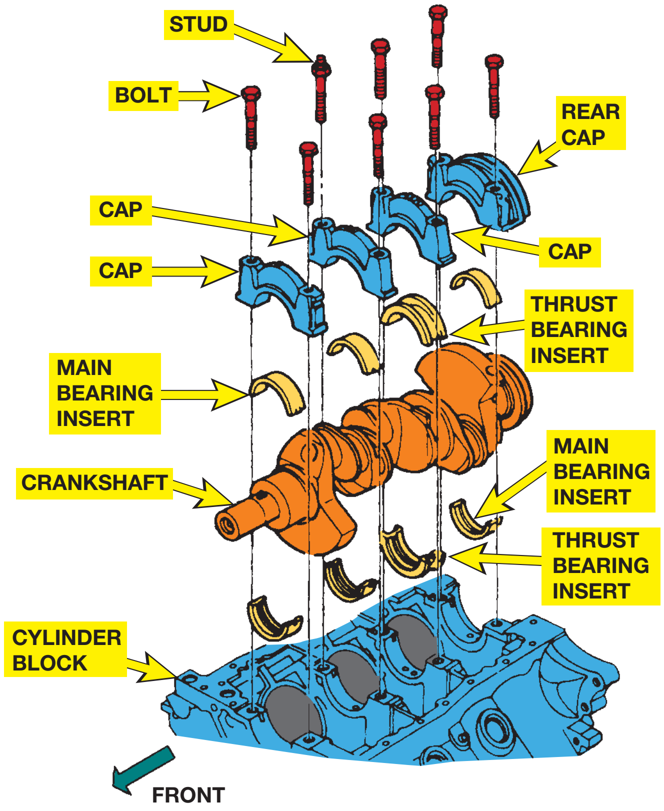


FIGURE 31–12 Two-bolt main bearing caps provide adequate bottom end strength for most engines.

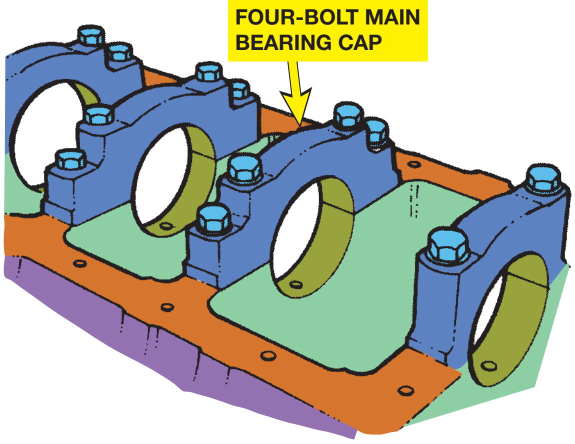


FIGURE 31–13 High-performance and truck engines often use four-bolt main bearing caps for greater durability.

Heavy-duty and high-performance engines often use additional main bearing support bolts. A four-bolt, and even six-bolt, main cap can be of a cross-bolted design in a deep skirt block or of a parallel design in a shallow skirt block. ● **SEE FIGURES 31–13 AND 31–14**.

Expansion force of the combustion chamber gases will try to push the head off the top and the crankshaft off the bottom of the block. The engine is held together with the head bolts and main bearing cap bolts screwed into bolt bosses and ribs in the block. The extra bolts on the main bearing cap help to support the crankshaft when there are high combustion pressures and mechanical loads, especially during high engine speed operation. Many engines use a **girdle** that ties all of the main bearing caps together to add strength to the lower part of the block. ● **SEE FIGURE 31–15**.

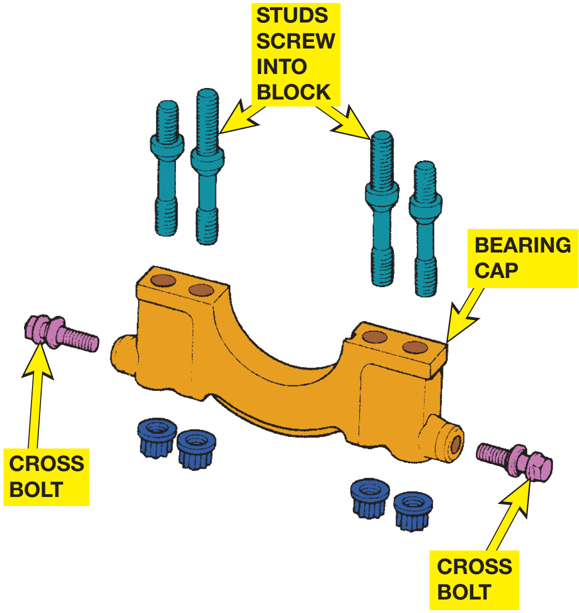


FIGURE 31–14 Some engines add to the strength of a four-bolt main bearing cap by also using cross bolts through the bolt on the sides of the main bearing caps.

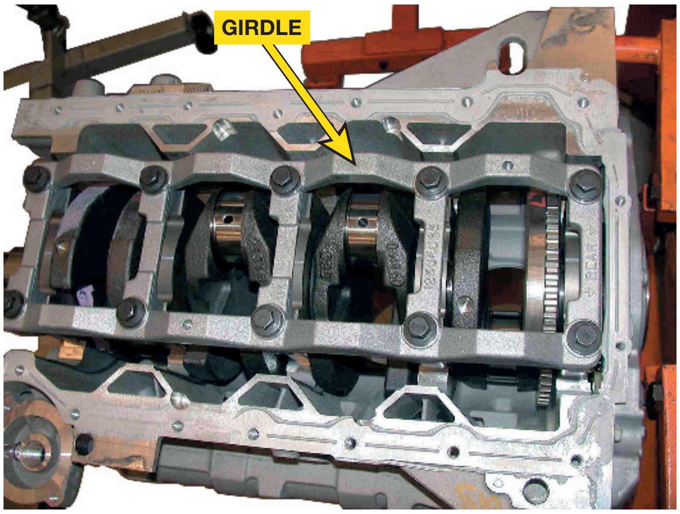


FIGURE 31–15 A girdle is used to tie all of the main bearing caps together.

ENGINE BLOCK SERVICE

PROCEDURES The engine block is the foundation of the engine. All parts of the block must be of the correct size and they must be aligned. The parts must also have the proper finishes if the engine is to function dependably for a normal service life.

After a thorough cleaning, the block should be inspected for cracks or other flaws before machine work begins. After the block has been cleaned and cracked checked, the block should be prepared in the following sequence:

OPERATION 1 Main bearing housing bore alignment, often called "align boring" (or honing)

OPERATION 2 Machining of the block deck surface parallel to the crankshaft

OPERATION 3 Cylinder boring and honing

FREQUENTLY ASKED QUESTION

What Is a Seasoned Engine?

A new engine is machined and assembled within a few hours after the heads and block are cast from melted iron. Newly cast parts have internal stresses within the metal. The stress results from the different thickness of the metal sections in the head. Forces from combustion in the engine, plus continued heating and cooling, gradually relieve these stresses. By the time the engine has accumulated 20,000 to 30,000 miles (32,000 to 48,000 km), the stresses have been completely relieved. This is why some engine rebuilders prefer to work with used heads and blocks that are stress relieved. Used engines are often called "seasoned" because of the reduced stress and movement these components have as compared with new parts.

MAIN BEARING HOUSING BORE ALIGNMENT The main bearing journals of a straight crankshaft are in alignment. If the main bearing housing bores in the block are not in alignment, the crankshaft will bend as it rotates. This condition increases rotational friction of the crankshaft and will lead to premature bearing failure or a broken crankshaft. The original stress in the block casting is gradually relieved as the block is used. Some slight warpage may occur as the stress is relieved. In addition, the continued pounding caused by combustion will usually cause some stretch in the main bearing caps. ● **SEE FIGURE 31–16**.

The main bearing bores gradually bow upward and elongate vertically. This means that the bearing bore becomes smaller at the centerline as the block distorts, pinching the bore inward at the sides. ● **SEE FIGURE 31–17**.

The procedure includes the following steps:

STEP 1 The first step in determining the condition of the main bearing bores is to determine if the bore alignment in the block is straight. These bores are called the **saddles**. A precision ground straightedge and a feeler gauge are used to determine the amount of warpage. The amount of variation along the entire length of the block should not exceed 0.0015 inch (0.038 mm).

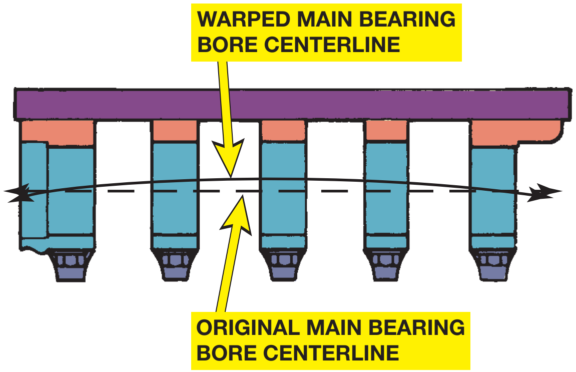

WARPED MAIN BEARING BORE CENTERLINE
ORIGINAL MAIN BEARING BORE CENTERLINE

FIGURE 31–16 The main bearing bores of a warped block usually bend into a bowed shape. The greatest distortion is in the center bores.

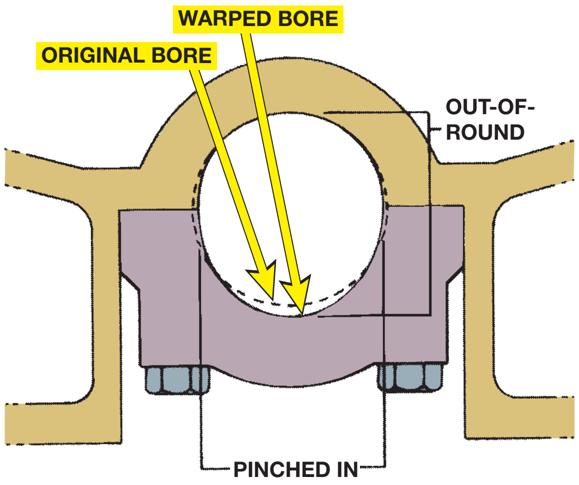


FIGURE 31–17 When the main bearing caps bow downward, they also pinch in at the parting line.

CAUTION: When performing this measurement, be sure that the block is resting on a flat surface. If the engine is mounted to an engine stand, the weight of the block on the unsupported end can cause an error in the measurement of the main bearing bores and saddle alignment.

STEP 2 If the block saddles exceed one-and-a-half thousandth of an inch distortion, then align honing is required to restore the block. If the block saddles are straight, the bores should be measured to be sure that the bearing caps are not distorted. ● **SEE FIGURE 31–18**.

STEP 3 The bearing caps should be installed and the retaining bolts tightened to the specified torque before measuring the main bearing bores. Using a telescoping gauge, measure each bore in at least two directions. Check the service information for the specified main bearing bore diameter. The bearing bore should not vary by more than one-half of a thousandth of an inch or 0.0005 inch (0.0127 mm). A dial bore gauge is often used to measure the main bearing bore. Set up the dial bore gauge in the fixture with the necessary extensions to achieve the nominal main bearing bore diameter.

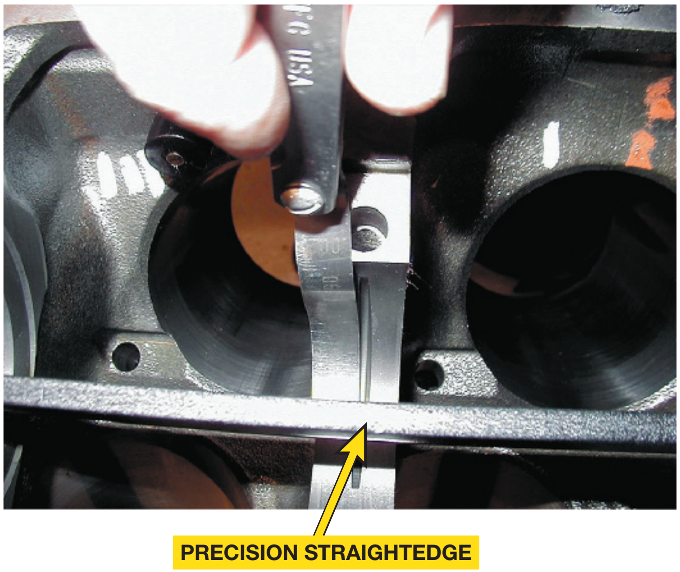


FIGURE 31–18 The main bearing bore alignment can be checked using a precision straightedge and a feeler gauge.

Check the service information for the specified main bearing bore diameter and determine the exact middle of the range.

ARBOR CHECK METHOD The arbor is installed, then all main caps are tightened to specifications. After tightening, the arbor is checked to make sure it rotates freely, indicating a true centerline. However, because of all the different diameters required, it is an expensive method. ● **SEE FIGURE 31–19**.

MACHINING THE DECK SURFACE OF THE BLOCK An engine should have the same combustion chamber size in each cylinder. For this to occur, each piston must come up an equal distance from the block deck. The connecting rods are attached to the rod bearing journals of the crankshaft. Pistons are attached to the connecting rods. As the crankshaft rotates, the pistons come to the top of the stroke. When all parts are sized equally, all the pistons will come up to the same level. This can only happen if the block deck is parallel to the main bearing bores. Therefore, the flatness of the block deck should be checked. ● **SEE FIGURE 31–20**.

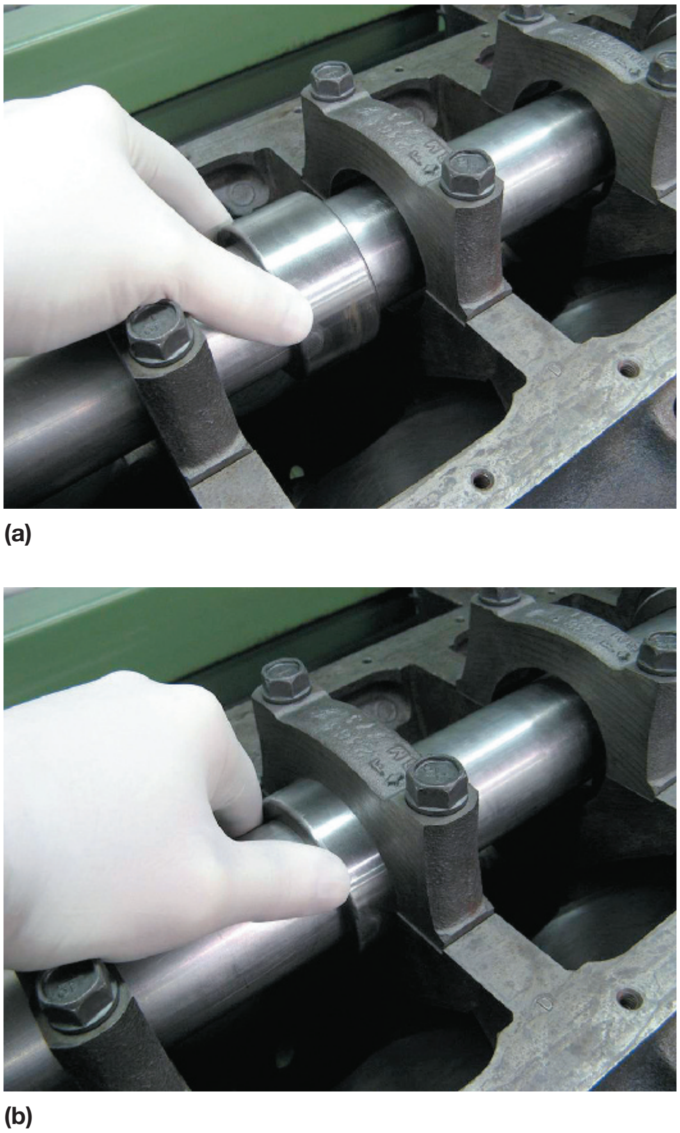


FIGURE 31–19 (a) A precision arbor can be used to check the main bearing bore alignment. (b) If the sleeve can be inserted into all of the main bearing bores, then they are aligned.

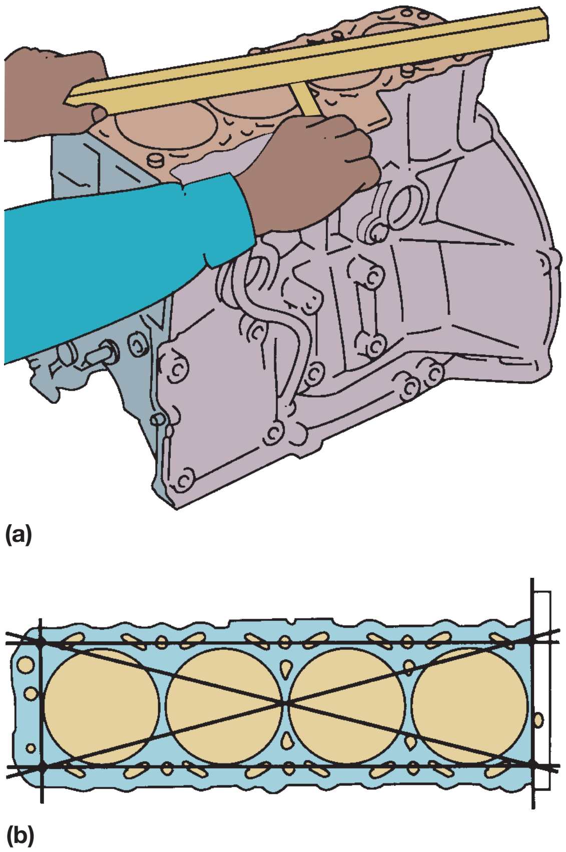


FIGURE 31–20 (a) Checking the flatness of the block deck surface using a straightedge and a feeler gauge. (b) To be sure that the top of the block is flat, check the block in six locations as shown.

The block deck must be resurfaced in a surfacing machine that can control the amount of metal removed when it is necessary to match the size of the combustion chambers. This procedure is called **decking the block**. The block is set up on a bar located in the main bearing saddles, or set up on the oil pan rails of the block. The bar is parallel to the direction of cutting head movement. The block is leveled sideways, and then the deck is resurfaced in the same manner as the head is resurfaced. ● **FIGURE 31–21** shows a block deck being resurfaced by grinding.

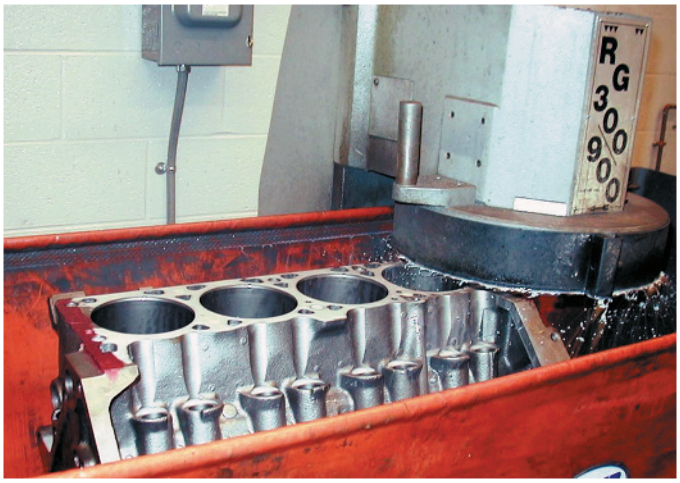


FIGURE 31–21 Grinding the deck surface of the block.

DECK SURFACE FINISH

The surface finish of the block deck should be

- 60 to 100 Ra (65 to 110 RMS) for cast iron
- 50 to 60 Ra (55 to 65 RMS) for aluminum block decks to be assured of a proper head gasket surface

The surface finish is determined by the type of grinding stone used, as well as the speed and coolant used in the finishing operation. The higher the surface finish number the rougher the surface.

CYLINDER BORING

Cylinders should be measured across the engine (perpendicular to the crankshaft), where the greatest wear occurs. In other words, measure the bores at 90 degrees to the piston pin. Most wear will be found just below the ridge, and the least amount of wear will occur below the lowest ring travel. ● **SEE FIGURE 31–22**.

The cylinder should be checked for out-of-round and taper. ● **SEE FIGURE 31–23**.

Most cylinders are serviceable if they

- are a maximum of 0.003 inch (0.076 mm) out-of-round
- have no more than a 0.005 inch (0.127 mm) taper
- have no deep scratches in the cylinder wall

NOTE: Always check the specifications for the engine being serviced. For example, the General Motors 4.8, 5.3, 5.7, 6, and 6.2 liter LS series V-8s have a maximum out-of-round of only 0.0003 inch (3/10 of one-thousandths of an inch). This specification is about one-third of the normal dimension of about 0.001 inch.

The most effective way to correct excessive cylinder out-of-round, taper, or scoring is to rebore the cylinder. The rebored cylinder requires the use of a new, oversize piston.

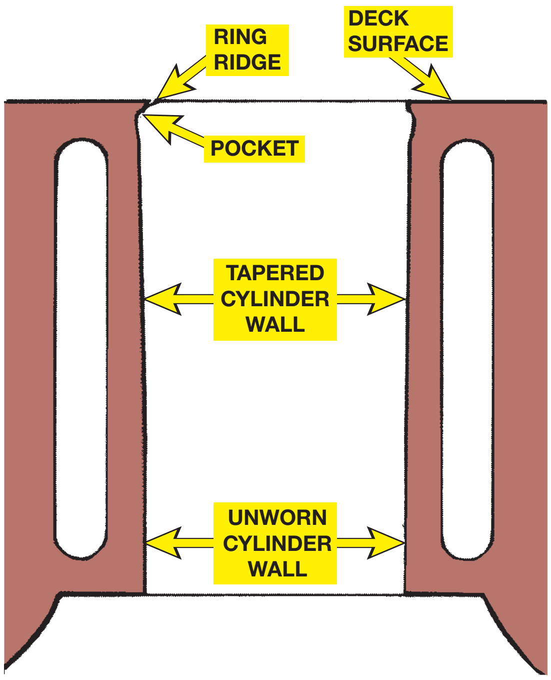


FIGURE 31–22 Cylinders wear in a taper, with most of the wear occurring at the top of the cylinder where the greatest amount of heat and pressure are created. The ridge is formed because the very top part of the cylinder is not contacted by the rings.

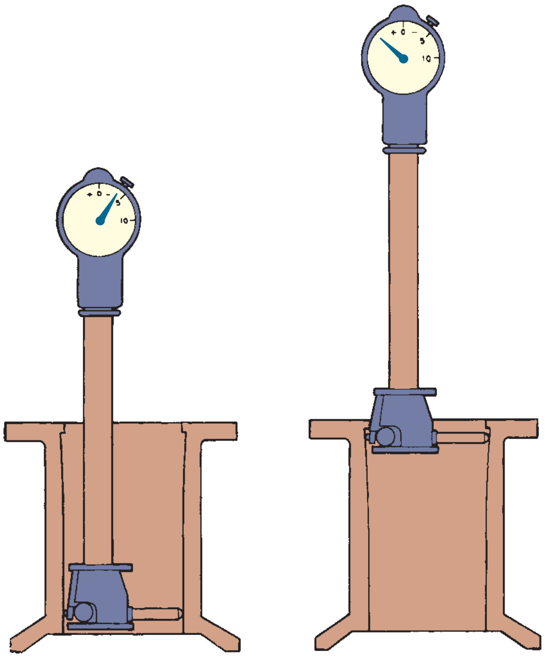


FIGURE 31–23 Using a dial bore gauge to measure the bore diameter at the top just below the ridge (maximum wear section) and at the bottom below the ring travel (minimum wear section). The difference between these two measurements is the amount of cylinder taper. Take the measurements in line with the crankshaft and then repeat the measurements at right angles to the centerline of the block in each cylinder to determine out-of-round.

The maximum bore oversize is determined by two factors:

1. Cylinder wall thickness—at least 0.17 inch (4 mm) for street engines and 0.2 inch (5 mm) for high-performance or racing applications
2. Size of the available oversize pistons

CYLINDER HONING It is important to have the proper surface finish on the cylinder wall for the rings to seat against. Honing includes two basic operations depending on the application:

1. When installing new piston rings on a cylinder that is not being bored, some ring manufacturers recommend breaking the hard surface glaze on the cylinder wall with a hone before installing new piston rings. This process is often called "deglazing" the cylinder walls.
2. The cylinder wall should be honed to straighten the cylinder when the wall is wavy or scuffed. If honing is being done with the crankshaft remaining in the block, the crankshaft should be protected to keep honing chips from getting on the shaft.

Two types of hones are used for cylinder service:

- A *deglazing hone* removes the hard surface glaze remaining in the cylinder. It is a flexible hone that follows the shape of the cylinder wall, even when the wall is wavy. It cannot be used to straighten the cylinder. A brush-type (ball-type) deglazing hone is shown in ● **FIGURE 31–24**.
- A *sizing hone* can be used to straighten the cylinder and to provide a suitable surface for the piston rings. Honing the cylinder removes the fractured metal that is created by boring. The cylinders must be honed a minimum of 0.002 inch (0.05 mm) after boring to cut below the rough surface and provide an adequate finish. Honing leaves a plateau surface that can support the oil film for the rings and piston skirt. This plateau surface is achieved by first using a coarse stone followed by a smooth stone to achieve the desired surface. The process of using a course and fine stone is called **plateau honing**. ● **SEE FIGURE 31–25**.

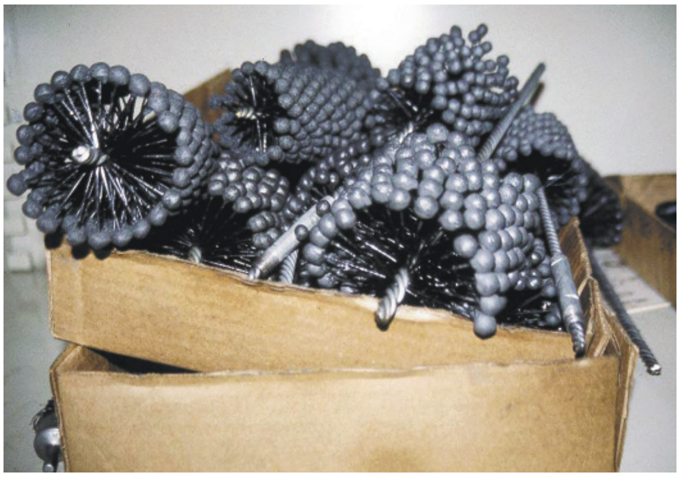


FIGURE 31–24 An assortment of ball-type deglazing hones. This type of hone does not straighten wavy cylinder walls.

The honing stones are held in a rigid fixture with an expanding mechanism to control the size of the hone. The sizing hone can be used to straighten the cylinder taper by honing the lower cylinder diameter more than the upper diameter. As it rotates, the sizing hone only cuts the high spots so that cylinder out-of-round is also reduced. The cylinder wall surface finish is about the same when the cylinder is refinished with either type of hone. ● **SEE FIGURE 31–26**.

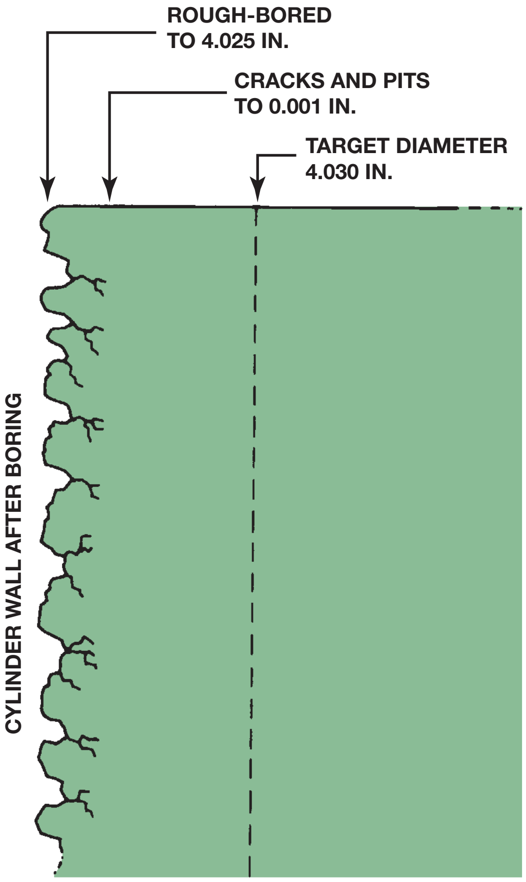


FIGURE 31–25 After boring, the cylinder surface is rough, pitted, and fractured to a depth of about 0.001 inch.

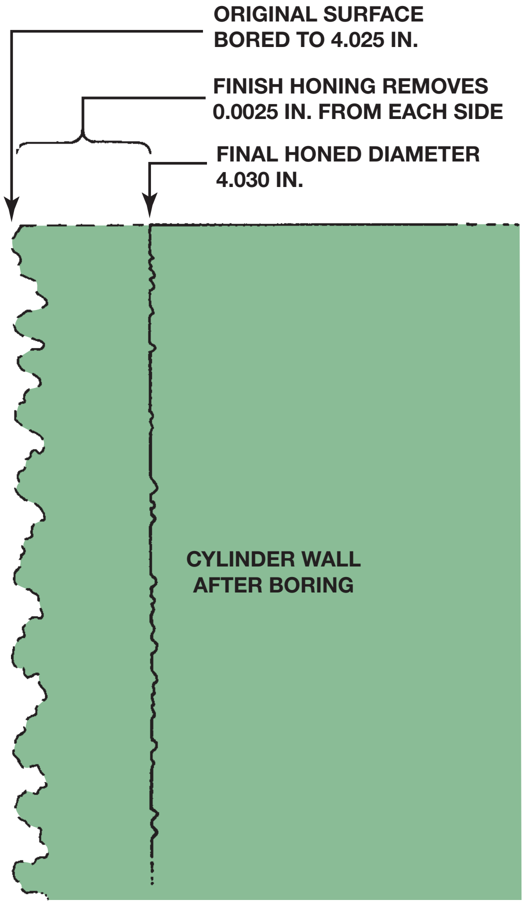


FIGURE 31–26 Honing enlarges the cylinder bore to the final size and leaves a plateau surface finish that retains oil.

The hone is stroked up and down in the cylinder as it rotates to produce a **crosshatch finish** on the cylinder wall, which aides in proper ring break-in. The speed that the operator moves the hone up and down controls the angle. Always check service information for the specified crosshatch angle.

The angle of the crosshatch should be between 20 and 60 degrees. Higher angles are produced when the hone is stroked more rapidly in the cylinder. A typical honed cylinder is pictured in ● **FIGURE 31–27**.

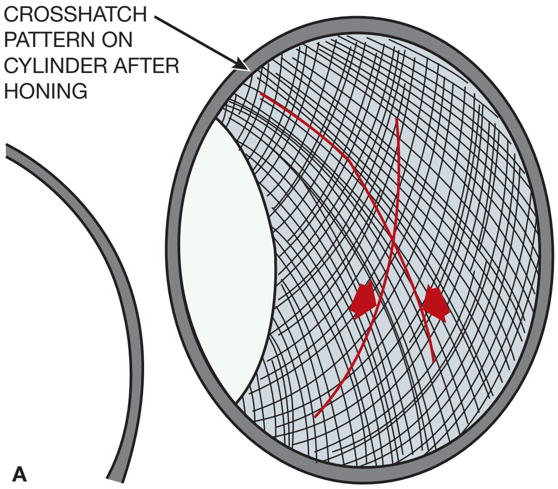


FIGURE 31–27 The crosshatched pattern holds oil to keep the rings from wearing excessively, and also keeps the rings against the cylinder wall for a gas-tight fit.

BLOCK PREPARATION FOR ASSEMBLY

BLOCK CLEANING Cleaning the honed cylinder wall is an important part of the honing process. If any grit remains on the cylinder wall, it will rapidly wear the piston rings. This wear will cause premature failure of the reconditioning job. The best way to clean the honed cylinders is to scrub the cylinder wall with a brush using a mixture of soap or detergent and water.

BLOCK DETAILING Before the engine block can be assembled, a final detailed cleaning should be performed.

1. All oil passages (galleries) should be cleaned by running a long bottle-type brush through all holes in the block.
2. All tapped holes should have the sharp edges at the top of the holes removed (chamfered) and cleaned with the correct size of thread chaser to remove any dirt and burrs. ● **SEE FIGURES 31–28 AND 31–29**.
3. Coat the newly cleaned block with fogging oil to prevent rust. Cover the block with a large plastic bag to keep out dirt until it is time to assemble the engine.

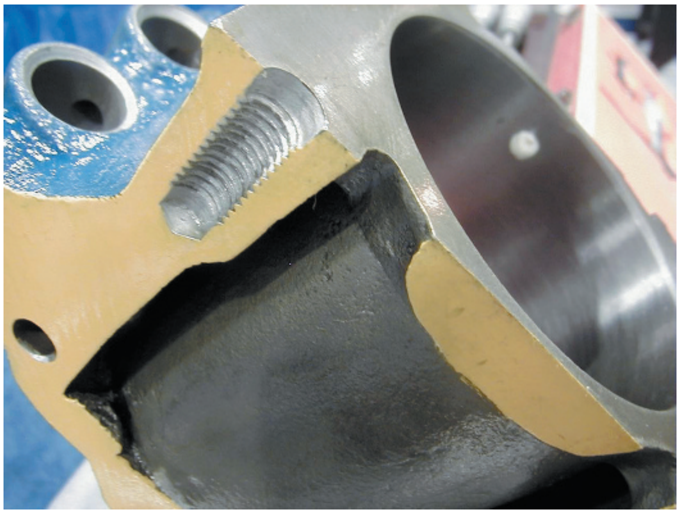


FIGURE 31–28 Notice on this cutaway engine block that some of the head bolt holes do not extend too far into the block and dead end. Debris can accumulate at the bottom of these holes, and it must be cleaned out before final assembly.

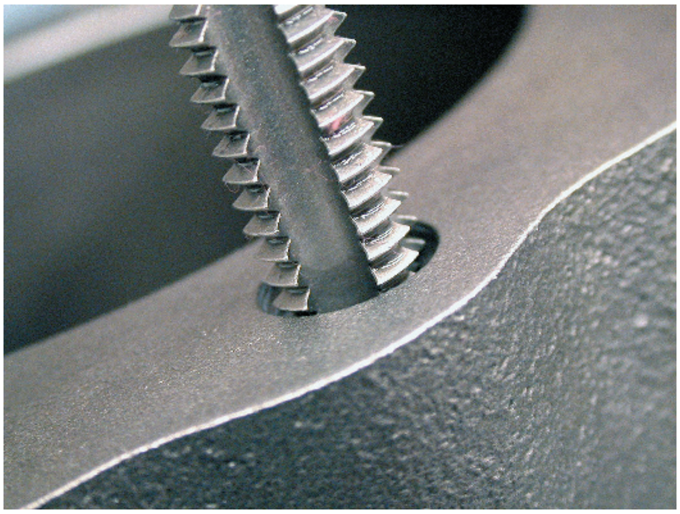


FIGURE 31–29 A tread chaser or bottoming tap should be used in all threaded holes before assembling the engine.

REVIEW QUESTIONS

1. How is Styrofoam used to cast an engine block?
2. What does "decking the block" mean?
3. What is the difference between deglazing and honing a cylinder?
4. What is the best method to use to clean an engine block after honing?
5. What procedures should be performed to detail the block and get it ready to be reassembled?

CHAPTER QUIZ

1. The block deck is the ___________.
   - **a.** bottom (pan rail) of the block
   - **b.** top surface of the block
   - **c.** valley surface of a V-type engine
   - **d.** area where the engine mounts are attached to the block
2. When honing a cylinder the specified crosshatch angle is usually ___________.
   - **a.** parallel
   - **b.** between 20 and 60 degrees
   - **c.** at least 90 degrees
   - **d.** All of these are correct
3. An aluminum engine block usually has main bearing caps made of ___________.
   - **a.** aluminum
   - **b.** cast iron
   - **c.** steel
   - **d.** carbon steel
4. Cast iron has about how much carbon content?
   - **a.** Less than 1%
   - **b.** 2%
   - **c.** 3%
   - **d.** 4% or higher
5. Engine blocks can be manufactured using which method(s)?
   - **a.** Sand cast
   - **b.** Sand cast or die cast
   - **c.** Extruded cylinder
   - **d.** Machined from a solid piece of metal (either cast iron or aluminum)
6. A bedplate is located between the ___________ and the ___________.
   - **a.** cylinder bores; water jacket
   - **b.** cylinder head; block deck
   - **c.** bottom of the block; oil pan
   - **d.** block deck; cylinder bore
7. Detailing an engine block includes ___________.
   - **a.** cleaning dirt or debris at the bottom of threaded holes
   - **b.** using a bottle brush to clean all passages
   - **c.** coating the block with fogging oil to help prevent rust or corrosion
   - **d.** All of the above
8. A high-performance engine block often has which features?
   - **a.** Aluminum main bearing caps
   - **b.** Wet sleeves
   - **c.** Four-bolt main bearing caps
   - **d.** All of these
9. An engine block should be machined in which order?
   - **a.** Align honing, cylinder boring, block deck machining
   - **b.** Block decking, align honing, cylinder boring
   - **c.** Cylinder boring, align honing, block decking
   - **d.** Align honing, block decking, cylinder boring
10. After the engine block has been machined, it should be cleaned using ___________.
    - **a.** soap and water
    - **b.** SAE 10W-30 oil and a shop cloth
    - **c.** sprayed-on brake cleaner to remove the cutting oil
    - **d.** sprayed-on WD-40

Chapter

32

CRANKSHAFTS, BALANCE SHAFTS, AND BEARINGS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose of the crankshaft.
- Describe crankshaft construction.
- Describe crankshaft oiling holes.
- Discuss engine crankshaft types.
- Explain the purpose and function of counterweights.
- Explain externally and internally balanced engines.
- Compare flat-plane and cross-plane crankshafts.
- Explain engine balance.
- Explain the purpose of balance shafts.
- Discuss crankshaft service.
- Describe engine bearings.
- Discuss the importance of bearing clearance.
- Discuss camshaft bearings.

KEY TERMS:

Aluminum 365 • Amplitude 360 • Babbitt 365 • Bank 357 • Bearing crown 364 • Bearing shell 365 • Billet 356 • Case hardening 355 • Conformability 366 • Copper-lead alloy 365 • Corrosion resistance 367 • Counterweights 359 • Crankpins 355 • Crankshaft centerline 354 • Crush 367 • Elastomer 360 • Electroplating 365 • Embedability 367 • Fatigue life 366 • Flying web 358 • Frequency 360 • Full round bearing 368 • Fully counterweighted 359 • Half-shell bearing 365 • Hub 360 • Inertia ring 360 • Nitriding 355 • Overlay 365 • Plain bearing 364 • Precision insert-type bearing shells 365 • Primary vibration 361 • Resonate 360 • Score resistance 367 • Secondary vibration 361 • Sleeve bearing 364 • Splay angle 358 • Split-type (half-shell) bearing 368 • Spread 367 • Spun bearing 367 • Surface finish 355 • Thrust bearing 355 • Tuftriding 356 • Work hardened 366

CRANKSHAFT

PURPOSE AND FUNCTION Power from expanding gases in the combustion chamber is delivered to the crankshaft through the piston, piston pin, and connecting rod. The connecting rods and their bearings are attached to a bearing journal on the crank throw. The crank throw is offset from the **crankshaft centerline**. The distance between the centerline of the connecting rod bearing journal and the centerline of the crankshaft main bearing journal determines the stroke of the engine. The engine stroke is calculated by multiplying the distance between the two centerlines by 2. The combustion force is applied to the crank throw after the crankshaft has moved past top center. This produces the turning effort or torque, which rotates the crankshaft. The crankshaft rotates on the main bearings. These bearings are split in half so that they can be assembled around the crankshaft main bearing journals. The crankshaft includes the following parts:

- Main bearing journals
- Rod bearing journals
- Crankshaft throws
- Counterweights
- Front snout
- Flywheel flange
- Keyways
- Oil passages

● **SEE FIGURE 32–1**.

MAIN BEARING JOURNALS The crankshaft rotates in the cylinder block supported on main bearings. ● **SEE FIGURE 32–2**.

The main bearings support the crankshaft and allow it to rotate easily without excessive wear. The number of cylinders usually determines the number of main bearings.

- Four-cylinder engines and V-8 engines usually have five main bearings.
- Inline 6-cylinder engines usually have seven main bearings.
- V-6 engines normally have only four main bearings.

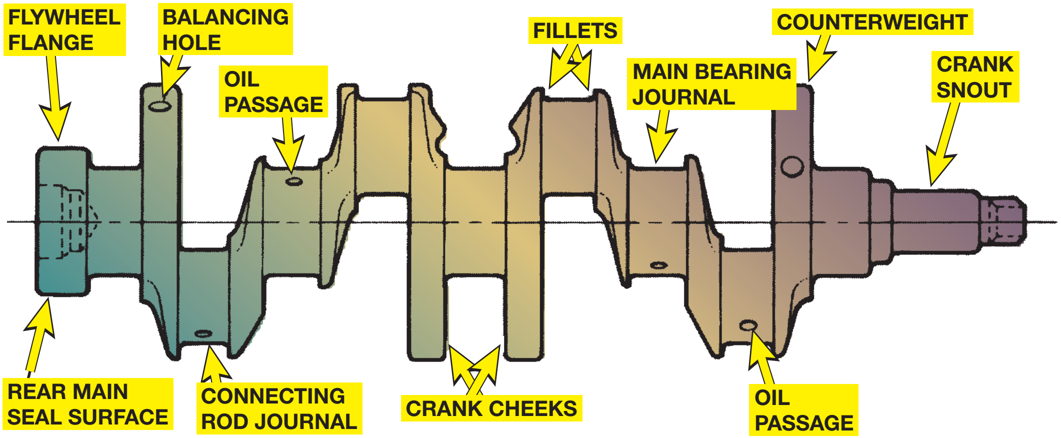

FLYWHEEL FLANGE
BALANCING HOLE
OIL PASSAGE
FILLETS
MAIN BEARING JOURNAL
COUNTERWEIGHT
CRANK SNOUT
REAR MAIN SEAL SURFACE
CONNECTING ROD JOURNAL
CRANK CHEEKS
OIL PASSAGE

FIGURE 32–1 Typical crankshaft with main journals that are supported by main bearings in the block. Rod journals are offset from the crankshaft centerline.

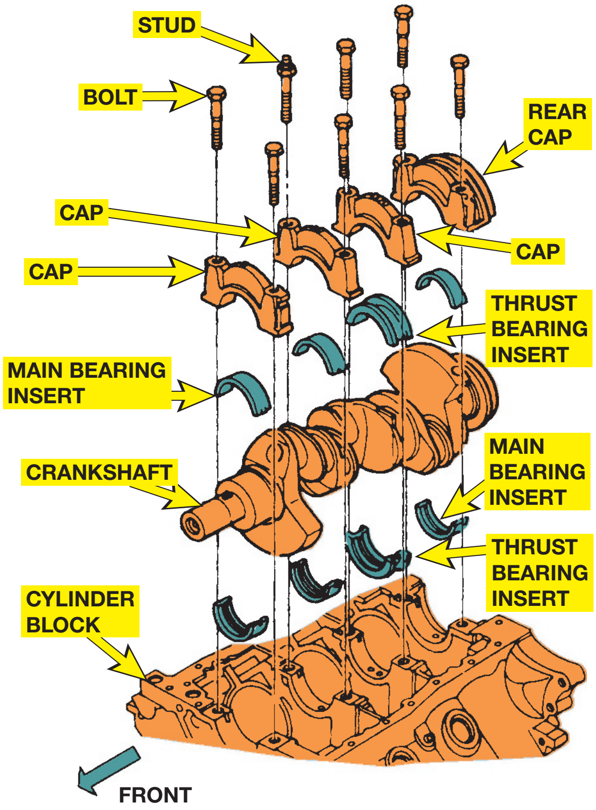

STUD
BOLT
REAR CAP
CAP
CAP
CAP
THRUST BEARING INSERT
MAIN BEARING INSERT
CRANKSHAFT
MAIN BEARING INSERT
THRUST BEARING INSERT
CYLINDER BLOCK
FRONT

FIGURE 32–2 The crankshaft rotates on main bearings. Longitudinal (end-to-end) movement is controlled by the thrust bearing.

The crankshaft also must be able to absorb loads applied longitudinally (end to end) or thrust loads from the clutch on a manual transmission vehicle or the torque converter on a vehicle equipped with an automatic transmission. Thrust loads are forces that push and pull the crankshaft forward and rearward in the engine block. A **thrust bearing** supports these loads and maintains the front-to-rear position of the crankshaft in the block. ● **SEE FIGURE 32–3**.

The thrust surface on many engines is usually located at the middle or one of the end main bearings. On most engines, the bearing insert for the main bearing is equipped with thrust bearing flanges that ride against the thrust surface.

ROD BEARING JOURNALS The rod bearing journals, also called **crankpins** or throws, are offset from the centerline of the crank. Insert-type bearings fit between the big end of the connecting rod and the crankpin of the crankshaft.

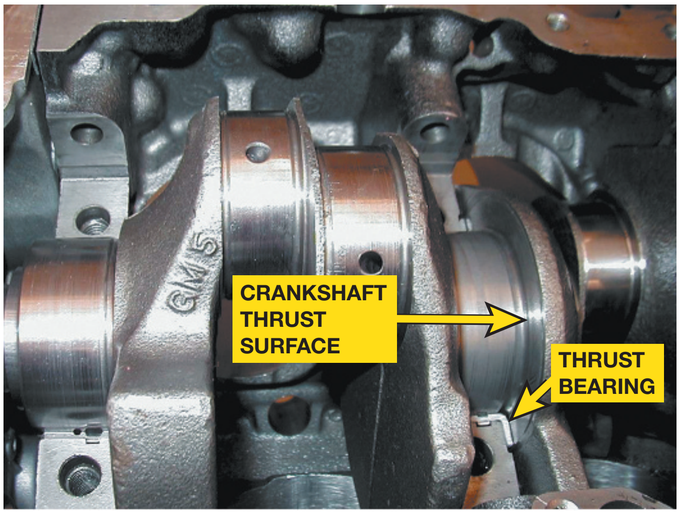

CRANKSHAFT THRUST SURFACE
THRUST BEARING

FIGURE 32–3 A ground surface on one of the crankshaft cheeks next to a main bearing supports thrust loads on the crank.

The crankshaft throw offset measures one-half of the stroke and has a direct relationship to the displacement of the engine. The engine stroke is equal to twice the leverage distance or two times the length of the crankshaft throw. ● **SEE FIGURE 32–4**.

SURFACE FINISH All crankshaft journals are ground to a very smooth finish. **Surface finish** is measured in microinches; and the smaller the number, the smoother the surface. The typical specification for main and rod crankshaft journals is between 10 and 20 roughness average (Ra). This very smooth surface finish is achieved by polishing the crank journals after the grinding operation.

JOURNAL HARDNESS To improve wear resistance, some manufacturers harden the crankshaft journals. Methods used to harden the crankshaft journals include the following:

- **Case hardening**, where only the outer portion of the surface is hardened. Case hardening involves heating the crankshaft and adding carbon to the journals where it causes the outer surface to become harder than the rest of the crankshaft. If the entire crankshaft was hardened, it would become too brittle to absorb the torsional stresses of normal engine operation.
- **Nitriding**, where the crankshaft is heated to about 1,000°F (540°C) in a furnace filled with ammonia gas, and then allowed to cool. The process adds nitrogen (from the

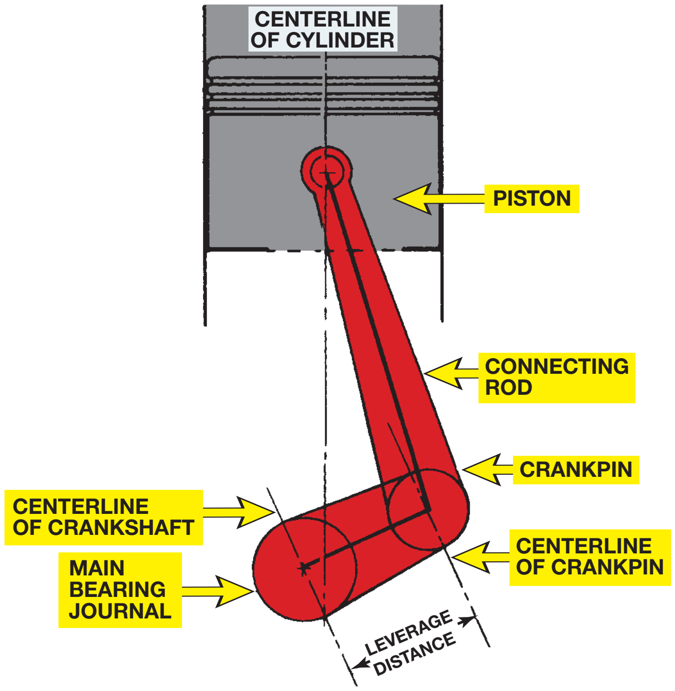


FIGURE 32–4 The distance from the crankpin centerline to the centerline of the crankshaft determines the stroke, which is the leverage available to turn the crankshaft.

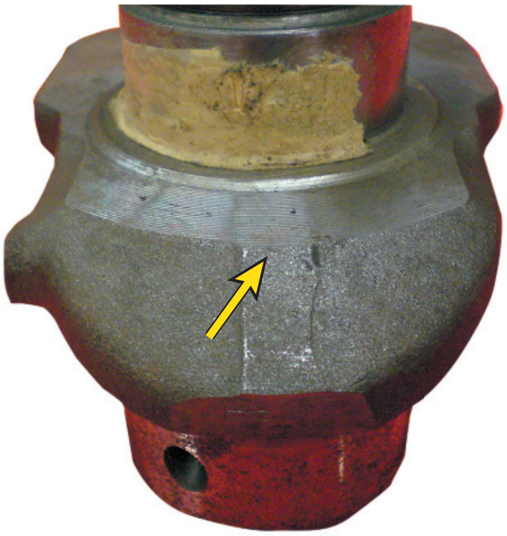


FIGURE 32–5 Wide separation lines of a forged crankshaft.

ammonia) into the surface of the metal, thus forming hard nitrides in the surface of the crankshaft to a depth of about 0.007 inch (0.8 mm).

- **Tuftriding**, another variation of this process, involves heating the crankshaft in a molten cyanide salt bath. Tuftriding is a trade name of General Motors.

CRANKSHAFT CONSTRUCTION

FORGED Crankshafts used in high-production automotive engines may be either forged or cast. Forged crankshafts are stronger than the cast crankshaft, but they are more expensive. Forged crankshafts may have a wide separation line. The wide separation line is the result of a grinding process to remove the metal that was extruded from the forging die during the forging process. ● **SEE FIGURE 32–5**.

Most high-performance forged crankshafts are made from SAE 4340 or a similar type of steel. The crankshaft is formed from a hot steel billet through the use of a series of forging dies. Each die changes the shape of the billet slightly. The crankshaft blank is finally formed with the last die. The blanks are then machined to finish the crankshaft. Forging makes a very dense, tough crankshaft with the metal's grain structure running parallel to the principal direction of stress.

Two methods are used to forge crankshafts:

- One method is to forge the crankshaft *in place*. This is followed by straightening. The forging in place method is primarily used with forged 4- and 6-cylinder crankshafts.
- A second method is to forge the crankshaft in a *single plane.* It is then twisted in the main bearing journal to index the throws at the desired angles. Most newer crankshafts are not twisted.

CAST CRANKSHAFTS Casting materials and techniques have improved cast crankshaft quality so that cast crankshafts are used in most production automotive engines. Automotive crankshafts may be cast in steel, nodular iron, or malleable iron. Advantages of a cast crankshaft are as follows:

- Crankshaft material and machining costs are less than they are with forging. The reason is that the crankshaft can be made close to the required shape and size, including all complicated counterweights. The only machining required on a carefully designed cast crankshaft is the grinding of bearing journal surfaces and the finishing of front and rear drive ends.
- Metal grain structure in the cast crankshaft is uniform and random throughout; therefore, the shaft is able to handle loads from all directions.
- Counterweights on cast crankshafts are slightly larger than counterweights on a forged crankshaft because the cast shaft metal is less dense and therefore somewhat lighter.

The narrow mold parting surface lines can be seen on the cast crankshaft in ● **FIGURE 32–6**.

BILLET CRANKSHAFTS A billet crankshaft is machined from a solid piece of forged steel called a **billet**. This solid piece of steel, usually SAE 4340, is then machined through several operations to create a finished crankshaft.

The advantages of a billet crankshaft include

- uniform grain structure created by the forging process
- stiff, strong, and very durable

The disadvantage is the high cost. Billet crankshafts tend to be very expensive because of the large amount of material removal during the machining process and the high material cost and the additional heat treatment required. ● **SEE FIGURE 32–7**.

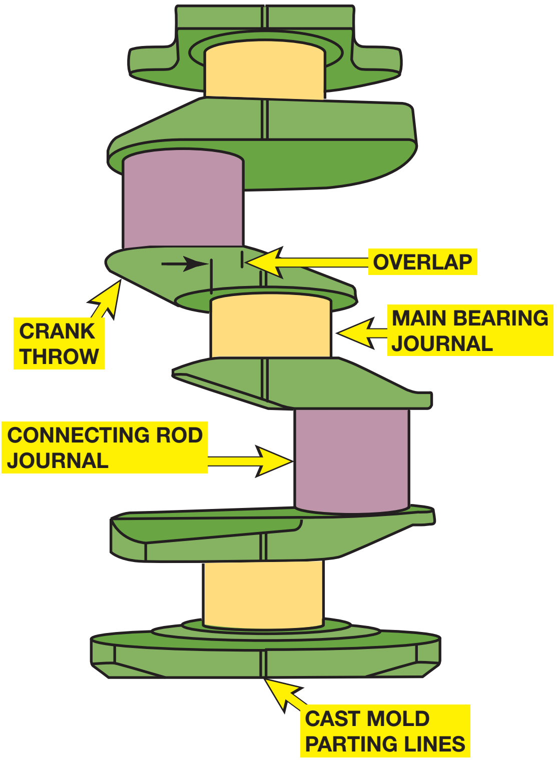


FIGURE 32–6 Cast crankshaft showing the bearing journal overlap and a straight, narrow cast mold parting line. The amount of overlap determines the strength of the crankshaft.

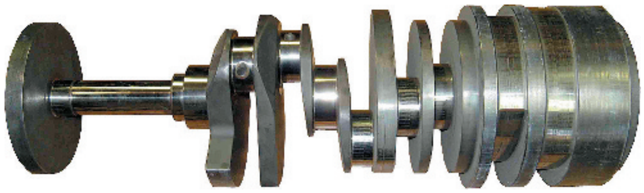


FIGURE 32–7 A billet crankshaft showing how it is machined from a solid chuck of steel, usually 4340 steel, at the right and the finished crankshaft on the left.

CRANKSHAFT OILING HOLES

PURPOSE AND FUNCTION The crankshaft is drilled to allow oil from the main bearing oil groove to be directed to the connecting rod bearings. ● **SEE FIGURE 32–8**.

The oil on the bearings forms a hydrodynamic oil film to support bearing loads. Some of the oil may be sprayed out through a spit or bleed hole in the connecting rod. The rest of the oil leaks from the edges of the bearing. It is thrown from the bearing against the inside surfaces of the engine. Some of the oil that is thrown from the crankshaft bearings will land on the camshaft to lubricate the lobes. A part of the throw-off, oil splashes on the cylinder wall to lubricate the piston and rings.

Stress tends to concentrate at oil holes drilled through the crankshaft journals. These holes are usually located where the crankshaft loads and stresses are the lowest. The edges of the oil holes are carefully chamfered to relieve as much stress concentration as possible. Chamfered oil holes are shown in ● **FIGURE 32–9**.

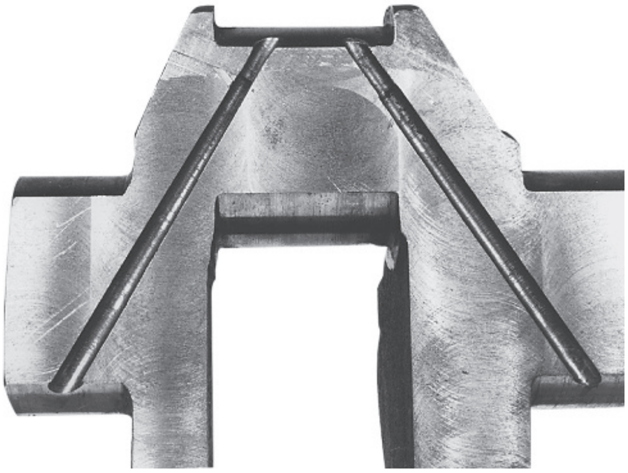


FIGURE 32–8 Crankshaft sawed in half, showing drilled oil passages between the main and rod bearing journals.

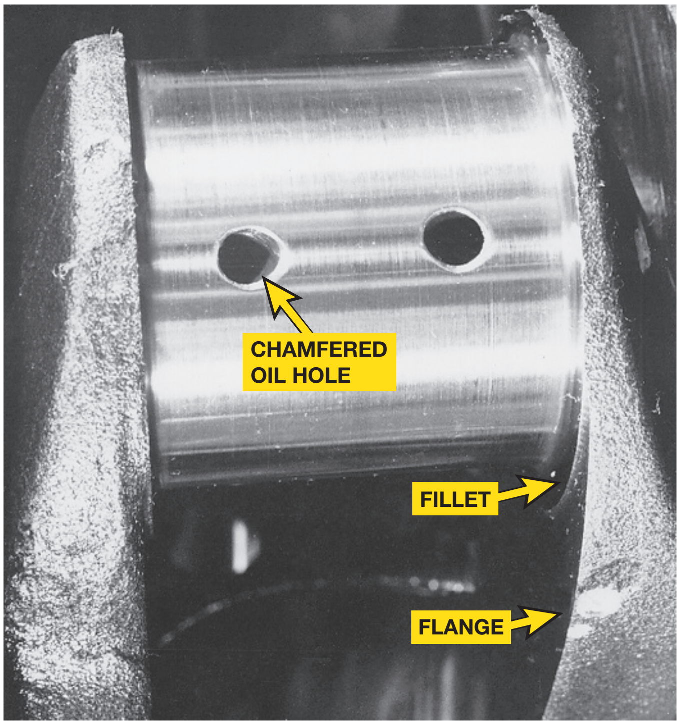


FIGURE 32–9 Typical chamfered hole in a crankshaft bearing journal.

ENGINE CRANKSHAFT TYPES

V-8 ENGINE ARRANGEMENT The V-8 engine has four inline cylinders in each of the two blocks that are placed at a 90-degree angle to each other. Each group of four inline cylinders is called a **bank**. The crankshaft for the V-8 engine has four throws. The connecting rods from two cylinders are connected to each throw, one from each bank. This arrangement results in a condition of being only minimally unbalanced.

The V-8 engine crankshaft has two planes, so there is one throw every 90 degrees. A plane is a flat surface that cuts through the part. These planes could be seen if the crankshaft were cut lengthwise through the center of the main bearing and crankpin journals. Looking at the front of the crankshaft:

- The first throw is at 360 degrees (up).
- The second throw is at 90 degrees (to the right).

- The third throw is at 270 degrees (to the left).
- The fourth throw is at 180 degrees (down).

In operation with this arrangement, one piston reaches top center at each 90 degrees of crankshaft rotation so that the engine operates smoothly with even firing at each 90 degrees of crankshaft rotation.

FOUR-CYLINDER ENGINE CRANKSHAFTS The crankshaft used on 4-cylinder inline engines has four throws on a single plane. There is usually a main bearing journal between each throw, making it a five main bearing crankshaft. Pistons also move as pairs in this engine.

- Pistons in cylinders 1 and 4 move together, and pistons 2 and 3 move together.
- Each piston in a pair is 360 degrees out-of-phase with the other piston in the 720 degree four-stroke cycle. With this arrangement, the 4-cylinder inline engine fires one cylinder at each 180 degrees of crankshaft rotation.

A 4-cylinder opposed (flat) engine and a 90-degree V-4 engine have crankshafts that look like that of the 4-cylinder inline engine.

FIVE-CYLINDER ENGINE CRANKSHAFTS The inline 5-cylinder engine has a five-throw crankshaft with one throw at each 72 degrees. Six main bearings are used on this crankshaft. The piston in one cylinder reaches top center at each 144 degrees of crankshaft rotation. Dynamic balancing has been one of the major problems with this engine design, yet the vibration was satisfactorily dampened and isolated on both the Audi and Acura 5-cylinder engines.

FREQUENTLY ASKED QUESTION

What Does a "Cross-Drilled Crankshaft" Mean?

A cross-drilled crankshaft means that there are two instead of only one oil hole leading from the main bearing journal to the rod bearing journal. Oil is supplied to the main bearing journals through oil galleries in the block. A cross-drilled crankshaft has two outlet holes for oil to reach the drilled passage that supplies oil to the rod journal. ● **SEE FIGURE 32–10**.

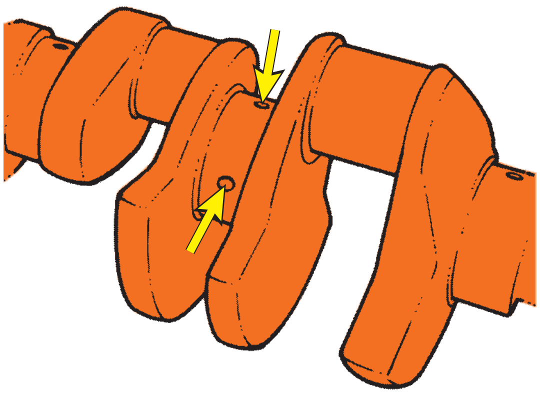


FIGURE 32–10 A cross-drilled crankshaft is used on some production engines and is a common racing modification.

CASE STUDY

The Mysterious Engine Vibration

A Buick 3.8 liter V-6 engine vibrated the whole car after a new short block had been installed. The technician who had installed the replacement engine did all of the following:

1. Checked the spark plugs
2. Checked the spark plug wires
3. Disconnected the torque converter from the flex plate (drive plate) to eliminate the possibility of a torque converter or automatic transmission pump problem
4. Removed all accessory drive belts one at a time

Yet the vibration still existed.

Another technician checked the engine mounts and found that the left (driver's side) engine mount was out of location, ripped, and cocked. The transmission mount was also defective. After the technician replaced both mounts and made certain that all mounts were properly set, the vibration was eliminated.

Summary:

Complaint—Vehicle vibrated after a replacement engine block was installed.

Cause—Defective engine and transmission mounts.

Correction—Both mounts were replaced which corrected the vibration.

THREE-CYLINDER ENGINE CRANKSHAFTS A 3-cylinder engine uses a 120-degree three-throw crankshaft with four main bearings. This engine requires a balancing shaft that turns at crankshaft speed, but in the opposite direction, to reduce the vibration to an acceptable level.

INLINE SIX-CYLINDER ENGINE CRANKSHAFT Inline six-cylinder engine crankshafts ride on four or seven main bearings and use six crank throws in three planes 120-degrees apart. An inline six cylinder is in perfect primary and secondary balance.

90-DEGREE V-6 ENGINE CRANKSHAFTS The crank throws for an even-firing V-6 engine are split, making separate crankpins for each cylinder. The split throw can be seen in ● **FIGURE 32–11**.

This angle between the crankpins on the crankshaft throws is called a **splay angle**. A flange was left between the split crankpin journals. This provides a continuous fillet or edge for machining and grinding operations. It also provides a normal flange for the rod and bearing. This flange between the splayed crankpin journals is sometimes called a **flying web**.

60-DEGREE V-6 ENGINE CRANKSHAFTS The 60-degree V-6 engine is similar to the even-firing 90-degree V-6 engine. The adjacent pairs of crankpins on the crankshaft used in the 60-degree V-6 engine have a splay angle of 60 degrees.

The crankshaft of the 60-degree V-6 engine also uses four main bearings.

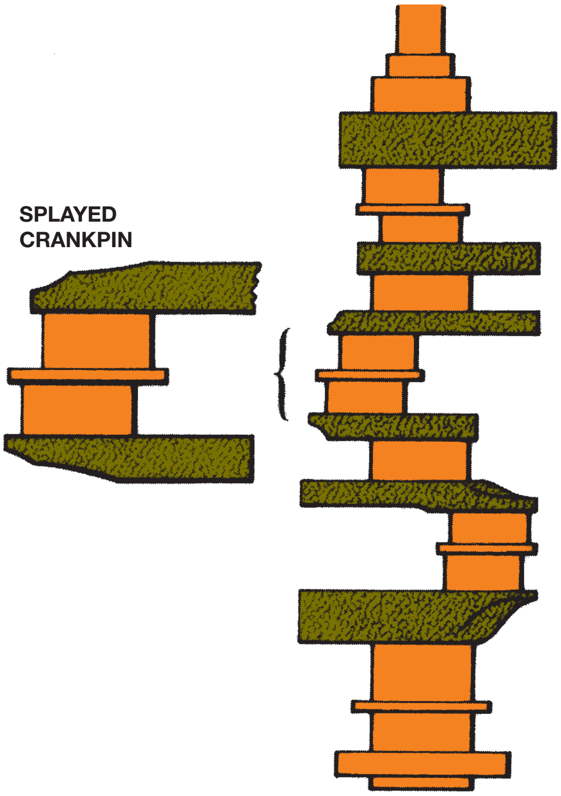

SPLAYED
CRANKPIN

FIGURE 32–11 A splayed crankshaft design is used to create an even-firing 90-degree V-6.

COUNTERWEIGHTS

PURPOSE AND FUNCTION Crankshafts are balanced by **counterweights**, which are cast, forged, or machined as part of the crankshaft. A crankshaft that has counterweights on both sides of each connecting rod journal is called **fully counterweighted**. ● **SEE FIGURE 32–12**.

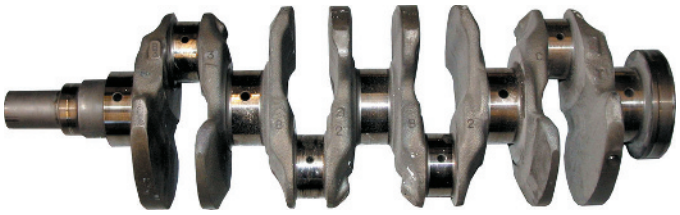


FIGURE 32–12 A fully counterweighted 4-cylinder crankshaft.

A fully counterweighted crankshaft is the smoothest running and most durable design, but it is also the heaviest and most expensive to manufacture. Most vehicle manufacturers do not use fully counterweighted crankshafts in an effort to lighten the rotating mass of the engine. An engine with a light crankshaft allows the engine to accelerate quicker. Even crankshafts that are not fully counterweighted are still balanced.

VIBRATION DAMAGE Each time combustion occurs, the force deflects the crankshaft as it transfers torque to the output shaft.

FREQUENTLY ASKED QUESTION

What Is an Offset Crankshaft?

To reduce side loads, some vehicle manufacturers offset the crankshaft from center. For example, if an engine rotates clockwise as viewed from the front, the crankshaft may be offset to the left to reduce the angle of the connecting rod during the power stroke. ● **SEE FIGURE 32–13**.

The offset usually varies from 1/16 to 1/2 inch, depending on make and model. Many inline 4-cylinder engines used in hybrid electric vehicles use an offset crankshaft.

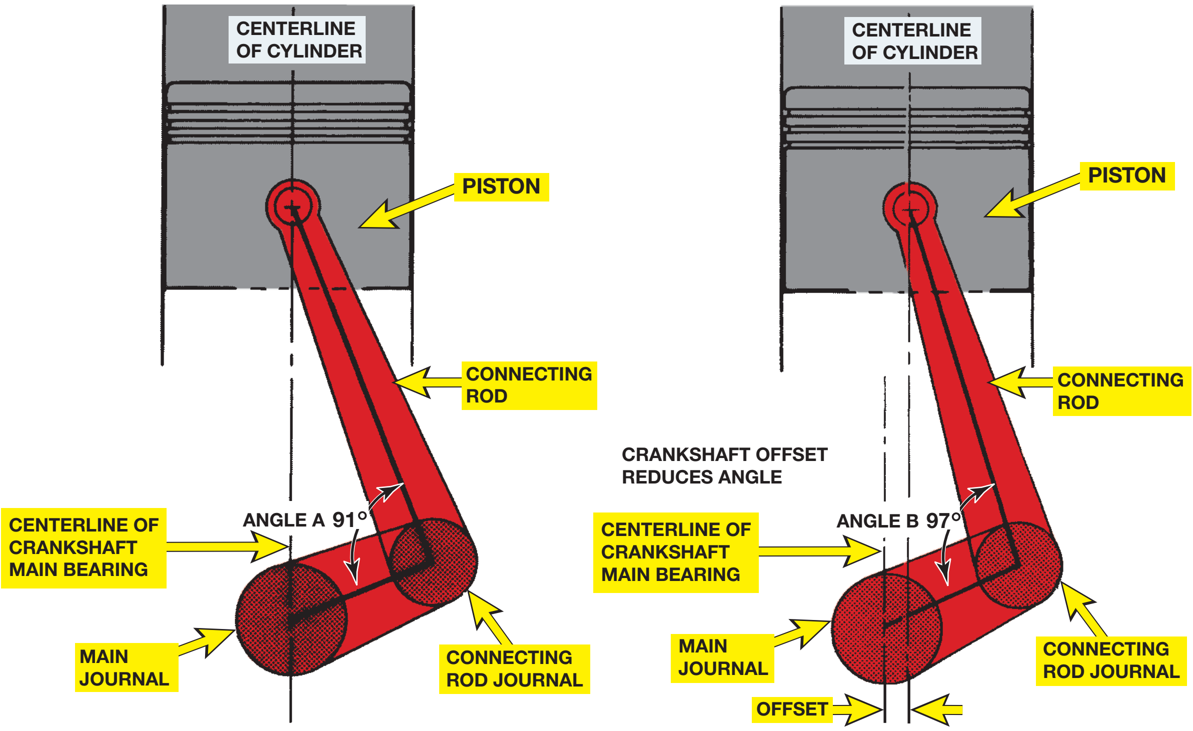

CENTERLINE
OF CYLINDER
PISTON
CONNECTING
ROD
CENTERLINE OF
CRANKSHAFT
MAIN BEARING
ANGLE A 91°
MAIN
JOURNAL
CONNECTING
ROD JOURNAL
CENTERLINE
OF CYLINDER
PISTON
CONNECTING
ROD
CRANKSHAFT OFFSET
REDUCES ANGLE
CENTERLINE OF
CRANKSHAFT
MAIN BEARING
ANGLE B 97°
MAIN
JOURNAL
CONNECTING
ROD JOURNAL
OFFSET

FIGURE 32–13 The crank throw is halfway down on the power stroke. The piston on the left without an offset crankshaft has a sharper angle than the engine on the right with an offset crankshaft.

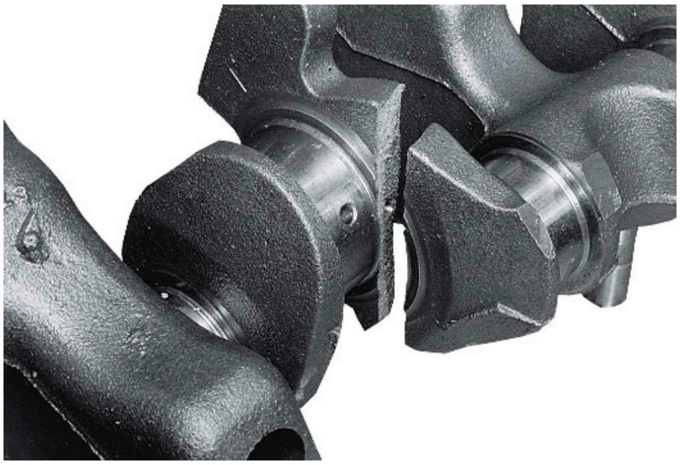


FIGURE 32–14 A crankshaft broken as a result of using the wrong torsional vibration damper.

This deflection occurs in two ways, to bend the shaft sideways and to twist the shaft in torsion. The crankshaft must be rigid enough to keep the deflection forces to a minimum.

Crankshaft deflections are directly related to the operating roughness of an engine. When back-and-forth deflections occur at the same vibration **frequency** (number of vibrations per second) as that of another engine part, the parts will vibrate together. When this happens, the parts are said to **resonate**. These vibrations may become great enough to reach the audible level, producing a thumping sound. If this type of vibration continues, the crankshaft may fail. ● **SEE FIGURE 32–14**.

Harmful crankshaft twisting vibrations are dampened with a torsional vibration damper. It is also called a harmonic balancer. This damper or balancer usually consists of a cast-iron **inertia ring** mounted to a cast-iron **hub** with an **elastomer** sleeve.

NOTE: Push on the rubber (elastomer sleeve) of the vibration damper with your fingers or a pencil. *If the rubber does not spring back, replace the damper.*

Elastomers are actually synthetic, rubberlike materials. The inertia ring size is selected to control the **amplitude** of the crankshaft vibrations for each specific engine model. ● **SEE FIGURE 32–15**.

EXTERNALLY AND INTERNALLY BALANCED ENGINES

DEFINITION Most crankshaft balancing is done during manufacture. Holes are drilled in the counterweight to lighten and improve balance. Sometimes these holes are drilled after the crankshaft is installed in the engine. Some manufacturers are able to control casting quality so closely that counterweight machining for balancing is not necessary.

Engine manufacturers balance an engine in one of two ways:

- **Externally balanced.** Weight is added to the harmonic balancer (vibration damper) and flywheel or the flexplate.
- **Internally balanced.** All rotating parts of the engine are individually balanced, including the harmonic balancer and flywheel (flexplate).

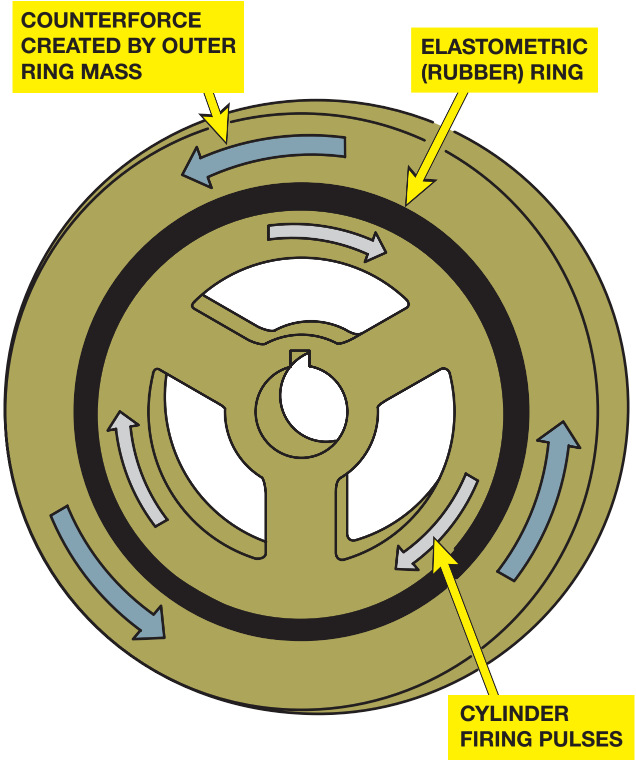

COUNTERFORCE CREATED BY OUTER RING MASS
ELASTOMETRIC (RUBBER) RING
CYLINDER FIRING PULSES

FIGURE 32–15 The hub of the harmonic balancer is attached to the front of the crankshaft. The elastomer (rubber) between the inertia ring and the center hub allows the absorption of crankshaft firing impulses.

For example, the 350 cu. inch Chevrolet V-8 is internally balanced, whereas the 400 cu. inch Chevrolet V-8 uses an externally balanced crankshaft. The harmonic balancer used on an externally balanced engine has additional weight.

FLAT-PLANE VS. CROSS-PLANE CRANKSHAFTS

CROSS-PLANE CRANKSHAFTS The cross-plane crankshaft is used in most every production V8 sold in America today. A cross-plane crankshaft has four crank journals with two connecting rods per journal arranged at 90-degree intervals. When viewing this type of crankshaft from either end, it looks like plus sign. Using the traditional V8 firing order of most OHV V8s, a cross-plane crankshaft will produce unevenly spaced firings within each side (cylinder bank) resulting in a balance between the two banks. A cross-plane crankshaft requires counterweights that are required to keep the engine properly balanced reducing vibration and provides smoother operation, but adds rotational mass. ● **SEE FIGURE 32–16**.

Advantages: Smooth, vibration-free performance; distinctive American muscle car exhaust sound

Disadvantages: Heavier and requires larger crankcase.

FLAT-PLANE CRANKSHAFTS The flat-plane crank is a type of crankshaft for use in internal combustion engines that have a 180-degree angle between crank throws. No matter the firing order, flat plane engines will always alternate back and forth

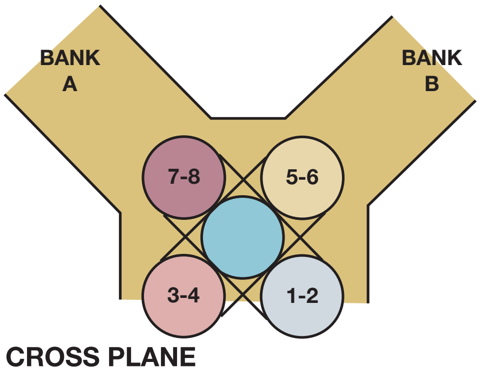


FIGURE 32–16 An end view of a typical cross-plane crankshaft that has four rod bearing journals spaced 90 degrees apart with two connecting rods attached to each throw.

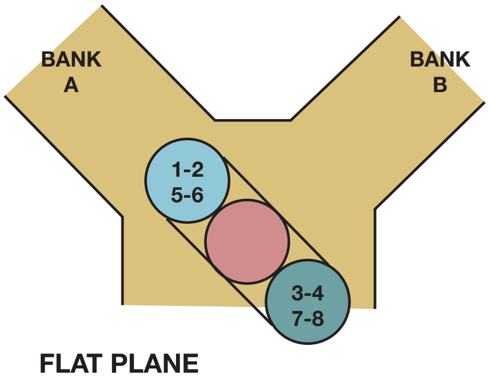


FIGURE 32–17 An end view of a typical flat-plane crankshaft that has four rod bearing journals spaced 180 degrees apart with two connecting rods attached to each throw.

between the two cylinder banks. This produces more efficient exhaust scavenging without the need to have header primaries cross over from one bank to the other. Another thing that differentiates a flat plane crankshaft from a cross-plane crank is the lack of massive counterweights. Without the additional mass of the counterweights, the lighter flat plane cranks will spin more easily than their cross-plane counterparts, making them more ideal for high-revving, high-rpm applications. The downside is flat-plane crankshafts tend to create more vibration within the engine without the help of counterweights. Flat plane crankshafts are typically found on race cars and high-end exotic cars because of their high-rpm performance. In most cases, race car drivers do not mind a little extra vibration in their engine, and exotic car companies will spend money on lighter-weight materials to reduce vibration in street-oriented cars. It also gives the Shelby GT350 a totally different sound from other American performance cars. ● **SEE FIGURE 32–17.**

Advantages: Lighter, more compact, more responsive (high-revving), better exhaust scavenging.

Disadvantages: Prone to vibration, lower torque levels.

ENGINE BALANCE

PRIMARY AND SECONDARY BALANCE Anything that rotates will vibrate. This means that an engine will vibrate during operation, although engine designers attempt to reduce the vibration as much as possible.

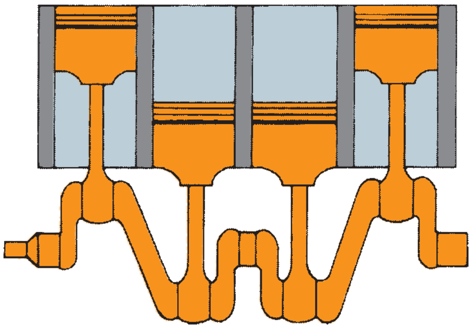


FIGURE 32–18 In a 4-cylinder engine, the two outside pistons move upward at the same time as the inner pistons move downward, which reduces primary unbalance.

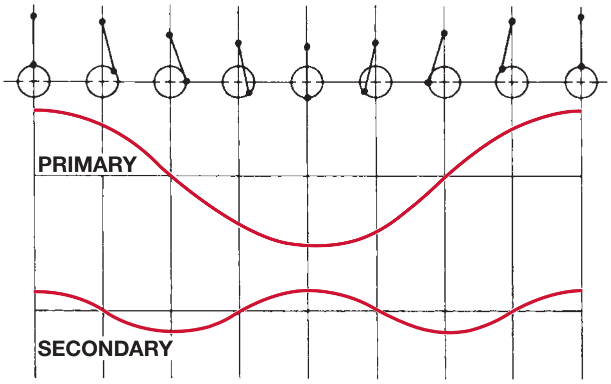


FIGURE 32–19 Primary and secondary vibrations in relation to piston position.

- **Primary balance.** When pistons move up and down in the cylinders, they create a **primary vibration**, which is a strong low-frequency vibration.

  A counterweight on the crankshaft opposite the piston/rod assembly helps reduce this vibration. An inline 4-cylinder engine has very little primary vibration because as two pistons are traveling upward in the cylinders, two are moving downward at the same time, effectively canceling out primary unbalances. ● **SEE FIGURE 32–18.**
- **Secondary balance.** Four-cylinder engines, however, suffer from a vibration at twice engine speed. This is called a **secondary vibration**, which is a weak high-frequency vibration caused by a slight difference in the inertia of the pistons at top dead center compared to bottom dead center. This vibration is most noticeable at high engine speeds, especially if the engine size is greater than 2 liters. The larger the displacement of the engine, the larger the bore and the heavier the pistons contribute to the buzzing-type secondary vibration. ● **SEE FIGURE 32–19.**

BALANCE SHAFTS

PURPOSE AND FUNCTION Some engines use balance shafts to dampen normal engine vibrations. *Dampening* is reducing the vibration to an acceptable level. A balance shaft that is turning at crankshaft speed, but in the opposite direction, is used on a 3-cylinder inline engine. Weights on the ends of the balance shaft move in a direction opposite to the direction of the end piston. When the piston goes up, the weight goes down, and when the piston goes down, the weight goes up. This reduces the end-to-end rocking action on the 3-cylinder inline engine.

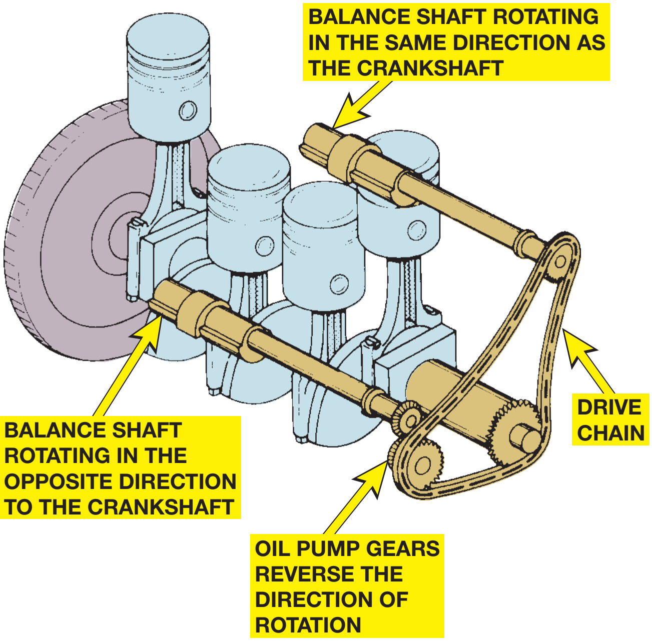

BALANCE SHAFT ROTATING IN THE SAME DIRECTION AS THE CRANKSHAFT
DRIVE CHAIN
BALANCE SHAFT ROTATING IN THE OPPOSITE DIRECTION TO THE CRANKSHAFT
OIL PUMP GEARS REVERSE THE DIRECTION OF ROTATION

FIGURE 32–20 Two counter-rotating balance shafts used to counter-balance the vibrations of a 4-cylinder engine.

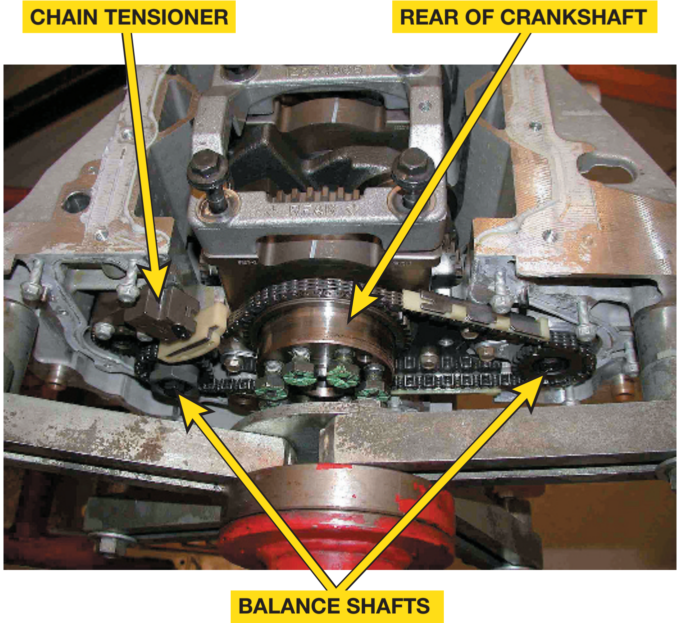

CHAIN TENSIONER
REAR OF CRANKSHAFT
BALANCE SHAFTS

FIGURE 32–21 This General Motors 4-cylinder engine uses two balance shafts driven by a chain at the rear of the crankshaft.

Another type of balance shaft system is designed to counter-balance vibrations on a four-stroke, 4-cylinder engine. Two shafts are used, and they turn at *twice* the engine speed. In most applications, both shafts rotate in the same direction and are driven by a chain or gear off the crankshaft. Counterweights on the balance shafts are positioned to oppose the natural rolling action of the engine, as well as the secondary vibrations caused by the piston and rod movements. ● **SEE FIGURE 32–20**.

BALANCE SHAFT APPLICATIONS Balance shafts are commonly found on the larger displacement (over 2 liters) 4-cylinder automotive engines.

- Most 4-cylinder engines larger than 2.2 liters use balance shafts. These are often located underneath the crankshaft. ● **SEE FIGURE 32–21**.
- Since the late 1980s, both Ford and General Motors added a balance shaft to many of their V-6 engines. These 90-degree V-6 engines use a split crank journal to create an even-firing arrangement, but these engines suffer from forces that cause the engine to rock back and forth. This motion is called a *rocking couple* and is dampened by the use of a balance shaft. ● **SEE FIGURE 32–22**.

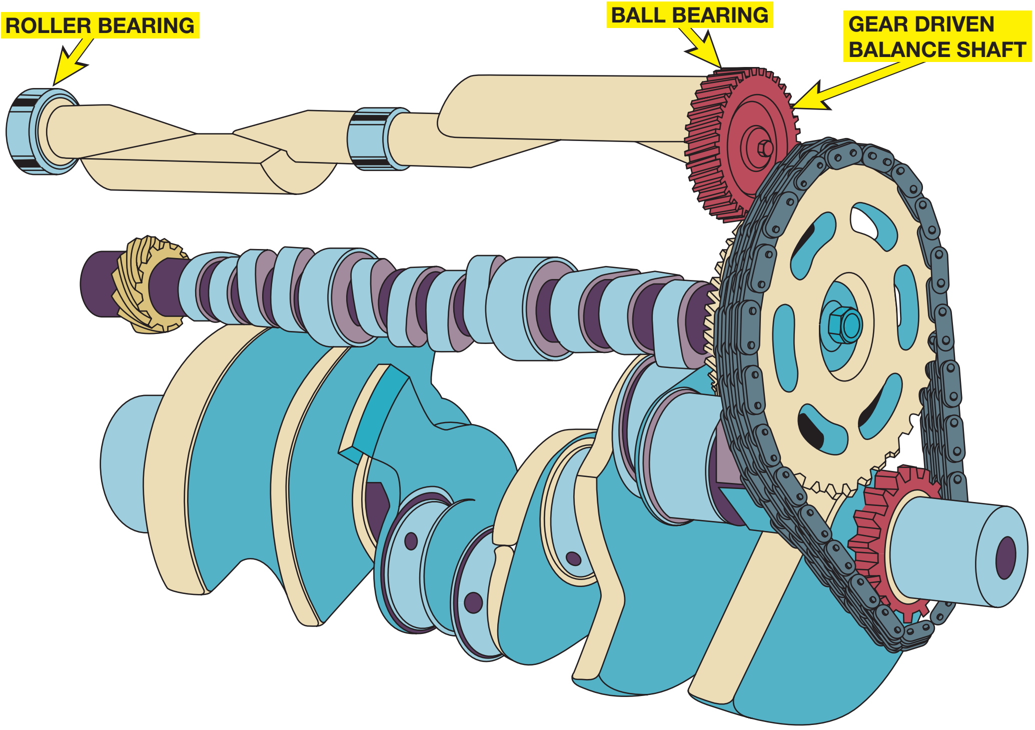

ROLLER BEARING
BALL BEARING
GEAR DRIVEN BALANCE SHAFT

FIGURE 32–22 Many 90-degree V-6 engines use a balance shaft to reduce vibrations and effectively cancel a rocking motion (rocking couple) that causes the engine to rock front to back.

The addition of balance shafts makes a big improvement in the smoothness of the engine. In V-6 engines, the improvement is most evident during idling and low-speed operation, whereas in the 4-cylinder engines, balance shafts are especially helpful at higher engine speeds. The V-6 engines that use a 60-degree design do not create a rocking couple and, therefore, do not need a balance shaft.

CRANKSHAFT SERVICE

CRANKSHAFT VISUAL INSPECTION Crankshaft damage includes the following:

- Worn journals
- Scored bearing journals
- Bends or warpage
- Cracks
- Thread damage (flywheel flange or front snout)
- Worn front or rear seal surfaces

Damaged shafts must be reconditioned or replaced. The crankshaft is one of the most highly stressed engine parts. *The stress on the crankshaft increases by four times every time the engine speed doubles.* Any sign of a crack is a cause to reject the crankshaft. Most cracks can be seen during a close visual inspection. Crankshafts should also be checked with Magnaflux, which will highlight tiny cracks that would lead to failure.

Bearing journal scoring is a common crankshaft defect. Scoring appears as scratches around the bearing journal surface. Generally, there is more scoring near the center of the bearing journal, as shown in ● **FIGURE 32–23**.

Crankshaft journals should be inspected for nicks, pits, or corrosion. Roughness and slight bends in journals can be corrected by grinding the journals.

NOTE: If your fingernail catches on a groove when rubbed across a bearing journal, the journal is too rough to reuse and must be reground. Another test is to rub a copper penny across the journal. If any copper remains on the crankshaft, it must be reground.

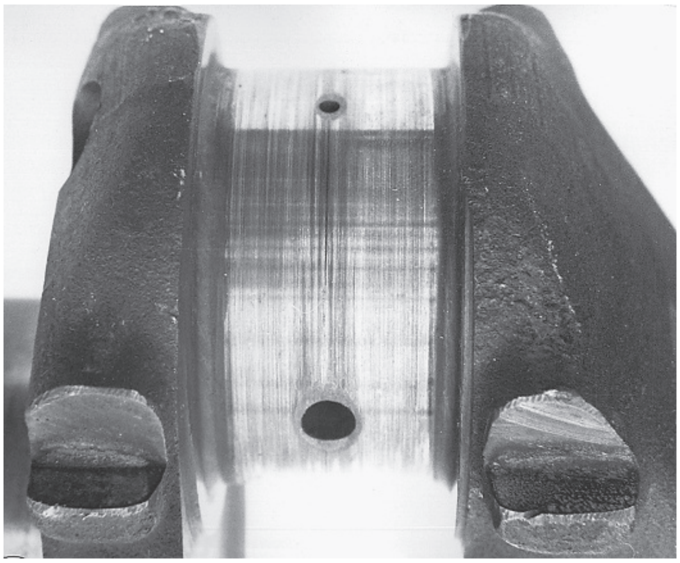


FIGURE 32–23 Scored connecting rod bearing journal.

MEASURING THE CRANKSHAFT Crankshafts should be carefully measured to determine the following:

- Size of main and rod bearing journals compared to factory specifications
- Each journal checked for out-of-round condition
- Each journal checked for taper

● **SEE FIGURES 32–24 AND 32–25.**

STORING CRANKSHAFTS All crankshafts should be coated with oil to keep them from rusting, and stored vertically until time for engine assembly. All crankshafts should be placed on the floor vertically to help prevent warping due to gravity. ● **SEE FIGURE 32–26.**

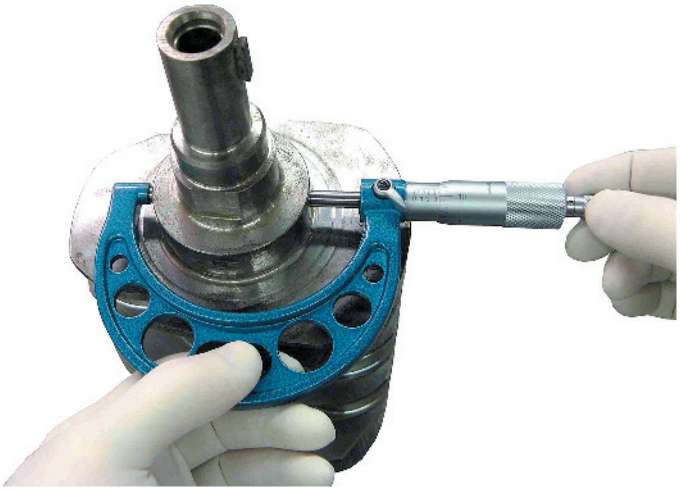


FIGURE 32–24 All crankshaft journals should be measured for diameter as well as taper and out-of-round.

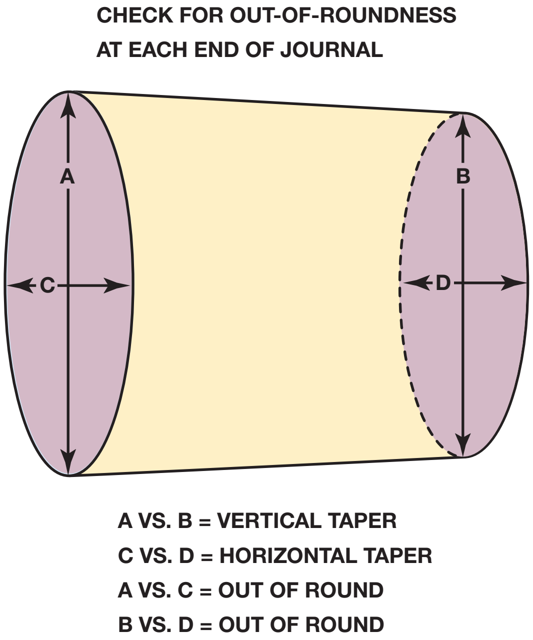


FIGURE 32–25 Check each journal for taper and out-of-round.

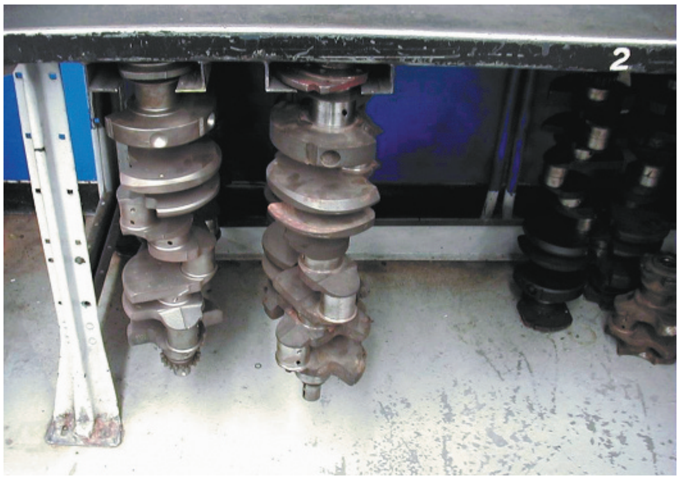


FIGURE 32–26 Crankshafts should be stored vertically to prevent possible damage or warpage. This clever bench-mounted tray for crankshafts not only provides a safe place to store crankshafts but is also out of the way and cannot be accidentally tipped.

ENGINE BEARINGS

INTRODUCTION Engine bearings are the main supports for the major moving parts of any engine. Engine bearings are important for the following reasons:

1. The clearance between the bearings and the crankshaft is a major factor in maintaining the proper oil pressure throughout the engine. Most engines are designed to provide the maximum protection and lubrication to the engine bearings above all else.
2. Engine durability relies on bearing life. Bearing failure usually results in immediate engine failure.
3. Engine bearings are designed to support the operating loads of the engine and, with the lubricant, provide minimum friction. This must be achieved at all designed engine speeds. The bearings must be able to operate for long periods of time, even when small foreign particles are in the lubricant.

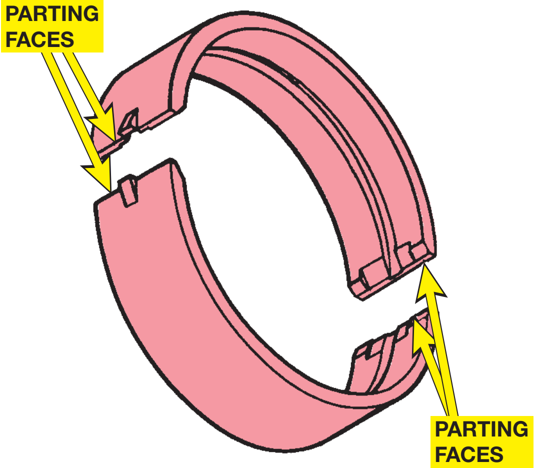


FIGURE 32–27 The two halves of a plain bearing meet at the parting faces.

TYPES OF BEARINGS Most engine bearings are one of the following two types:

- **Plain bearing**
- **Sleeve bearing**

● **SEE FIGURE 32–27.**

Most bearing halves, or shells, do not have uniform thickness. The wall thickness of most bearings is largest in the center, called the **bearing crown**. The bearing thickness then tapers to a thinner measurement at each parting line. ● **SEE FIGURE 32–28.**

The tapered wall keeps bearing clearances close at the top and bottom of the bearing, which are the more loaded areas and allow more oil flow at the sides of the bearing. Both need a constant flow of lubricating oil. In automotive engines, the lubricating system supplies oil to each bearing continuously when the engine

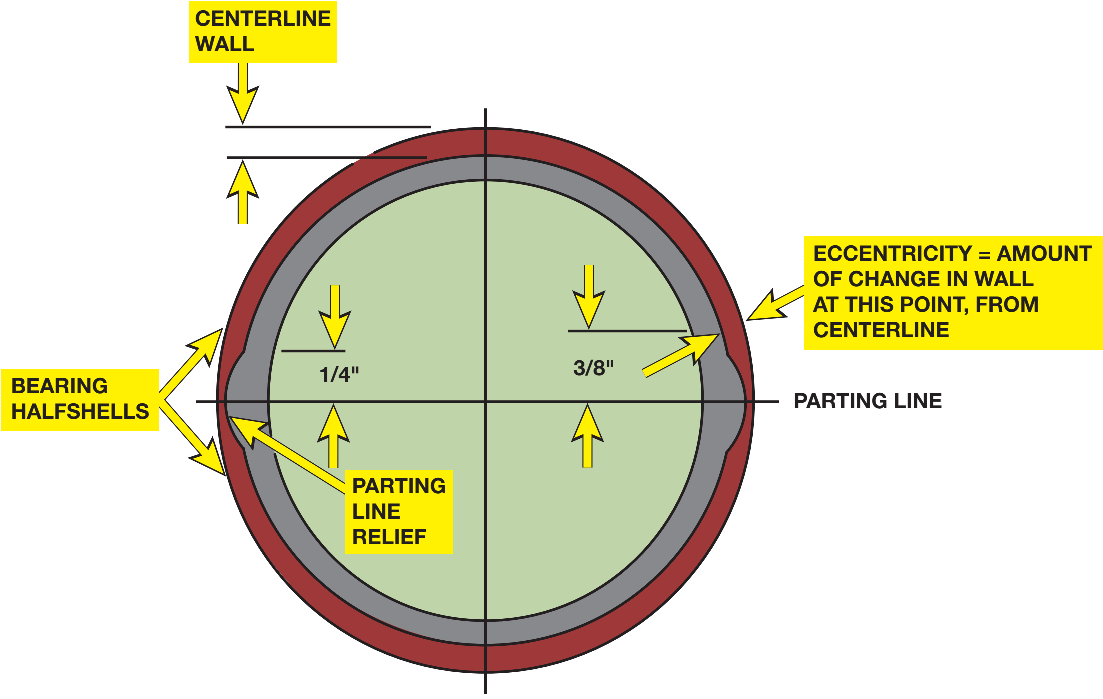


FIGURE 32–28 Bearing wall thickness is not the same from the center to the parting line. This is called *eccentricity* and is used to help create an oil wedge between the journal and the bearing.

runs. Bearings and journals *only* wear when the parts come in contact with each other or when foreign particles are present.

Oil enters the bearing through the oil holes and grooves. It spreads into a smooth wedge-shaped oil film that supports the bearing load.

BEARING MATERIALS

Three materials are used for automobile engine bearings:

- **Babbitt**
- **Copper-lead alloy**
- **Aluminum**

A layer of the bearing materials that is 0.01 to 0.02 inch (0.25 to 0.5 mm) thick is applied over a low carbon steel backing. An engine bearing is called a **bearing shell**, which is a steel backing with a surface coating of bearing material. The steel provides support needed for the shaft load. The bearing material meets the rest of the bearing operating requirements:

- **Babbitt.** Babbitt is the oldest automotive bearing material. Isaac Babbitt (1799–1862) first formulated this material in 1839. An excellent bearing material, it was originally made from a combination of lead, tin, and antimony. Lead and tin are alloyed with small quantities of copper and antimony to give it the required strength. Babbitt is still used in applications in which material is required for soft shafts running under moderate loads and speeds. It will work with occasional borderline lubrication and oil starvation without failure.
- **Trimetal.** Copper-lead alloy is a stronger and more expensive bearing material than babbitt. It is used for intermediate- and high-speed applications. Tin, in small quantities, is often alloyed with the copper-lead bearings. This bearing material is most easily damaged by corrosion from acid accumulation in the engine oil. Corrosion results in bearing journal wear as the bearing is eroded by the acids. Many of the copper-lead bearings have an **overlay**, or third layer, of metal. This overlay is usually of babbitt. Babbitt-overlayed bearings have high fatigue strength, good conformity, good embedability, and good corrosion resistance. The overplated bearing is a premium bearing. It is also the most expensive because the overplating layer, from 0.0005 to 0.001 inch (0.0125 to 0.025 mm) thick, is put on the bearing with an **electroplating** process. The layers of bearing material on a bearing shell are illustrated in ● **FIGURE 32–29**.
- **Aluminum.** Aluminum was the last of the three materials to be used for automotive bearings. Automotive bearing aluminum has small quantities of tin and silicone alloyed with it. This makes a stronger but more expensive bearing than either babbitt or copper-lead alloy. Most of its bearing characteristics are equal to or better than those of babbitt and copper lead. **Aluminum bearings** are well suited to high-speed, high-load conditions and do not contain lead, which is a benefit to the environment both at the manufacturing plant and for the technician who may be exposed to the bearings.

BEARING MANUFACTURING

Modern automotive engines use **precision insert-type bearing shells**, sometimes called **half-shell bearings**. The bearing is manufactured to very close tolerance so that it will fit correctly in each application. The bearing, therefore, must be made from precisely correct materials under closely controlled manufacturing conditions. ● **FIGURE 32–30** shows the typical bearing types found in most engines.

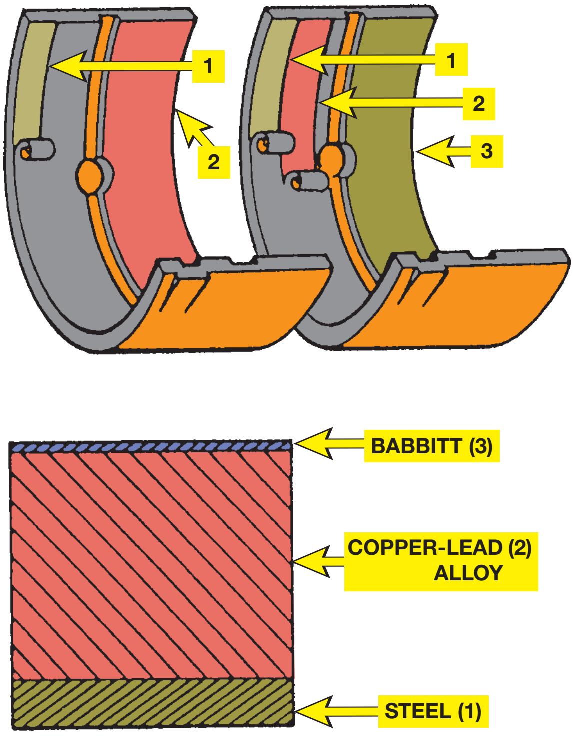


FIGURE 32–29 Typical two- and three-layer engine bearing inserts showing the relative thickness of the various materials.

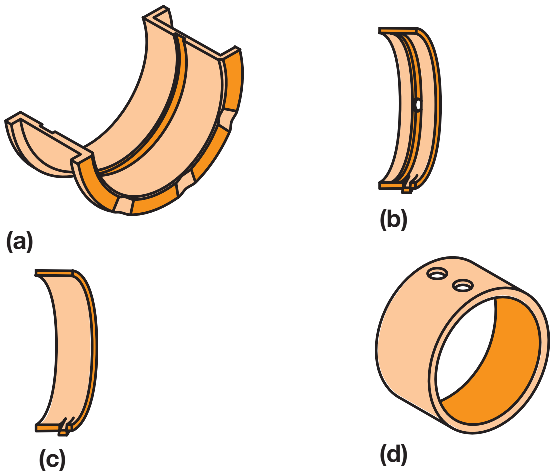


FIGURE 32–30 Typical bearing shell types found in modern engines: (a) half-shell thrust bearing, (b) upper main bearing insert, (c) lower main bearing insert, and (d) full round-type camshaft bearing.

BEARING SIZES

Bearings are usually available in standard (std.) size, and in measurements 0.010, 0.020, and 0.030 inch *undersize*. ● **SEE FIGURE 32–31**.

Even though the bearing itself is thicker for use on a machined crankshaft, the bearing is referred to as undersize because the crankshaft journals are undersize. Factory bearings may be available in 0.0005 or 0.001 inch undersize for precision fitting of a production crankshaft.

Before purchasing bearings, be sure to use a micrometer to measure *all* main and connecting rod journals. Replacement bearings are also available in 0.001, 0.002, and 0.003 inch, to

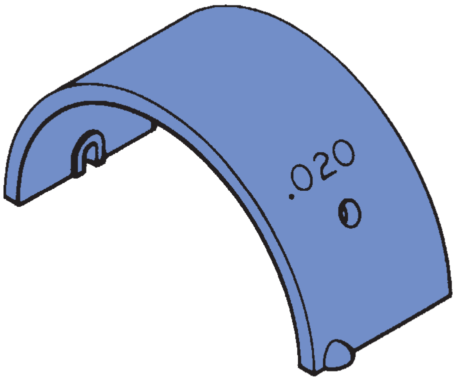


FIGURE 32–31 Bearings are often marked with an undersize dimension. This bearing is used on a crankshaft with a ground journal that is 0.020 inch smaller in diameter than the stock size.

allow the technician to achieve the proper bearing clearance without needing to machine the crankshaft.

BEARING LOADS The forces on the engine bearings vary with engine speed and load. On the intake stroke, the inertia force is opposed by the force of drawing in the air–fuel mixture. On the compression and power strokes, there is also an opposing force on the rod bearings. On the exhaust stroke, however, there is no opposing force to counteract the inertia force of the piston coming to a stop at TDC. The result is a higher force load on the *bottom* rod bearing due to inertia at TDC of the exhaust stroke. These forces tend to stretch the big end of the rod in the direction of rod movement.

1. As engine speed (RPM) increases, rod bearing loads decrease because of the balancing of inertia and opposing loads.
2. As engine speed (RPM) increases, the main bearing loads increase.

NOTE: This helps explain why engine blocks with four-bolt main bearing supports are only needed for high-engine speed stability.

3. Because the loads on bearings vary and affect both rod and main bearings, it is generally recommended that *all* engine bearings be replaced at one time.

BEARING FATIGUE Bearings tend to flex or bend slightly under changing loads. This is especially noticeable in reciprocating engine bearings. Bearing metals, like other metals, tend to fatigue and break after being flexed or bent a number of times. Flexing starts fatigue, which shows up as fine cracks in the bearing surface because the bearing material became **work hardened**. These cracks gradually deepen almost to the bond between the bearing metal and the backing metal. The cracks then cross over and intersect with each other. In time, this will allow a piece of bearing material to fall out. The length of time before fatigue will cause failure is called the **fatigue life** of the bearing. ● **SEE FIGURE 32–32**.

BEARING CONFORMABILITY The ability of bearing materials to creep or flow slightly to match shaft variations is called **conformability**. The bearing conforms to the shaft during the engine break-in period. In modern automobile engines, there is

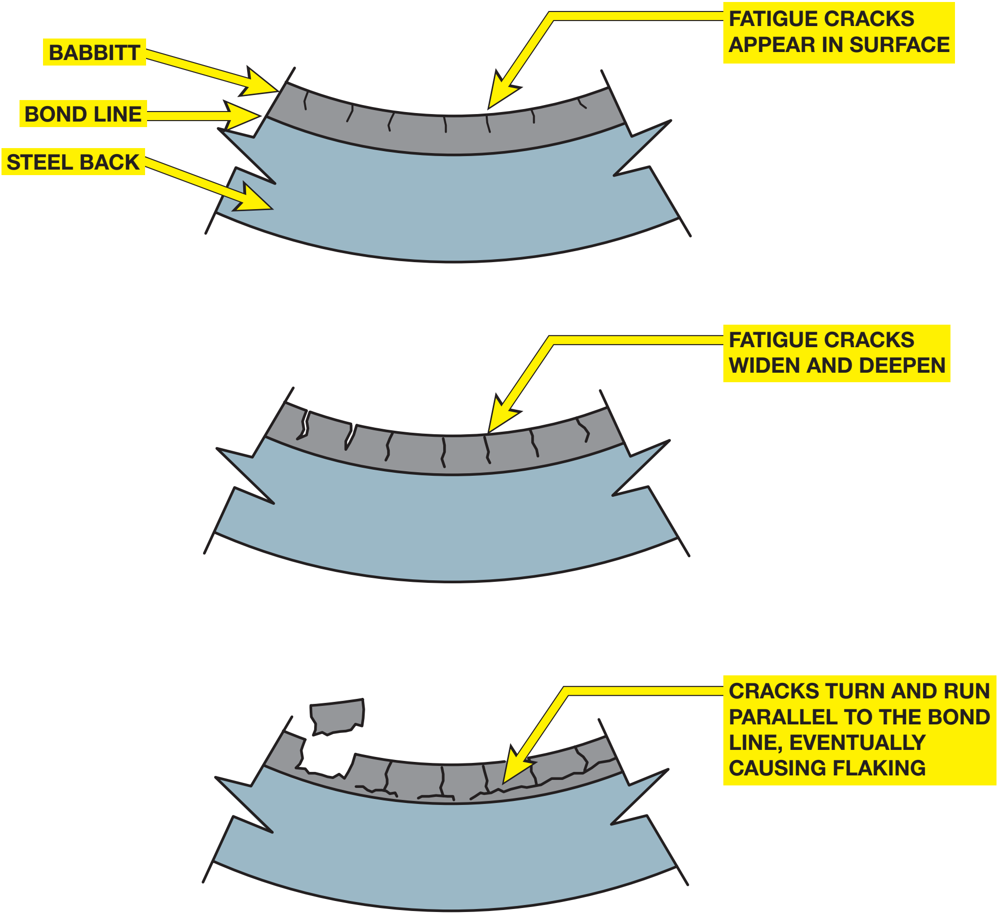

BABBITT
BOND LINE
STEEL BACK
FATIGUE CRACKS APPEAR IN SURFACE
FATIGUE CRACKS WIDEN AND DEEPEN
CRACKS TURN AND RUN PARALLEL TO THE BOND LINE, EVENTUALLY CAUSING FLAKING

FIGURE 32–32 Work-hardened bearing material becomes brittle and cracks, leading to bearing failure.

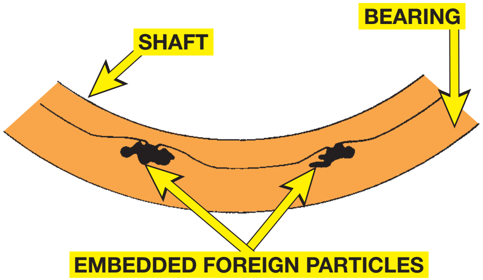


FIGURE 32–33 Bearing material covers foreign material (such as dirt) as it embeds into the bearing.

little need for bearing conformability or break-in, because automatic processing has achieved machining tolerances that keep the shaft very close to the designed size.

BEARING EMBEDABILITY

Engine manufacturers have designed engines to produce minimum crankcase deposits. This has been done by providing them with oil filters, air filters, and closed crankcase ventilation systems that minimize contaminants. Still, some foreign particles get into the bearings. The bearings must be capable of embedding these particles into the bearing surface so that they will not score the shaft. To fully embed the particle, the bearing material gradually works across the particle, completely covering it. The bearing property that allows it to do this is called **embedability**. ● **SEE FIGURE 32–33**.

BEARING DAMAGE RESISTANCE

Under some operating conditions, the bearing will be temporarily overloaded. This will cause the oil film to break down and allow the shaft metal to come in contact with the bearing metal. As the rotating crankshaft contacts the bearing high spots, the spots become hot from friction. The friction causes localized hot spots in the bearing material that seize or weld to the crankshaft. The crankshaft then breaks off particles of the bearing material and pulls the particles around with it, scratching or scoring the bearing surface.

Bearings have a characteristic called **score resistance**. It prevents the bearing materials from seizing to the shaft during oil film breakdown.

By-products of combustion form acids in the oil. The bearings' ability to resist attack from these acids is called **corrosion resistance**. Corrosion can occur over the entire surface of the bearing. This will remove material and increase the oil clearance. It can also leach or eat into the bearing material, dissolving some of the bearing material alloys. Either type of corrosion will reduce bearing life.

BEARING CLEARANCE

IMPORTANCE OF PROPER CLEARANCE

The bearing-to-journal clearance may be from 0.0005 to 0.0025 inch (0.025 to 0.06 mm), depending on the engine. Doubling the journal clearance will allow more than *four* times more oil to flow from the edges of the bearing. The oil clearance must be large enough to allow an oil film to build up, but small enough to prevent excess oil leakage, which would cause loss of oil pressure. A large amount of oil leakage at one of the bearings would starve other bearings farther along in the oil system. This would result in the failure of the oil-starved bearings.

CHECKING BEARING CLEARANCE

Bearing oil clearance can be checked in the following ways:

1. Using Plastigage® between the crankshaft journal and the bearing. The thin plastic-like strip material will deform depending on the clearance.
2. Measuring the crankshaft journal diameter and the inside diameter of the bearing as it is installed and subtracting the two measurements. The difference is the bearing clearance.

BEARING SPREAD AND CRUSH

The bearing design also includes bearing **spread** and **crush**. ● **SEE FIGURE 32–34**.

- **Bearing spread.** The bearing shell has a slightly larger arc than the bearing housing. This difference, called bearing spread, makes the shell 0.005 to 0.02 inch (0.125 to 0.5 mm) wider than the housing bore. Spread holds the bearing shell in the housing while the engine is being assembled.
- **Bearing crush.** When the bearing is installed, each end of the bearing shell is slightly above the parting surface. When the bearing cap is tightened, the ends of the two bearing shells touch and are forced together. This force is called bearing crush. Crush holds the bearing in place and keeps the bearing from turning when the engine runs. Crush must exert a force of at least 12,000 PSI (82,740 kPa) at 250°F (121°C) to hold the bearing securely in place. A stress of 40,000 PSI (275,790 kPa) is considered maximum to avoid damaging the bearing or housing. ● **SEE FIGURE 32–35**.

  Bearing shells that do not have enough crush may rotate with the shaft. The result is called a **spun bearing**. ● **SEE FIGURE 32–36**.
- **Bearing tang.** A *tang* or lip helps locate the bearing shell in the housing. When the bearing clearance and "crush" have been worn or destroyed, the bearing can "spin," thus

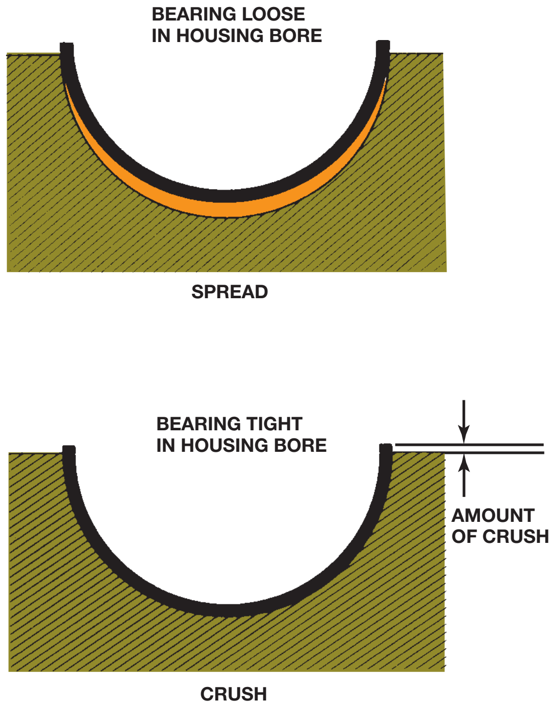


FIGURE 32–34 Bearing spread and crush.

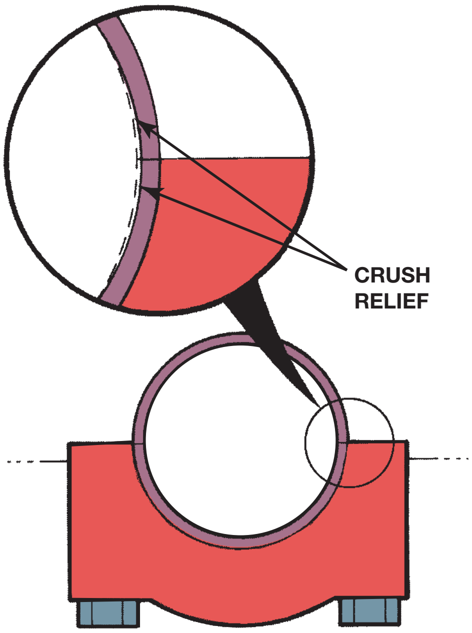


FIGURE 32–35 Bearings are thinner at the parting line faces to provide crush relief.

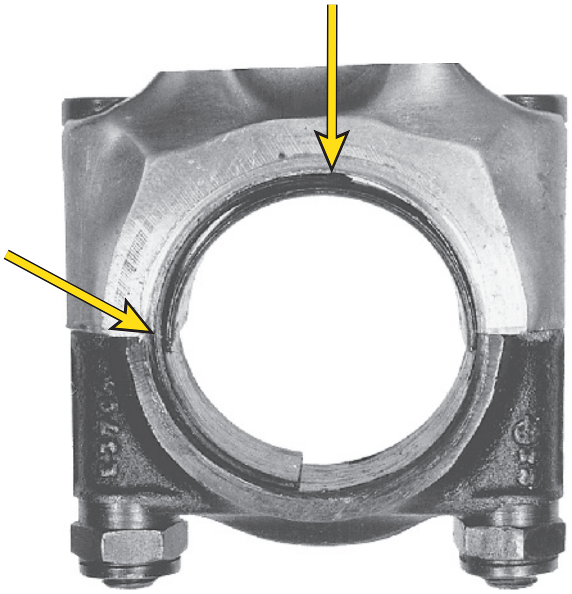


FIGURE 32–36 Spun bearing. The lower cap bearing has rotated under the upper rod bearing.

creating catastrophic failure. The tang often helps prevent this from occurring. ● **SEE FIGURE 32–37**.

Many newer engines do *not* use a tang on the bearing. Always check service information for the exact bearings and procedures to use for the engine being serviced.

Replacement bearings should be of a quality as good as or better than that of the original bearings. The replacement bearings must also have the same oil holes and grooves.

CAUTION: Some bearings may have oil holes in the top shell only. If these are installed incorrectly, no oil will flow to the connecting or main rods, resulting in instant engine failure. To help the oil spread across the entire bearing, some bearings use an oil groove. ● SEE FIGURE 32–38.

Modified engines have more demanding bearing requirements and therefore usually require a higher quality bearing to provide satisfactory service.

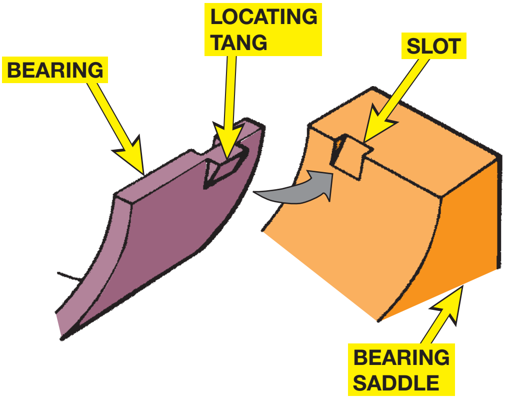


FIGURE 32–37 The tang (lug) and slot help index the bearing in the bore.

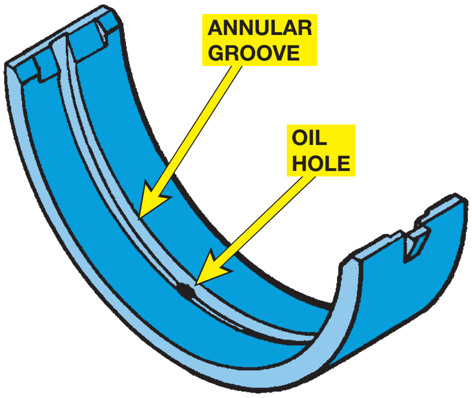


FIGURE 32–38 Many bearings are manufactured with a groove down the middle to improve the oil flow around the main journal.

FREQUENTLY ASKED QUESTION

What Keeps Engine Bearings without a Lug (Tab) from Spinning?

A bearing will spin out of position of friction between the bearing and the crankshaft surface is greater than the forces caused by the crush. Because today engines are assembled by robots, the lug (tab) is not used to simplify assembly. When fitting lug less bearings into a housing that used to use a lug-type bearing, the technician has to be sure that the bearing is centered and the oil hole aligned.

CAMSHAFT BEARINGS

TYPES OF CAMSHAFT BEARINGS The camshaft in pushrod engines rotates in sleeve bearings that are pressed into bearing bores within the engine block. Overhead camshaft bearings may be one of two sleeve-type bushings, depending on the design of the bearing supports.

- **Full round bearings**
- **Split-type (half-shell) bearings**

The split-type bearing has direct contact with aluminum saddles integral with the head, depending on the design of the

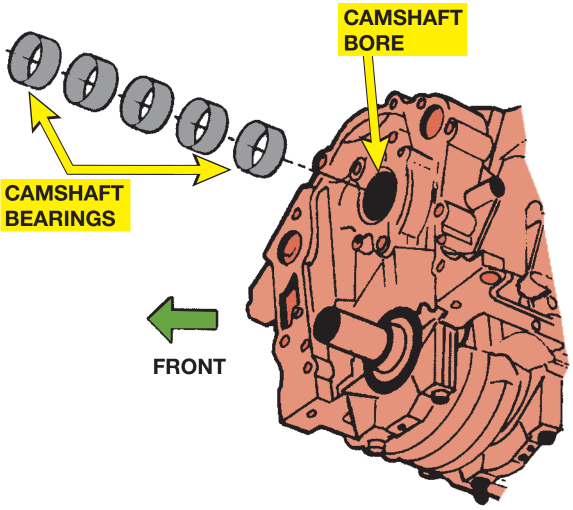


FIGURE 32–39 Cam-in-block engines support the camshaft with sleeve-type bearings.

bearing supports. The integral aluminum head bearing design often requires the replacement of the entire cylinder head in the event of bearing failure from lack of lubrication.

In pushrod engines, the cam bearings are installed in the block. ● **SEE FIGURE 32–39**.

CAMSHAFT BEARING INSTALLATION The best rule of thumb to follow is to replace the cam bearings whenever the main bearings are replaced. The replacement cam bearings must have the correct outside diameter to fit snugly in the cam bearing bores of the block. They must have the correct oil holes and be positioned correctly. ● **SEE FIGURE 32–40**.

Cam bearings must also have the proper inside diameter to fit the camshaft bearing journals. Details regarding cam bearings include the following:

- In many engines, each cam bearing is a different size. The largest is in the front and the smallest is in the rear.
- The cam bearing journal size must be checked and each bearing identified before assembly is begun.
- The location of each new cam bearing can be marked on the outside of the bearing with a felt-tip marker to help avoid mixing up bearings. Marking in this way will not affect the bearing size or damage the bearing in any way.
- Many vehicle manufacturers specify that the cam bearings should be installed "dry" (not oiled) to prevent the cam bearing from moving (spinning) after installation. If the cam bearing was oiled, the rotation of the camshaft could cause the cam bearing to rotate and block oil holes that lubricate the camshaft.
- Many aluminum cylinder heads have "integral" cam bearings that are not replaceable. The entire cylinder head may need to be replaced if a lubrication problem occurs to the cam bearings because the entire cylinder head may need to be replaced.

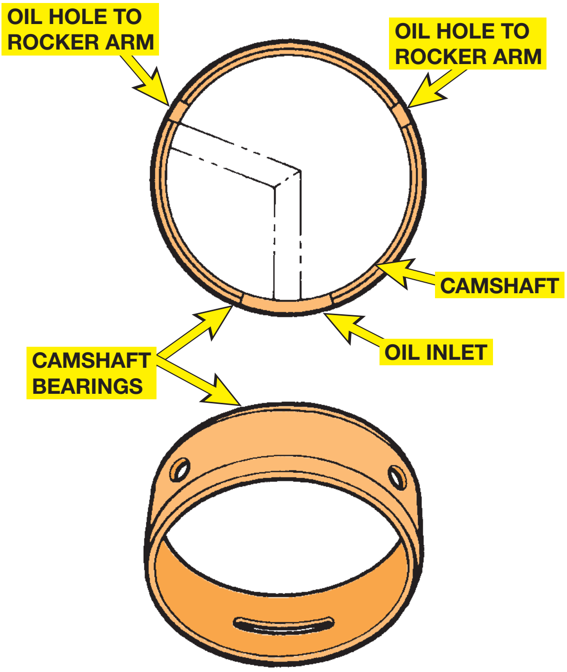


FIGURE 32–40 Camshaft bearings must be installed correctly so that oil passages are not blocked.

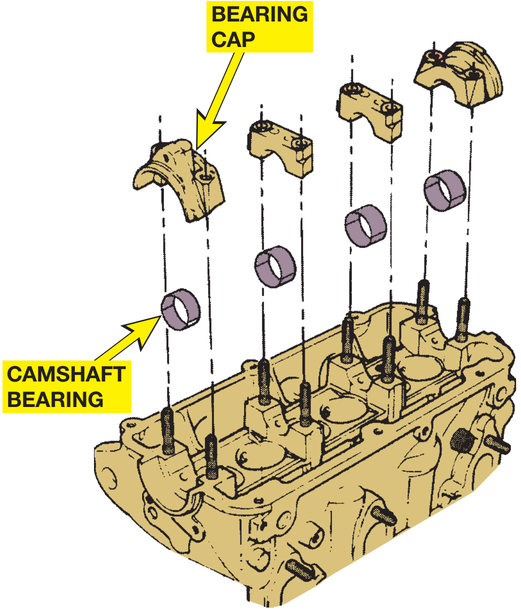


FIGURE 32–41 Some overhead camshaft engines use split bearing inserts.

- Camshaft bearings used on overhead camshaft engines may be either full round or split, depending on the engine design. ● **SEE FIGURE 32–41**.

Always follow the installation tool instructions when installing cam bearings.

REVIEW QUESTIONS

1. How many degrees of crankshaft rotation are there between cylinder firings on an inline 4-cylinder engine, an inline 6-cylinder engine, and a V-8 engine?
2. What are the types of engine bearing materials?
3. What is the difference between bearing crush and bearing spread?
4. Why is it important that crankshafts be stored vertically?
5. What are the two types of camshaft bearings?

CHAPTER QUIZ

1. A typical V-8 engine crankshaft has ____________ main bearings.
   a. three
   b. four
   c. five
   d. seven
2. A four-cylinder engine fires one cylinder at every __________ degrees of crankshaft rotation.
   a. 27
   b. 180
   c. 120
   d. 90
3. A crankshaft should be inspected for all of these EXCEPT ____________.
   a. cracks
   b. scored journals
   c. thread damage
   d. excessive weight
4. Which of the following is NOT true of a fully counterweighted crankshaft?
   a. It is the smoothest running type.
   b. It has the most durable design.
   c. It is the least expensive to manufacture.
   d. It is the heaviest type.
5. Which of the following causes primary vibrations in an engine?
   a. Harmonic balancer
   b. Pistons
   c. Flexplate
   d. Flywheel
6. A balance shaft used in a 90-degree V-6 engine is used to correct which of these types of force?
   a. Primary vibration
   b. Secondary vibration
   c. Rocking couple
   d. Rolling couple
7. A flat crankshaft is used in ____________.
   a. some high-performance vehicles
   b. most V-8 engines
   c. all in-line engines
   d. All of the above
8. Typical journal-to-bearing clearance is ____________.
   a. 0.00015 to 0.00018 inch
   b. 0.0005 to 0.0025 inch
   c. 0.15 to 0.25 inch
   d. 0.02 to 0.035 inch
9. Bearing ____________ occurs when a bearing shell is slightly above the parting surface of the bearing cap.
   a. overlap
   b. crush
   c. cap lock
   d. interference fit
10. In ____________ engines, the cam bearings are installed in the block.
    a. overhead cam
    b. rotary
    c. two-stroke
    d. pushrod

Chapter

33

GASKETS AND SEALANTS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the need for gaskets and sealants.
- Describe head gaskets and the types of head gaskets.
- Discuss cover gasket materials.
- Discuss gasket failures.
- Discuss the purpose and function of oil seals.
- Discuss the purpose and function of assembly sealants.

KEY TERMS:

Anaerobic sealers 376 • Armor 373 • Fire ring 373 • Formed in place gaskets (FIPG) 374 • Fretting 375 • Multilayered steel (MLS) gaskets 373 • No-retorque-type gaskets 372 • Room-temperature vulcanization (RTV) 376 • Rubber-coated metal (RCM) gaskets 374

PURPOSE AND FUNCTION

NEED FOR GASKETS AND SEALANTS Gaskets and sealants are used in engines to seal gaps and potential gaps between two or more parts. Gaskets and sealants must be able to withstand the following:

- Temperatures to which the engine part may be exposed during normal operation
- Vibrations produced in the engine and the accessories that are attached to the engine
- Acids and other chemicals that are found in and throughout an engine
- Expanding and contracting at different rates (They must be able to seal even though the two parts are expanding and contracting at different rates. This happens when the engine is started at low temperature all the way to normal operating temperature and it repeats this cycle every time the engine is operated.) ● **SEE FIGURE 33–1**.

HEAD GASKETS

REQUIREMENTS NEEDED The head gasket is under the highest clamping loads. It must seal passages that carry coolant and often is required to seal a passage that carries hot engine oil. The most demanding job of the head gasket is to seal the combustion chamber. As a rule of thumb, about 75% of the head bolt clamping force is used to seal the combustion chamber. The remaining 25% seals the coolant and oil passages. ● **SEE FIGURE 33–2**.

The gasket must seal when the temperature is as low as −40°F (−40°C) and as high as 400°F (204°C). The combustion pressures can get up to 1,000 PSI (6,900 kPa) on gasoline engines.

Cylinder head bolts are tightened to a specified torque, which stretches the bolt. The following forces are applied to a head gasket:

- The combustion pressure tries to push the head upward and the piston downward on the power stroke. This puts additional stress on the head bolts, and it reduces the

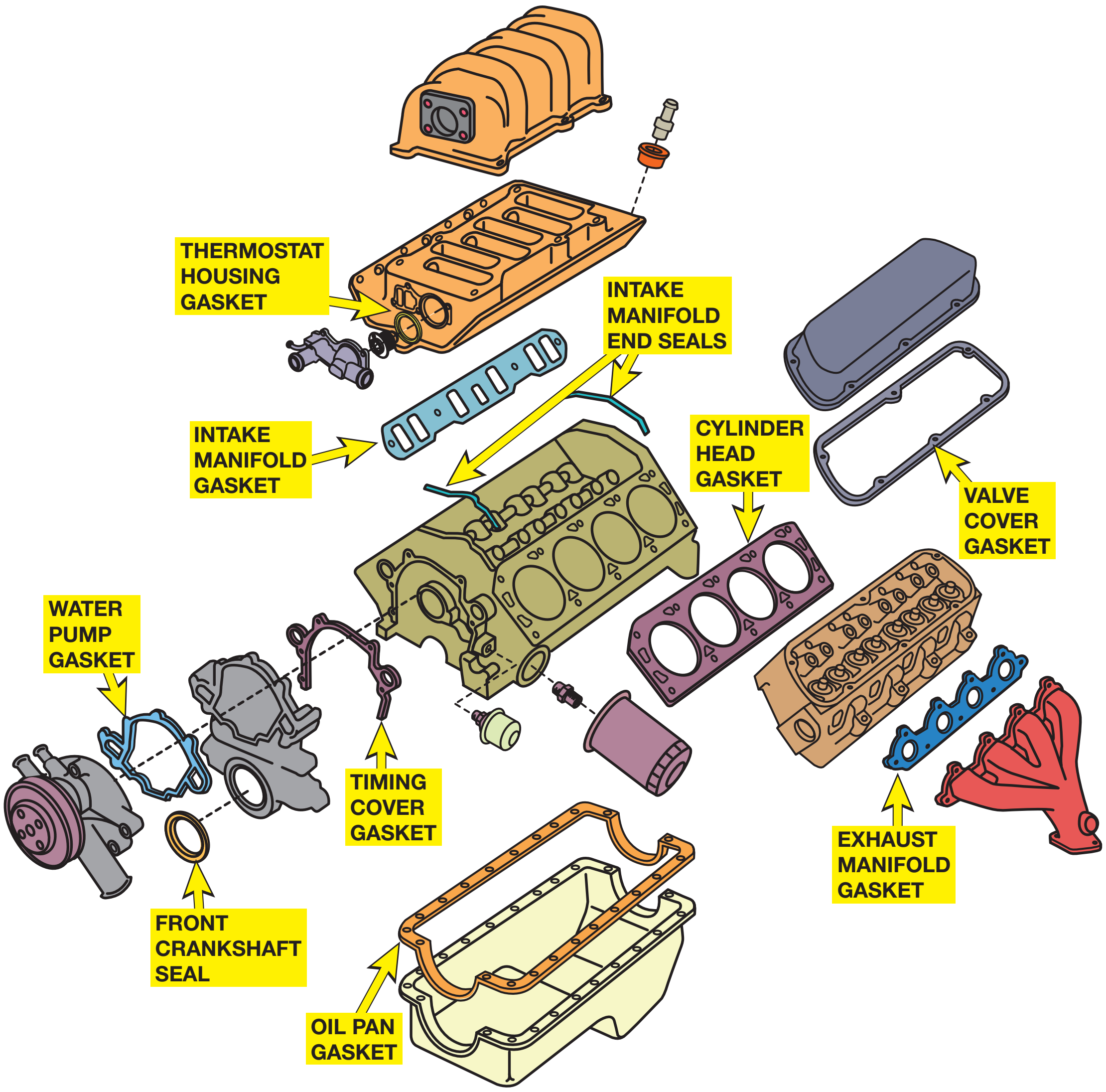

THERMOSTAT HOUSING GASKET
INTAKE MANIFOLD END SEALS
CYLINDER HEAD GASKET
INTAKE MANIFOLD GASKET
VALVE COVER GASKET
WATER PUMP GASKET
TIMING COVER GASKET
EXHAUST MANIFOLD GASKET
FRONT CRANKSHAFT SEAL
OIL PAN GASKET

FIGURE 33–1 Gaskets are used in many locations in the engine.

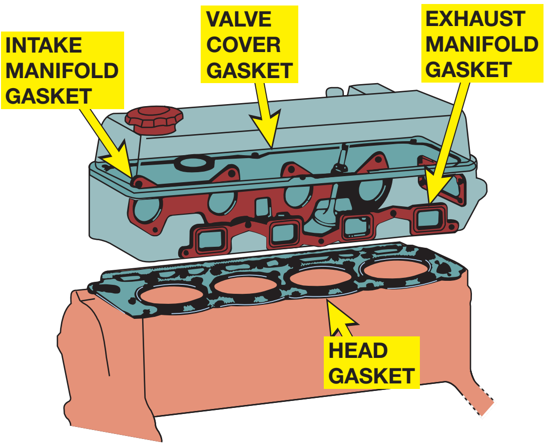

INTAKE MANIFOLD GASKET
VALVE COVER GASKET
EXHAUST MANIFOLD GASKET
HEAD GASKET

FIGURE 33–2 Gaskets help prevent leaks between two surfaces.

clamping load on the head gasket, just when the greatest seal is needed.

- A partial vacuum during the intake stroke tries to pull the head down against the gasket.
- As the crankshaft rotates, the force on the head changes from pressure on the combustion stroke to vacuum on the intake stroke, then back to pressure.

Newer engines have lightweight thin-wall castings. The castings are quite flexible, so that they move as the pressure in the combustion chamber changes from high pressure to vacuum. The gasket must be able to compress and recover fast enough to maintain a seal as the pressure in the combustion chamber changes back and forth between pressure and vacuum. As a result, head gaskets are made of several different materials that are assembled in numerous ways, depending on the engine.

NOTE: Older head gasket designs often contained asbestos and required that the head bolts be retorqued after the engine had been run to operating temperature. Head gaskets today are dense and do not compress like those older-style gaskets. Therefore, most head gaskets are called no-retorque-type gaskets, meaning the cylinder head bolts do not have to be retorqued after the engine has run. New gaskets do not contain asbestos.

TYPES OF HEAD GASKETS

- **Perforated steel core gaskets.** A perforated steel core gasket uses a wire mesh core with fiber facings. Another design has rubber-fiber facings cemented to a solid steel core with an adhesive. ● **SEE FIGURES 33–3 AND 33–4**.

  The thickness of the gasket is controlled by the thickness of the metal core. The facing is thick enough to compensate for minor warpage and surface defects. The fiber

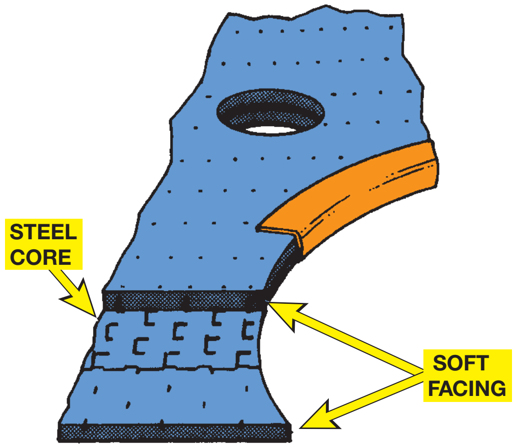


FIGURE 33–3 A typical perforated steel core head gasket with a graphite or composite facing material.

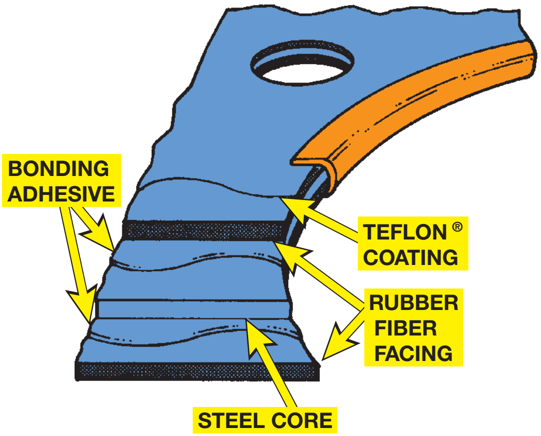


FIGURE 33–4 A solid steel core head gasket with a nonstick coating, which allows some movement between the block and the head, and is especially important on engines that use cast-iron blocks with aluminum cylinder heads.

TECH TIP

Wow! I Can't Believe a Cylinder Can Deform That Much!

An automotive instructor used a dial bore gauge in a 4-cylinder, cast-iron engine block to show students how much a block can deform. Using just one hand, the instructor was able to grasp both sides of the block and then squeeze it. The dial bore gauge showed that the cylinder deflected about 0.0003 inch (3/10,000 of an inch) just by squeezing the block with one hand—and that was with a cast-iron block!

After this demonstration, the students were more careful during engine assembly and always used a torque wrench on each and every fastener that was installed in or on the engine block.

facing is protected around the combustion chamber with a metal **armor** (also called a **fire ring**). ● **SEE FIGURE 33–5**.

The metal also increases the gasket thickness around the cylinder so that it uses up to 75% of the clamping force and forms a tight combustion seal.

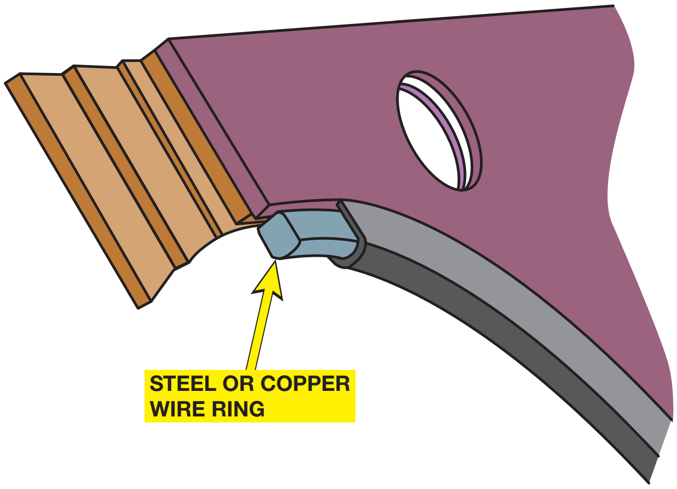


FIGURE 33–5 The armor ring can be made from steel or copper.

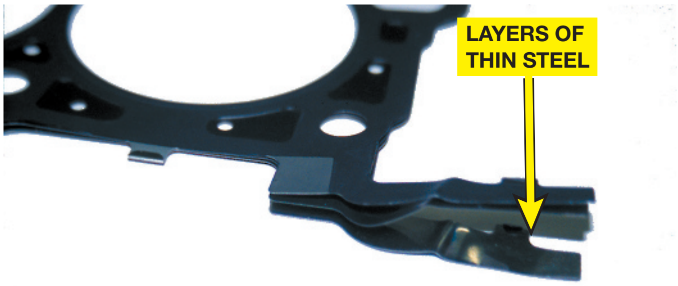


FIGURE 33–6 Multilayer steel (MLS) gaskets are used on many newer all-aluminum engines, as well as on engines that use a cast block with aluminum cylinder heads. This type of gasket allows the aluminum to expand without losing the sealing ability of the gasket.

- **Multilayered steel gaskets.** The **multilayered steel (MLS) gaskets** are constructed in the following manner:
  - Three to five layers of stainless steel sheet are separated by elastomer (rubber) material.
  - The elastomer material is between the layers of the sheet metal and on both surfaces.
  - The multiple layers of metal provide a springlike effect to the gasket, which allows it to keep the combustion chamber sealed.

  The many layers of thin steel reduce bore and overhead camshaft distortion with less clamping force loss than previous designs. ● **SEE FIGURE 33–6**.

  The use of multilayered steel gaskets also reduces the torque requirement and, therefore, reduces the stresses on the fastener and engine block. MLS gaskets are used in most engines that use aluminum cylinder heads and cast iron blocks. The use of MLS head gaskets requires that both the head and the block deck surface have a smooth surface finish of 15 to 30 microinches. This smooth surface finish allows the head to move slightly during operation and not damage the gasket.

COVER GASKET MATERIALS

COVER GASKET REQUIREMENTS Cover gaskets are used to seal valve covers, oil pans, timing chain, and other covers. The gasket must be *impermeable* to the fluids it is designed to seal in or out. The gasket must *conform* to the shape of the surface, and it must be *resilient,* or elastic, to maintain the sealing force as it is compressed. Gaskets work best when they are compressed about 30%.

CORK GASKETS Older engines often used gaskets made from cork. Cork is the bark from a Mediterranean cork oak tree. It is made of very small, flexible, 14-sided, air-filled fiber cells, about 0.001 inch (0.025 mm) in size. Disadvantages of cork gaskets include the following:

- Because cork is mostly wood, it expands when it gets wet and shrinks when it dries. This causes cork gaskets to change in size when they are in storage and while installed in the engine.
- Oil gradually wicks through the organic binder of the cork, so a cork gasket often looks like it is leaking.
- Problems with cork gaskets led the gasket industry to develop cork cover gaskets using synthetic rubber as a binder for the cork. This type of gasket is called a *cork-rubber gasket.* These cork-rubber gaskets are easy to use, and they outlast the old cork gaskets.

FIBER GASKETS Some oil pans use fiber gaskets. Covers with higher clamping forces use gaskets with fibers that have greater density. For example, timing covers may have either fiber or paper gaskets.

SYNTHETIC RUBBER GASKETS Molded, oil-resistant synthetic rubber is being used in more applications to seal covers. When it is compounded correctly, it forms a superior cover gasket. It operates at high temperatures for a longer period of time than does a cork-rubber cover gasket. ● **SEE FIGURE 33–7**.

RUBBER-COATED METAL GASKETS The **rubber-coated metal (RCM) gasket** uses a metal core to give strength to the gasket. The metal is coated with a layer on both sides with silicone rubber and molded in sealing beads. RCM gaskets are used in many places, including

- Water pump gaskets
- Valve cover gaskets

Oil pan gaskets

● **SEE FIGURE 33–8**.

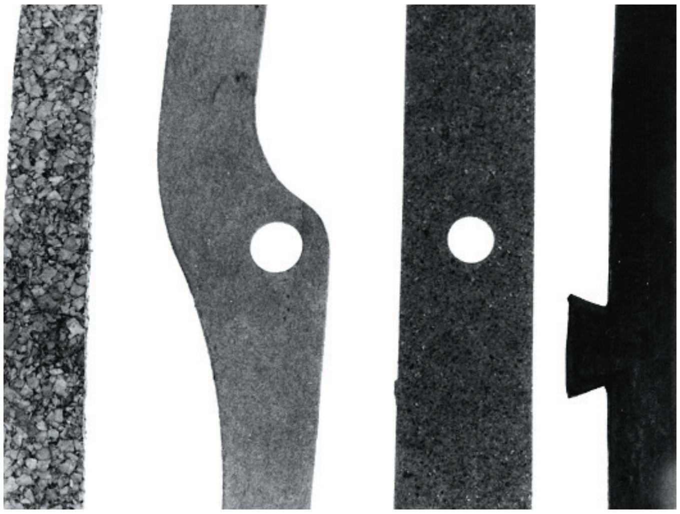


FIGURE 33–7 Left to right: cork-rubber, paper, composite, and synthetic rubber (elastomer) gaskets.

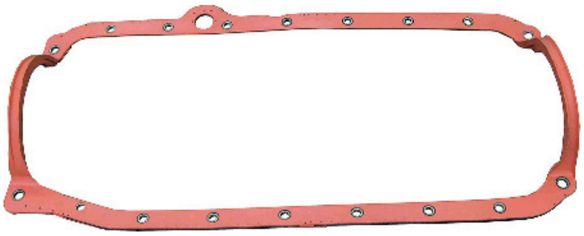


FIGURE 33–8 Rubber-coated steel gaskets have replaced many oil pan gaskets that once had separate side rail gaskets and end seals.

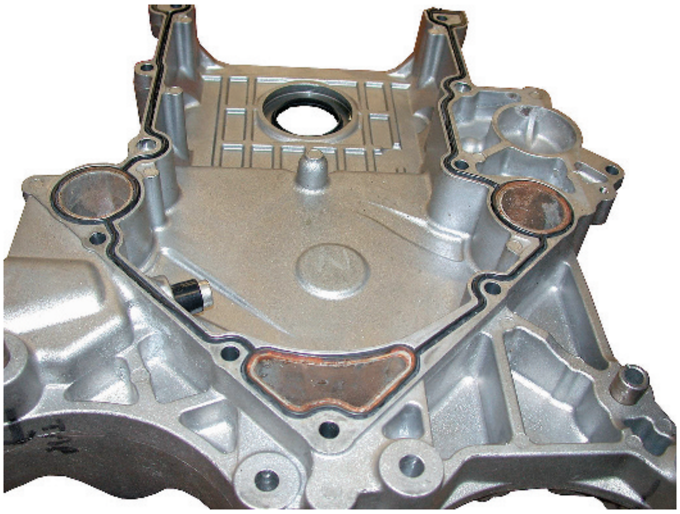


FIGURE 33–9 Formed in place gaskets often use silicone rubber and are applied at the factory using a robot. Check gasket manufacturers for the correct gasket replacement.

FORMED IN PLACE GASKETS **Formed in place gaskets (FIPG)** are commonly used because they can be applied at the engine plant using a robot. The sealing material is extruded and placed onto the sealing surface, the two parts being sealed are placed together, and the fasteners tightened. When FIPG are being replaced during an engine repair or overhaul, check service information for the exact gasket material to use. ● **SEE FIGURE 33–9**.

PLASTIC/RUBBER GASKETS Most intake manifold gaskets use a nylon (usually nylon 6.6) reinforced body with silicone rubber sealing surfaces.

The nylon is used for two reasons:

1. It provides a thermal barrier to help stop the heat from the cylinder heads to flow to the intake manifold. This helps keep the intake air cooler, resulting in increased engine power.
2. The nylon plastic is strong and provides a stable foundation for the silicone rubber seal.

● **SEE FIGURE 33–10**.

GASKET FAILURES

CAUSES OF GASKET FAILURE Gaskets can fail to seal properly, but the root cause is often a severe condition. A head gasket can fail for the following reasons:

- Detonation (spark knock or ping) may cause extreme pressure to be exerted on the armor of the head gasket, causing it to deform.

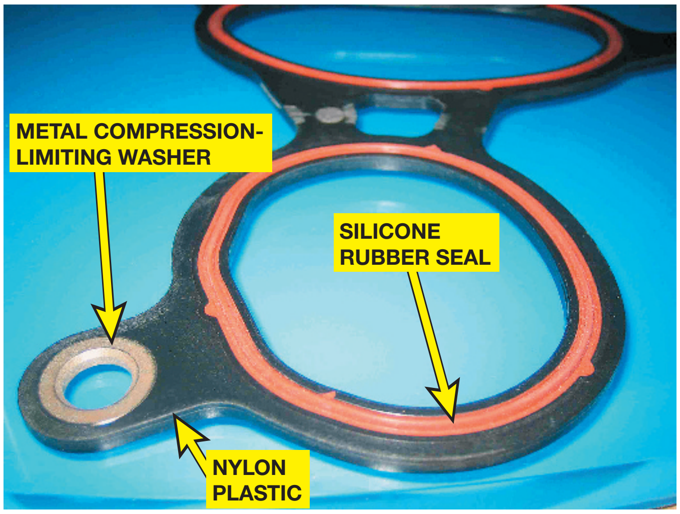


FIGURE 33–10 A typical intake manifold gasket showing the metal washer at each fastener location, which keeps the gasket from being compressed too much.

TECH TIP

Rubber and Contact Cement

One of the reasons why gaskets fail is due to their movement during installation. Some gaskets, such as cork or rubber valve cover gaskets or oil pan gaskets, can be held onto the cover using a rubber or contact cement.

To use a rubber or contact cement, use the following steps:

STEP 1 Apply a thin layer to one side of the gasket and to the cover where the gasket will be placed.

STEP 2 Allow the surfaces to air dry until touch free.

STEP 3 Carefully place the gaskets onto the cover, being sure to align all of the holes.

CAUTION: Do not attempt to remove the gasket and reposition it. The glue is strong and the gasket will be damaged if removed. If the gasket has been incorrectly installed, remove the entire gasket, clean the gasket surface, and repeat the installation using a new gasket.

- A plugged PCV system can increase crankcase pressure, resulting in engine gasket failures, such as oil pan, valve cover, timing cover, and main oil seals.
- Improper installation, such as incorrect torquing sequence, can cause gasket failure.

FRETTING **Fretting** is a condition that can destroy intake manifold gaskets, caused by the unequal expansion and contraction of two different engine materials. For example, if the intake manifold is constructed of aluminum and the cylinder heads are cast iron, the intake manifold expands more than the cylinder heads. This causes a shearing effect, which can destroy the gasket. Therefore, before assembling an engine, check for the latest design gaskets that are often different from the type originally used in the engine. ● **SEE FIGURE 33–11**.

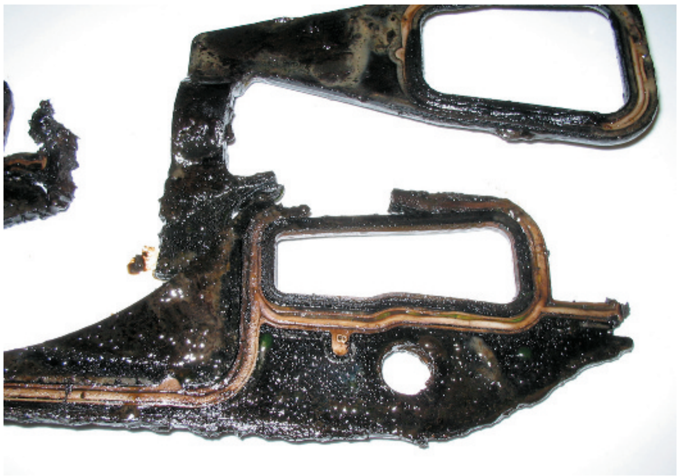


FIGURE 33–11 This intake manifold gasket was damaged due to fretting. Newer designs allow for more movement between the intake manifold and the cylinder head.

OIL SEALS

PURPOSE AND FUNCTION Oil seals allow the shaft to rotate and seal the area around the shaft to prevent oil or coolant from leaking. Seals come in varied sizes and styles.

SEAL MATERIALS Most seals use a steel backing for strength and a variety of sealing materials, including

- Buna-N
- Viton® (fluorocarbon)
- Teflon® (polytetrafluorethylene, also called PTFE)

● **SEE FIGURE 33–12**.

CAUTION: Do not use oil on a Teflon® seal because this type of seal requires that some of the material be transferred to the rotating shaft to seal properly. If oil is used on the seal, the seal will leak.

TECH TIP

Hints for Gasket Usage

1. **Never reuse an old gasket.** A used gasket or seal has already been compressed, has lost some of its resilience, and has taken a set. If a used gasket does reseal, it will not seal as well as a new gasket or seal.
2. **A gasket should be checked to make sure it is the correct gasket.** Also check the list on the outside of the gasket set to make sure that the set has all the gaskets that may be needed *before* the package is opened.
3. **Read the instruction sheet.** An instruction sheet is included with most gaskets. It includes a review of the things the technician should do to prepare and install the gaskets, to give the best chance of a good seal. The instruction sheet also includes special tips on how to seal spots that are difficult to seal or that require special care to seal on a particular engine.

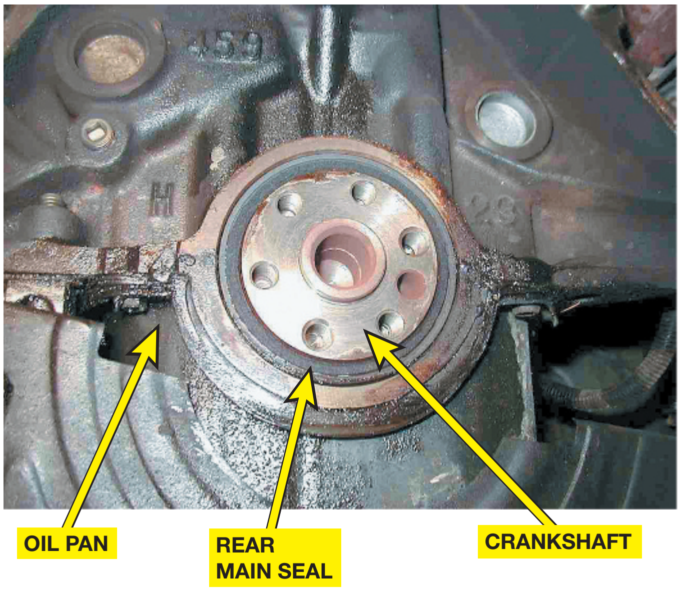


FIGURE 33–12 A rear main seal has to be designed to seal oil from leaking around the crankshaft under all temperature conditions.

TECH TIP

Always Check the VIN

There are so many variations in engines that it is important that the correct gasket or seal be used. For example, a similar engine may be used in a front-wheel-drive or a rear-wheel-drive application, and this could affect the type or style of gasket or seal used. For best results, the wise technician should know the vehicle identification number (VIN) when ordering any engine part.

ASSEMBLY SEALANTS

RTV SILICONE RTV silicone is used by most technicians in sealing engines. **RTV**, or **room-temperature vulcanization,** means that the silicone rubber material cures at room temperature. It is not really the temperature that causes RTV silicone to cure, but the moisture in the air. RTV silicone cures to a tack-free state in about 45 minutes. It takes 24 hours to fully cure.

RTV silicone is available in several different colors. The color identifies the special blend within a manufacturer's product line. Equal grades of silicone made by different manufacturers may have different colors. RTV silicone can be used in two ways in engine sealing:

1. It can be used as a gasket substitute between a stamped cover and a cast surface.
2. It is used to fill gaps or potential gaps. A joint between gaskets or between a gasket and a seal is a potential gap.

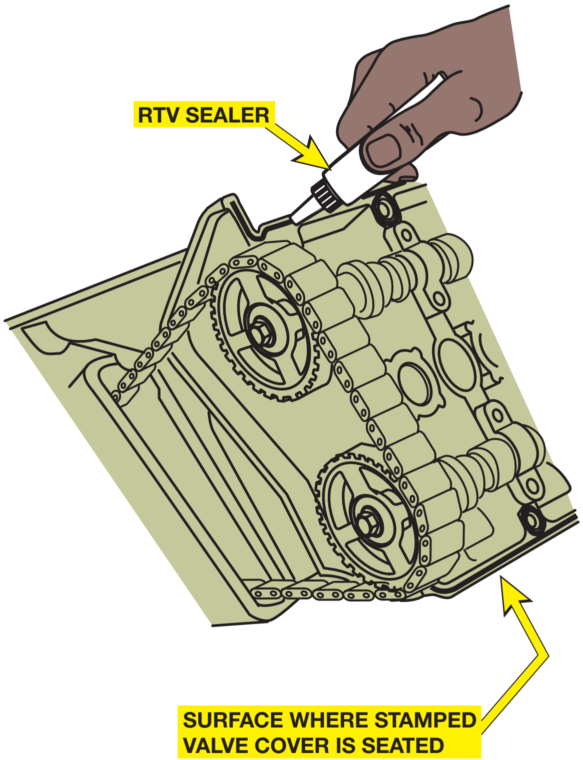


FIGURE 33–13 Room-temperature vulcanization (RTV) is designed to be a gasket substitute on nonmachined surfaces. Be sure to follow the instructions as printed on the tube for best results.

RTV precautions include

1. Some RTV silicone sealers use *acetic acid,* and the fumes from this type can be drawn through the engine through the PCV system and cause damage to oxygen sensors. Always use an *amine-type* RTV silicone or one that states on the package that it is safe for oxygen sensors.
2. RTV should not be used with a gasket as a sealer because it is slippery and could easily cause the gasket to move out of proper location.
3. RTV silicone should *never* be used around fuel because fuel cuts through it. Silicone should not be used as a sealer on gaskets. It squeezes out to leave a bead inside and a bead outside the flange. The inside bead might fall into the engine, plugging passages and causing engine damage. The thin film still remaining on the gasket stays uncured, just as it would be in the original tube. The uncured silicone is likely to let the gasket or seal slip out of place. ● **SEE FIGURE 33–13**.

ANAEROBIC SEALERS **Anaerobic sealers** cure in the absence of air. They are used as thread lockers (such as Loctite®), and they are used to seal rigid machined joints between cast parts. Anaerobic sealers lose their sealing ability at temperatures above 300°F (149°C). On production lines, the curing process is speeded up by using ultraviolet light.

When the anaerobic sealer is used on threads, air does not get to it, so it hardens to form a seal to prevent the fastener from loosening. Anaerobic sealers can be used to seal machined

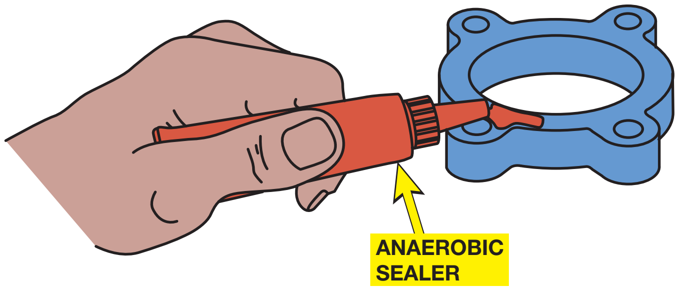


FIGURE 33–14 Anaerobic sealer is used to seal machined surfaces. Always follow the instructions on the tube for best results.

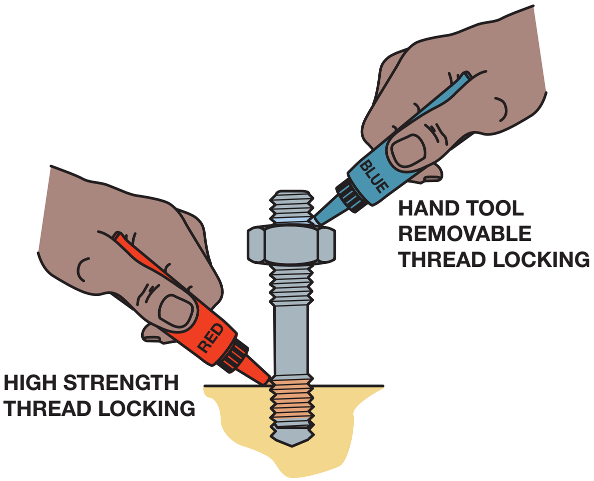

BLUE
HAND TOOL REMOVABLE THREAD LOCKING
RED
HIGH STRENGTH THREAD LOCKING

FIGURE 33–15 The strength of the thread locker depends on whether the fastener is to be removed by hand (blue). High-strength thread locker (red) can only be removed if heated.

surfaces without a gasket. The surfaces *must* be thoroughly clean to get a good seal. Special primers are recommended for use on the sealing surface to get a better bond with anaerobic sealers. ● **SEE FIGURES 33–14 AND 33–15**.

NONHARDENING SEALERS Sealers are nonhardening materials. Examples of sealer trade names include

- Form-A-Gasket 2
- Pli-A-Seal
- Tight Seal 2
- Aviation Form-A-Gasket
- Brush Tack
- Copper Coat

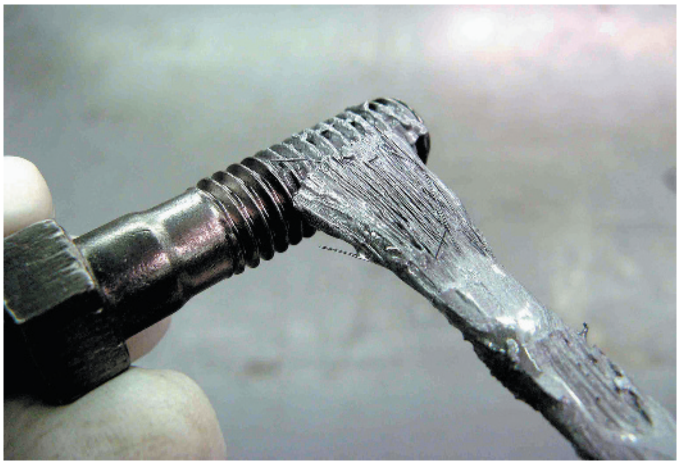


FIGURE 33–16 Applying antiseize compound to the threads of a bolt helps prevent the threads from galling or rusting.

- Spray Tack
- High Tack

Sealers are always used to seal the threads of bolts that break into coolant passages. Sealers for sealing threads may include Teflon. Sealer is often recommended for use on shim-type head gaskets and intake manifold gaskets. These gaskets have a metal surface that does not conform to any small amounts of surface roughness on the sealing surface. The sealer fills the surface variations between the gasket and the sealing surface.

Sealer may be used as a sealing aid on paper and fiber gaskets if the gasket needs help with sealing on a scratched, corroded, or rough surface finish. The sealer may be used on one side or on both sides of the gasket.

CAUTION: Sealer should never be used on rubber or cork-rubber gaskets. Instead of holding the rubber gasket or seal, it helps the rubber to slip out of place because the sealer never hardens.

ANTISEIZE COMPOUNDS Antiseize compounds are used for the following:

- On fasteners in the engine to prevent seizing.
- Exhaust manifold bolts or nuts, and oxygen sensors, keep them from seizing. The antiseize compound minimizes the chance of threads being pulled or breaking as the oxygen sensor is removed. Always follow the vehicle manufacturer's recommendations found in service information. ● **SEE FIGURE 33–16**.

SEALANT SUMMARY ● **SEE CHART 33–1**.

PRODUCTS	COMMON TRADE NAMES	USES	EXAMPLES
RTV (room-temperature vulcanization)	Silicone	As a gasket substitute or fill gaps	Valve covers, oil pans, intake manifold end seals, timing covers, transmission pans
Anaerobic sealer (thread-locker) medium strength	Loctite® **Blue**	Keeps fasteners from vibrating loose	For nut and bolt applications 1/4 to 3/4 inch (6 to 20 mm)
Anaerobic sealer (thread-locker) high temperature, high strength	Loctite® **Red**	Heavy-duty applications	For larger fasteners 3/8 to 1 inch (9.5 to 25 mm)
Antiseize (general purpose)	Neverseez™ Kopr Kote™ E-Z Break™	For preventing corrosion seizing	Oxygen sensors, spring bolts, exhaust manifold bolts/nuts
Antiseize (nickel)	Neverseez™ Thred-Gard™	For stainless steel and other metal applications	Harsh chemical environments
Hardening gasket sealant	Permatex® **#1**	Holds gaskets in place during assembly; also seals paper and cork gaskets	Transmission and engine oil pan gaskets, timing cover (paper gaskets) valve cover gaskets, and intake manifold gaskets
Nonhardening sealant	Permatex® **#2**	Allows repeated disassembly and reassembly	Thermostat housings, differential coverings, intake manifolds, fuel injectors and fuel pumps, transmission and torque converter seals
Aviation cement/contact cement	Aviation Form-A- Gasket #3™	Holds gaskets in place for assembly	All types of hoses and gaskets

CHART 33–1

Summary chart showing where sealants are used and their common trade names.

REVIEW QUESTIONS

1. What is the purpose of a gasket?
2. What are the types of cover gaskets?
3. Why is armor used in head gaskets?
4. What is the difference between RTV and anaerobic sealers?
5. What is needed for an anaerobic sealer to cure?

CHAPTER QUIZ

1. What force causes a head gasket to be drawn downward during engine operation?
   - **a.** Intake stroke vacuum
   - **b.** Gravity
   - **c.** Head bolt torque
   - **d.** Exhaust gas pressure
2. Where is a multilayered steel (MLS) gasket most often used in an engine?
   - **a.** Valve cover gasket
   - **b.** Oil pan gasket
   - **c.** Head gasket
   - **d.** Intake manifold gasket
3. A steel or copper wire used in a head gasket around the cylinder is called _________.
   - **a.** armor
   - **b.** fire ring
   - **c.** ridge block
   - **d.** Either a or b
4. A one-piece oil pan gasket often uses _________ in the middle to add strength.
   - **a.** plastic (nylon)
   - **b.** steel
   - **c.** hard rubber
   - **d.** carbon fiber
5. Some gaskets use a steel washer around each bolt hole. The purpose of this washer is to _________.
   - **a.** improve the strength of the gasket
   - **b.** help seal around the bolt hole
   - **c.** help prevent the gasket from shrinking
   - **d.** prevent the gasket from being overly compressed
6. A gasket failure caused by the movement of dissimilar materials is called _________.
   - **a.** fretting
   - **b.** corrosion
   - **c.** collapsing
   - **d.** tearing

7. Which type of oil seal must NOT have oil applied for it to work correctly?
a. Silicone rubber
b. Buna-N
c. Teflon®
d. Viton®

8. What precautions should be followed when using gaskets?
a. Never reuse an old gasket.
b. A gasket should be checked to make sure it is the correct gasket.
c. Read the instruction sheet.
d. All of the above.

9. Which type of sealer is to be used on nonmachined surfaces?
a. RTV
b. Anaerobic sealer
c. Either a or b
d. Neither a nor b

10. Which product requires heat to remove?
a. Red thread locker
b. Blue thread locker
c. RTV
d. Antiseize

Chapter

34

ENGINE ASSEMBLY AND TESTING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe steps to take when starting to assemble the engine.
- Explain short block preparation.
- Explain cylinder head preparation.
- Discuss trial assembly.
- Discuss final short block assembly.
- Describe camshaft installation.
- Describe piston/rod installation.
- Explain the cylinder head installation procedure.
- Discuss torque-to-yield head bolts.
- Explain valve train assembly.
- Explain final assembly of an engine.
- Explain dynamometer testing.

KEY TERMS:

Assembly lube 383 • Clamping force 393 • Corrected torque 404 • Correction factor 403 • Dry bulb temperature 403 • Expansion plugs 384 • Fogging oil 383 • Freeze plugs 384 • Lash 398 • Piston ring compressor 390 • Soft core plugs 384 • Torque angle 395 • Torque-to-yield (TTY) 395 • Transducers 403 • Welsh plugs 384

DETAILS, DETAILS, DETAILS

Successful engine assembly depends on getting all of the details right. Where to start? Start when all parts have been purchased or prepared for assembly.

When starting to assemble the engine, be sure to have all of the instructions from all of the parts used.

- **Read.** Read *all* instructions that are included with all new parts and gaskets. Often very important information or suggested specifications are included and may be at the end.
- **Understand.** Be sure to fully understand everything that is stated in the instructions. If unsure as to what is meant, ask a knowledgeable technician or call the company to be sure that all procedures are clearly understood. ● **SEE FIGURE 34–1**.
- **Follow.** Be sure to follow *all* of the instructions. Do not pick the easy procedures and skip others.

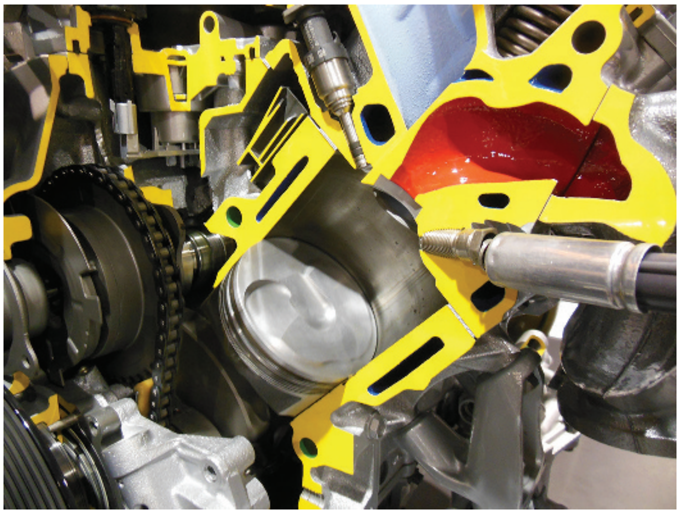


FIGURE 34–1 A direct injected engine cutaway showing the relationship of the fuel injector, and spark plug.

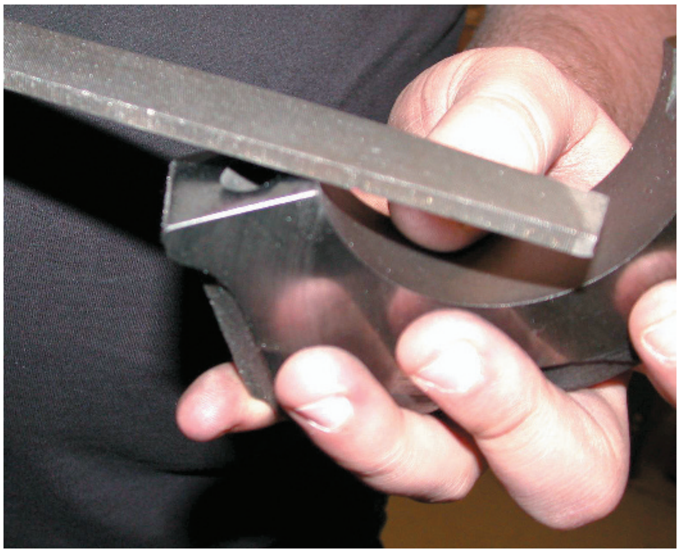


FIGURE 34–2 Deburring all sharp edges is an important step to achieve proper engine assembly.

SHORT BLOCK PREPARATION

ITEMS TO CHECK The following engine block details should be checked:

- All passages should be clean and free of rust and debris.
- All gasket surfaces are properly cleaned and checked for burrs and scratches.
- All cups and plugs should be installed.
- The final bore dimension is correct for the piston.
- The surface finish of the cylinder bore matches with the specified finish required for the piston rings that are going to be used.
- All sharp edges and burrs have been removed. ● **SEE FIGURE 34–2**.
- The main bearing bores (saddles) are straight and inline.
- The lifter bores have been honed and checked for proper dimension.

SURFACE FINISH The surface finish is important for the proper sealing of any gasket.

- **Surface too rough.** If the surface finish is too rough, the gasket will not be able to seal the deep grooves in the surface.
- **Surface too smooth.** If the surface finish is too smooth, the gasket can move out of proper location, causing leakage.

Surface finish is measured in microinches, usually abbreviated by using the Greek letter mu (μ) and the abbreviation for inches together (μinch).

- The higher the microinch finish, the rougher the surface.
- The lower the microinch finish, the smoother the surface. The specification for surface finish is usually specified in roughness average, or Ra.

● **SEE CHART 34–1** for the acceptable roughness for the head gasket surface.

ENGINE PART MATERIAL	GASKET MATERIAL	ACCEPTABLE SURFACE FINISH (RA)
Cast iron/cast iron	Composite	60 to 80 μinch
Aluminum/cast iron	Composite	20 to 30 μinch
Aluminum/cast iron	Rubber-coated multilayered steel (MLS)	15 to 30 μinch

CHART 34–1

The surface finish of the block and cylinder head depends on the type of gasket being used.

Check the instruction sheet that comes with the gasket for the specified surface finish.

CHECKING SURFACES BEFORE ASSEMBLY All surfaces of an engine should be clean and straight and have the specified surface finish and flatness. Flatness is a measure of how much the surface varies in any 6 inch (152 mm) span. An industry standard maximum limit for flatness is usually 0.002 inch (0.051 mm). If the surface is not flat, the gaskets will not be able to seal properly.

TECH TIP

Be Aware of BMW Engine Procedures

If rebuilding a BMW engine, check service information carefully because most BMW engines require that threaded inserts be installed in all head bolt threads. Performing this operation can increase the cost and time needed. Always follow all recommended service procedures on the engine being serviced. ● **SEE FIGURE 34–3**.

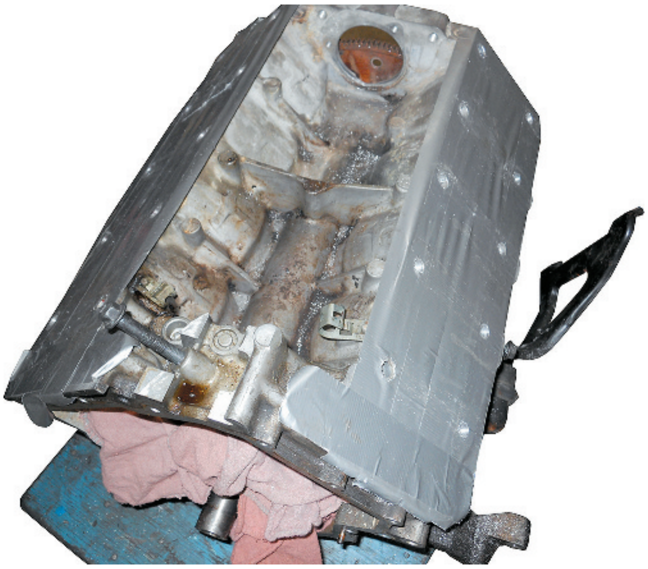


FIGURE 34–3 A Cadillac Northstar engine being rebuilt. The shop doing the work is installing Heli-coils® in all threaded cylinder head bolt holes as a precaution. Using duct tape to cover the engine helps prevent aluminum chips from getting into passages.

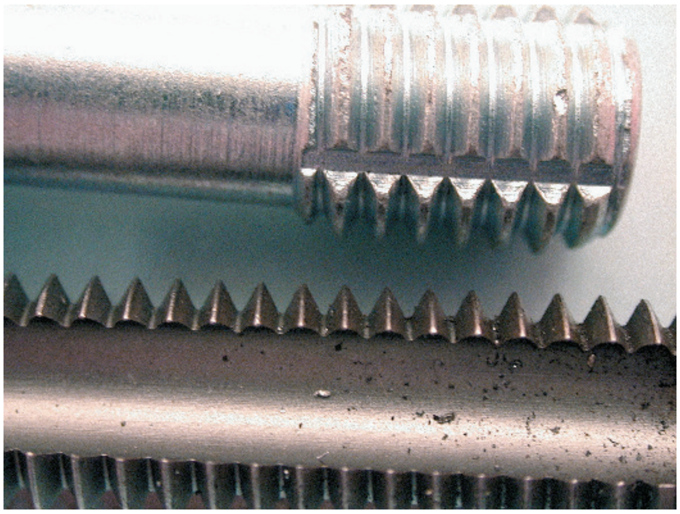


FIGURE 34–4 A thread chaser (top) is the preferred tool to clean threaded holes because it cleans without removing metal compared to a tap (bottom).

PREPARING THREADED HOLES

STEP 1 All threads in the block should be thoroughly cleaned. Many experts recommend using a thread chaser, because a tap could cut and remove metal. A chaser will restore the threads without removing metal. ● **SEE FIGURE 34–4**.

STEP 2 Check that all liquid has been removed from the bolt holes in the block. If liquid is in the bottom of a blind hole, the block can be cracked when the bolt is installed.

CYLINDER HEAD PREPARATION

ITEMS TO CHECK Check the following details on the cylinder head(s):

- The surface finish of the fire deck is as specified for the head gasket type to be used.
- All valves should be checked for leakage by pouring mineral spirits into the intake and exhaust parts and look for leakage past the valves.
- All valve springs should be checked for even spring pressure and installed height.
- Check for proper pushrod length. If the cylinder head(s) has been machined and/or the block deck machined, the pushrods may be too long. If the pushrods are too long, the rocker arm geometry will not be correct. One problem that can occur with incorrect rocker arm geometry is spring bind, which can cause severe engine damage.
- If replacement rocker arms are used, be sure that the geometry and total lift will be okay.

TECH TIP

Keep the Engine Covered

Using a large plastic trash bag is an excellent way to keep the engine clean when storing it between work sessions. ● **SEE FIGURE 34–5**.

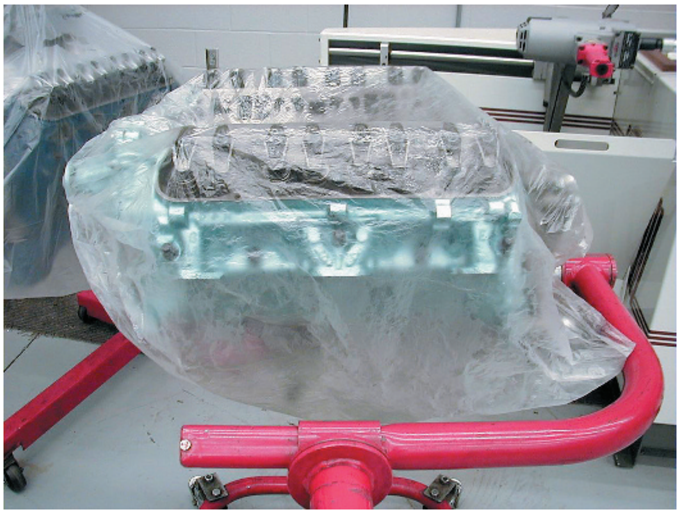


FIGURE 34–5 Using a plastic trash bag is an excellent way to keep the engine clean during all stages of assembly.

CASE STUDY

Valve Springs Can Vary

A technician was building a small block Chevrolet V-8 and found that many of the valve springs did not have the same tension. Using a valve spring tester, the technician visited a local parts store and measured all of the valve springs that the store had in stock. The technician selected and purchased the 16 valve springs that were within specification and within a very narrow range of tension. Although having all valve springs equal may or may not affect engine operation, the technician was pleased that all of the valve springs were equal.

Summary:

Complaint—A technician discovered that valve springs did not all have the same tension.
Cause—Due to manufacturing tolerances, valve springs can vary in tension.
Correction—The technician tested all available springs and selected those that were the most equal in tension.

TRIAL ASSEMBLY

SHORT BLOCK Before performing final engine assembly, the wise technician checks that all parts will fit and work. This is especially important if using a different crankshaft that changes the stroke. ● **SEE FIGURE 34–6**.

VALVE TRAIN Another place where a trial fit is needed is in the valve train. Some timing chain mechanisms require more space than the stock component so some machining may be needed.

If there is a problem, further investigation will be needed because the pushrods may be too long due to machining of the block deck and/or cylinder head. Rotate the engine and check for proper clearance throughout the entire opening and closing of the valves. Use a feeler gauge between the coils of the valve

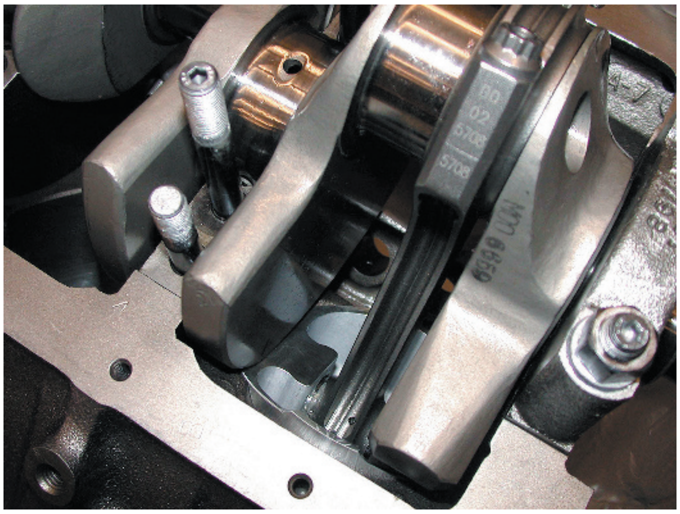


FIGURE 34–6 A trial assembly showed that some grinding of the block will be needed to provide clearance for the counterweight of the crankshaft. Also, notice that the engine has been equipped with studs for the four-bolt main bearing caps.

Fogging
Oil
Prevents Corrosion Whe
Storing Inboard or
Outboard Engines For

FIGURE 34–7 Fogging oil is used to cover bare metal parts when the engine is being stored to prevent corrosion.

TECH TIP

Fogging Oil and Assembly Lube

When assembling an engine, the parts should be coated with a light oil film to keep them from rusting. This type of oil is commonly referred to as **fogging oil** and is available in spray cans. ● **SEE FIGURE 34–7**.

During engine assembly, the internal parts should be lubricated. While engine oil or grease could be used, most experts recommend the use of a specific lubricant designed for engine assembly. This lubricant, designed to remain on the parts and not drip or run, is called **assembly lube**. ● **SEE FIGURE 34–8**.

PERFECT CIRCLE
ENGINE
& BEARING
ASSEMBLY
LUBE

FIGURE 34–8 Engine assembly lube is recommended to be used on engine parts during assembly.

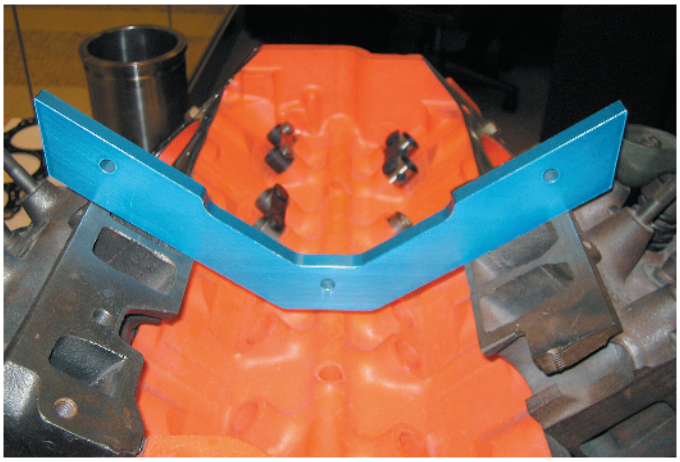


FIGURE 34–9 An angle gauge being used to check the angle between the cylinder heads on this small block Chevrolet V-8 engine.

spring to check for coil bind. If coil bind occurs, a different camshaft or valve spring should be used.

CHECK THE ANGLE BETWEEN HEADS During the trial assembly, use a gauge to check that the heads are at the correct angle to ensure proper intake manifold gasket sealing. If the angle is not correct, remachining of the head or block will be needed. ● **SEE FIGURE 34–9**.

FINAL SHORT BLOCK ASSEMBLY

BLOCK PREPARATION All surfaces should be checked for damage resulting from the machining processes. Items that should be done before assembly begins include the following:

1. The block, including the oil gallery passages, should be thoroughly cleaned. ● **SEE FIGURES 34–10 AND 34–11**.
2. All threaded bolt holes should be chamfered.
3. All threaded holes should be cleaned with a thread chaser before final assembly.

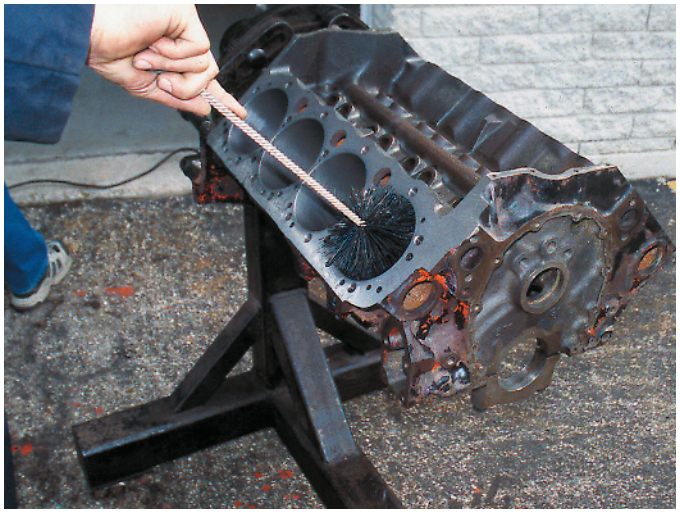


FIGURE 34–10 The best way to thoroughly clean cylinders is to use soap (detergent), water, and a large washing brush. This method floats the machining particles out of the block and washes them away.

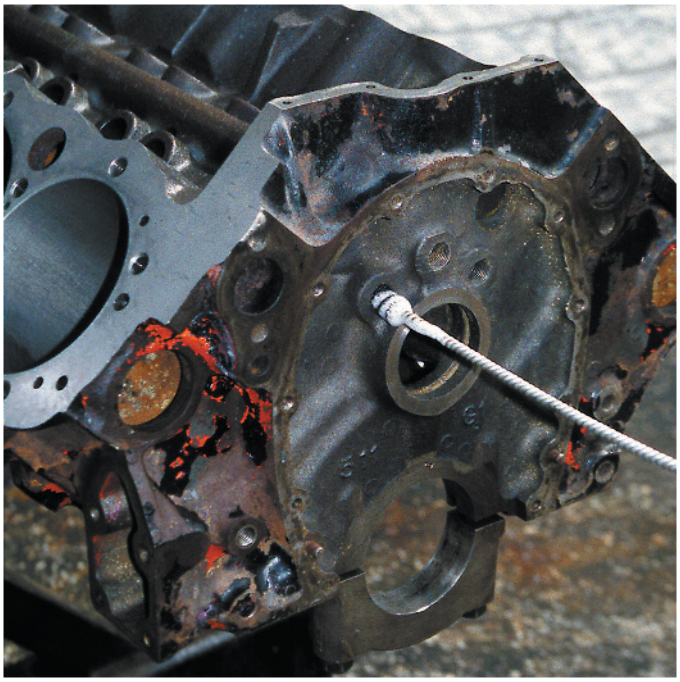


FIGURE 34–11 All oil galleries should be cleaned using soap (detergent), water, and a long oil gallery cleaning brush.

INSTALLING CUPS AND PLUGS

Oil gallery plugs should be installed using sealant on the threads.

CAUTION: Avoid using Teflon tape on the threads of oil gallery plugs or coolant drain plugs. The tape is often cut by the threads, and thin strips of the tape are then free to flow through the oil galleries where the tape can cause a clog, thereby limiting lubricating engine oil to important parts of the engine.

Core holes left in the external block wall are machined and sealed with **soft core plugs** or **expansion plugs** (also called **freeze plugs** or **Welsh plugs**).

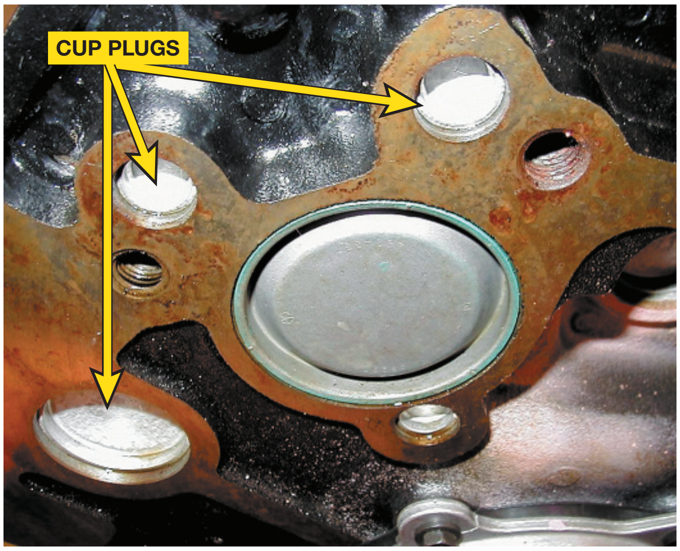


FIGURE 34–12 This engine uses many cup plugs to block off coolant and oil passages as well as a large plug over the end of the camshaft bore.

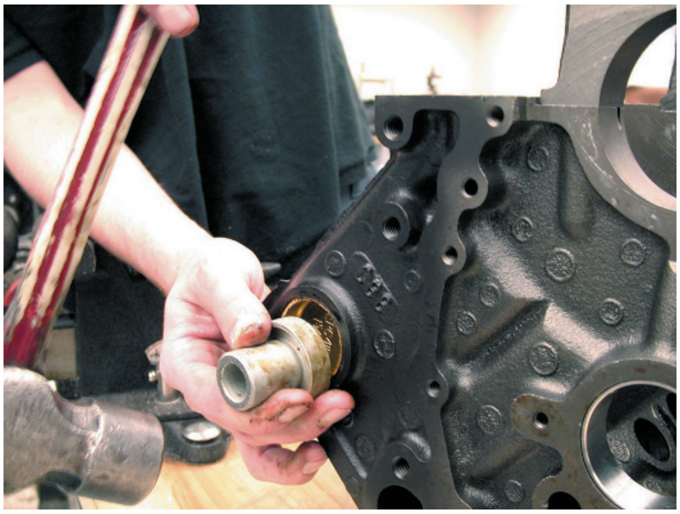


FIGURE 34–13 Sealer should be applied to the cup plug before being driven into the block.

Soft plugs are of two designs:

- **Convex type.** The core hole is counterbored with a shoulder. The convex soft plug is placed in the counterbore, convex side out. It is driven in with a fitted seating tool. This causes the edge of the soft plug to enlarge to hold it in place. A convex plug should be driven in until it reaches the counterbore of the core plug hole.
- **Cup type.** This most common type fits into a smooth, straight hole. The outer edge of the cup is slightly bell mouthed. The bell mouth causes it to tighten when it is driven into the hole to the correct depth with a seating tool. An installed cup-type soft plug is shown in ● **FIGURE 34–12**.

A cup plug is installed about 0.02 to 0.05 inch (0.5 to 1.3 mm) below the surface of the block, using sealant to prevent leaks. ● **SEE FIGURE 34–13**.

CAM BEARINGS

A cam bearing installing tool is required to insert the new cam bearing without damaging the bearing.

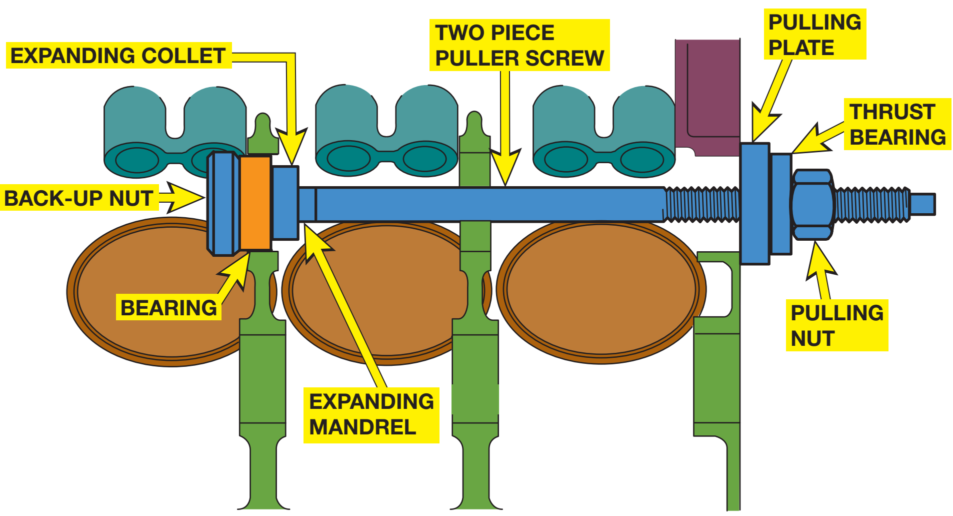


FIGURE 34–14 Screw-type puller being used to install a new cam bearing. Most cam bearings are crush fit. The full round bearing is forced into the cam bearing bore. Most vehicle manufacturers specify that the cam bearings be installed "dry" without lubrication to help prevent them from spinning, which would cause the bearing to block the oil feed hole.

FREQUENTLY ASKED QUESTION

What Causes Premature Bearing Failure?

According to a major manufacturer of engine bearings, the major causes of premature (shortly after installation) bearing failure include the following:

Dirt (45%)
Misassembly (13%)
Misalignment (13%)
Lack of lubrication (11%)
Overloading or lugging (10%)
Corrosion (4%)
Other (4%)

Many cases of premature bearing failure may result from a combination of several of these items. Therefore, to help prevent bearing failure, *keep everything as clean as possible.*

A number of tool manufacturers design and sell cam bearing installation tools. Their common feature is a shoulder on a bushing that fits inside the cam bearing, with a means of keeping the bearing aligned as it is installed.

The bearing is placed on the bushing of the tool and rotated to properly align the oil hole. The bearing is then forced into the bearing bore of the block by either a pulling screw or a slide hammer. A pulling screw type of tool is illustrated in ● **FIGURE 34–14**.

The installed bearing must be checked to ensure that it has the correct depth and that the oil hole is indexed with the oil passage in the block. No additional service is required on cam bearings that have been properly installed. The opening at the back of the camshaft is closed with a cup plug.

MEASURING MAIN BEARING CLEARANCE The main bearings are properly fit *before* the crankshaft is lubricated or turned. The oil clearance of both main and connecting rod bearings is set by selectively fitting the bearings. In this way, the oil clearance can be adjusted to within 0.0005 inch (0.013 mm) of the desired clearance.

CAUTION: Avoid touching bearings with bare hands. The oils on your fingers can start corrosion of the bearing materials. Always wear protective cloth or rubber gloves to avoid the possibility of damage to the bearing surface.

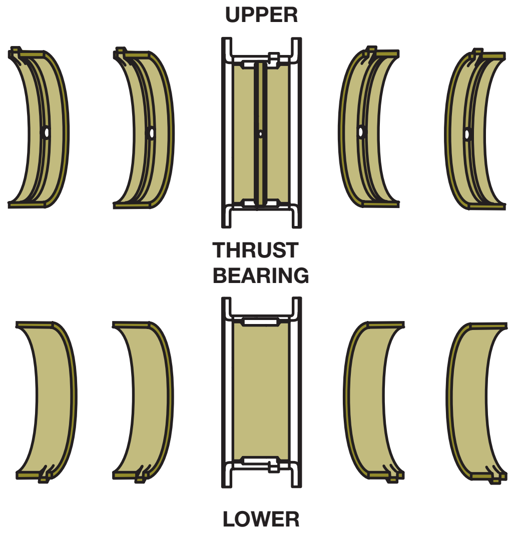


FIGURE 34–15 Typical main bearing set. Note that the upper halves are grooved for better oil flow and the lower halves are plain for better load support. This bearing set uses the center main bearing for thrust control. Notice that the upper bearing set has the holes for oil, whereas the lower set does not.

Bearings are usually made in 0.010, 0.020, and 0.030 inch (0.254, 0.508, 0.762 mm) *undersize* for use on reground journals. ● **SEE FIGURE 34–15** for a typical main bearing set.

The crankshaft bearing journals should be measured with a micrometer to select the required bearing size.

- Each of the main bearing caps will only fit one location and the caps must be positioned correctly.
- The correct-size bearings should be placed in the block and cap, making sure that the bearing tang locks into its slot.
- The upper main bearing has an oil feed hole. The lower bearing does not have an oil hole.
- Lower the crankshaft squarely so that it does not damage the thrust bearing. Carefully rest the clean crankshaft in the block on the upper main bearings.
- After making sure that there is no oil on the crank journal of the bearing, place a strip of Plastigage® (gauging plastic) on each main bearing journal. Install the main bearing caps and tighten the bolts to specifications.

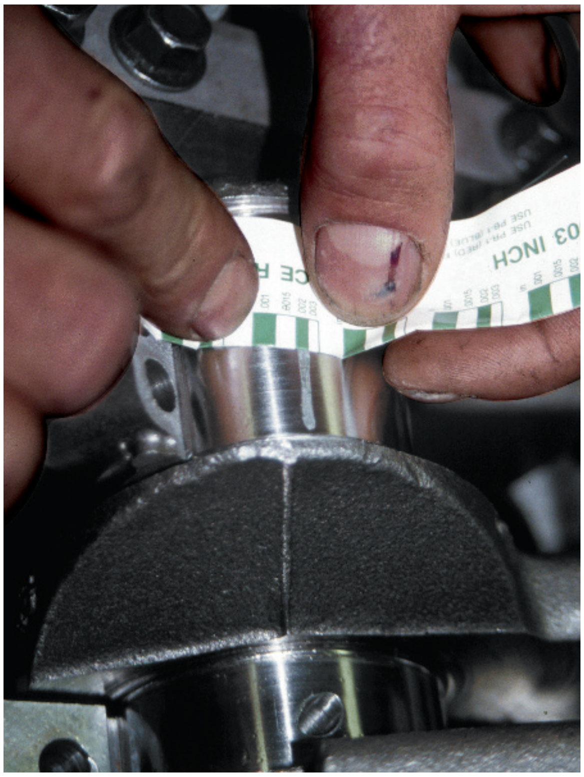


FIGURE 34–16 The width of the plastic gauging strip determines the oil clearance of the main bearing. An alternate method of determining oil clearance includes careful measurement of the crankshaft journal and bearings.

- Remove each cap and check the width of the Plastigage® with the markings on the gauge envelope, as shown in ● **FIGURE 34–16**.
- The width of the plastic strip indicates the oil clearance.

CORRECTING BEARING CLEARANCE Oil clearances normally run from 0.0005 to 0.002 inch (half a thousandth to two thousandths).

- The oil clearance can be reduced by 0.001 inch (0.0254 mm) by replacing both bearing shells with bearing shells that are 0.001 inch (0.0254 mm) undersize.
- The clearance can be reduced by 0.0005 inch (0.0127 mm) by replacing only one of the bearing shells with a bearing shell that is 0.001 inch (0.0254 mm) smaller.
- This smaller bearing shell should be placed in the engine block side of the bearing (the upper shell). Oil clearance can be adjusted accurately using this procedure. Try to avoid mismatching the bearing shells by more than a 0.001 inch (0.0254 mm) difference in size.

LIP SEAL INSTALLATION Seals are always used at the front and rear of the crankshaft. Overhead cam engines may also have a seal at the front end of the camshaft and at the front end of an auxiliary accessory shaft. Either a lip seal or a rope seal is used in these locations. ● **SEE FIGURE 34–17**.

The rear crankshaft oil seal is installed after the main bearings have been properly fit. The lip seal may be molded in a steel case or it may be molded around a steel stiffener. The counterbore or guide that supports the seal must be thoroughly clean.

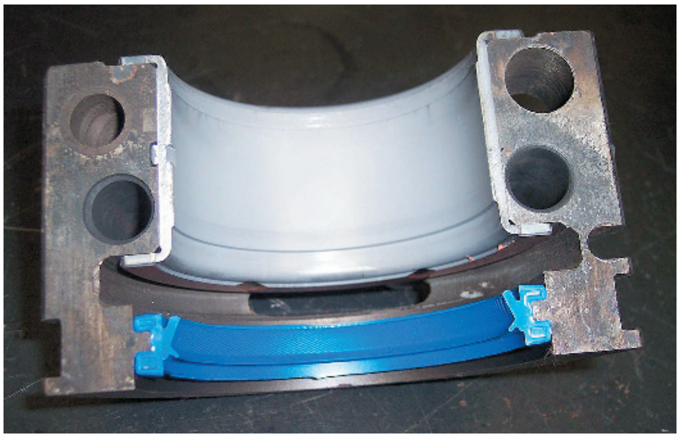


FIGURE 34–17 Lip-type rear main bearing seal in place in the rear main bearing cap. The lip should always be pointing toward the inside of the engine.

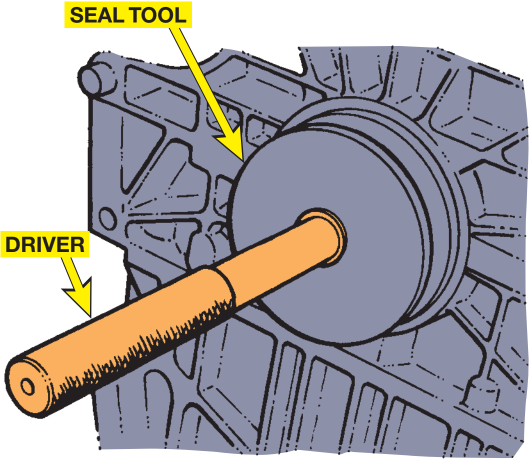


FIGURE 34–18 Always use the proper driver to install a main seal. Never pound directly on the seal.

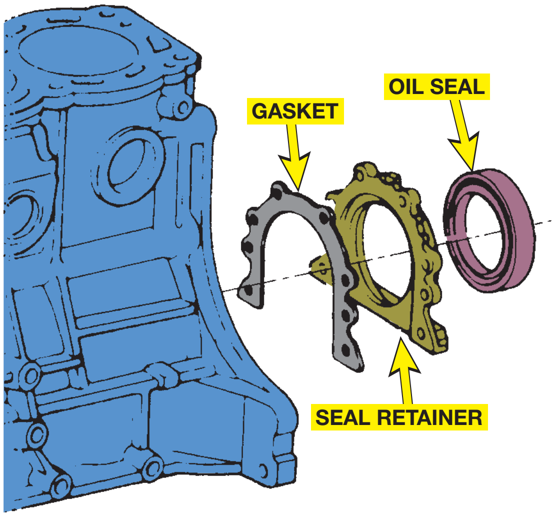


FIGURE 34–19 The rear seal for this engine mounts to a retainer plate. The retainer is then bolted to the engine block.

In most cases, the back of the lip seal is dry when it is installed. Occasionally, a manufacturer will recommend the use of sealants behind the seal. Check service information for the specified sealing instructions. The lip of the seal should be well lubricated before the shaft and cap are installed. ● **SEE FIGURES 34–18 AND 34–19**.

TECH TIP

"One to Three"

When engine technicians are talking about clearances and specifications, the unit of measure most often used is thousandths of an inch (0.001 inch). Therefore, a clearance expressed as "one to three" would actually be a clearance of 0.001 to 0.003 inch (0.0254 to 0.076 inch). The same applies to parts of a thousandth of an inch. For example, a specification of 0.0005 to 0.0015 inch (0.0127 to 0.038 inch) would be spoken of as simply being "one-half to one and one-half." The unit of a thousandth of an inch is assumed, and this method of speaking reduces errors and misunderstandings.

NOTE: Most engine clearance specifications fall within one to three thousandths of an inch. The written specification could be a misprint. Therefore, if the specification does not fall within this general range, double-check the clearance value using a different source.

CAUTION: Teflon seals should *not* be lubricated. This type of seal should be installed dry. When the engine is first started, some of the Teflon transfers to the crankshaft, to create a Teflon-to-Teflon surface. Even touching the seal with your hands could remove some of the outer coating on the seal and cause a leak. Carefully read, understand, and follow the installation instructions that come with the seal.

ROPE SEAL INSTALLATION Some older engines use rope-type seals at both the front and rear of the crankshaft. Rope-type seals, usually called *braided fabric seals,* are sometimes used as rear crankshaft oil seals. Rope-type oil seals must be compressed tightly into the groove so that no oil can leak behind them. With the crankshaft removed, the upper half of the rope seal is put in a clean groove and compressed by rolling a round object against it to force it tightly into the groove. A piece of pipe, a large socket, or even a hammer handle can be used for this.

When the seal is fully seated in the groove, the ends that extend above the parting surface are cut to be flush with the surface using a sharp single-edge razor blade or a sharp tool specially designed to cut the seal. Some technicians find that leaving a little of the seal higher than the bearing cap creates a better seal because when the bearing cap is installed and tightened, the extra seal length forces the rope seal further into the groove. ● **SEE FIGURE 34–20**.

CRANKSHAFT INSTALLATION The main bearing caps and crankshaft should be removed after checking for proper bearing clearance. The surface of the bearings should be given a thin coating of oil or assembly lubricant to provide initial lubrication for engine start-up. Install the crankshaft using the following steps:

STEP 1 The crankshaft should be carefully placed in the bearings to avoid damage to the thrust bearing surfaces.

STEP 2 The bearing caps are installed with their identification numbers correctly positioned. The caps were originally machined in place, so they can only fit correctly in their original position.

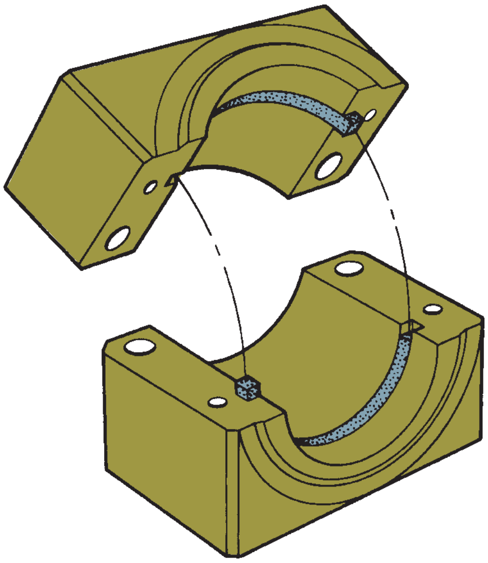


FIGURE 34–20 Many engine builders prefer to stagger the parting lines of a rope-type seal.

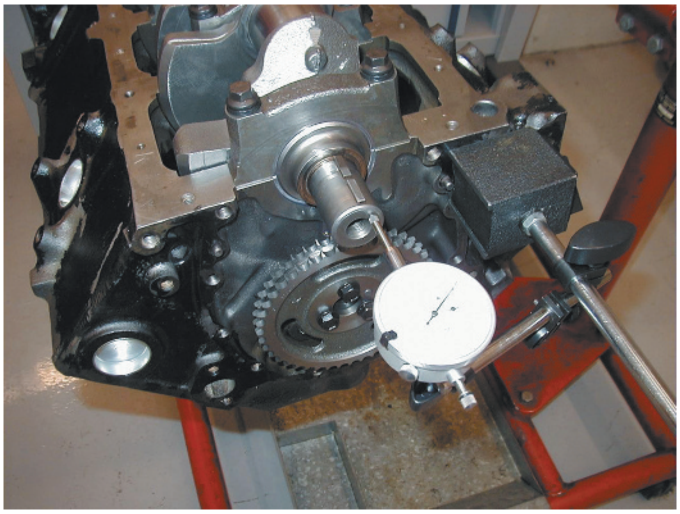


FIGURE 34–21 A dial indicator is being used to check the crankshaft end play, known as thrust bearing clearance. Always follow the manufacturer's recommended testing procedures.

STEP 3 The main bearing cap bolts are tightened finger tight, and the crankshaft is rotated. It should rotate freely.

THRUST BEARING CLEARANCE Tighten all main bearing cap bolts to factory specification except for the bearing cap that is used for thrust (usually the center or the rear cap). Pry the crankshaft forward and rearward to align the cap half of the thrust bearing with the block saddle half. Most engine specifications for thrust bearing clearance (also called *crankshaft end play*) can range from 0.002 to 0.012 inch (0.02 to 0.3 mm). This clearance or play can be measured with a

- Feeler gauge
- Dial indicator ● **SEE FIGURE 34–21**.

If the clearance is too great, oversize main thrust bearings may be available for the engine. Semifinished bearings may have to be purchased and machined to size to restore proper tolerance.

NOTE: Some engines use a separate replaceable thrust bearing. ● **SEE FIGURE 34–22.**

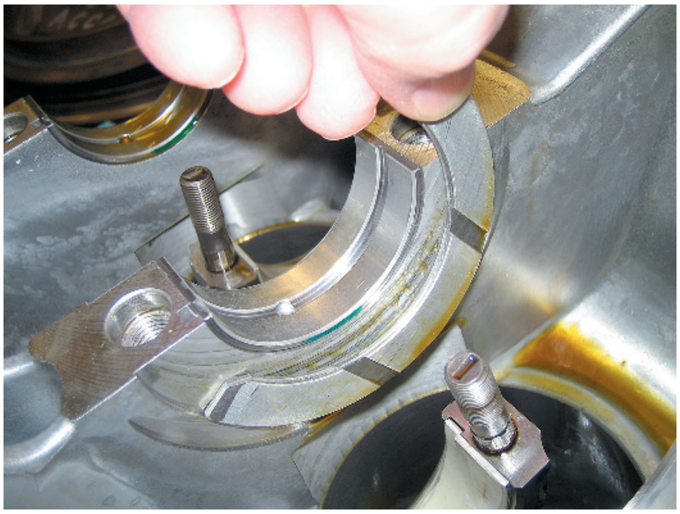


FIGURE 34–22 A thrust bearing insert being installed before the crankshaft is installed.

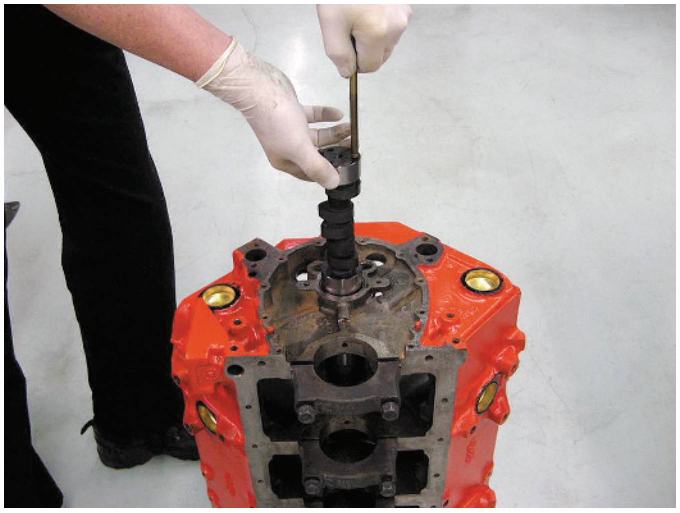


FIGURE 34–23 Installing a camshaft is easier if the engine is vertical so gravity can help, and this method reduces the possibility of damaging the cam bearings.

TECH TIP

Use a Long Bolt to Hold the Camshaft

To help install a camshaft without harming the cam bearings, install a long bolt into one of the end threaded holes in the camshaft. Then tilt the engine vertically so that gravity will cause the camshaft to fall straight down while holding onto the camshaft using the long bolt. ● **SEE FIGURE 34–23**.

MAIN BEARING TIGHTENING PROCEDURE Tighten the main bearing caps to the specified assembly torque, and in the specified sequence. The procedure specified usually includes tightening the main bearing cap bolts in three stages:

- Torque to one-third of the specified torque.
- Then tighten to two-thirds of the specified torque.
- Finally tighten the bolts to the factory specified torque.

Many manufacturers require that the crankshaft be pried forward or rearward during the main bearing tightening process. The crankshaft should turn freely after all main bearing cap bolts are fully torqued.

CRANKSHAFT ROTATING TORQUE It should never require over 5 pound-feet (lb-ft) (6.75 newton-meters, or N-m) of torque to rotate the crankshaft. An increase in the torque needed to rotate the crankshaft is often caused by a foreign particle that was not removed during cleanup. It may be on the bearing surface, on the crankshaft journal, or between the bearing and saddle.

INSTALLING THE CAMSHAFT

PRELUBRICATION When the camshaft is installed, the lobes must be coated with a special lubricant that contains molydisulfide. This special lube helps to ensure proper initial lubrication to the critical cam lobe sections of the camshaft. Many manufacturers recommend multiviscosity engine oil such as SAE 5W-30 or SAE 10W-30. Some camshaft manufacturers recommend using straight SAE 30 or SAE 40 engine oil and not a multiviscosity oil for the first oil fill. Some manufacturers also recommend the use of an antiwear additive such as zinc dithiophosphate (ZDP).

CAMSHAFT PRECAUTIONS Whenever repairing an engine, follow these rules regarding the camshaft and lifters:

1. When installing a new camshaft, always install new valve lifters (tappets).
2. When installing new lifters, if the original cam is not excessively worn and if the pushrods all rotate with the original camshaft, the camshaft may be reused.

TECH TIP

Two Choices If Using Flat-Bottom Lifters

An old or rebuilt engine that uses flat-bottom lifters must use one of two lubricants.

1. Oils that contain at least 0.15% or 1,500 parts per million (ppm) of zinc in the form of ZDDP. Oils that contain this much zinc are designed for off-road use only and in a vehicle that does not have a catalytic converter, such as racing oils. If the vehicle is equipped with a catalytic converter, replace the camshaft and lifters to roller type, so that newer oils with lower levels of zinc can be used.
2. Use a newer oil and an additive such as
   - **a.** GM engine oil supplement (EOS) (Part #1052367 or #88862586)
   - **b.** Comp Cams® camshaft break-in oil additive (Part #159)
   - **c.** Crane Cams® Moly Paste (Part #99002-1)
   - **d.** Crane Cams® Super Lube oil additive (Part #99003-1)
   - **e.** Lumati Assembly lube (Part #99010)
   - **f.** Mell-Lube camshaft tube oil additive (Part # M-10012)
   - **g.** Other available additives designed to protect the camshaft (● **SEE FIGURE 34–24**.)

NEW!
SINCE 1950
HIGH PERFORMANCE
ZINC ENHANCED
ENGINE PROTECTOR (ZEP)
"MPZ" blends Moly, Phosphorus, & Zinc
Provides Wear and Friction Fighting Chemistries for:
• Hot Rods, Muscle Cars, Sports Cars
• Exotics, Classics, and Collector Cars
• Low-Mileage and all Storage Vehicles
Mixes with all Synthetic and Petroleum Based Oils
Treats 6 quarts or 6 liters of oil
12 FL. OZ.
TMPZ
335 mL

FIGURE 34–24 A commercial additive designed to protect a flat-bottom lifter camshaft used in older vehicles when using newer oils that do not have enough ZDDP to protect the camshaft and lifters.

NOTE: Some manufacturers recommend that a new camshaft always be installed when replacing valve lifters.

3. *Never* use a hydraulic lifter camshaft with solid lifters or hydraulic lifters with a solid lifter camshaft.

PISTON/ROD INSTALLATION

CHECKING PISTON RINGS Before installing the piston assemblies, all piston rings should be checked for proper side clearance and ring gap. ● **SEE FIGURE 34–25**.

Typical ring gap clearances are about 0.004 inch (0.102 mm) per inch of cylinder bore. ● **SEE CHART 34–2**.

NOTE: If the gap is greater than recommended, some engine performance is lost. However, too small a gap will result in scuffing because ring ends can be forced together during operation, which forces the rings to scrape the cylinders.

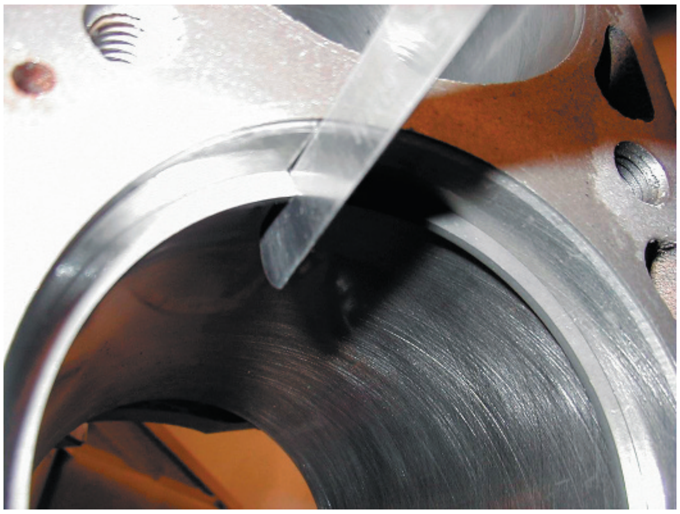


FIGURE 34–25 A feeler gauge is used to check piston ring gap.

PISTON DIAMETER (INCHES)	RING GAP (INCHES)
2 to 3	0.007 to 0.018
3 to 4	0.01 to 0.02
4 to 5	0.013 to 0.023

CHART 34–2

The approximate ring gap based on the size of the bore in inches. Always check service information for the exact specifications for the engine being assembled.

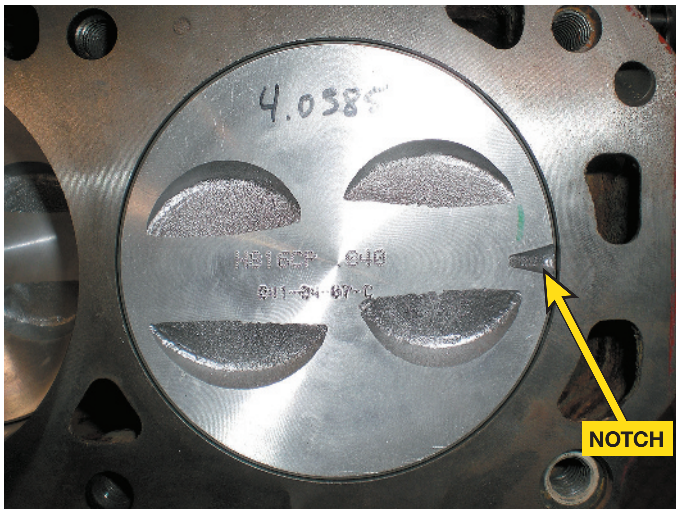

4.0385
NOTCH

FIGURE 34–26 The notch on a piston should always face toward the front of the engine.

- If the ring gap is too large, the ring should be replaced with one having the next oversize diameter.
- If the ring gap is too small, the ring should be removed and filed to make the gap larger.

PISTON MARKINGS Care must be taken to ensure that the pistons and rods are in the correct cylinder. They must face in the correct direction. There is usually a *notch* on the piston head indicating the *front.* Using this will correctly position the piston pin offset toward the right side of the engine. ● **SEE FIGURE 34–26**.

- The connecting rod *identification marks* on pushrod 4- and 6-cylinder inline engines are normally placed on the camshaft side.
- On V-type engines, the connecting rod cylinder identification marks are on the side of the rods that can be seen from the bottom of the engine when the piston and rod assemblies are installed in the engine. Make sure the connecting rod has been installed on the piston correctly—the chamfer on the side of the big end should face outward (toward the crank throw). ● **SEE FIGURE 34–27**.
- Check service information for any special piston and rod assembly instructions.

CONNECTING ROD BEARING CLEARANCE The rod cap, with the bearing in place, is put on the rod. There are two methods that can be used to check for proper connecting rod bearing clearance.

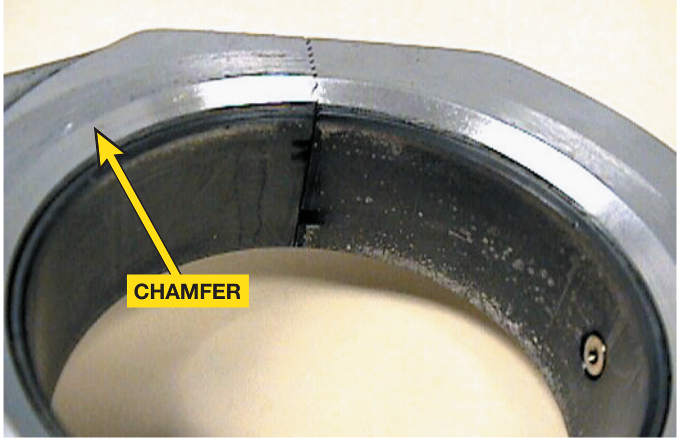


FIGURE 34–27 On V-type engines that use paired rod journals, the side of the rod with the large chamfer should face toward the crank throw (outward).

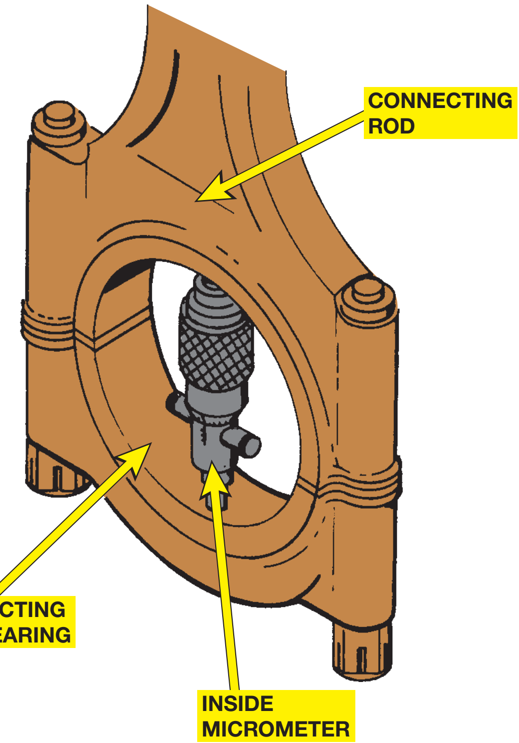


FIGURE 34–28 An inside micrometer can be used to measure the inside diameter of the big end of the connecting rod with the bearings installed. This dimension subtracted from the rod journal diameter is equal to the bearing clearance.

- Use Plastigage® following the same procedure discussed for main bearing clearance.
- Measure the assembled connecting rod big end devices with the bearing installed and the caps torqued to specification. Subtract the diameter of the rod journal to determine the bearing clearance. ● **SEE FIGURE 34–28**.

NOTE: Be certain to check for piston-to-crankshaft counterweight clearance. Most manufacturers specify a minimum 0.06 inch (1.5 mm).

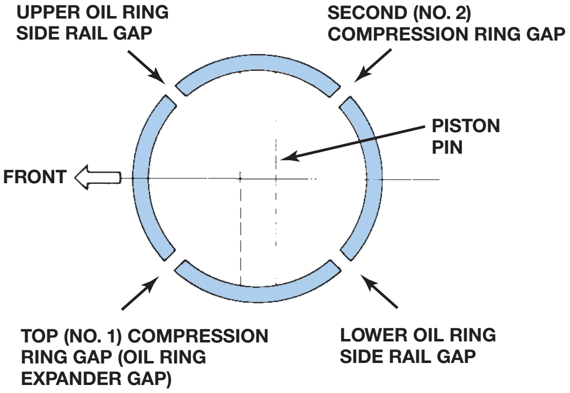

UPPER OIL RING SIDE RAIL GAP
SECOND (NO. 2) COMPRESSION RING GAP
PISTON PIN
FRONT
TOP (NO. 1) COMPRESSION RING GAP (OIL RING EXPANDER GAP)
LOWER OIL RING SIDE RAIL GAP

FIGURE 34–29 One method of piston ring installation showing the location of ring gaps. Always follow the manufacturer's recommended method for the location of ring gaps and for ring gap spacing.

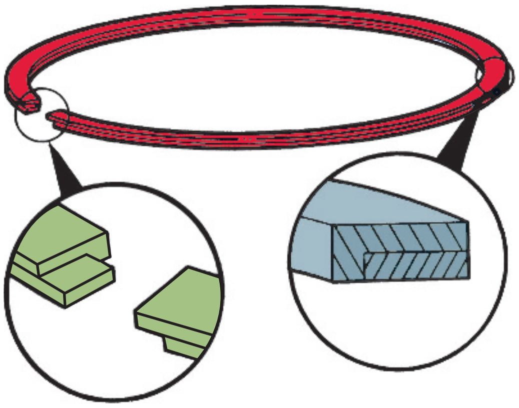


FIGURE 34–30 A gapless ring is made in two pieces that overlap.

PISTON INSTALLATION To install a piston, perform the following steps:

STEP 1 Apply a coating of clean engine oil to the cylinder walls. This oil should be spread over the entire cylinder wall surface by hand.

STEP 2 Apply oil or assembly lube to the rod bearings.

STEP 3 Align the piston ring gaps (ring gap stagger) to the locations specified in service information. ● **SEE FIGURE 34–29**.

STEP 4 Using a squirt-type oil can, squirt oil over the rings and the skirt of the piston.

NOTE: Special types of piston rings (overlapping or gapless) are installed dry, without oil. ● SEE FIGURE 34–30. Some manufacturers recommend oiling only the oil control ring. Always check the piston ring instruction sheet for the exact procedure.

STEP 5 The **piston ring compressor** is then put on the piston to hold the rings in their grooves. ● **SEE FIGURES 34–31 AND 34–32**.

STEP 6 Rotate the crankshaft so the crankshaft journal is at the bottom (BDC) to help prevent the rod from touching the crankshaft when the piston is installed.

STEP 7 Remove the bearing cap from the rod and install the bearings.

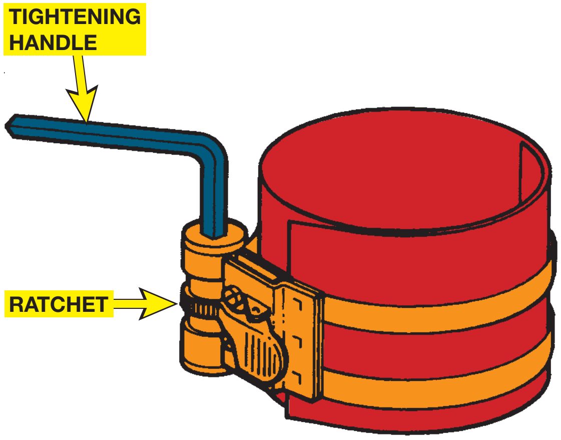


FIGURE 34–31 This style of ring compressor uses a ratchet to contract the spring band and compress the rings into their grooves.

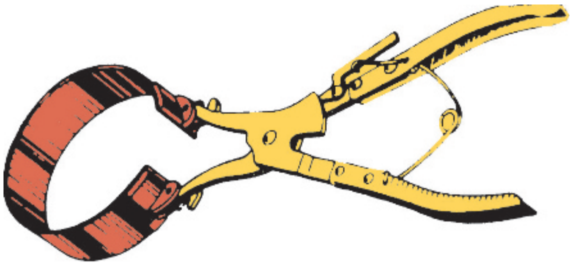


FIGURE 34–32 This pliers-like tool is used to close the metal band around the piston to compress the rings. An assortment of bands is available to service different size pistons.

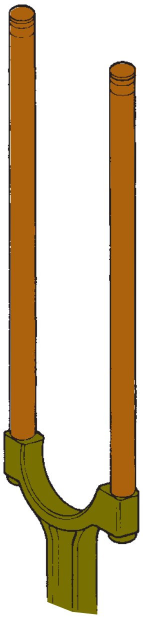


FIGURE 34–33 When threaded onto the rod bolts, these guides not only help align the rod but also protect the threads and holds the bearing shell in place. The soft ends also will not damage the crankshaft journals.

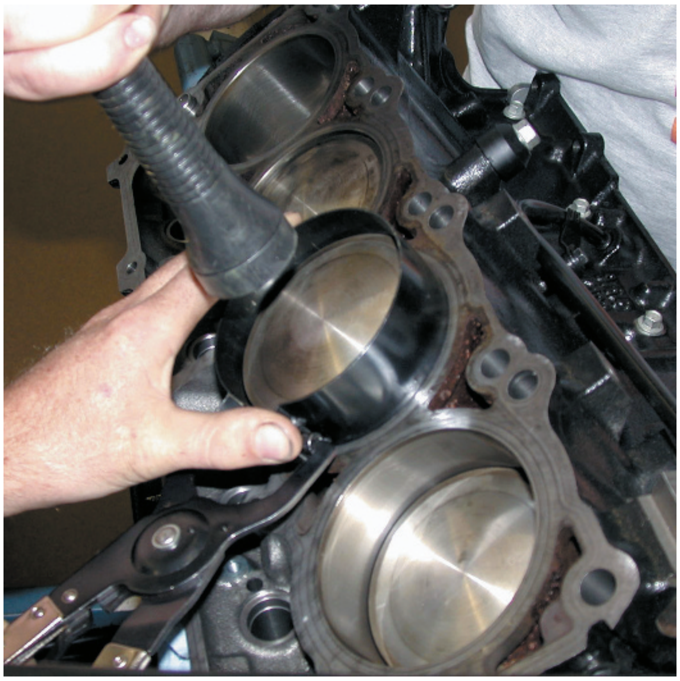


FIGURE 34–34 Installing a piston using a ring compressor to hold the rings into the ring grooves of the piston and then using a hammer handle to drive the piston into the bore. Connecting rod bolt protectors have been installed to help prevent possible damage to the crankshaft during piston installation.

STEP 8 Install protectors over the rod bolts. These help prevent damage to the crankshaft journal when the piston/rod assembly is installed. ● **SEE FIGURE 34–33**.

STEP 9 The upper rod bearing should be in the rod and the piston should be turned so that the notch on the piston head is facing the front of the engine.

STEP 10 The piston and rod assembly is placed in the cylinder through the block deck. The ring compressor must be kept tightly against the block deck as the piston is pushed into the cylinder.

The ring compressor holds the rings in their grooves so that they will enter the cylinder. ● **SEE FIGURE 34–34**.

STEP 11 The piston is pushed into the cylinder until the rod bearing is fully seated on the journal.

CONNECTING ROD SIDE CLEARANCE The connecting rods should be checked to ensure that they still have the correct side clearance. This is measured by fitting the correct thickness of feeler gauge between the connecting rod and the crankshaft cheek of the bearing journal. ● **SEE FIGURE 34–35**.

- *If the side clearance is too great,* excessive amounts of oil may escape that can cause lower-than-normal oil pressure. To correct excessive clearance:
    1. Weld and regrind or replace the crankshaft.
    2. Carefully measure all connecting rods and replace those that are too thin or mismatched.
- *If the side clearance is too small,* there may not be enough room for heat expansion. To correct a side clearance that is too small:
    1. Regrind the crankshaft.
    2. Replace the rods.

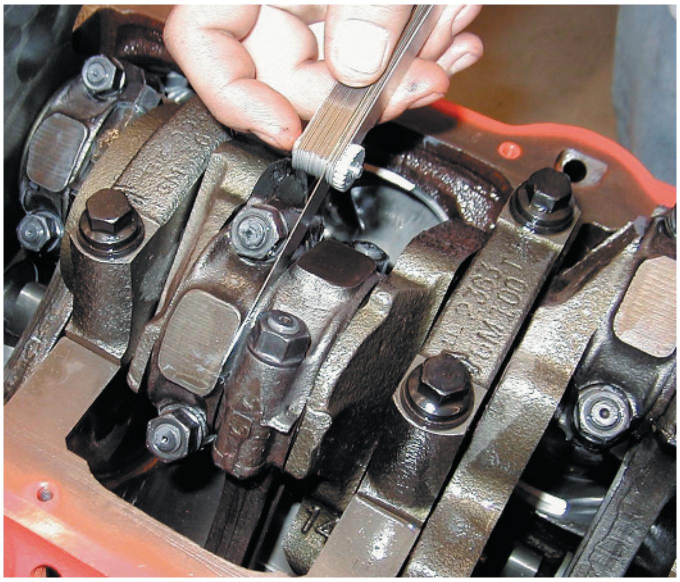


FIGURE 34–35 The connecting rod side clearance is measured with a feeler gauge.

TECH TIP

Tightening Tip for Rod Bearings

Even though the bearing clearances are checked, it is still a good idea to check and record the torque required to rotate the crankshaft with all piston rings dragging on the cylinder walls. The retaining nuts on one bearing should be torqued, and then the torque that is required to rotate the crankshaft should be rechecked and recorded. Follow the same procedure on all rod bearings. If tightening any one of the rod bearing caps causes a large increase in the torque required to rotate the crankshaft, immediately stop the tightening process. Determine the cause of the increased rotating torque using the same method as used on the main bearings. Rotate the crankshaft for several revolutions to ensure that the assembly is turning freely and that there are no tight spots.

The rotating torque of the crankshaft with all connecting rod cap bolts fully torqued should be as follows:

- 4-cylinder engine: 20 lb-ft maximum (88 N-m)
- 6-cylinder engine: 25 lb-ft maximum (110 N-m)
- 8-cylinder engine: 30 lb-ft maximum (132 N-m)

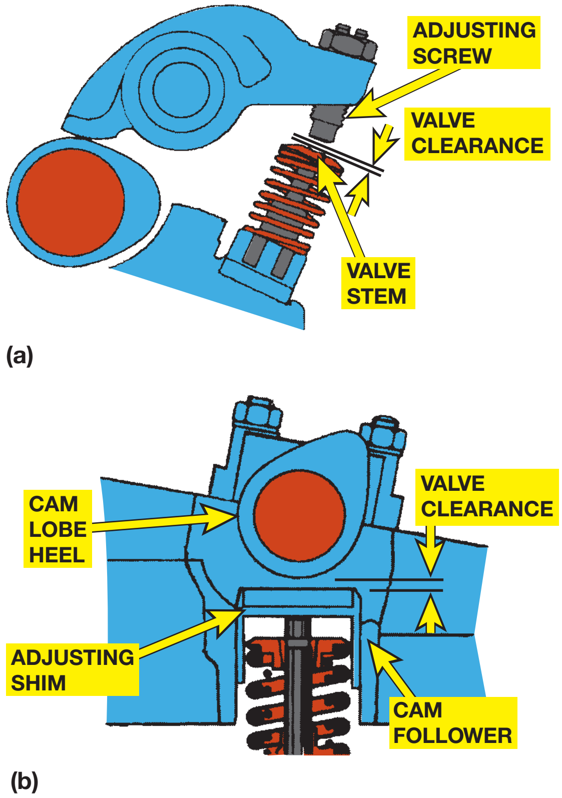


FIGURE 34–36 Valve clearance allows the metal parts to expand and maintain proper operation, both when the engine is cold and at normal operating temperature. (a) Adjustment is achieved by turning the adjusting screw. (b) Adjustment is achieved by changing the thickness of the adjusting shim.

CYLINDER HEAD INSTALLATION

INSTALLING THE CAMSHAFT FOR OHC ENGINES On some overhead camshaft engines, the camshaft is installed before the head is fastened to the block deck. Some engines have the camshaft located directly over the valves. The cam bearings on these engines can be either one piece or split. In other engine types, the camshaft bearings are split to allow the camshaft to be installed without the valves being depressed. The cam bearings and journals are lubricated before assembly. The cam bearing caps must be tightened evenly to avoid bending the camshaft. The valve clearance or lash is checked with the overhead camshaft in place. Some engines use shims under a follower disk, as shown in ● **FIGURE 34–36**.

On these engine types, the camshaft is turned so that the follower is on the base circle of the cam. The clearance of each bucket follower can be checked with a feeler gauge. The amount of clearance is recorded and compared with the specified clearance, and then a shim of the required thickness is put in the top of the bucket followers, as shown in ● **FIGURE 34–37**.

Always follow the vehicle manufacturer's recommended procedures.

HEAD BOLT TORQUE SEQUENCE The torque put on the bolts is used to control the clamping force that is applied to the gasket. The clamping force is correct only when the threads are clean and properly lubricated.

CAUTION: Always use the specified lubricant on the threads. If SAE 30 engine oil is specified, do not use SAE 10W-30 or any other viscosity because using the incorrect viscosity oil can affect the clamping force exerted on the head gaskets.

In general, the head bolts are tightened in a specified torque sequence in three steps. The procedure starts with the head bolts

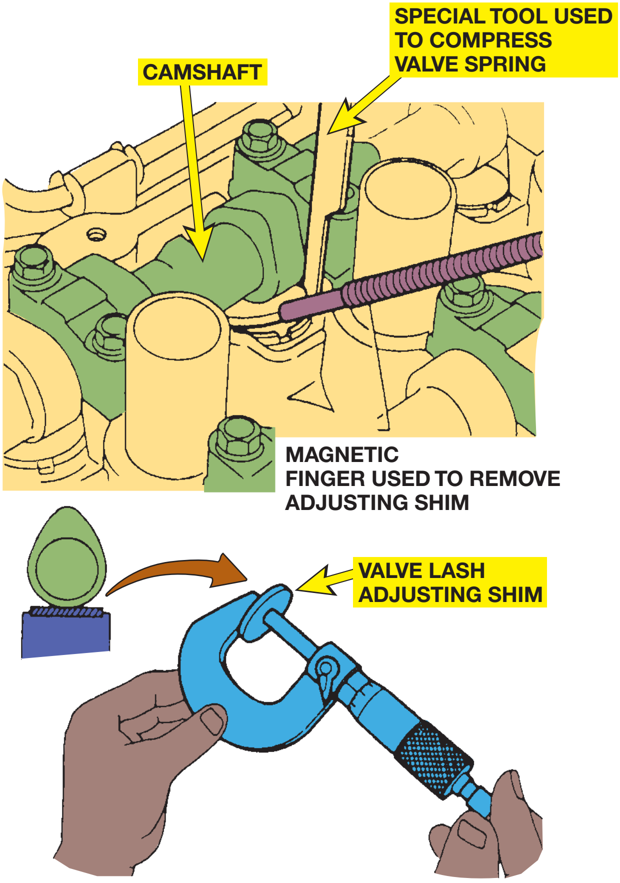

SPECIAL TOOL USED TO COMPRESS VALVE SPRING
CAMSHAFT
MAGNETIC FINGER USED TO REMOVE ADJUSTING SHIM
VALVE LASH ADJUSTING SHIM

FIGURE 34–37 Some overhead camshaft engines use valve lash adjusting shims to adjust the valve lash. A special tool is usually required to compress the valve spring so that a magnet can remove the shim.

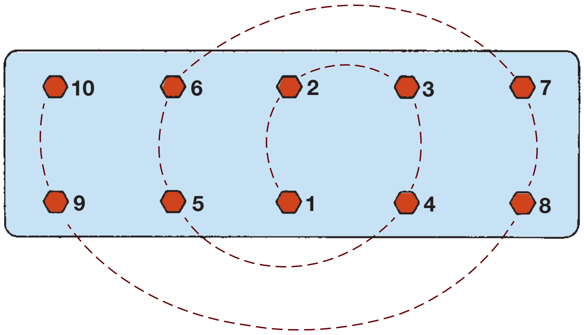


FIGURE 34–38 Typical cylinder head tightening sequence.

in the center and then moves to those farther and farther from the center. This procedure helps spread the forces toward the ends of the cylinder.

By tightening the head bolts in three steps, the head gasket has time to compress and conform to the block deck and cylinder head gasket surfaces. Follow that sequence and tighten the bolts in the following manner:

1. Tighten to *one-third* the specified torque.
2. Tighten them a second time following the torque sequence to *two-thirds* the specified torque.
3. Follow the sequence with a final tightening to the specified torque. ● **SEE FIGURES 34–38 AND 34–39**.

CLAMPING FORCE **Clamping force** is the amount of force exerted on a gasket. The clamping force is not the same as the torque applied to the fastener. When tightening a bolt or

TECH TIP

Watch Out for Wet and Dry Holes

Many engines, such as the small block Chevrolet V-8, use head bolts that extend through the top deck of the block and end in a coolant passage. These bolt holes are called *wet holes.* When installing head bolts into holes that end up in the coolant passage, always use sealer on the threads of the head bolt. Some engines have head bolts that are "wet," whereas others are "dry" because they end in solid cast-iron material. Dry hole bolts do not require sealant, but they still require some oil on the threads of the bolts for lubrication. Do not put oil into a dry hole because the bolt may bottom out in the oil. The liquid oil cannot compress, so the force of the bolt being tightened is transferred to the block by hydraulic force, which can crack the block.

NOTE: Apply oil to a shop cloth and rotate the bolt in the cloth to lubricate the threads. This procedure lubricates the threads without applying too much oil.

TECH TIP

The Piece of Paper Demonstration

Some students and beginning technicians forget the correct order to tighten head bolts or other fasteners of a component. Try the following demonstration:

- Place a single sheet of paper on a table.
- Place both hands on the paper in the center and then move your hands outward.
- Nothing should have happened and the paper should have not moved.
- Now place your hands on the paper at the ends and move them toward the center.
- The paper will wrinkle as the hands move toward the center.

This demonstration shows that the forces are moved away toward the ends of the cylinder head if the fasteners are tightened from the inside toward the outside. However, if the cylinder head bolts were tightened incorrectly, the head would likely crack due to the forces exerted during the tightening.

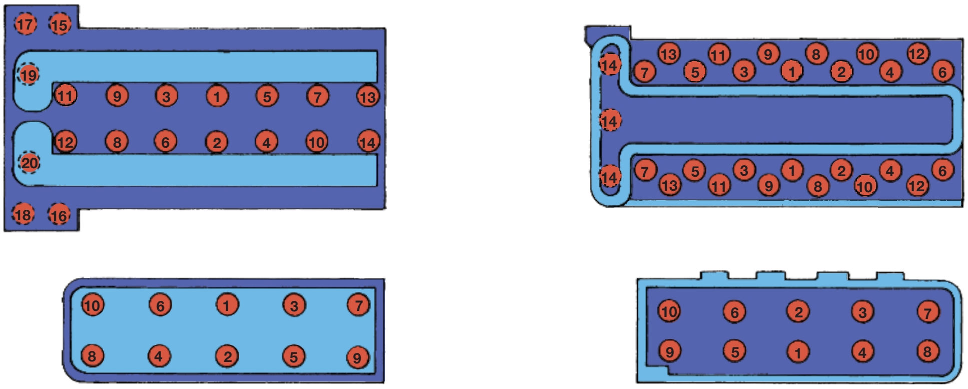


FIGURE 34–39 Examples of cylinder head bolt torquing sequences.

TECH TIP

Always "Exercise" New Bolts

New bolts and studs are manufactured by rolling the threads and heat treating. Due to this operation, the threads usually have some rough areas, which affect the clamping force on the gasket. Many engine building experts recommend that all new bolts be installed in the engine using a new or used gasket and torqued to specifications at least five times, except for torque-to-yield bolts. This process burnishes the ramps of the threads and makes the fastener provide a more even clamping force. Using the recommended lubricant, the bolts should be torqued and removed and then torqued again.

FREQUENTLY ASKED QUESTION

Why Do Both Head Gaskets Have "Front" Marked?

A common question asked by beginning technicians or students include how to install head gaskets on a V-6 engine that is mounted transversely (sideways) in the vehicle. The technician usually notices that "front" is marked on one gasket and therefore installs that gasket on the block, on top of the forward-facing cylinder bank. Then, the technician notices that the other gasket is also marked with "front." How could both be marked "front"? There must be some mistake. The mistake is in the terminology used. In the case of head gaskets, the "front" means toward the accessory drive belt end of the engine and *not* on the cylinder bank toward the front of the vehicle. ● **SEE FIGURE 34–40**.

nut, about 80% of the applied torque is used to overcome friction between the threads. Therefore, it is very important that the threads be clean and lubricated with the proper (specified) lubricant.

FASTENER CONSIDERATION Because most of the torque applied to a fastener is absorbed by friction, it is extremely important that the following steps be performed:

STEP 1 Clean the threads of all fasteners before using.

STEP 2 Check service information for the specified thread lubricant.

THREAD LUBRICANT If using aftermarket bolts or studs, such as ARP (American Racing Products®), use the lubricant and torque that the company specifies. Do not use ARP lubricant and the factory torque specifications or the fasteners will be greatly overtightened. The same applies if using thread sealant to the threads of fasteners being installed in wet holes (holes that extend into the cooling passages). Many vehicle manufacturers recommend the use of 30 weight engine oil (SAE 30).

CAUTION: SAE 5W-30 or SAE 10W-30 is not the same as SAE 30 engine oil. Multiviscosity oil such as SAE 5W-30 is actually SAE 5W oil with additives to provide the protection of SAE 30 oil when it gets hot. Always use the exact oil specified by the vehicle manufacturer.

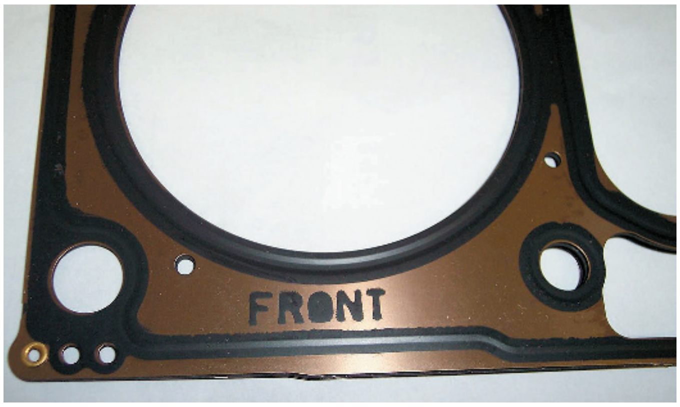


FIGURE 34–40 Typical head gasket markings. The front means that the gasket should be at the accessory drive belt end of the block.

TECH TIP

Creep Up on the Torque Value

Do not jerk or rapidly rotate a torque wrench. For best results and more even torque, slowly apply force to the torque wrench until it reaches the preset value or the designated torque. Jerky or rapidly moving the torque wrench will often cause the torque to be uneven and not accurate.

TORQUE-TO-YIELD HEAD BOLTS

DEFINITION AND TERMINOLOGY Many engines use a tightening procedure called the **torque-to-yield (TTY)** method. The purpose of the TTY procedure is to have a more consistent clamping load from bolt to bolt. This aids in head gasket sealing performance and eliminates the need for retorquing.

BOLT CONSTRUCTION Many torque-to-yield head bolts are made with a narrow section between the head and threads. As the bolts are tightened past their elastic limit, they yield and begin to stretch in this narrow section.

Torque-to-yield head bolts will not become any tighter once they reach this elastic limit, as seen on the graph in ● **FIGURE 34–41**.

The **torque angle** method also decreases the differences in clamping force that can occur depending on the condition or lubrication of the threads. ● **SEE FIGURE 34–42**.

As a result, many engine manufacturers specify *new* head bolts each time the head is installed. If these bolts are reused, they are likely to break during assembly or fail prematurely as the engine runs. If there is any doubt about the head bolts, replace them.

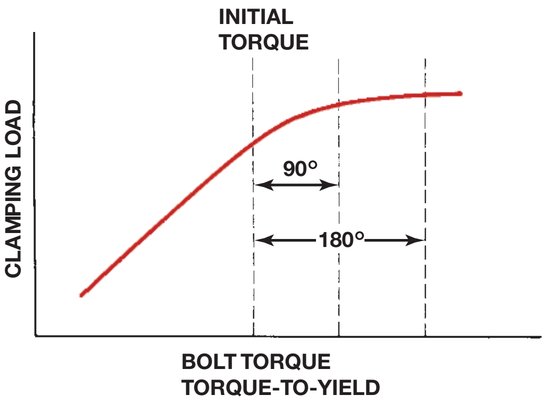


FIGURE 34–41 Due to variations in clamping force with turning force (torque) of head bolts, some engines are specifying the torque-to-yield procedure. The first step is to torque the bolts by an even amount called the initial torque. Final clamping load is achieved by turning the bolt a specified number of degrees. Bolt stretch provides the proper clamping force.

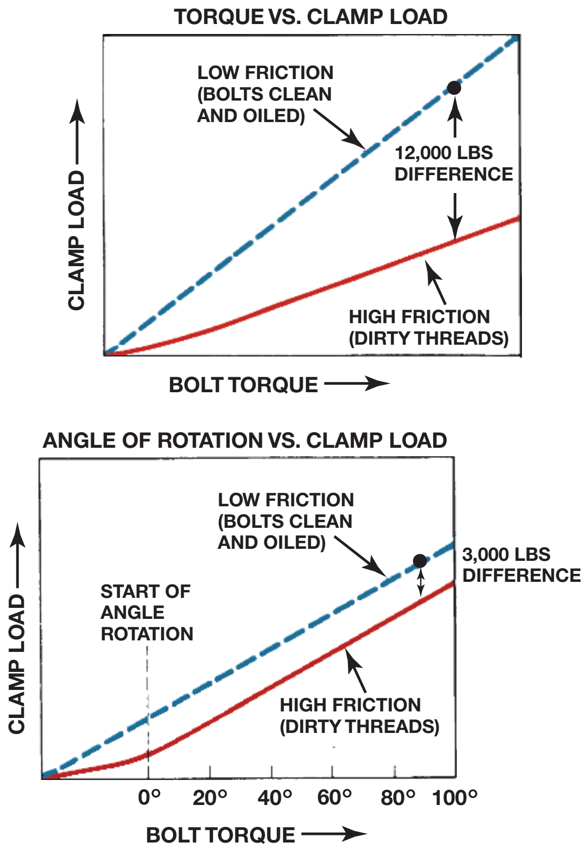


FIGURE 34–42 To ensure consistent clamp force (load), many manufacturers are recommending the torque-angle or torque-to-yield method of tightening head bolts. The torque-angle method specifies tightening fasteners to a low-torque setting and then giving an additional angle of rotation. Notice that the difference in clamping force is much smaller than it would be if just a torque wrench with dirty threads were used.

TORQUE-TO-YIELD PROCEDURE Torque-to-yield bolts are tightened to a specific initial torque, from 18 to 50 pound-feet (25 to 68 N-m). The bolts are then tightened an additional specified number of degrees, following the tightening sequence. In some cases, they are turned a specified number of degrees two or three times. Some specifications limit the maximum torque that can be applied to the bolt while the degree turn is being made. Torque tables in a service manual will show how much initial torque should be applied to the bolt and how many degrees the bolt should be rotated after torquing. Torque-to-yield head bolts should be tightened as per specified in service information.

The procedure includes the following steps:

STEP 1 Tighten the fasteners to an initial torque in the specified sequence.

STEP 2 Turn the fasteners a specific number of degrees using an angle gauge again following the same sequence.

STEP 3 Turn the fasteners another specific number of degrees again following the designated sequence.

For example, a specified head bolt tightening specification may include

- Initial torque, such as 44 lb-ft
- Rotate 90 degrees
- Rotate head bolts an additional 90 degrees ● **SEE FIGURES 34–43 AND 34–44**.

TORQUE ANGLE METHOD The *torque angle method,* also called the *torque-turn method,* does not necessarily mean torque-to-yield.

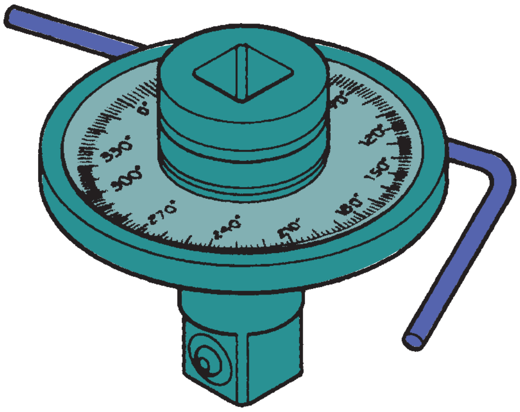


FIGURE 34–43 Torque angle can be measured using a special adaptor.

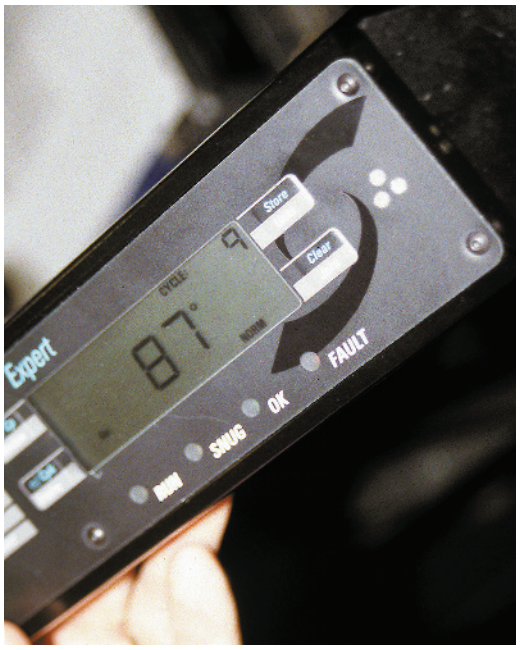


FIGURE 34–44 An electronic torque wrench showing the number of degrees of rotation. These very accurate and expensive torque wrenches can be programmed to display torque or number of degrees of rotation.

Some engine specifications call for a beginning torque and then a specified angle, but the fastener is not designed to yield. These head bolts can often be reused. Always follow the manufacturer's recommended procedures.

VALVE TRAIN ASSEMBLY

TIMING DRIVES FOR OHC ENGINES After the head bolts have been torqued, the cam drive can be installed on overhead cam (OHC) engines. This is done by aligning the timing marks of the crankshaft and camshaft drive sprockets with their respective timing marks. The location of these marks differs between engines, but the marks can be identified by looking carefully at the sprockets. ● **SEE FIGURES 34–45 AND 34–46**.

The tensioner may be on either or both sides of the timing belt or chain. After the camshaft drive is engaged, rotate the crankshaft through two full revolutions. On the first full revolution, the exhaust valve will be almost closed and the intake valve will just be starting to open when the *crankshaft* timing mark aligns. At the end of the second revolution, both valves should be closed, and all the timing marks should align on most engines. This is the position the crankshaft should have when cylinder 1 is ready to be fired.

NOTE: Always check the manufacturer's recommended timing chain installation procedure. Engines that use primary and secondary timing chains often require an exact detailed procedure for proper installation.

HYDRAULIC VALVE LIFTER INSTALLATION Most vehicle manufacturers recommend installing lifters *without* filling or pumping the lifter full of oil. If the lifter is filled with oil during engine start-up, the lifter may not be able to bleed down quickly enough and the valves may be kept open. Not only will the engine not operate correctly with the valves held open, but the piston also could hit the open valves, causing serious engine damage. Most manufacturers usually specify that the lifter be lubricated. Roller hydraulic lifters can be lubricated with engine oil, whereas flat lifters require that engine assembly lube or extreme pressure (EP) grease be applied to the base.

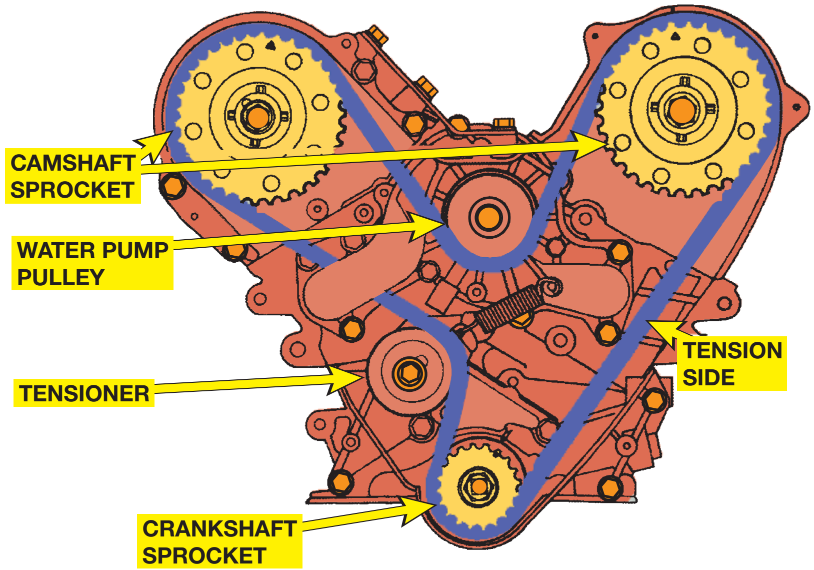


FIGURE 34–45 Both camshafts have to be timed on this engine and the timing belt also drives the water pump.

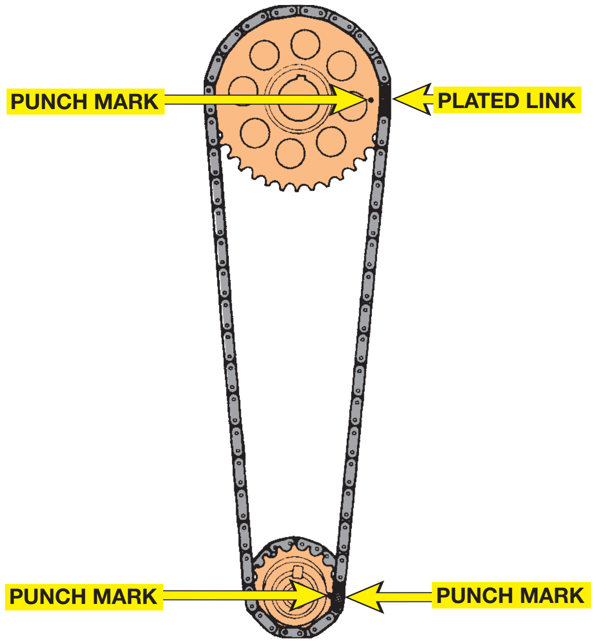


FIGURE 34–46 Some timing chains have plated links that are used to correctly position the chain on the sprockets.

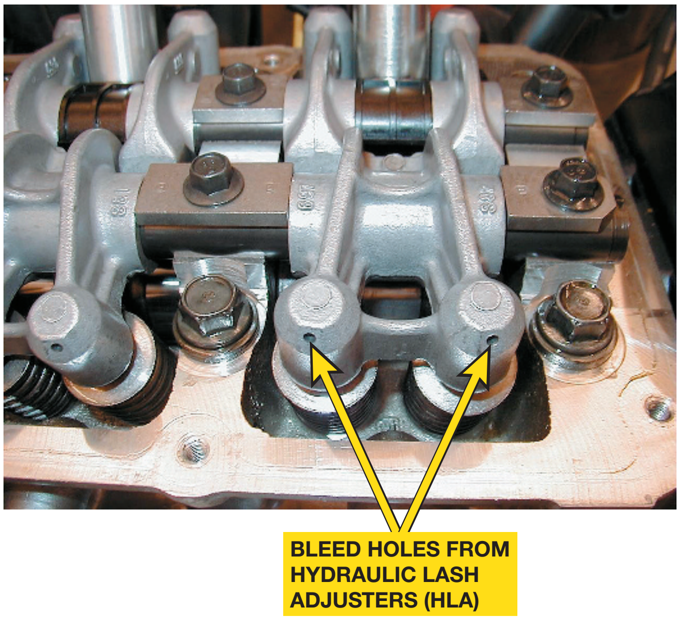


FIGURE 34–47 A special tool may be needed to bleed air from the hydraulic lash adjusters (HLA) through the bleed hole. These lash adjusters are part of the valve end of the rocker arms in this example.

BLEEDING HYDRAULIC LIFTERS Air trapped inside a hydraulic valve lifter can be easily bled by simply operating the engine at a fast idle (2500 RPM). Normal oil flow through the lifters will allow all of the air inside the lifter to be bled out.

NOTE: Some engines, such as many Nissan overhead camshaft engines, *must* have the air removed from the lifter before installation. This is accomplished by submerging the lifter in a container of engine oil and using a straightened paper clip to depress the oil passage check ball.

Check service information if in doubt about the bleeding procedure for the vehicle being serviced. ● **SEE FIGURE 34–47**.

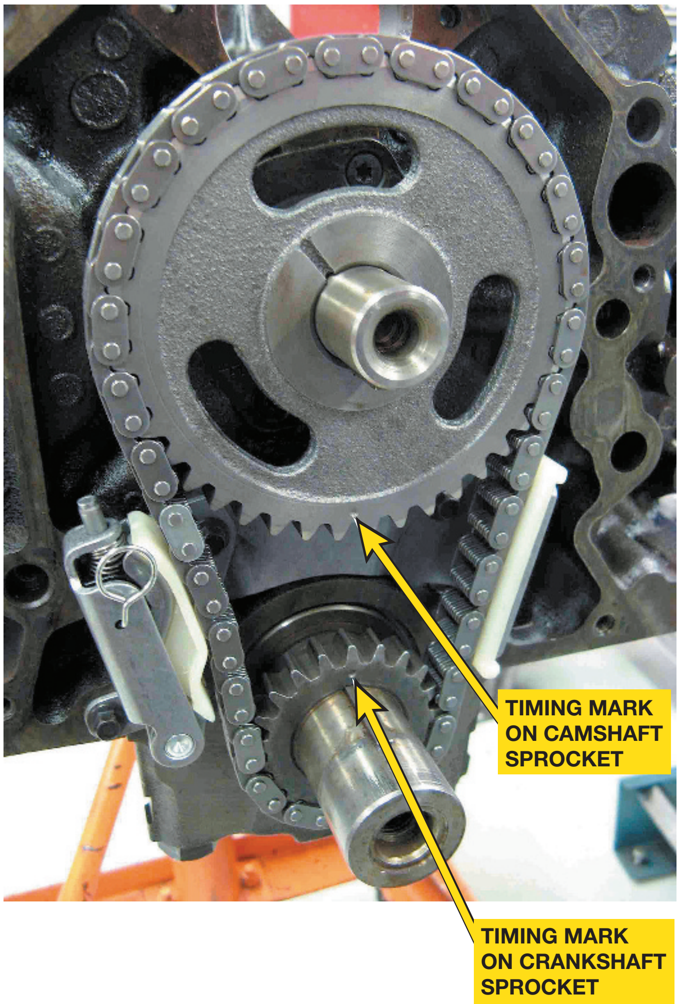

TIMING MARK ON CAMSHAFT SPROCKET
TIMING MARK ON CRANKSHAFT SPROCKET

FIGURE 34–48 Timing chain and gears can be installed after the crankshaft and camshaft have been installed and the timing marks are aligned with cylinder 1 at top dead center (TDC).

TECH TIP

Soak the Timing Chain

Many experts recommend that a new timing chain be soaked in engine oil prior to engine assembly to help ensure full lubrication at engine start-up. The timing chain is one of the last places in the engine to get lubrication when the engine first starts. This procedure may even extend the life of the chain.

TIMING CHAINS AND GEARS INSTALLATION On cam-in-block (OHV) engines, the timing gears or chain and sprocket can be installed after the crankshaft and camshaft. The timing marks should be aligned according to the factory specified marks. ● **SEE FIGURE 34–48**.

When used, the replaceable fuel pump eccentric is installed as the cam sprocket is fastened to the cam. The crankshaft should be rotated several times to see that the camshaft and timing gears or chain rotate freely. The timing mark alignment should be rechecked at this time. If the engine is equipped with a slinger ring, it should also be installed on the crankshaft, in front of the crankshaft gear.

TECH TIP

Watch Out for Different Length Pushrods

The very popular General Motors family of engines, including 2.8 liter, 3.1 liter, 3.4 liter, and 3.5 liter, each use different pushrod lengths for intake and exhaust valves. If the wrong pushrods are used, two things can occur:

1. The pushrod(s) can be bent.
2. The engine will run rough because the longer pushrod prevents the valve from closing all the way.

Always check service information for the exact location of the pushrods.

OHV ENGINE LIFTER AND PUSHROD INSTALLATION The outside of the lifters and the lifter bores in the block should be cleaned and coated with assembly lubricant. The lifters are installed in the lifter bores and the pushrods put in place. There are different length pushrods on some engines. Make sure that the pushrods are installed in the proper location. The rocker arms are then put in place, aligning with the valves and pushrods. Rocker arm shafts should have their retaining bolts tightened a little at a time, alternating between the retaining bolts. This keeps the shaft from bending as the rocker arm pushes some of the valves open.

HYDRAULIC LIFTER ADJUSTMENT The retaining nut on some rocker arms mounted on studs can be tightened to a specified torque. The rocker arm stud will have a shoulder on this type of rocker assembly. The rocker arm will be adjusted correctly at this torque when the valve tip has the correct height. Other types of rocker arms require tightening the nut to a position that will center the hydraulic lifter. The general procedure includes the following steps:

STEP 1 Rotate the engine until cylinder 1 is at TDC on the compression stroke to be assured that both the intake and exhaust valves are on the base circle of the cam lobes.

STEP 2 Tighten the retaining nut to the point that all free lash is gone and the pushrod cannot be easily rotated. ● **SEE FIGURE 34–49**.

STEP 3 From this point, the retaining nut is tightened by a specified amount, such as three-fourths of a turn or one and one-half turns.

STEP 4 Rotate the engine until the next cylinder in the firing order is at top dead center on the compression stroke. The valves on this next cylinder are adjusted in the same manner as those on cylinder 1. This procedure is repeated on each cylinder *following the engine firing order* until all the valves have been adjusted. Always follow the specified procedure found in service information.

SOLID LIFTER ADJUSTMENT The valve clearance or **lash** must be set on a solid lifter engine, so that the valves can positively seat. Check service information for the specified adjustment sequence to follow to set the lash. If this is not available, then the following procedure can be used on all engines requiring valve lash adjustment. The valve lash is adjusted with the valves completely closed. ● **SEE FIGURE 34–50**.

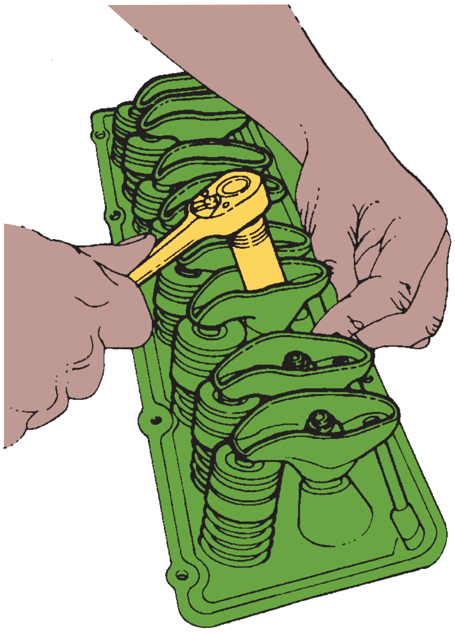


FIGURE 34–49 With the lifter resting on the base circle of the cam, zero lash is achieved by tightening the rocker arm lock nut until the pushrod no longer rotates freely.

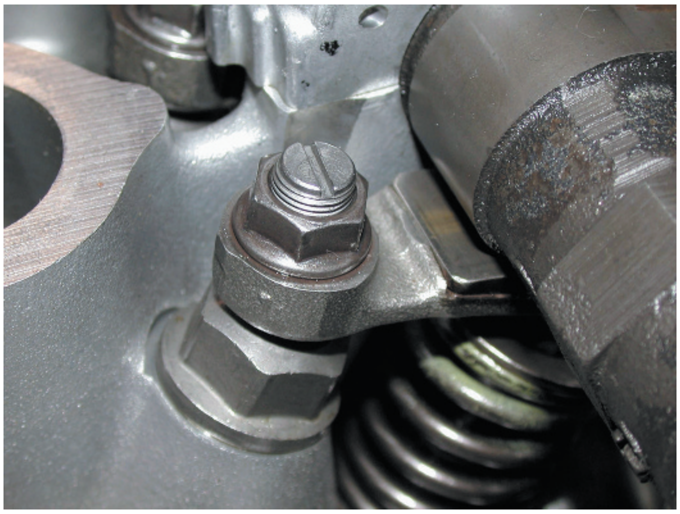


FIGURE 34–50 Most adjustable valves use a nut to keep the adjustment from changing. Therefore, to adjust the valves, the nut has to be loosened and the screw rotated until the proper valve clearance is achieved. Then the screw should be held while tightening the lock nut to keep the adjustment from changing. Double-check the valve clearance after tightening the nut.

The procedure is similar to that used to adjust hydraulic lifters that are adjustable except that a feeler gauge is used to check the lash. The same valve lash adjustment sequence is used on overhead cam engines. Those engines with rocker arms or with adjustable finger follower pivots are adjusted in the same way as pushrod engines with rocker arms.

FINAL ASSEMBLY

MANIFOLD INSTALLATION The intake manifold gasket for a V-type engine may be a one-piece gasket or it may have several pieces. V-type engines with open-type manifolds have a cover over the lifter valley. The cover may be a separate part or it may

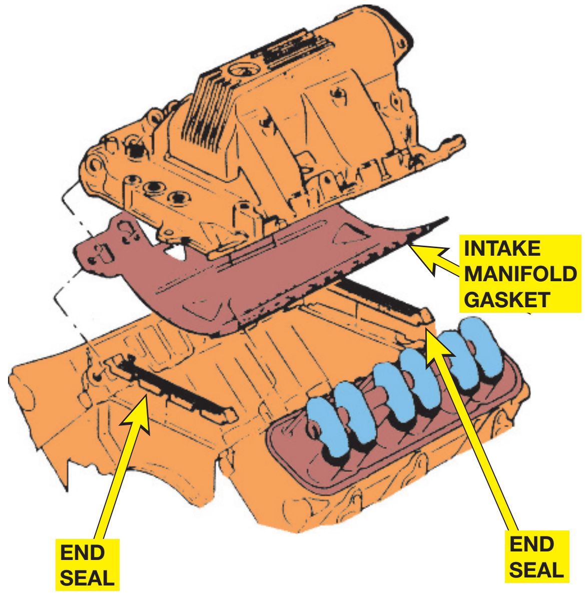


FIGURE 34–51 This intake manifold gasket includes end seals and a full shield cover for the valley to keep hot engine oil from heating the intake manifold.

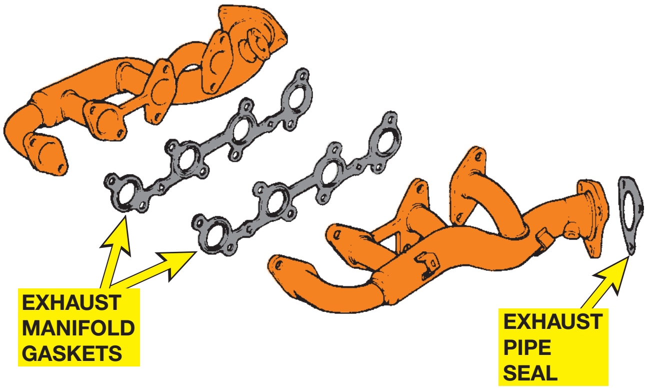


FIGURE 34–52 An exhaust manifold gasket is used on some engines. It seals the exhaust manifold to the cylinder head.

be part of a one-piece intake manifold gasket. Closed-type intake manifolds on V-type engines require gasket pieces (end seals) at the front and rear of the intake manifold. ● **SEE FIGURE 34–51**.

Inline engines usually have a one-piece intake manifold gasket. The intake manifold is put in place over the gaskets. Use a contact adhesive to hold the gasket and end seal if there is a chance they might slip out of place. Install the bolts and tighten to the specified torque following the correct tightening sequence.

Only some exhaust manifolds use gaskets. The exhaust manifold operates at very high temperatures, so there is usually some expansion and contraction movement in the manifold-to-head joint. It is very important to use attachment bolts, cap screws, and clamps of the correct type and length. ● **SEE FIGURE 34–52**. They must be properly torqued to avoid both leakage and cracks.

NOTE: If the exhaust manifold gasket has a metal facing on one side, place the metal facing toward the head.

TIMING COVER INSTALLATION The timing cover with seal and gasket installed are placed over the timing gears and/or chain and sprockets. The attaching bolts are loosely installed to allow the damper hub to align with the cover as it fits in the seal. The damper is installed on the crankshaft. On some engines, it is a press-fit and on others it is held with a large center bolt. After the damper is secured, the attaching bolts on the timing cover can be tightened to the specified torque.

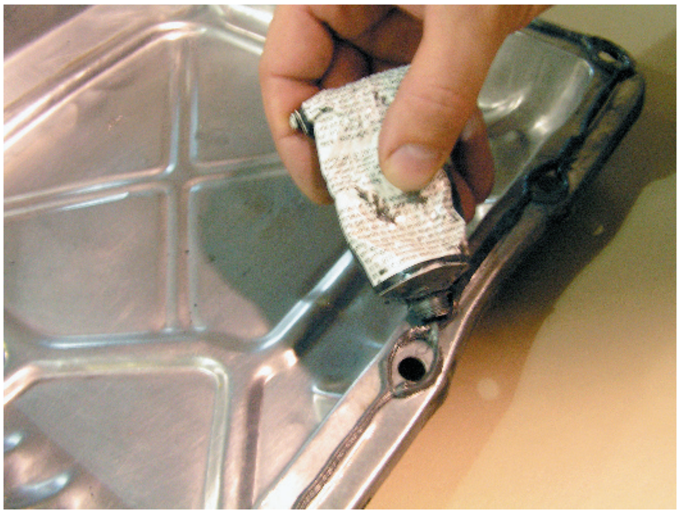


FIGURE 34–53 A 1/8 to 3/16 inch (3 to 5 mm) bead of RTV silicon on a parting surface with silicon going around the bolt hole.

Most timing covers are installed with a gasket, but some use RTV sealer in place of the gasket. A bead of RTV silicon 1/8 to 3/16 inch (3 to 5 mm) in diameter is put on the clean sealing surface. ● **SEE FIGURE 34–53**.

Sealing a cover using RTV silicon usually includes the following steps:

STEP 1 Encircle the bolt holes with the sealant.

STEP 2 Install the cover before the silicon begins to cure so that the uncured silicon bonds to both surfaces.

STEP 3 While installing the cover, do not touch the silicon bead, otherwise the bead might be displaced and cause a leak.

STEP 4 Carefully press the cover into place. Do not slide the cover after it is in place.

STEP 5 Install the assembly bolts finger tight, and let the silicon cure for about 30 minutes before tightening the cover bolts.

When installing *cast covers,* anaerobic compound (such as Loctite®) is often used as a gasket substitute.

VIBRATION DAMPER INSTALLATION Vibration dampers are seated in place by one of three methods:

- The damper hub of some engines is pulled into place using the hub attaching bolt.
- The second method uses a special installation tool that screws into the attaching bolt hole to pull the hub into place. The tool is removed and the attaching bolt is installed and torqued.
- The last method is used on engines that have no attaching bolt. These hubs depend on a press-fit to hold the hub on the crankshaft. The hub is seated using a special tube-type driver. Check service information for the exact procedure and tool to use.

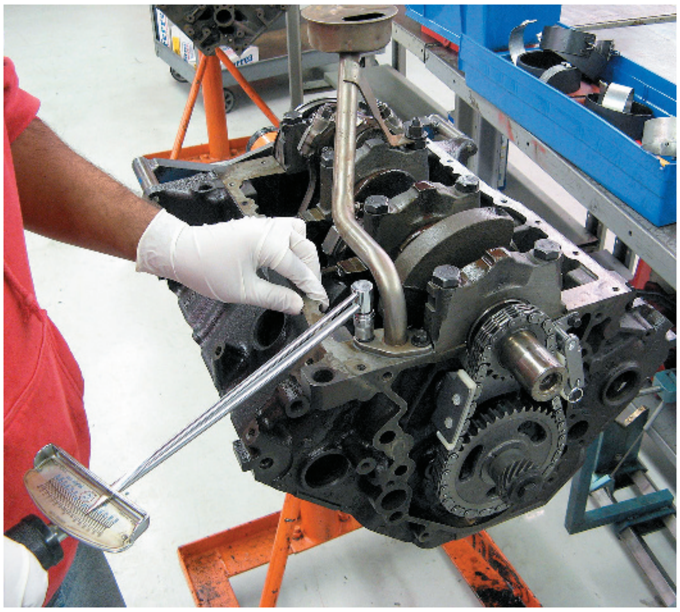


FIGURE 34–54 A beam-type torque wrench being used to tighten the oil pump pickup assembly to factory specification.

OIL PUMP INSTALLATION When an engine is rebuilt, the oil pump should be replaced with a new pump and oil pickup screen. Most vehicle manufacturers recommend that the oil pump and screen be replaced rather than cleaned. This ensures positive lubrication and long pump life. Oil pump gears should be coated with assembly lubricant before the cover is put on the pump. This provides initial lubrication, and it primes the pump so that it will draw the oil from the pan when the lubrication system is first operated. Torque the oil pump fasteners to factory specifications. ● **SEE FIGURE 34–54**.

TECH TIP

Check the Oil Pump Pickup to Oil Pan Clearance

Whenever installing the oil pan on a rebuilt engine, it is wise to check the clearance between the oil pump pickup and the bottom of the oil pan. This distance should be 3/16 to 3/8 inch (5 to 9 mm). To check the clearance, two methods can be used:

METHOD 1 With the engine upside down and the oil pump and pickup installed, measure the distance from the oil pan rail to the top (actually the bottom) of the oil pump pickup. Then measure the distance from the oil pan rail to the bottom of the oil pan and subtract the two measurements to get the clearance.

METHOD 2 Place about 1/2 inch (13 mm) of modeling clay on the pickup of the oil pump. Then temporarily install the oil pan with a gasket. Press down on the oil pan to compress the modeling clay. Remove the oil pan and measure the thickness of the clay. This thickness is the oil pan to oil pump pickup clearance. ● **SEE FIGURE 34–55**.

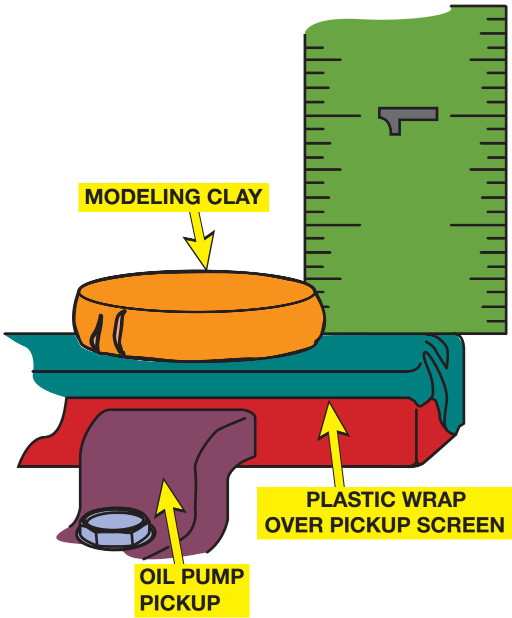


FIGURE 34–55 Using clay to determine the oil pan to oil pickup clearance, which should be about 1/4 inch (6 mm).

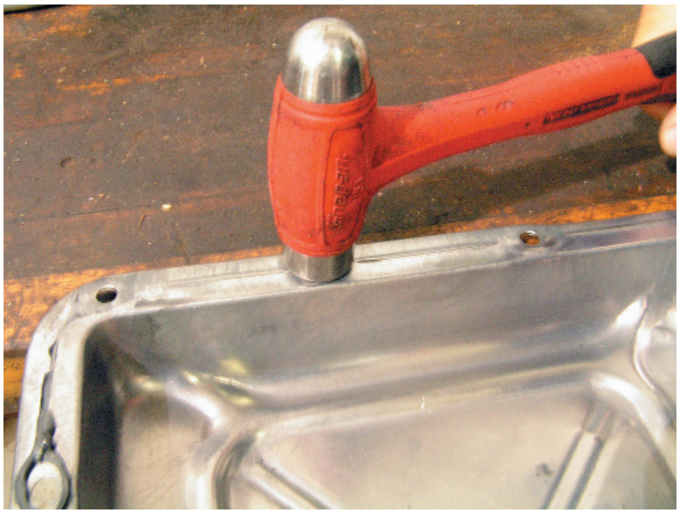


FIGURE 34–56 Using a hammer to straighten the gasket rail surface of the oil pan before installing a new gasket. When the retaining bolts are tightened, some distortion of sheet metal covers occurs. If the area around the bolt holes is not straightened, leaks can occur with the new gasket.

OIL PAN INSTALLATION The oil pan should be checked and straightened as necessary. ● **SEE FIGURE 34–56**.

With the oil pump in place, the oil pan gaskets are properly positioned. The oil pan is carefully placed over the gaskets. All oil pan bolts should be started into their holes before any are tightened. The bolts should be alternately snugged up and then they should be properly tightened to factory specifications. Always follow the instructions that come with the gasket for best results.

WATER PUMP INSTALLATION A reconditioned, rebuilt, or new water pump should be used. Once gaskets are fitted in place, the pump is secured with assembly bolts tightened to the correct torque.

A new thermostat should be installed being careful to check that the wax pellet side of the thermostat faces toward the engine. The thermostat housing with the proper gasket is installed, and the retaining bolts are tightened to the proper torque.

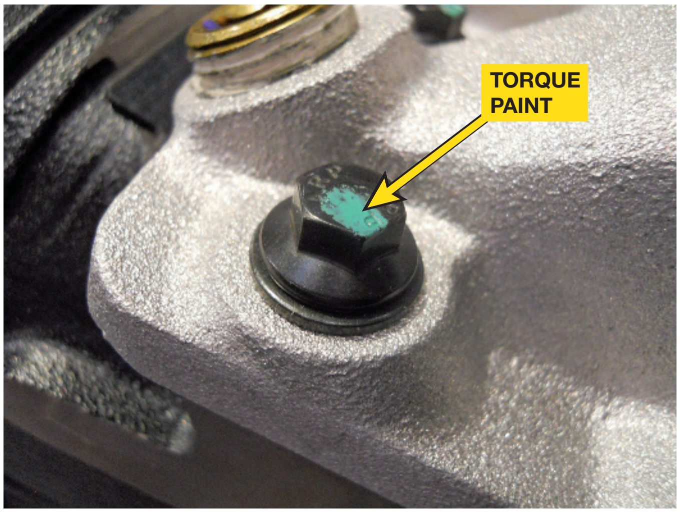


FIGURE 34–57 Torque paint applied to the head of the fastener indicates that it has been properly torqued to factory specification.

FREQUENTLY ASKED QUESTION

What Is "Torque Paint"?

Whenever a major fastener is tightened to the proper torque at the assembly plant, a dab of paint is applied to the head of the fastener to indicate that it was properly torqued. This is part of the quality control procedure used to help ensure that all fasteners are properly tightened to factory specification. ● **SEE FIGURE 34–57**.

ENGINE PAINTING Painting an engine helps prevent rust and corrosion and makes the engine look new. Standard engine paints with original colors are usually available at automotive parts stores. Engine paints should be used rather than other types of paints.

PRELUBRICATING THE ENGINE With oil in the engine and the distributor, if equipped, out of the engine, oil pressure should be established before the engine is started. This can be done on most engines by rotating the oil pump using an electric drive. This ensures that oil is delivered to all parts of the engine before the engine is started. Adapters are available that allow an electric drill motor to rotate the oil pump.

Engines that do not drive the oil pump with a distributor will require the use of a pressurized pre-lubing tool, such as the General Motor recommended J-45299 or the Goodson PL-40. ● **SEE FIGURE 34–58**.

SETTING IGNITION TIMING After oil pressure is established, the distributor, if equipped, can be installed. Rotate the crankshaft in its normal direction of rotation until there is compression on cylinder 1. This can be done with the starter or by using a wrench on the damper bolt. The compression stroke can be determined by covering the opening of spark plug 1 with a finger as the crankshaft is rotated. Continue to rotate the crankshaft slowly as compression is felt, until the timing marks on the damper align with the timing indicator on the timing cover.

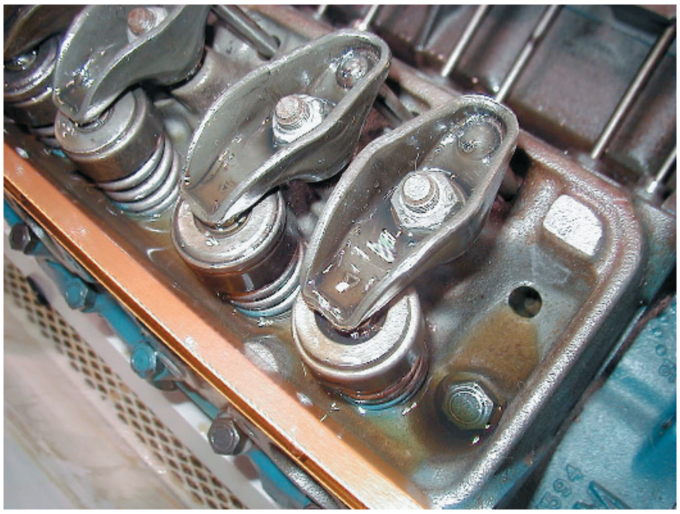


FIGURE 34–58 Oil should be seen flowing to each rocker arm as shown.

CASE STUDY

"Oops"

After overhauling a big block Ford V-8 engine, the technician used an electric drill to rotate the oil pump with a pressure gauge connected to the oil pressure sending unit hole. When the electric drill was turned on, oil pressure would start to increase (to about 10 PSI), then drop to zero. In addition, the oil was very aerated (full of air). Replacing the oil pump did not solve the problem. After hours of troubleshooting and disassembly, it was discovered that an oil gallery plug had been left out underneath the intake manifold. The oil pump was working correctly and pumped oil throughout the engine and out of the end of the unplugged oil gallery. It did not take long for the oil pan to empty and the oil pump began drawing in air that aerated the oil, which caused the oil pressure to drop. Installing the gallery plug solved the problem.

NOTE: Many overhead camshaft engines use an oil passage check valve in the block near the deck. The purpose of this valve is to hold oil in the cylinder head around the camshaft and lifters when the engine is stopped. Failure to reinstall this check valve can cause the valve train to be noisy after engine start-up.

Summary:

Complaint—Newly overhauled engine lost oil pressure shortly after start up.

Cause—An oil gallery plug was found to be missing.

Correction—The missing plug was installed and after reassembly, the engine oil pressure was normal.

The angle of the distributor gear drive will cause the distributor rotor to turn a few degrees when installed. Before the distributor is installed, the shaft must be positioned to compensate for the gear angle. After installation, the rotor should be pointing to tower 1 of the distributor cap.

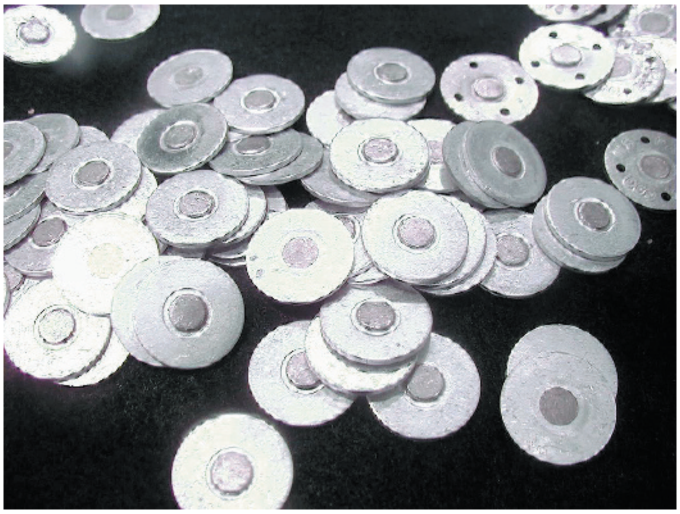


FIGURE 34–59 Heat tabs can be purchased from engine supply companies.

TECH TIP

Install Heat Tabs

The wise engine builder should install a heat tab to the back of the cylinder head(s). A heat tab uses a special heat-sensitive metal in the center of a mild steel disc. If the temperature of the cylinder head exceeds 250°F (121°C), the center of the tab will melt and flow out indicating that the engine was overheated. ● **SEE FIGURE 34–59**.

The distributor position should be close enough to the basic timing position to start the engine. If the distributor holddown clamp is slightly loose, the distributor housing can be adjusted to make the engine run smoothly after the engine has been started.

DYNAMOMETER TESTING

PURPOSES The purposes for using an engine dynamometer after an engine is assembled are varied. The testing

1. Allows the completed engine to be started and run to operating temperature
2. Permits checking for possible problems or leaks before the engine is installed in a vehicle
3. Allows the piston rings to seat and the engine to be partially broken in before being installed in a vehicle
4. Permits the technician to determine the output of the engine
5. Allows the opportunity to maximize the engine output by changing air–fuel ratios and valve or ignition timing until the best performance has been achieved

TYPES OF DYNAMOMETERS Basic types of dynamometers include

- A *brake type,* where a variable load is applied to the engine and the computer calculates the power output based on the readings taken from the load cell or strain gauge and engine RPM. Most brake types use a water impeller to create the load on the engine. ● **SEE FIGURE 34–60**.
- An *inertia type,* which measures engine power by using the engine to accelerate a known mass load. An inertia-type dynamometer is most often used to measure the power of an engine at the drive wheels of the vehicle. ● **SEE FIGURE 34–61**.

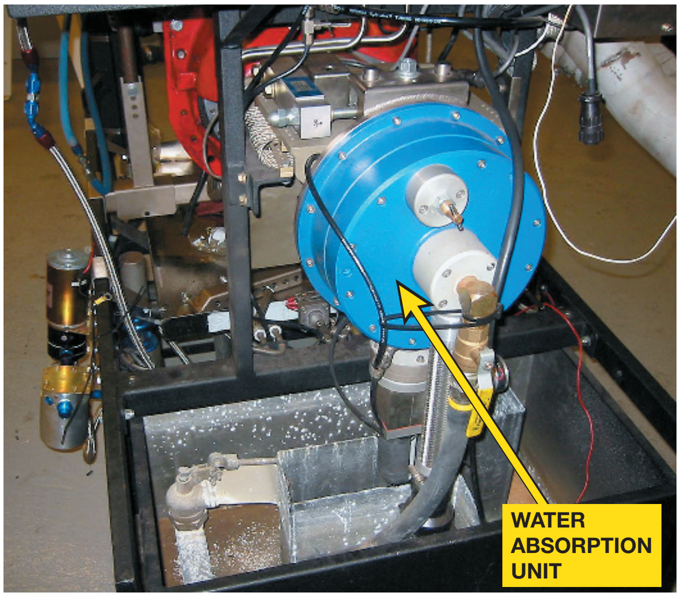


FIGURE 34–60 A dynamometer measures engine torque by applying a resistive force to the engine and measuring the force applied. Water is being used as the resistive load on this dynamometer.

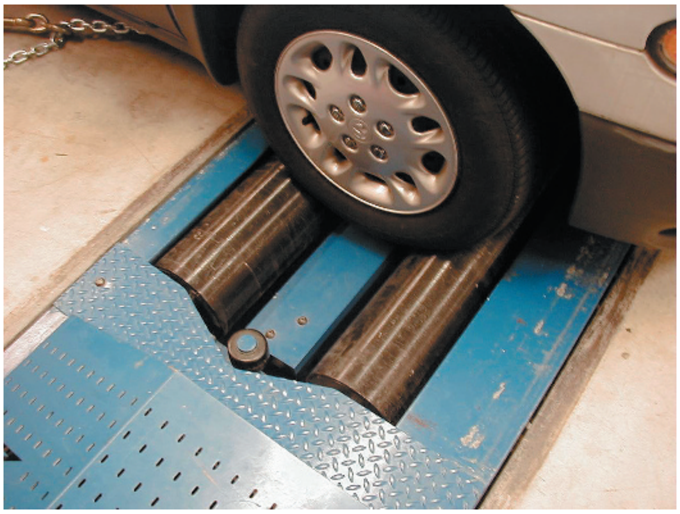


FIGURE 34–61 A chassis dynamometer is used to measure torque at the drive wheels. There is a power loss through the drive train so the measured values are about 20% less than when measuring engine output at the flywheel using an engine dynamometer.

TERMINOLOGY Numbers allow values to be assigned to virtually everything being measured or tested. The numbers help identify, quantify, and compare variables and performance.

Two types of data include

1. **Measured values.** Taken directly from the engine using sensors that read the actual data.
2. **Calculated values**. Those found by using basic numbers and a formula to obtain them.

MEASURED VALUES Measured units are those that are obtained directly from sensors and include

- **Torque.** As the name implies, this is the amount of twisting force that the engine puts out at the crank flange. Typically this is measured in foot-pounds.

NOTE: Dynamometers only measure torque output of an engine. Horsepower is not measured directly but is instead a calculated value.

- **Fuel flow.** Mass flow rate of fuel is calculated by the number of gallons per hour times pounds per gallon and is measured in pounds per hour. To determine this value, the specific gravity of the fuel has to be measured and entered into the computer prior to the engine tests so the program can calculate the fuel flow. Make sure there is enough fuel delivery for the engine by checking the gallons per hour prior to running each engine. Proper pressure (PSI) does not mean that there is enough volume being delivered to the engine especially under load conditions.
- **Manifold pressure.** Measured in inches of mercury (in. Hg), this value is called *manifold vacuum* in a normally aspirated engine.
- **Oil pressure.** This should be about 10 PSI per 1000 RPM.
- **Air inlet pressure.** Core value used to calculate the correction factor during the run, also referred to as dry bulb (DB) temperature. **Dry bulb temperature** is the temperature of a room where the thermometer is shielded from moisture. This reduces the effect of evaporation of moisture from the thermometer, which could affect the temperature reading.
- **Fuel temperature.** Used to calculate the density of fuel for fuel flow values.
- **Oil temperature.** Very important in run-to-run comparisons. Typically, the hotter the oil, the more horsepower an engine makes (up to a point). Oil that is too hot loses its cooling capability as well as some of its lubricating properties.
- **Engine coolant temperature.** This reading is important to monitor as a safety limit to help prevent possible engine damage if it goes too high.

Transducers are needed to measure the basic values. A transducer is a device that is able to convert various input signals such as pressures and temperature into an electrical signal that a computer can recognize. Typical dynamometer transducers include

- Magnetic pickups ● **SEE FIGURE 34–62**.
- Load cells
- Strain gauge flow meters
- Rotary potentiometers or rheostats
- Thermocouples
- Linear variable displacement transducers (LVDT)

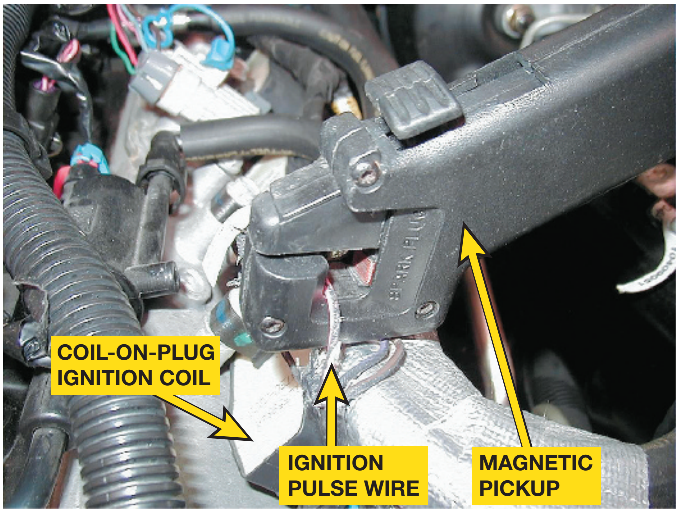


FIGURE 34–62 A magnetic pickup being used to monitor engine speed when the vehicle is being tested on a chassis dynamometer.

CALCULATED NUMBERS Calculated numbers are those that are obtained by using the measured values and processing them through software to obtain the following:

- **Corrected torque.** This is a calculated number determined by the actual torque multiplied by the correction factor. This is an important number and the reading should show a wide and flat band of torque over a broad engine speed range.
- **Corrected horsepower.** This is a calculated number showing the corrected observed horsepower.
- **Frictional horsepower.** This can best be thought of as the power required to rotate the engine over without firing and without pumping losses.
- **Volumetric efficiency.** This is a measure of the engine's cylinder filling efficiency; 100% represents filling a cylinder to its total swept volume. On a race engine, it is quite normal to see over 100% volumetric efficiency.
- **Mechanical efficiency.** This is the ratio of the engine's frictional torque divided by its corrected output torque. A value of 100% would indicate that the engine had no frictional losses.

STANDARDS For best results, perform testing on nice days with low relative humidity and high atmospheric pressure. These factors have a huge effect on the amount of air that the engine can "breathe" in, which in turn can dramatically affect horsepower readings. Testing on nice days is not always possible, so using corrected data allows the technician to compare test results from day to day and dynamometer to dynamometer. A **correction factor** is a value that is multiplied to the data values so that engine performance can be compared regardless of weather conditions. Over the years there have been many different correction factors specified by the Society of Automotive Engineers (SAE) including

- SAE J606
- SAE J607 (Using this correction factor results in higher numbers than if using other correction factors mainly due to the higher barometric pressure standard used.)
- SAE J1349
- SAE J1739

There are subtle differences between each of the testing standards. The result after the correction factor has been applied is called **corrected torque**. From the corrected torque values, the other units such as horsepower can be calculated.

FINAL NOTES

- Corrected numbers are to be applied to wide open throttle (WOT) runs only.
- Corrected numbers apply only to *normally aspirated* engines and are not to be used for turbocharged or supercharged engines.
- Double-check that the spark timing is set relative to top dead center (TDC).
- Double-check that the engine has good electrical grounds and adequate voltage.
- Be sure to have enough *good* fuel before starting to test an engine. Do not use any gasoline older than 90 days.

TECH TIP

Look at the Crossing Point

All dynamometers measure torque of an engine, then calculate the horsepower. Horsepower is torque multiplied by engine speed (RPM) divided by 5252 (a constant). Therefore, all graphs should show that the two curves for horsepower and torque should be the same at 5252 RPM. ● **SEE FIGURE 34–63**.

TECH TIP

Compare Dyno Results from the Same Dyno Only

There are too many variables between dynamometers to allow a fair comparison when testing an engine. If changes are made to the engine, try to use the same dynamometer and use the same correction factors. Using another dynamometer can result in readings that may not be equivalent when testing on the original tester.

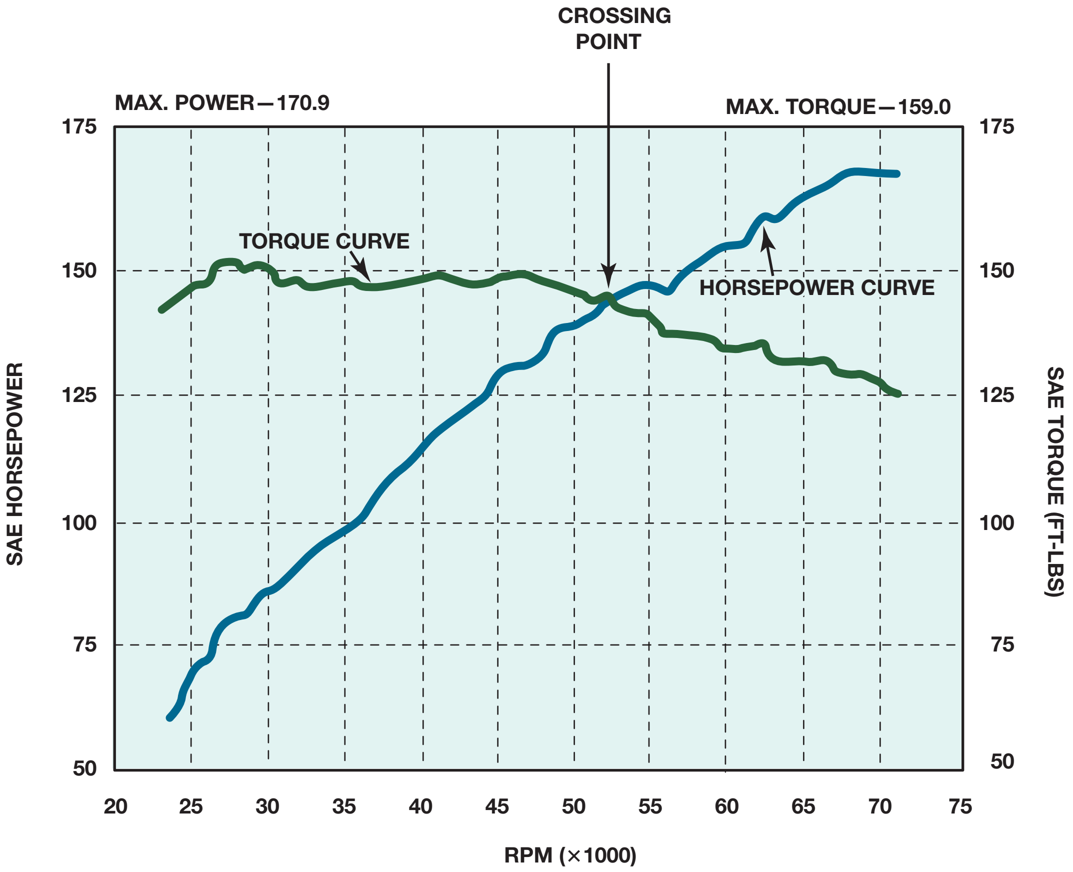
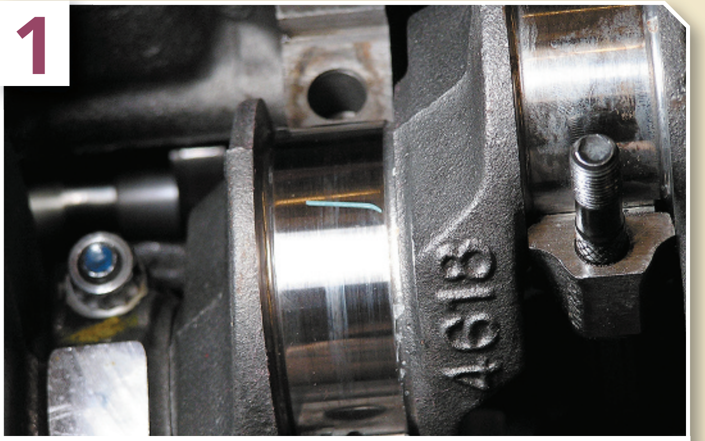


FIGURE 34–63 Because horsepower is calculated from measured torque, the horsepower and torque curves should always cross at exactly 5252 RPM.

PLASTIGAGE

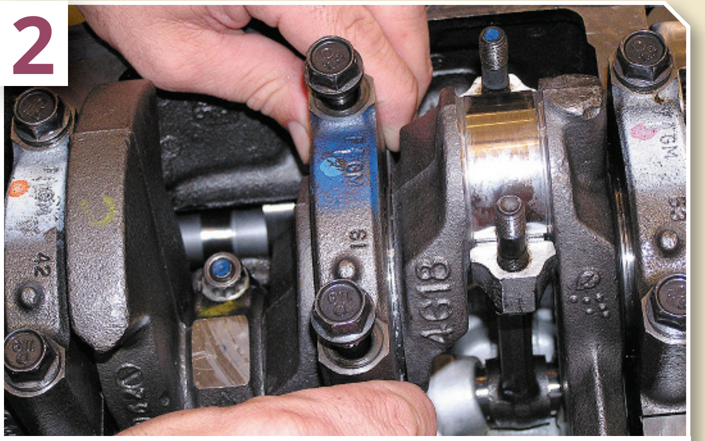
STEP BY STEP

1



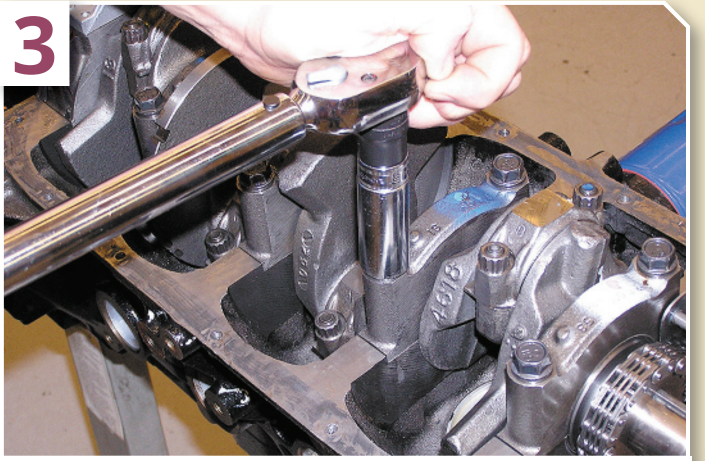
Clean the main bearing journal and then place a strip of Plastigage material across the entire width of the journal.

2



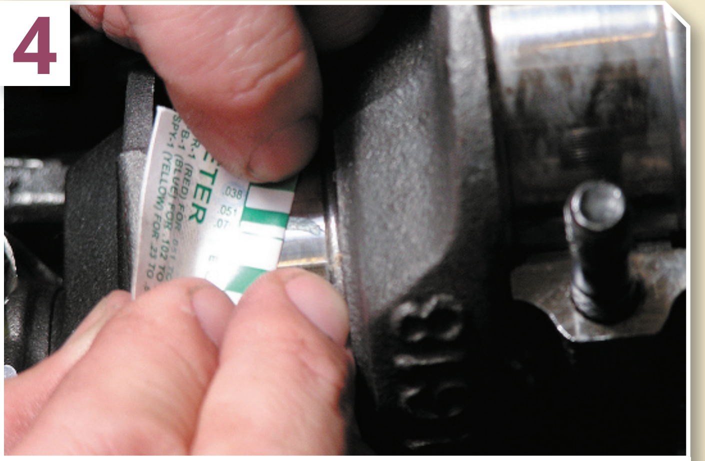
Carefully install the main bearing cap with the bearing installed.

3



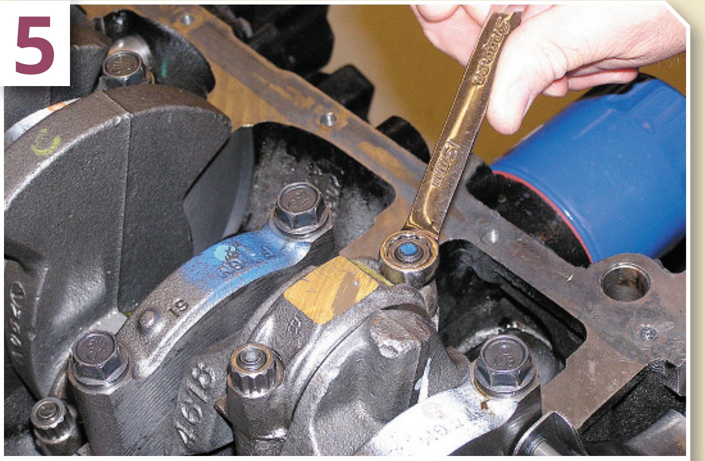
Torque main bearing cap bolts to factory specifications.

4



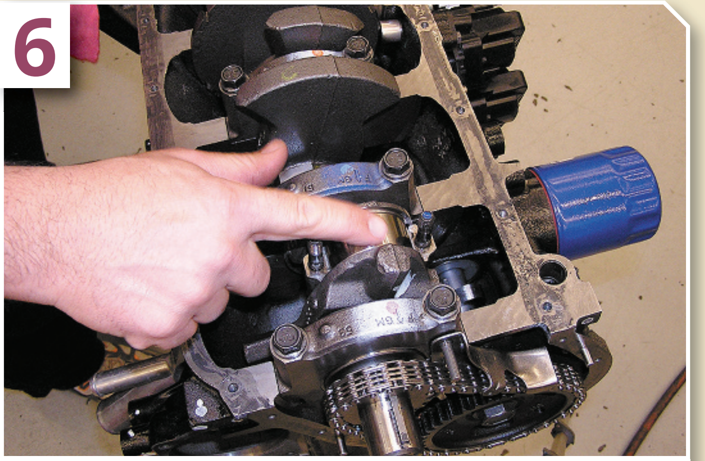
Carefully remove the bearing cap and, using the package that contained the Plastigage strips, measure the width of the compressed material. The gauge is calibrated in thousandths of the inch. Repeat for each main bearing.

5



To measure rod bearing oil clearance, start by removing the rod cap.

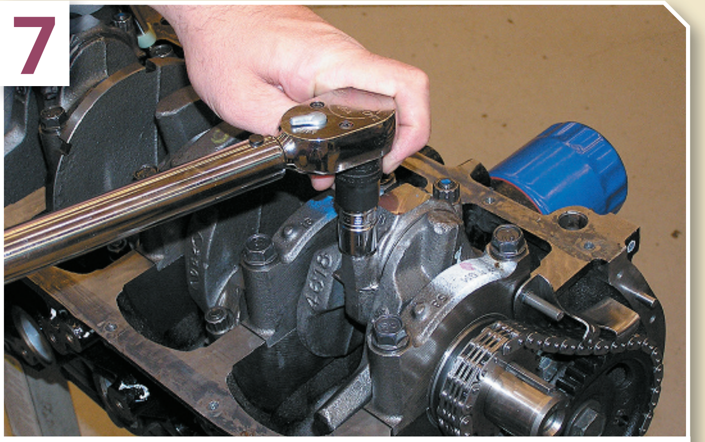
6



Clean the rod bearing journal and then place a strip of Plastigage across the entire width of the journal.

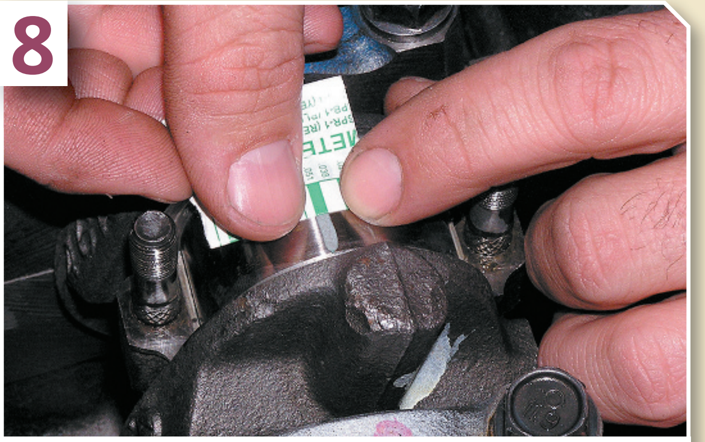
PLASTIGAGE

7



Torque the rod bearing cap nuts to factory specifications.

8



Remove the rod cap and measure the oil clearance using the markings on the Plastigage package. The wider the compressed gauge material, the narrower the bearing oil clearance. Repeat for all rod bearings.

REVIEW QUESTIONS

1. What items that need to be installed as part of the short block assembly?
2. How is crankshaft end play measured?
3. Why should Teflon seals not be oiled prior to being installed?
4. Why are torque-to-yield fasteners used for many head bolts?
5. What are the measured and the calculated values as a result of testing an engine on a dynamometer?

CHAPTER QUIZ

1. About how much of the turning torque applied to a head bolt is lost to friction?
   - **a.** 20%
   - **b.** 40%
   - **c.** 60%
   - **d.** 80%
2. Service information states that SAE 30 engine oil should be used when installing a camshaft. Technician A says that SAE 5W-30 will work. Technician B says that SAE 10W-30 will work. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Technician A says that the torque applied to the head bolts is the same as the clamping force on the gasket. Technician B says that the clamping force is the force actually applied to the surfaces of the gasket. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. A coating often used to keep an engine from rusting during assembly is called _____________.
   - **a.** engine oil
   - **b.** assembly lube
   - **c.** fogging oil
   - **d.** penetrating oil
5. Head gasket installation is being discussed. Technician A says that the surface finish of the cylinder head or block deck is very important for proper sealing to occur. Technician B says that if "front" is marked on a head gasket, the mark should be installed near the accessory drive belt end of the engine. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Technician A says that the threads in the block should be cleaned with a thread chaser. Technician B says that a bottoming tap should be used. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B

7. What can be used to check that heads are at the correct angle for the intake manifold on a V-type engine?
a. Metal rule
b. Angle gauge
c. Tape measure
d. Dial indicator

8. What is true about checking bearing clearance using Plastigage?
a. The journal should be clean and oil free.
b. The cap should be torqued to factory specifications.
c. The wider the strip means the narrower the oil clearance.
d. All of the above

9. An engine dynamometer directly measures ______________.
a. torque
b. horsepower
c. both horsepower and torque
d. fuel economy

10. Installing torque-to-yield head bolts requires the use of a ______________.
a. torque angle gauge
b. torque pressure gauge
c. bolt stretcher
d. pair of box-end wrenches

Chapter

35

ENGINE INSTALLATION AND BREAK-IN

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the preinstallation checklist.
- Explain the procedure for transmission installation.
- Explain the process of dressing the engine.
- Discuss engine installation.
- Explain engine start.
- Discuss the break-in precautions of an overhauled engine.

KEY TERMS:

Lugging 412 • Normal operating temperature 411

PREINSTALLATION CHECKLIST

NEED FOR A CHECKLIST Engine installation must be thoroughly checked to ensure that it is in proper condition to give the customer dependable operation for a long time. Using a checklist guarantees that all accessories are correctly reinstalled on the engine.

ENGINE INSTALLATION CHECKLIST Before installing or starting a new or rebuilt engine in a vehicle, be sure all of the following items have been checked:

1. Be sure the battery is fully charged.
2. Prelube the engine and check for proper oil pressure.
3. Check that all electrical wiring connecters and harnesses are properly installed. ● **SEE FIGURE 35–1**.
4. Check that all of the vacuum lines are correctly installed and routed.

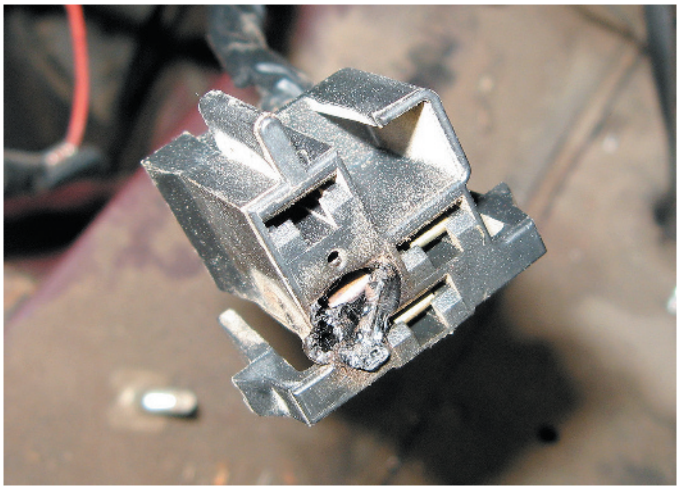


FIGURE 35–1 A partially melted electrical connector indicates that excessive current flow was present. The cause of the excessive current should be located and corrected before the engine is started.

5. Check that all fuel lines are properly connected and free from leaks.
6. Make sure all engine fluids are at the proper operating level, such as coolant, engine oil, and power steering fluid.
7. Check that fresh fuel is in the fuel tank.
8. Be sure that the radiator has been tested, is free from leaks, and flows correctly.
9. Check that all accessory drive belts are routed and tensioned correctly.

CAUTION: Be sure to have a fire extinguisher nearby when the engine is first started.

TRANSMISSION INSTALLATION

MANUAL TRANSMISSION INSTALLATION If the engine was removed with the transmission attached, the transmission should be reinstalled on the engine before other accessories are added. The flywheel is installed on the back of the crankshaft. Often, the attaching bolt holes are unevenly spaced so that the flywheel fits in only one way to maintain engine balance. The pilot bearing or bushing in the rear of the crankshaft is usually replaced with a new one to minimize the possibility of premature failure of this part.

The clutch is installed next and the installation usually includes the following steps:

STEP 1 Most experts recommend that a new clutch assembly or, at the least, a new clutch friction disc, be installed.

STEP 2 The clutch friction disc must be held in position using an alignment tool that is secured in the pilot bearing. This holds the disc in position while the pressure plate is being installed.

STEP 3 The engine bell housing is put on the engine, if it was not installed before. The alignment of this type of bell housing is then checked. ● **SEE FIGURE 35–2**.

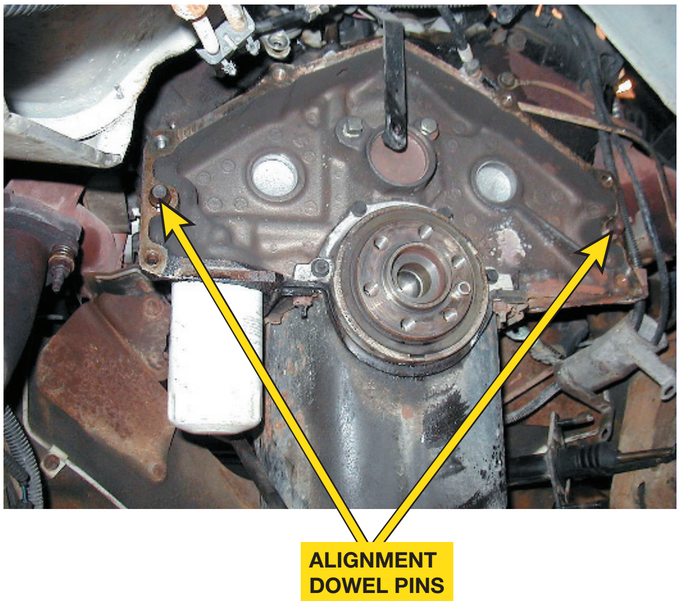


FIGURE 35–2 Bell housing alignment dowel pins are used to ensure proper alignment between the engine block and the transmission.

CAUTION: Perfectly round cylinders can be distorted whenever another part of the engine is bolted and torqued to the engine block. For example, it has been determined that after the cylinders are machined, the rear cylinder bore can be distorted to be as much as 0.006 inch (0.15 mm) out-of-round after the bell housing is bolted onto the block! To help prevent this distortion, always apply the specified torque to all fasteners going into the engine block and tighten in the recommended sequence.

STEP 4 The clutch release yoke should be checked for free movement. Usually, the clutch release bearing is replaced to ensure that the new bearing is securely attached to the clutch release yoke.

STEP 5 The transmission is installed by carefully guiding the transmission input (clutch) shaft straight into the clutch disc and pilot bearing. Rotate the transmission output shaft as needed to engage the splines of the clutch disc. The assembly bolts are secured when the transmission fully mates with the bell housing.

CAUTION: Always adjust the clutch free play before starting the engine to help prevent engine thrust bearing or clutch release bearing damage.

AUTOMATIC TRANSMISSION INSTALLATION On engines equipped with an automatic transmission, the drive (flex) plate is attached to the back of the crankshaft. Its assembly bolts are tightened to the specified torque. The bell housing is part of the transmission case on most automatic transmissions. Installing an automatic transmission usually includes the following steps:

STEP 1 The torque converter should be installed on the transmission before the transmission is put on the engine.

STEP 2 Rotate the torque converter while it is pushed onto the transmission shafts until the splines of all shafts are engaged in the torque converter. ● **SEE FIGURE 35–3**.

STEP 3 The torque converter is held against the transmission as the transmission is fitted on the back of the engine. The transmission mounting bolts are attached finger tight.

STEP 4 The torque converter should be rotated to make sure that there is no binding. The bell housing is secured to the block and then the torque converter is fastened to the drive plate.

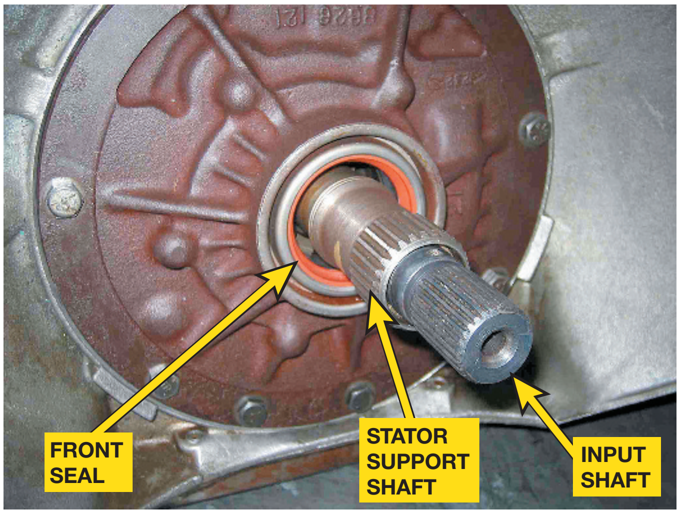


FIGURE 35–3 The internal splines inside the torque converter must be properly aligned with all of the splines of the automatic transmission.

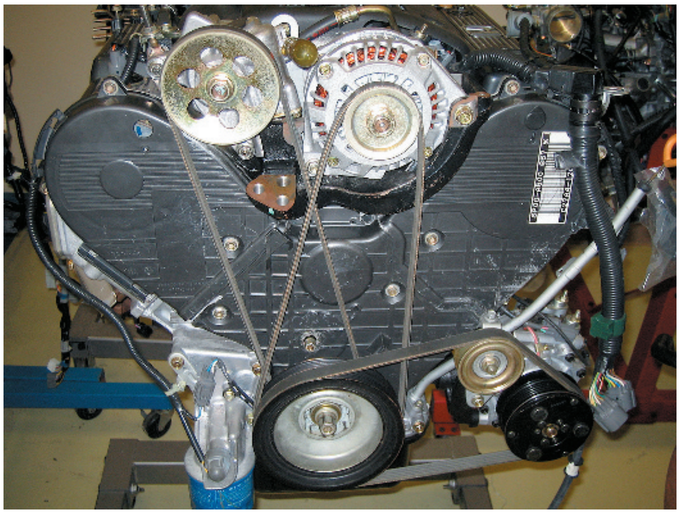


FIGURE 35–4 It is often easier to install all of the accessory drive belts before the engine is installed in the vehicle.

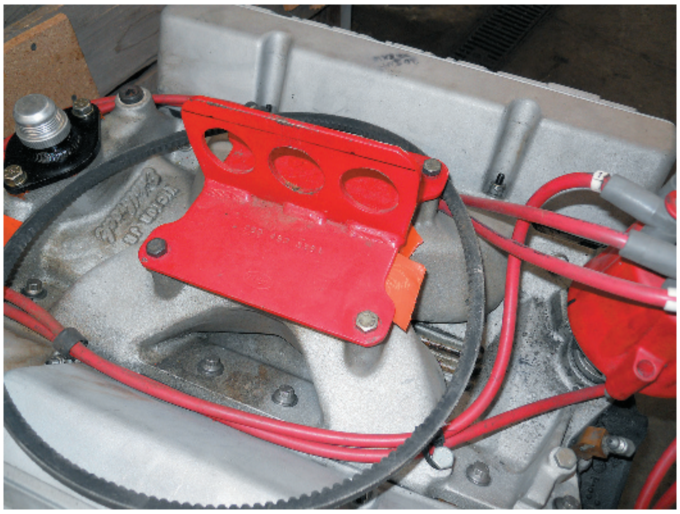


FIGURE 35–5 A fixture installed that is used as a place to attach the hosting chains.

DRESSING THE ENGINE

"Dressing the engine" is a term used to describe the process of attaching all of the auxiliary items to the engine. The items include

- Starter motor
- Fuel rail and related fuel system components
- New oxygen sensor(s), to ensure that the engine is operating at the correct air–fuel ratio
- Engine/transmission wiring harness
- Ignition components, such as the ignition coil(s) and spark plug wires, if equipped
- All belt-driven engine accessories, mounted on the front of the engine (Some engines drive all these accessories with one belt. Other engines use as many as four belts. Check service information or decals under the hood to determine the specific belt routing for the accessories used on the engine.) ● **SEE FIGURE 35–4**.
- Front accessories, such as the power steering pump, alternator, and air-conditioning compressor (These accessories may be installed before the engine is installed in the vehicle. On some vehicles, it is easier to put the engine in the chassis before installing the front accessories.)

Always check service information for the exact procedure to follow.

ENGINE INSTALLATION

SECURING THE ENGINE A sling, either a chain or lift cable, is attached to the manifold, head bolts, or lifting brackets on the top of the engine. A hoist is attached to the sling and snugged up to take the weight and to make sure that the engine is supported and balanced properly. ● **SEE FIGURE 35–5**.

INSTALLING THE ENGINE

- **Rear-wheel drive.** The engine must be tipped as it was during removal to let the transmission go into the engine compartment first. The transmission is worked under the floor pan on rear-wheel-drive vehicles as the engine is lowered into the engine compartment. The front engine mounts are aligned and the rear cross-member and rear engine mount are installed. The engine mount bolts are installed, and the nuts are torqued. Then the hoist is removed.
- **Front-wheel drive.** Many engines for front-wheel-drive vehicles are installed from underneath the vehicle. Often the entire drivetrain package is placed back in the vehicle while it is attached to the cradle. The vehicle is positioned on a hoist and is lowered onto the engine cradle assembly to install. Always check the recommended procedure for the vehicle being serviced.

RECONNECTING COMPONENTS AND CONNECTORS The following items should be connected to the engine assembly:

- Throttle and cruise control linkages or cables.
- Exhaust system to the exhaust manifolds.
- If any of the steering linkage was previously disconnected, it can be reattached while work is being done under the vehicle.
- After the engine is in place, the front engine accessories can all be installed, if they were not installed before the engine was put in the chassis.
- The air-conditioning compressor is reattached to the engine, with care being taken to avoid damaging the air-conditioning hoses and lines.

COOLING SYSTEM The radiator is installed and secured in place, followed by the cooling fan and shroud. The fan and new drive belts are then installed and adjusted. New radiator hoses, including new heater hoses, and new coolant should be installed.

ELECTRICAL SYSTEM Under the hood, the following electrical components need to be mounted and connected:

- Connect all wiring to the starter and alternator as required.
- Connect the instrument and computer sensor wires to the sensors on the engine.

FREQUENTLY ASKED QUESTION

What Is Break-In Engine Oil?

Many years ago, vehicle manufacturers used straight weight oil, such as SAE 30 nondetergent engine oil, as break-in oil. Today, the engine oil recommended for break-in (running in) is the same type of oil that is recommended for use in the engine. No special break-in oil is recommended or used by the factory in new vehicles. Always use the specified viscosity oil as recommended by the vehicle manufacturer.

- Double-check the condition and routing of all wiring, being certain that wires have not been pinched or broken, before installing a fully charged battery.
- Attach the positive cable first and then the ground cable.
- Ensure that the starter cranks the engine.
- Install and time the distributor (if equipped), then connect the ignition cables to the spark plugs, again being sure that they are routed according to service information.

ENGINE START

PRECAUTIONS The engine installation should be given one last inspection to ensure that everything has been put together correctly before the engine is started. If the engine overhaul and installation are done properly, the engine should crank and start on its own fully charged battery without the use of a fast charger or jumper battery. As soon as the engine starts and shows oil pressure, it should be brought up to a fast idle speed and *kept there* to ensure that the engine gets proper lubrication. The fast-running oil pump develops full pressure, and the fast-turning crankshaft throws plenty of oil on the cam and cylinder walls.

NOTE: In camshaft-in-block engines, the only lubrication sent to the contact point between the camshaft lobes and the lifters (tappets) is from the splash off the crankshaft and connecting rods. At idle, engine oil does not splash enough for proper break-in lubrication of the camshaft.

Maintaining engine speed above 1,500 RPM for the first 10 minutes of engine operation must be performed to break in a flat-bottom lifter camshaft. If the engine speed is decreased to idle (about 600 RPM), the lifter (tappet) is in contact with and exerting force *on* the lobe of the cam for a longer period of time than occurs at higher engine speeds. The pressure and volume of oil supplied to the camshaft area are also increased at the higher engine speeds. Therefore, to ensure long camshaft and lifter life, make certain that the engine starts quickly after reassembly to prevent long cranking periods and subsequent low engine speeds after a new camshaft and lifters have been installed.

NOTE: Many molydisulfide greases used during assembly can start to clog oil filters within 20 minutes after starting the engine. Most engine rebuilders recommend changing the oil and filter after 30 minutes of running time.

After the engine has started, the following items should be checked:

1. Is the valve train quiet? Some engines require several minutes to quiet down.
2. Record the engine vacuum. It should be 17 to 21 inch Hg (sea level).
3. Check for any gasoline, coolant, or oil leaks. Stop the engine and repair the leaks as soon as possible.
4. Check the charging system for proper operation. The charging voltage should be 13.5 to 15 volts.

As soon the engine is at operating temperature and running well, the vehicle should be driven to a road having minimum traffic. Perform the following during the test drive:

- The vehicle should be accelerated, full throttle, from 30 to 50 mph (48 to 80 km/h).
- Then, the throttle is fully closed while the vehicle is allowed to return to 30 mph (48 km/h). This sequence is repeated 10 to 12 times.
- The acceleration sequence puts a high load on the piston rings to properly seat them against the cylinder walls. The piston rings are the only part of the modern engine that needs to be broken in. Good ring seating is indicated by a dry coating inside the tailpipe at the completion of the ring-seating drive.

The vehicle is returned to the service area, where the engine is again checked for visible fluid leaks. If the engine is dry, it is ready to be turned over to the customer.

The oil and filter should be changed at 500 miles (800 km) to remove any dirt that may have been trapped in the engine during assembly, and to remove the material that has worn from the surfaces during the break-in period.

A well-designed engine that has been correctly reconditioned and assembled using the techniques described should give reliable service for many miles.

NORMAL OPERATING TEMPERATURE **Normal operating temperature** is the temperature at which the upper radiator hose is hot and pressurized. Another standard method used to determine when normal operating temperature is reached is to observe the operation of the electric cooling fan, when the vehicle is so equipped. Many manufacturers define normal operating temperature as being reached when the cooling fan has cycled on and off at least once after the engine has been started. Some vehicle manufacturers specify that the cooling fan should cycle twice. This method also helps assure the technician that the engine is not being overheated. ● **SEE FIGURE 35–6.**

HOW TO WARM UP A COLD ENGINE The greatest amount of engine wear occurs during start-up. The oil in a cold engine is thick, and it requires several seconds to reach all the moving parts of an engine. After the engine starts, allow the engine to idle until the oil pressure peaks. This takes from 15 to 60 seconds, depending on the outside temperature. *Do not allow the engine to idle for longer than five minutes.* Because an engine warms up faster under load, drive the vehicle in a normal manner until the engine is fully warm. Avoid full-throttle acceleration until the engine is completely up to normal operating temperature. This method of engine warm-up also warms the rest of the powertrain, including transmission and final drive-component lubricants.

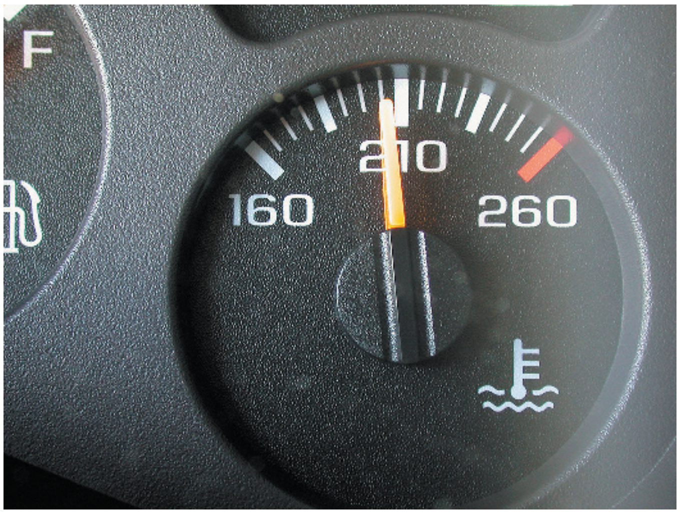


FIGURE 35–6 Even though the dash gauge may show normal operating temperature, a scan tool or an infrared pyrometer can also be used to verify proper coolant temperature.

BREAK-IN PRECAUTIONS

Any engine overhaul represents many hours of work and a large financial investment. Precautions should be taken to protect the investment, including the following:

1. Never add cold water to the cooling system while the engine is running.
2. Never lug any engine. **Lugging** means increasing the throttle opening without increasing engine speed (RPM). An example where lugging an engine can occur is when the vehicle is driven at a low speed, such as 15 mph, with the manual transmission in third or fourth gear instead of in second gear, as per the recommended speed for that gear, as published in the owner manual.
3. Applying loads to an engine for *short periods* of time creates higher piston ring pressure against the cylinder walls and assists the breaking-in process by helping to seat the rings.
4. Change the oil and filter at 500 miles (800 km) or after 20 hours of operation.
5. Check for leaks after the engine has gone through several warm-up and cooling down periods.

REVIEW QUESTIONS

1. How are the clutch and bell housing installed?
2. What should be done to help prevent rear cylinder distortion when the bell housing is being installed on the engine?
3. Why should the clutch, if equipped, be adjusted before starting the engine?
4. What is involved in "dressing the engine"?
5. What is meant by lugging an engine?

CHAPTER QUIZ

1. Before installing or starting a new or rebuilt engine, all of the following items should have been checked, EXCEPT _________.
    - **a.** battery fully charged
    - **b.** pre-lube engine and check for proper oil pressure
    - **c.** check that all of the vacuum lines are correctly installed and routed
    - **d.** rear axle is topped off
2. "Dressing the engine" means _________.
    - **a.** installing all of the exterior engine components
    - **b.** cleaning the engine
    - **c.** changing the oil and oil filter
    - **d.** Both b and c
3. If the bell housing is not properly torqued to the engine block, _________.
    - **a.** the bell housing will distort
    - **b.** the engine block will crack
    - **c.** the rear cylinder can be distorted (become out-of-round)
    - **d.** the crankshaft will crack
4. Break-in engine oil is _________.
    - **a.** of the same viscosity and grade as that specified for normal engine operation
    - **b.** SAE 40
    - **c.** SAE 30
    - **d.** SAE 20W-50
5. Normal operating temperature is reached when _________.
    - **a.** the radiator cap releases coolant into the overflow
    - **b.** the upper radiator hose is hot and pressurized
    - **c.** the electric cooling fan has cycled at least once (if the vehicle is so equipped)
    - **d.** Both b and c
6. Which computer sensor should be replaced to help ensure that the engine is operating at the correct air–fuel ratio?
    - **a.** Throttle position sensor
    - **b.** Oxygen sensor
    - **c.** Manifold absolute pressure sensor
    - **d.** Engine coolant temperature sensor
7. How should the vehicle be driven to best break in a newly overhauled engine?
    - **a.** At a steady low speed
    - **b.** At varying speeds and loads
    - **c.** At high speed and loads
    - **d.** At idle speed and little or no load
8. Which type of vehicle is the engine most likely to be installed from underneath the vehicle?
    - **a.** Rear-wheel drive (RWD)
    - **b.** Front-wheel drive (FWD)
    - **c.** Four-wheel drive (4WD)
    - **d.** Both a and c
9. Engine vacuum on a normal stock rebuilt engine should be _________.
    - **a.** 10 to 15 inch Hg
    - **b.** 12 to 16 inch Hg
    - **c.** 17 to 21 inch Hg
    - **d.** 19 to 23 inch Hg
10. Why must flat-bottom camshafts be broken in at a fast idle?
    - **a.** The cam in a cam-in-block engine is only lubricated by splash oil
    - **b.** The flat-bottom of the lifters must become slightly concave in order to rotate
    - **c.** Both a and b are correct
    - **d.** Neither a nor b are correct

SECTION VII

ELECTRICAL SYSTEMS (A6)

CHAPTERS

36 Electrical Fundamentals
37 Electrical Circuits and Ohm's Law
38 Series, Parallel, and Series-Parallel Circuits
39 Circuit Testers and Digital Meters
40 Digital Storage Oscilloscopes
41 Automotive Wiring and Wire Repair
42 Wiring Schematics and Circuit Testing
43 Capacitance and Capacitors
44 Magnetism and Electromagnetism
45 Electronic Fundamentals
46 CAN and Network Communications
47 Automotive 12-Volt Batteries
48 12-Volt Battery Testing and Service
49 Starting System Parts and Operation
50 Starting System Diagnosis and Service
51 Charging System Parts and Operation
52 Charging System Diagnosis and Service
53 Lighting and Signaling Circuits
54 Driver Information and Navigation Systems
55 Security and Immobilizer Systems
56 Airbag and Pretensioner Circuits
57 Body Electrical Accessories
58 Advanced Driver Assist Systems (ADAS)
59 Audio System Operation and Diagnosis

Chapter 36

ELECTRICAL FUNDAMENTALS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the fundamentals of electricity.
- Explain how electrons move through a conductor.
- Explain the units of electrical measurement, and discuss the relationship among volts, amperes, and ohms.
- Discuss the different sources of electricity.
- Explain conductors and resistance.
- Describe the function of resistors.

KEY TERMS:

Ammeter 417 • Ampere 417 • Bound electrons 415
• Conductors 416 • Conventional theory 417 • Coulomb 417
• Electrical potential 418 • Electricity 414 • Electrochemistry 420
• Electromotive force (EMF) 418 • Electron theory 417
• Free electrons 415 • Insulators 416 • Ion 415
• Neutral charge 414 • Ohmmeter 418 • Ohms 418
• Peltier effect 419 • Photoelectricity 419 • Piezoelectricity 419
• Positive temperature coefficient (PTC) 420 • Potentiometer 421
• Resistance 418 • Rheostat 421 • Semiconductor 416
• Static electricity 419 • Thermocouple 419 • Thermoelectricity 419
• Valence ring 415 • Volt 417 • Voltmeter 418 • Watt 418

ELECTRICITY

INTRODUCTION The electrical system is one of the most important systems in a vehicle today. Every year more and more components and systems use electricity. Those technicians who really know and understand automotive electrical and electronic systems are in great demand.

Electricity may be difficult for some people to learn for the following reasons:

- It cannot be seen.
- Only the results of electricity can be seen.
- It has to be detected and measured.
- The test results have to be interpreted.

BACKGROUND Our universe is composed of matter, which is *anything* that has mass and occupies space. All matter is made from slightly over 100 individual components called *elements*. The smallest particle that an element can be broken into and still retain the properties of that element is known as an atom. ● **SEE FIGURE 36–1**.

DEFINITION **Electricity** is the movement of electrons from one atom to another. The dense center of each atom is called the nucleus. The nucleus contains:

- *Protons*, which have a positive charge
- *Neutrons*, which are electrically neutral (have no charge)

Electrons, which have a negative charge, surround the nucleus in orbits. Each atom contains an equal number of electrons and protons. The physical aspect of all protons, electrons, and neutrons are the same for all atoms. It is the *number* of electrons and protons in the atom that determines the material and how electricity is conducted. Because the number of negative-charged electrons is balanced with the same number of positive-charged protons, an atom has a **neutral charge** (no charge).

NOTE: As an example of the relative sizes of the parts of an atom, consider that if an atom were magnified so that the nucleus were the size of the period at the end of this sentence, the whole atom would be bigger than a house.

POSITIVE AND NEGATIVE CHARGES The parts of the atom have different charges. The orbiting electrons are negatively charged, while the protons are positively charged. Positive charges are indicated by the "plus" sign (+) and negative charges by the "minus" sign (–), as shown in ● **FIGURE 36–2**.

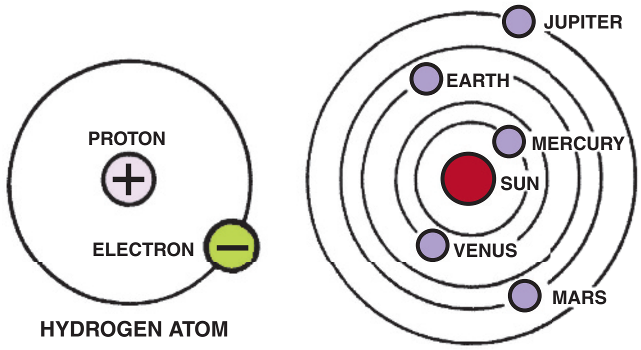


FIGURE 36–1 In an atom (left), electrons orbit protons in the nucleus just as planets orbit the sun in our solar system (right).

These same + and – signs are used to identify parts of an electrical circuit. Neutrons have no charge at all. They are neutral. In a normal, or balanced, atom, the number of negative particles equals the number of positive particles. That is, there are as many electrons as there are protons. ● **SEE FIGURE 36–3**.

MAGNETS AND ELECTRICAL CHARGES An ordinary magnet has two ends, or poles. One end is called the south pole and the other is called the north pole. If two magnets are brought close to each other with like poles together (south to south or north to north), the magnets push each other apart, because like poles repel each other. If the opposite poles of the magnets are

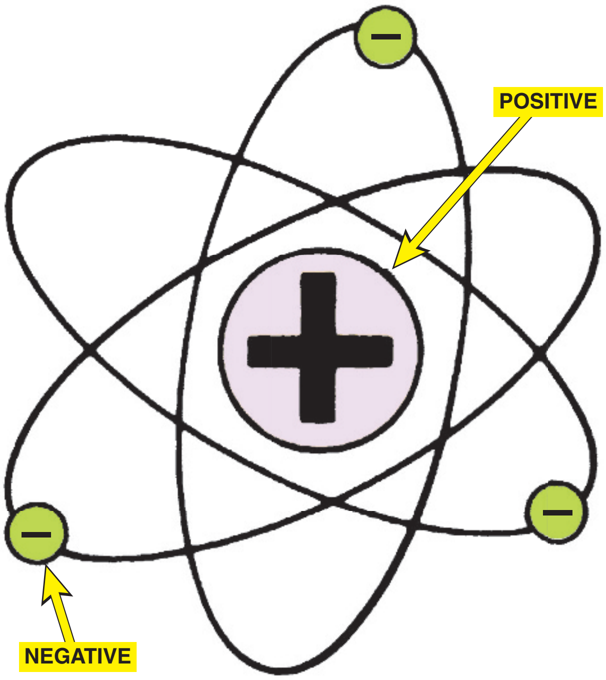


FIGURE 36–2 The nucleus of an atom has a positive (+) charge and the surrounding electrons have a negative (–) charge.

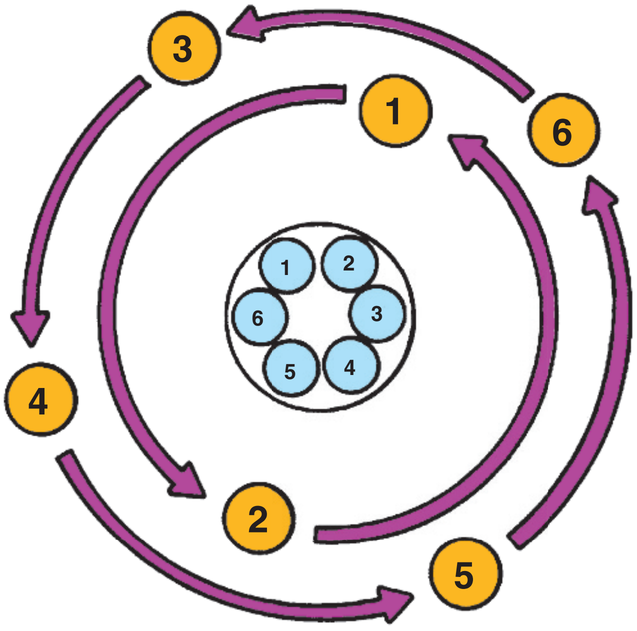


FIGURE 36–3 This figure shows a balanced atom. The number of electrons is the same as the number of protons in the nucleus.

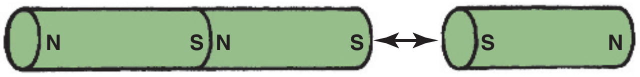


FIGURE 36–4 Unlike charges attract and like charges repel.

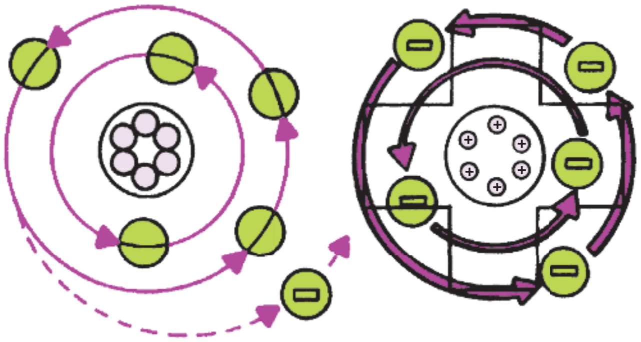


FIGURE 36–5 An unbalanced, positively charged atom (ion) attracts electrons from neighboring atoms.

brought close to each other, south to north, the magnets snap together, because unlike poles attract each other.

The positive and negative charges within an atom are like the north and south poles of a magnet. Charges that are alike repel each other, similar to the poles of a magnet. ● **SEE FIGURE 36–4.**

That is why the negative electrons continue to orbit around the positive protons. They are attracted and held by the opposite charge of the protons. The electrons keep moving in orbit because they repel each other.

IONS When an atom loses any electrons, it becomes unbalanced. It has more protons than electrons, and therefore has a positive charge. If it gains more electrons than protons, the atom is negatively charged. When an atom is not balanced, it becomes a charged particle called an **ion**. Ions try to regain their balance of equal protons and electrons by exchanging electrons with neighboring atoms. The flow of electrons during the “equalization” process is defined as the flow of electricity. ● **SEE FIGURE 36–5.**

ELECTRON SHELLS Electrons orbit around the nucleus in definite paths. These paths form shells, like concentric rings, around the nucleus. Only a specific number of electrons can orbit within each shell. If there are too many electrons for the first and closest shell to the nucleus, the others orbit in additional shells until all electrons have an orbit within a shell. There can be as many as seven shells around a single nucleus. ● **SEE FIGURE 36–6.**

FREE AND BOUND ELECTRONS The outermost electron shell or ring, called the **valence ring**, is the most important part of understanding electricity. The number of electrons in this outer ring determines the valence of the atom and indicates its capacity to combine with other atoms.

If the valence ring of an atom has three or fewer electrons in it, the ring has room for more. The electrons there are held very loosely, and it is easy for a drifting electron to join the valence ring and push another electron away. ● **SEE FIGURE 36–7.** These loosely held electrons are called **free electrons**. When the valence ring has five or more electrons in it, it is fairly full. The electrons are held tightly, and it is hard for a drifting electron to push its way into the valence ring. These tightly held electrons are called **bound electrons**. ● **SEE FIGURE 36–8.**

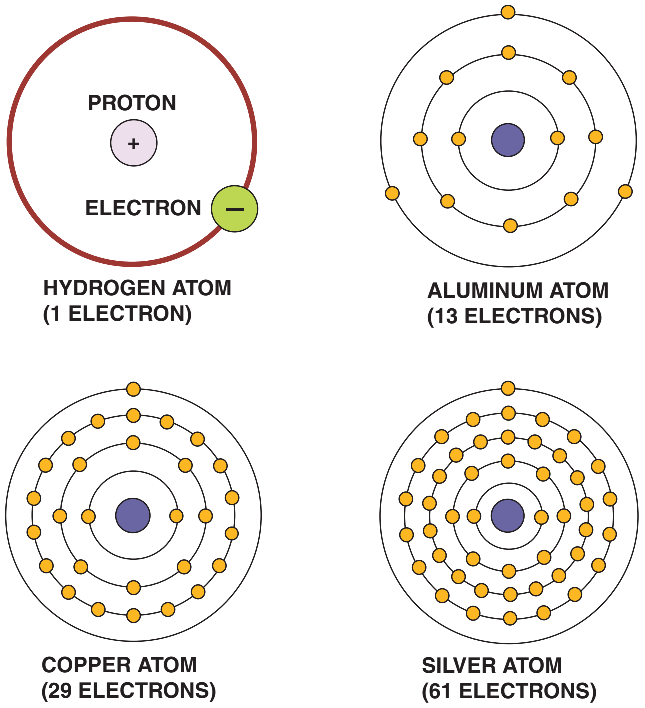


FIGURE 36–6 The hydrogen atom is the simplest atom, with only one proton, one neutron, and one electron. More complex elements contain higher numbers of protons, neutrons, and electrons.

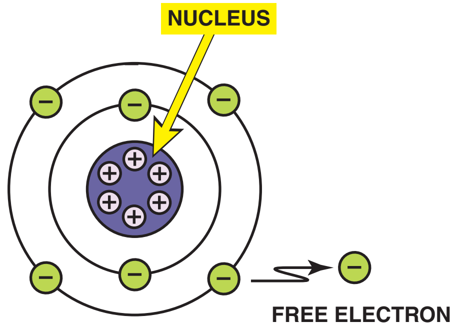


FIGURE 36–7 Electrons in the outer orbit, or shell, can often be drawn away from the atom and become free electrons.

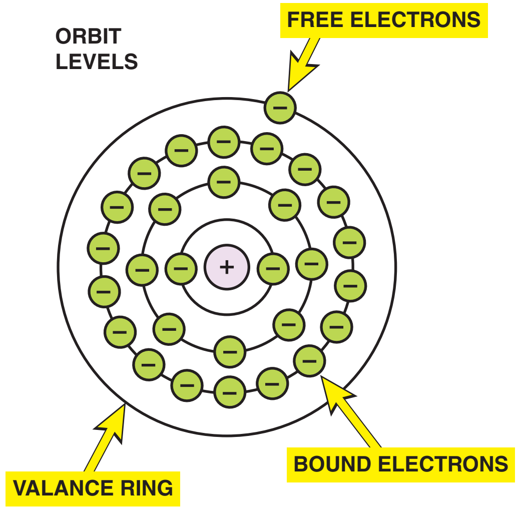


FIGURE 36–8 As the number of electrons increases, they occupy increasing energy levels that are farther from the center of the atom.

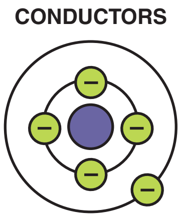


FIGURE 36–9 A conductor is any element that has one to three electrons in its outer orbit.

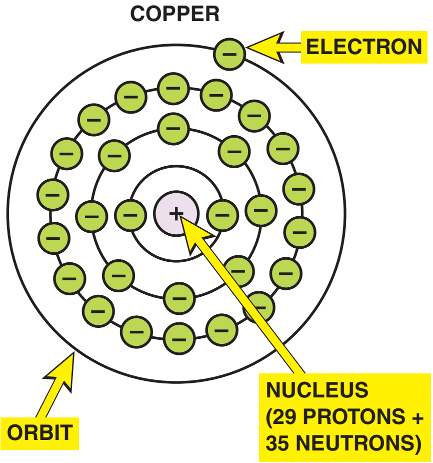


FIGURE 36–10 Copper is an excellent conductor of electricity because it has just one electron in its outer orbit, making it easy to be knocked out of its orbit and flow to other nearby atoms. This causes electron flow, which is the definition of electricity.

The movement of these drifting electrons is called current. Current can be small, with only a few electrons moving, or it can be large, with a tremendous number of electrons moving. Electric current is the controlled, directed movement of electrons from atom to atom within a conductor.

CONDUCTORS **Conductors** are materials with fewer than four electrons in their atom's outer orbit. ● **SEE FIGURE 36–9**.

Copper is an excellent conductor because it has only one electron in its outer orbit. This orbit is far enough away from the nucleus of the copper atom that the pull or force holding the outermost electron in orbit is relatively weak. ● **SEE FIGURE 36–10**.

Copper is the conductor most used in vehicles because the price of copper is reasonable compared to the relative cost of other conductors with similar properties. Examples of other commonly used conductors include

- Silver
- Gold
- Aluminum
- Steel
- Cast iron

FREQUENTLY ASKED QUESTION

Is Water a Conductor?

Pure water is an insulator; however, if anything is in the water, such as salt or dirt, then the water becomes conductive. Because it is difficult to keep it from becoming contaminated, water is usually thought of as being capable of conducting electricity, especially high-voltage household 110 or 220 volt outlets.

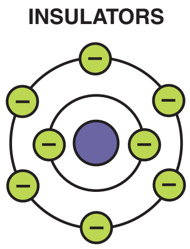


FIGURE 36–11 Insulators are elements with five to eight electrons in the outer orbit.

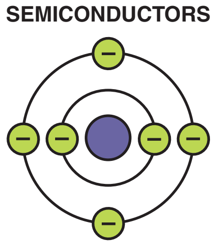


FIGURE 36–12 Semiconductor elements contain exactly four electrons in the outer orbit.

INSULATORS Some materials hold their electrons very tightly; therefore, electrons do not move through them very well. These materials are called insulators. **Insulators** are materials with more than four electrons in their atom's outer orbit. Because they have more than four electrons in their outer orbit, it becomes easier for these materials to acquire (gain) electrons than to release electrons. ● **SEE FIGURE 36–11**.

Examples of insulators include plastics, nylon, porcelain, fiberglass, wood, glass, rubber, ceramics (spark plugs), and varnish for covering (insulating) copper wires in alternators and starters.

SEMICONDUCTORS Materials with exactly four electrons in their outer orbit are neither conductors nor insulators, but are called **semiconductors**. Semiconductors can be either an insulator or a conductor in different design applications. ● **SEE FIGURE 36–12**.

Examples of semiconductors include

- Silicon
- Germanium
- Carbon

Semiconductors are used mostly in transistors, computers, and other electronic devices.

HOW ELECTRONS MOVE THROUGH A CONDUCTOR

CURRENT FLOW The following events occur if a source of power, such as a battery, is connected to the ends of a conductor—a positive charge (lack of electrons) is placed on one end of the conductor and a negative charge (excess of electrons) is placed on the opposite end of the conductor. For current to flow, there *must* be an imbalance of excess electrons at one end of the circuit and a deficiency of electrons at the opposite end of the circuit.

- The negative charge repels the free electrons from the atoms of the conductor, whereas the positive charge on the opposite end of the conductor attracts electrons.
- As a result of this attraction of opposite charges and repulsion of like charges, electrons flow through the conductor.
  ● **SEE FIGURE 36–13**.

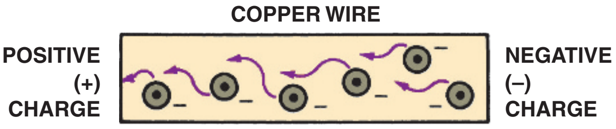


FIGURE 36–13 Current electricity is the movement of electrons through a conductor.

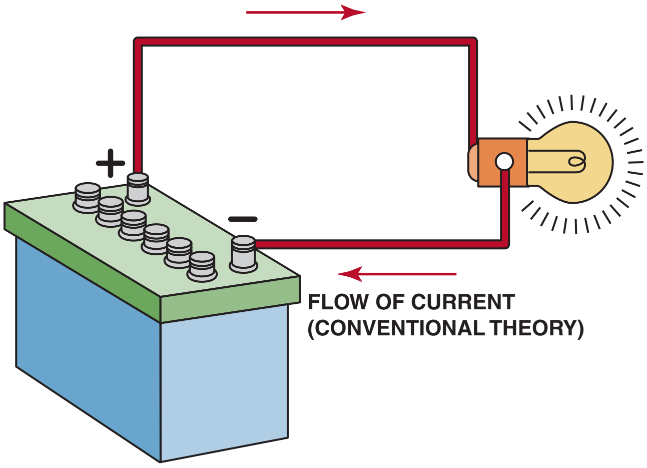


FIGURE 36–14 Conventional theory states that current flows through a circuit from positive (+) to negative (–). Automotive electricity uses the conventional theory in all electrical diagrams and schematics.

CONVENTIONAL THEORY VERSUS ELECTRON THEORY

- **Conventional theory.** It was once thought that electricity had only one charge and moved from positive to negative. This theory of the flow of electricity through a conductor is called the **conventional theory** of current flow. ● **SEE FIGURE 36–14**.
- **Electron theory.** The discovery of the electron and its negative charge led to the **electron theory**, which states that there is electron flow from negative to positive.
- Most automotive applications use the conventional theory. We use the conventional theory (positive to negative) unless stated otherwise.

UNITS OF ELECTRICITY

Electricity is measured using meters or other test equipment. The three fundamentals of electricity-related units include the ampere, volt, and ohm.

FREQUENTLY ASKED QUESTION

What Is Static Electricity?

Static electricity means that isolated motionless electrical charges are present on an insulator. Static electricity is commonly created by friction. Static electricity occurs when an imbalance of electric charges is created on the surface of a material. This static charge can remain until it is discharged to a conductor. Static electricity can be created when using a hair comb or taking off a sweater. ● **SEE FIGURE 36–15**.

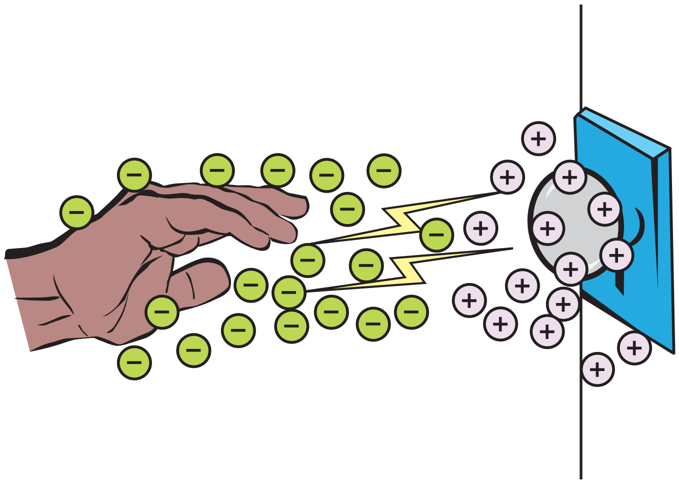


FIGURE 36–15 A static electrical charge can build up in the body if walking on an insulated floor such as on carpet. Then the static charge can discharge to a conductor, such as a door knob, resulting in a mild shock and often heard as a snapping sound.

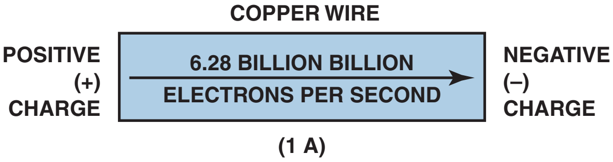


FIGURE 36–16 One ampere is the movement of 1 coulomb (6.28 billion billion electrons) past a point in 1 second.

AMPERES The **ampere** is the unit used throughout the world to measure current flow. When 6.28 billion billion electrons (the name for this large number of electrons is a **coulomb**) move past a certain point in 1 second, this represents 1 ampere of current. ● **SEE FIGURE 36–16**.

The ampere is the electrical unit for the amount of electron flow, just as "gallons per minute" is the unit that can be used to measure the quantity of water flow. It is named for the French electrician André Marie Ampére (1775–1836). The conventional abbreviations and measurement for amperes are as follows:

1. The ampere is the unit of measurement for the amount of current flow.
2. *A* and *amps* are acceptable abbreviations for *amperes*.
3. The capital letter *I*, for *intensity*, is used in mathematical calculations to represent amperes.
4. Amperes do the work in the circuit. It is the movement of the electrons through a lightbulb or motor that actually makes the electrical device work. Without amperage through a device, it will not work at all.
5. Amperes are measured by an **ammeter** (not ampmeter). ● **SEE FIGURE 36–17**.

VOLTS The **volt** is the unit of measurement for electrical pressure. It is named for an Italian physicist, Alessandro Volta (1745–1827). The comparable unit using water pressure as an example would be pounds per square inch (PSI). It is possible to have very high pressures (volts) and low water flow (amperes). It is also possible to have high water flow (amperes) and low pressures (volts).

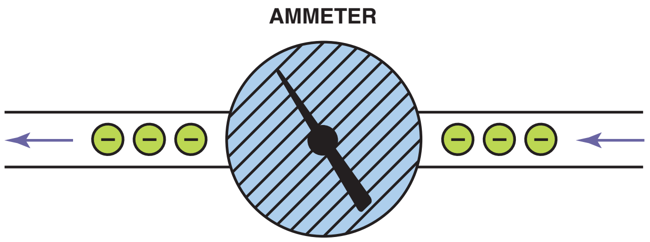


FIGURE 36–17 An ammeter is installed in the path of the electrons similar to a water meter used to measure the flow of water in gallons per minute. The ammeter displays current flow in amperes.

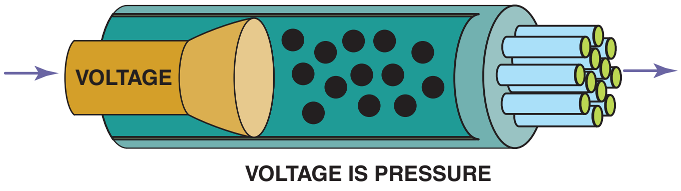


FIGURE 36–18 Voltage is the electrical pressure that causes the electrons to flow through a conductor.

Voltage is also called **electrical potential** because if there is voltage present in a conductor, there is a potential (possibility) for current flow. This electrical pressure is a result of the following:

- Excess electrons remain at one end of the wire or circuit.
- There is a lack of electrons at the other end of the wire or circuit.
- The natural effect is to equalize this imbalance, creating a pressure to allow the movement of electrons through a conductor.
- It is possible to have pressure (volts) without any flow (amperes). For example, a fully charged 12 volt battery placed on a workbench has 12 volts of pressure potential, but because there is no conductor (circuit) connected between the positive and negative terminals of the battery, there is no flow (amperes). Current only flows when there is pressure and a circuit for the electrons to flow in order to "equalize" to a balanced state.

  Voltage does *not* flow through conductors, but voltage does cause current (in amperes) to flow through conductors. ● **SEE FIGURE 36–18**.

The conventional abbreviations and measurement for voltage are as follows:

1. The volt is the unit of measurement for the amount of electrical pressure.
2. **Electromotive force**, abbreviated **EMF,** is another way of indicating voltage.
3. *V* is the generally accepted abbreviation for *volts*.
4. The symbol used in calculations is *E*, for *electromotive force*.
5. Volts are measured by a **voltmeter**. ● **SEE FIGURE 36–19**.

OHMS

Resistance to the flow of current through a conductor is measured in units called **ohms**, named after the German physicist George Simon Ohm (1787–1854). The resistance to the flow of free electrons through a conductor results from the countless collisions the electrons cause within the atoms of the conductor. ● **SEE FIGURE 36–20**.

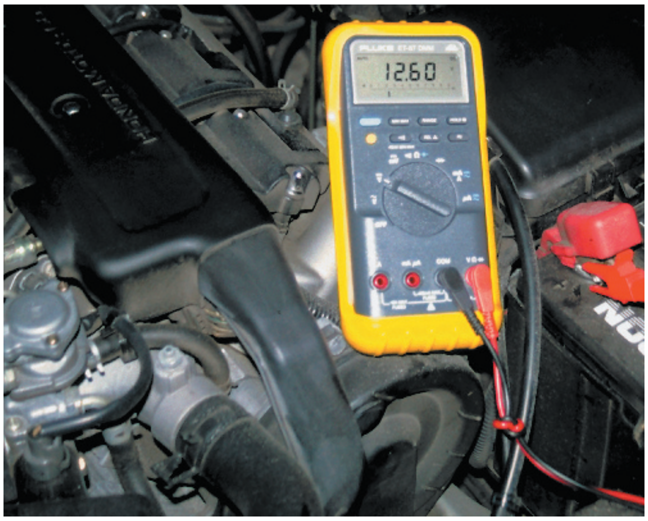


FIGURE 36–19 This digital multimeter set to read DC volts is being used to test the voltage of a vehicle battery. Most multimeters can also measure resistance (ohms) and current flow (amperes).

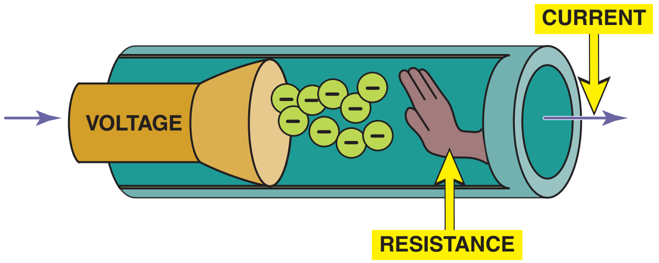


FIGURE 36–20 Resistance to the flow of electrons through a conductor is measured in ohms.

The conventional abbreviations and measurement for resistance are as follows:

1. The ohm is the unit of measurement for electrical resistance.
2. The symbol for ohms is Ω (Greek capital letter omega), the last letter of the Greek alphabet.
3. The symbol used in calculations is *R*, for *resistance*.
4. Ohms are measured by an **ohmmeter**.
5. Resistance to electron flow depends on the material used as a conductor.

WATTS

A **watt** is the electrical unit for *power*, the capacity to do work. It is named after a Scottish inventor, James Watt (1736–1819). The symbol for power is *P*. Electrical power is calculated as amperes times volts:

$$\boldsymbol{P} \textbf{ (power)} = \boldsymbol{I} \textbf{ (amperes)} \times \boldsymbol{E} \textbf{ (volts)}$$

The formula can also be used to calculate the amperage if the wattage and the voltage are known. For example, a 100 watt lightbulb powered by 120 volt AC in the shop requires how many amperes?

$$I \text{ (amperes)} = P \text{ (watts)} \div E \text{ (volts)}$$

$$I = 0.83 \text{ amperes}$$

● **SEE FIGURE 36–21**.

FIGURE 36–21 A display at the Henry Ford Museum in Dearborn, Michigan, which includes a hand-cranked generator and a series of lightbulbs. This figure shows a young man attempting to light as many bulbs as possible. The crank gets harder to turn as more bulbs light because it requires more power to produce the necessary watts of electricity.

SOURCES OF ELECTRICITY

FRICTION When certain different materials are rubbed together, the friction causes electrons to be transferred from one to the other. Both materials become electrically charged. These charges are not in motion, but stay on the surface where they were deposited. Because the charges are stationary, or static, this type of voltage is called **static electricity**. Walking across a carpeted floor creates a buildup of a static charge in your body, which is an insulator, and then the charge is discharged when you touch a metal conductor.

HEAT When pieces of two different metals are joined together at both ends and one junction is heated, current passes through the metals. The current is very small, only millionths of an ampere, but this is enough to use in a temperature-measuring device called a **thermocouple**. ● **SEE FIGURE 36–22**.

Some engine temperature sensors operate in this manner. This form of voltage is called **thermoelectricity**.

Thermoelectricity was discovered and has been known for over a century. In 1823, a German physicist, Thomas Johann Seebeck, discovered that a voltage was developed in a loop containing two dissimilar metals, provided the two junctions were maintained at different temperatures. A decade later, a French scientist, Jean Charles Athanase Peltier, found that electrons moving through a solid can carry heat from one side of the material to the other side. This effect is called the **Peltier effect**. A Peltier effect device is often used in portable coolers to keep food items cool if the current flows in one direction and keep items warm if the current flows in reverse.

LIGHT In 1839, Edmond Becquerel noticed that by shining a beam of sunlight over two different liquids, he could develop an electric current. When certain metals are exposed to light, some of the light energy is transferred to the free electrons of the metal. This excess energy breaks the electrons loose from the surface of the metal. They can then be collected and made to flow in a conductor. ● **SEE FIGURE 36–23**.

This **photoelectricity** is widely used in light-measuring devices.

PRESSURE The first experimental demonstration of a connection between the generation of a voltage due to pressure applied to a crystal was published in 1880 by Pierre and Jacques Curie. Their experiment consisted of voltage being produced when prepared crystals, such as quartz, topaz, and Rochelle salt, had a force applied. ● **SEE FIGURE 36–24**.

This current is used in crystal microphones, underwater hydrophones, and certain stethoscopes. The voltage created is called **piezoelectricity**. A gas-grill igniter uses the principle of piezoelectricity to produce a spark, and engine-knock sensors

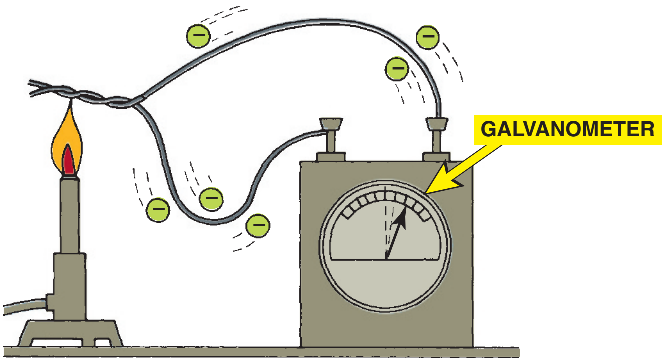


FIGURE 36–22 Electron flow is produced by heating the connection of two different metals. A galvanometer is an analog (needle-type) meter designed to detect weak voltage signals.

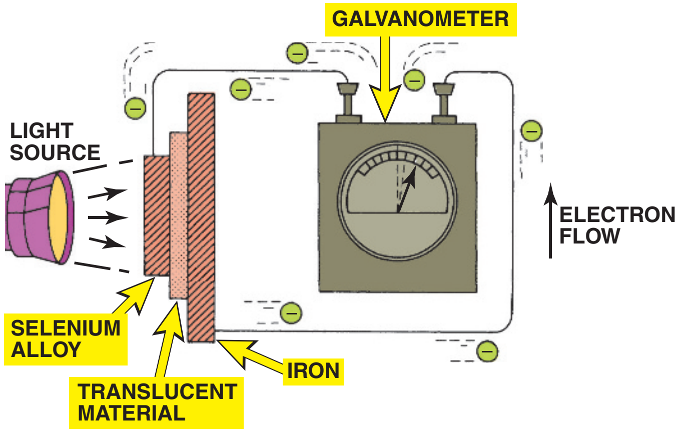


FIGURE 36–23 Electron flow is produced by light striking a light-sensitive material.

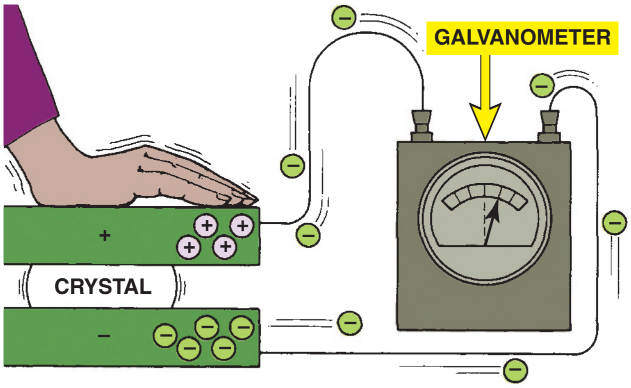


FIGURE 36–24 Electron flow is produced by pressure on certain crystals.

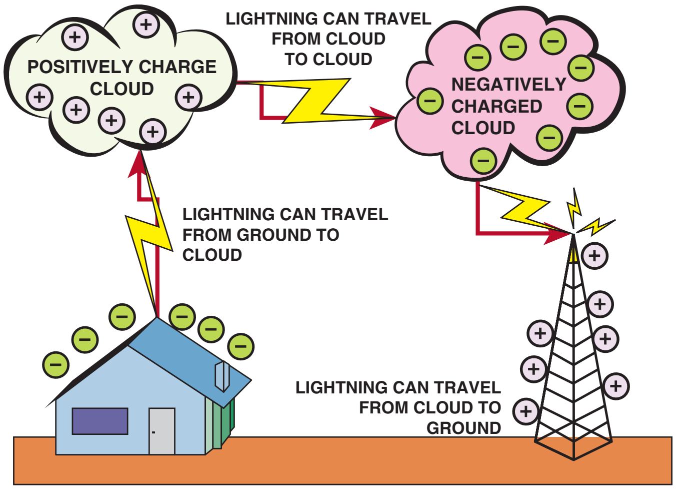

LIGHTNING CAN TRAVEL FROM CLOUD TO CLOUD
POSITIVELY CHARGE CLOUD
NEGATIVELY CHARGED CLOUD
LIGHTNING CAN TRAVEL FROM GROUND TO CLOUD
LIGHTNING CAN TRAVEL FROM CLOUD TO GROUND

FIGURE 36–25 Lightning is created by the static charges that build up in clouds and can discharge to another cloud or to the earth.

FREQUENTLY ASKED QUESTION

How Much Voltage and Current Is Discharged in a Lightning Strike?

Cloud-to-cloud and cloud-to-ground lightning bolts are common occurrences. Most lightning strikes carry from 5,000 amperes to over 200,000 amperes with voltages from 40,000 volts to over 120,000 volts. However, the lightning strike lasts for only a few microseconds so actual power in each strike is low. ● **SEE FIGURE 36–25**.

(KS) use piezoelectricity to create a voltage signal for use as an input for an engine computer input signal.

CHEMICAL Two different materials (usually metals) placed in a conducting and reactive chemical solution create a difference in potential, or voltage, between them. This principle is called **electrochemistry** and is the basis of the automotive battery.

MAGNETISM Electricity can be produced if a conductor is moved through a magnetic field or a moving magnetic field is moved near a conductor. This is the principle on which many automotive devices work, including the following:

- Starter motor
- Alternator
- Ignition coils
- Solenoids and relays

CONDUCTORS AND RESISTANCE

All conductors have some resistance to current flow. The following are principles of conductors and their resistance:

- **If the conductor length is doubled, its resistance doubles.** This is the reason why battery cables are designed to be as short as possible.
- **If the conductor diameter is increased, its resistance is reduced.** This is the reason starter motor cables are larger in diameter than other wiring in the vehicle.
- **As the temperature increases, the resistance of the conductor also increases.** This is the reason for installing heat shields on some starter motors. The heat shield helps to protect the conductors (copper wiring inside the starter) from excessive engine heat, and so reduces the resistance of starter circuits. Because the resistance in a conductor increases with increase in temperature, the conductor is called a **positive temperature coefficient (PTC)** resistor.
- **Materials used in the conductor have an impact on its resistance.** Silver has the lowest resistance among all materials used as conductors, but is expensive. Copper is the next lowest in resistance and is reasonably priced. ● **SEE CHART 36–1** for a comparison of materials.

1	Silver
2	Copper
3	Gold
4	Aluminum
5	Tungsten
6	Zinc
7	Brass (copper and zinc)
8	Platinum
9	Iron
10	Nickel
11	Tin
12	Steel
13	Lead

CHART 36–1

Conductor ratings (starting with the best).

RESISTORS

FIXED RESISTORS Resistance is the opposition to current flow. Resistors represent an electrical load, or resistance to current flow. Most electrical and electronic devices use resistors of specific values to limit and control the flow of current. Resistors can be made from carbon or other materials that restrict the flow of electricity and are available in various sizes

FREQUENTLY ASKED QUESTION

Why Is Gold Used If Copper Has Lower Resistance?

Copper is used for most automotive electrical components and wiring because it has low resistance and is reasonably priced. Gold is used in airbag connections and sensors because it does not corrode. Gold can be buried for hundreds of years and when dug up, is just as shiny as ever.

and resistance values. Most resistors have a series of painted color bands around them. These color bands are coded to indicate the degree of resistance. ● **SEE FIGURES 36–26 AND 36–27.**

VARIABLE RESISTORS Two basic types of mechanically operated variable resistors are used in automotive applications.

- A **potentiometer** is a three-terminal variable resistor where a wiper contact provides a variable voltage output. ● **SEE FIGURE 36–28**. Potentiometers are most commonly used as throttle position (TP) sensors on computer-equipped engines. A potentiometer is also used to control audio volume, bass, treble, balance, and fade.
- Another type of mechanically operated variable resistor is the **rheostat**. A rheostat is a *two*-terminal unit in which all of the current flows through the movable arm. ● **SEE FIGURE 36–29**. A rheostat was commonly used for dash light dimming control on older vehicles.

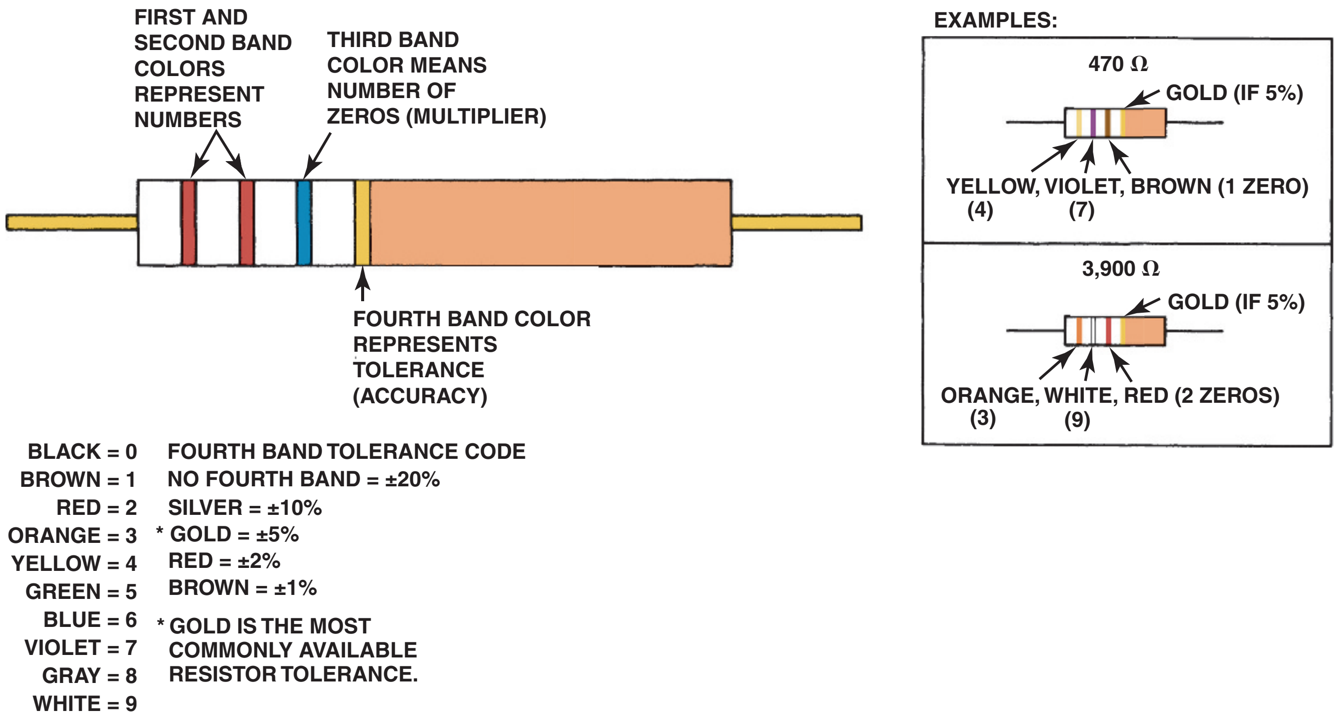

FIRST AND SECOND BAND COLORS REPRESENT NUMBERS
THIRD BAND COLOR MEANS NUMBER OF ZEROS (MULTIPLIER)
FOURTH BAND COLOR REPRESENTS TOLERANCE (ACCURACY)
BLACK = 0
BROWN = 1
RED = 2
ORANGE = 3
YELLOW = 4
GREEN = 5
BLUE = 6
VIOLET = 7
GRAY = 8
WHITE = 9
FOURTH BAND TOLERANCE CODE
NO FOURTH BAND = ±20%
SILVER = ±10%
* GOLD = ±5%
RED = ±2%
BROWN = ±1%
* GOLD IS THE MOST COMMONLY AVAILABLE RESISTOR TOLERANCE.
EXAMPLES:
470 Ω
GOLD (IF 5%)
YELLOW, VIOLET, BROWN (1 ZERO)
(4) (7)
3,900 Ω
GOLD (IF 5%)
ORANGE, WHITE, RED (2 ZEROS)
(3) (9)

FIGURE 36–26 This figure shows a resistor color-code interpretation.

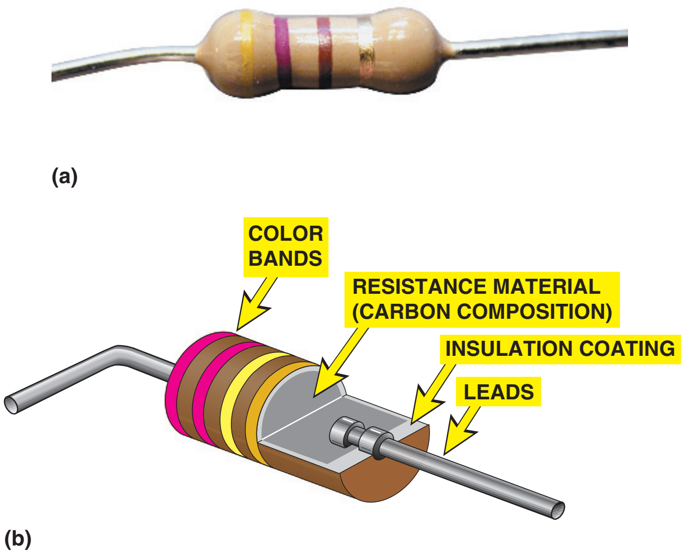

(a)
COLOR BANDS
RESISTANCE MATERIAL (CARBON COMPOSITION)
INSULATION COATING
LEADS
(b)

FIGURE 36–27 (a) A typical carbon resistor. (b) A cutaway view of a typical carbon resistor showing what is inside.

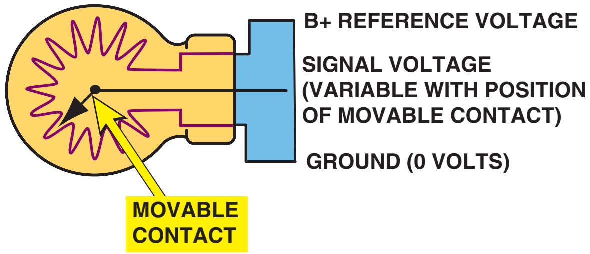

B+ REFERENCE VOLTAGE
SIGNAL VOLTAGE (VARIABLE WITH POSITION OF MOVABLE CONTACT)
GROUND (0 VOLTS)
MOVABLE CONTACT

FIGURE 36–28 A three-wire variable resistor is called a potentiometer.

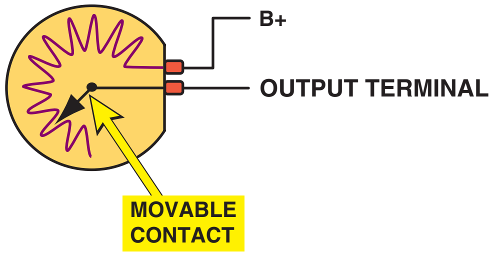

B+
OUTPUT TERMINAL
MOVABLE CONTACT

FIGURE 36–29 A two-wire variable resistor is called a rheostat.

REVIEW QUESTIONS

1. What is electricity?
2. What are ampere, volt, and ohm?
3. What are three examples of conductors and three examples of insulators?
4. What are the five sources of electricity?
5. What is the relationship between the length of a wire and its resistance?

CHAPTER QUIZ

1. An electrical conductor is an element with ___________ electrons in its outer orbit.
   - **a.** less than 2
   - **b.** less than 4
   - **c.** exactly 4
   - **d.** more than 4
2. Like charges ___________.
   - **a.** attract
   - **b.** repel
   - **c.** neutralize each other
   - **d.** add
3. Carbon and silicon are examples of ___________.
   - **a.** semiconductors
   - **b.** insulators
   - **c.** conductors
   - **d.** photoelectric materials
4. Which unit of electricity does the work in a circuit?
   - **a.** Volt
   - **b.** Ampere
   - **c.** Ohm
   - **d.** Coulomb
5. The ___________ is a unit of electrical pressure.
   - **a.** coulomb
   - **b.** volt
   - **c.** ampere
   - **d.** ohm
6. Creating electricity by exerting a force on a crystal is called ___________.
   - **a.** electrochemistry
   - **b.** piezoelectricity
   - **c.** thermoelectricity
   - **d.** photoelectricity
7. The fact that a voltage can be created by exerting force on a crystal is used in which type of sensor?
   - **a.** Throttle position (TP)
   - **b.** Manifold absolute pressure (MAP)
   - **c.** Barometric pressure (BARO)
   - **d.** Knock sensor (KS)
8. As temperature increases, ___________.
   - **a.** the resistance of a conductor decreases
   - **b.** the resistance of a conductor increases
   - **c.** the resistance of a conductor remains the same
   - **d.** the voltage of the conductor decreases
9. Technician A says that a two-wire variable resistor is called a rheostat. Technician B says that a three-wire variable resistor is called a potentiometer. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. A potentiometer, a three-wire variable resistor, is used in which type of sensor?
    - **a.** Throttle position (TP)
    - **b.** Manifold absolute pressure (MAP)
    - **c.** Barometric pressure (BARO)
    - **d.** Knock sensor (KS)

Chapter 37

ELECTRICAL CIRCUITS AND OHM'S LAW

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Identify the parts of a complete circuit.
- Describe the characteristics of different types of circuit faults.
- Explain Ohm's law as it applies to automotive circuits.
- Explain Watt's law as it applies to automotive circuits.

KEY TERMS:

Circuit 423 • Complete circuit 423 • Continuity 423 • Electrical load 423 • Grounded 425 • Load 423 • Ohm's law 426 • Open circuit 424 • Power path 423 • Power source 423 • Protection 423 • Return path (ground) 423 • Shorted 424 • Short-to-ground 425 • Short-to-voltage 424 • Watt 427 • Watt's law 427

CIRCUITS

DEFINITION A **circuit** is a complete path that electrons travel from a power source (such as a battery) through a **load**, such as a lightbulb, and back to the power source. It is called a *circuit* because the current must start and finish at the same place (power source).

For *any* electrical circuit to work at all, it must be continuous from the battery (power), through all the wires and components, and back to the battery (ground). A circuit that is continuous throughout is said to have **continuity**.

PARTS OF A COMPLETE CIRCUIT Every **complete circuit** contains the following parts. ● **SEE FIGURE 37–1**.

1. A **power source**, such as a vehicle's battery.
2. **Protection** from harmful overloads (excessive current flow). (Fuses, circuit breakers, and fusible links are examples of electrical circuit-protection devices.)
3. The **power path** for the current to flow through from the power source to the resistance. (This path from a power source to the load—a lightbulb in this example—is usually an insulated copper wire.)

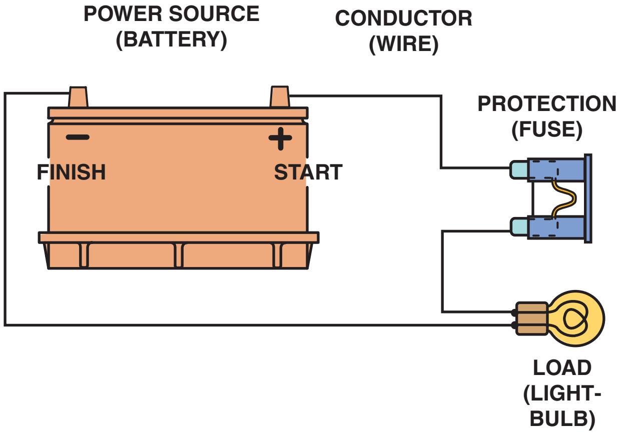


FIGURE 37–1 All complete circuits must have a power source, a power path, protection (fuse), an electrical load (lightbulb in this case), and a return path back to the power source.

4. The **electrical load** or resistance, which converts electrical energy into heat, light, or motion.
5. A **return path (ground)** for the electrical current from the load back to the power source so that there is a *complete* circuit. (This return, or ground, path is usually the metal body,

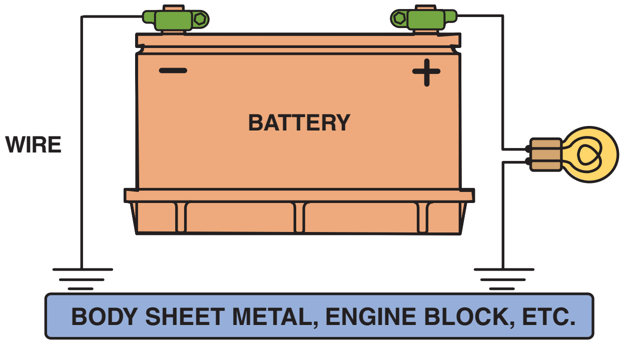

WIRE
BATTERY
−
+
BODY SHEET METAL, ENGINE BLOCK, ETC.

FIGURE 37–2 The return path back to the battery can be any electrical conductor, such as a copper wire or the metal frame or body of the vehicle.

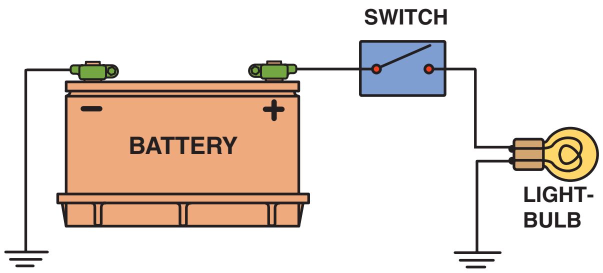

SWITCH
BATTERY
−
+
LIGHT-
BULB

FIGURE 37–3 An electrical switch opens the circuit and no current flows. The switch could also be on the return (ground) path wire.

frame, ground wires, and engine block of the vehicle. ● **SEE FIGURE 37–2**.

6. Switches and controls that turn the circuit on and off. ● **SEE FIGURE 37–3**.

CIRCUIT FAULT TYPES

OPEN CIRCUITS An **open circuit** is any circuit that is *not* complete, or that lacks continuity, such as a broken wire. ● **SEE FIGURE 37–4**.

Open circuits have the following features:

1. *No current at all* flows through an open circuit.
2. An open circuit may be created by a break in the circuit or by a switch that opens (turns off) the circuit and prevents the flow of current.
3. In any circuit containing a power load and ground, an opening anywhere in the circuit causes the circuit not to work.
4. A light switch in a home and the headlight switch in a vehicle are examples of devices that open a circuit to control its operation.
5. A fuse blows (opens) when the current in the circuit exceeds the fuse rating. This stops the current flow to prevent any harm to the components or wiring as a result of the fault.

SHORT-TO-VOLTAGE *If a wire (conductor) or component is shorted to voltage*, it is commonly referred to as being **shorted**. A **short-to-voltage** occurs when the power side of one circuit is electrically connected to the power side of another circuit. ● **SEE FIGURE 37–5**.

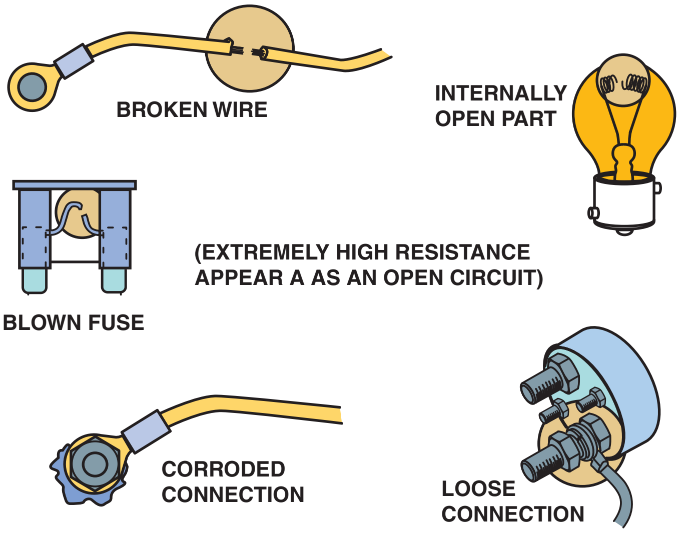

BROKEN WIRE
INTERNALLY
OPEN PART
(EXTREMELY HIGH RESISTANCE
APPEAR A AS AN OPEN CIRCUIT)
BLOWN FUSE
CORRODED
CONNECTION
LOOSE
CONNECTION

FIGURE 37–4 Examples of common causes of open circuits. Some of these causes are often difficult to find.

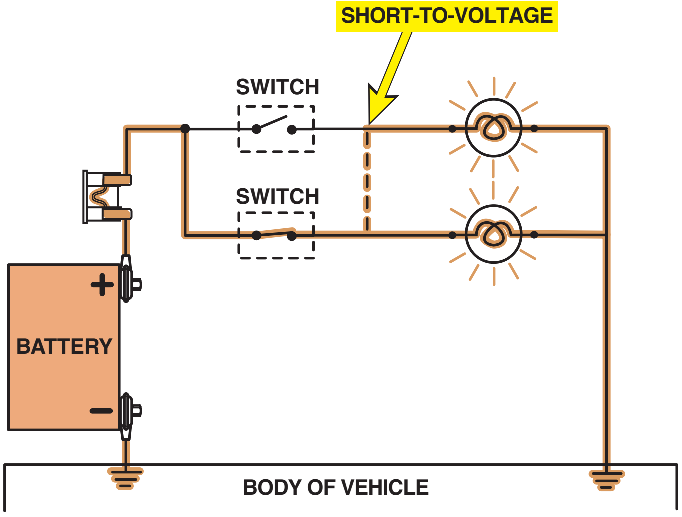

SHORT-TO-VOLTAGE
SWITCH
SWITCH
+
BATTERY
−
BODY OF VEHICLE

FIGURE 37–5 A short circuit permits electrical current to bypass some or all of the resistance in the circuit.

A short circuit has the following features:

1. It is a complete circuit in which the current usually bypasses *some* or *all* of the resistance in the circuit.
2. It involves the power side of the circuit.
3. It involves a copper-to-copper connection (two power-side wires touching together).

TECH TIP

“Open” Is a Four-Letter Word

An open in a circuit breaks the path of current flow. The open can be any break in the power side, load, or ground side of a circuit. A switch is often used to close and open a circuit to turn it on and off. Just remember,

Open = no current flow
Closed = current flow

Trying to locate an open circuit in a vehicle is often difficult and may cause the technician to use other four-letter words, such as “HELP”!

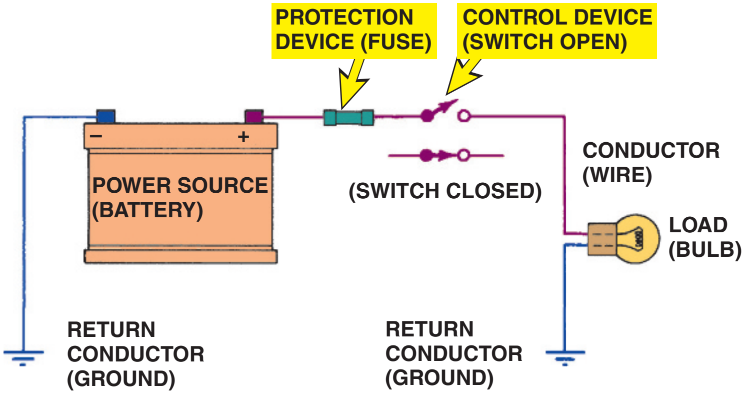

PROTECTION DEVICE (FUSE)
CONTROL DEVICE (SWITCH OPEN)
−
+
POWER SOURCE (BATTERY)
(SWITCH CLOSED)
CONDUCTOR (WIRE)
LOAD (BULB)
RETURN CONDUCTOR (GROUND)
RETURN CONDUCTOR (GROUND)

FIGURE 37–6 A fuse or circuit breaker opens the circuit to prevent possible overheating damage in the event of a short circuit.

4. It usually affects more than one circuit. In this case, if one circuit is electrically connected to another circuit, one of the circuits may operate when it is not supposed to because it is being supplied power from another circuit.
5. It *may* or *may not* blow a fuse. ● **SEE FIGURE 37–6**.

SHORT-TO-GROUND A **short-to-ground** is a type of short circuit that occurs when the current bypasses part of the normal circuit and flows directly to ground. A short-to-ground has the following features:

1. Because the ground return circuit is metal (vehicle frame, engine, or body), it is often identified as having current flowing from copper to steel.
2. It occurs at any place where a power path wire accidentally touches a return path wire or conductor. ● **SEE FIGURE 37–7**.
3. A defective component or circuit that is shorted to ground is commonly called **grounded**.
4. A short-to-ground almost always results in a blown fuse, damaged connectors, or melted wires.

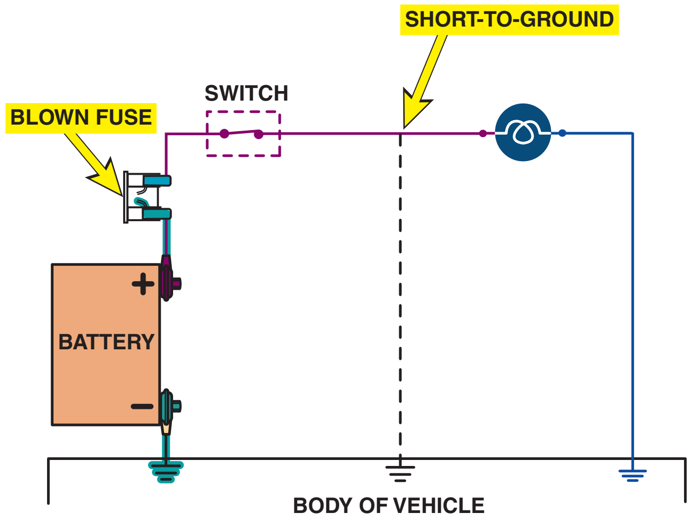

SHORT-TO-GROUND
SWITCH
BLOWN FUSE
+
BATTERY
−
BODY OF VEHICLE

FIGURE 37–7 A short-to-ground affects the power side of the circuit. Current flows directly to the ground return, bypassing some or all of the electrical loads in the circuit. There is no current in the circuit past the short. A short-to-ground will also causes the fuse to blow.

TECH TIP

Think of a Waterwheel

A beginner technician cleaned the positive terminal of the battery when the starter was cranking the engine slowly. When questioned by the shop supervisor as to why only the positive post had been cleaned, the technician responded that the negative terminal was "only a ground." The supervisor reminded the technician that the current, in amperes, is constant throughout a series circuit (such as the cranking motor circuit). If 200 amperes leave the positive post of the battery, then 200 amperes must return to the battery through the negative post.

The technician could not understand how electricity can do work (crank an engine), yet return the same amount of current, in amperes, as left the battery. The shop supervisor explained that even though the current is constant throughout the circuit, the voltage (electrical pressure or potential) drops to zero in the circuit. To explain further, the shop supervisor drew a waterwheel. ● **SEE FIGURE 37–8**.

As water drops from a higher level to a lower level, high potential energy (or voltage) is used to turn the waterwheel and results in low potential energy (or lower voltage). The same amount of water (or amperes) reaches the pond under the waterwheel as started in the fall above the waterwheel. As current (amperes) flows through a conductor, it performs work in the circuit (turns the waterwheel) while its voltage (potential) drops.

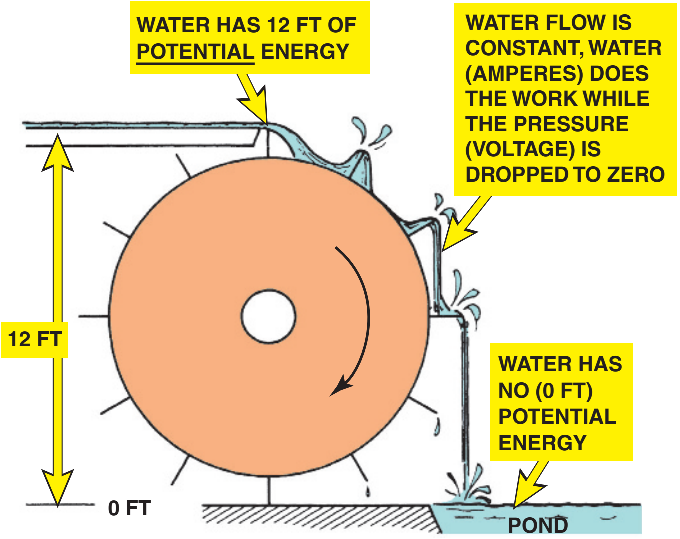

WATER HAS 12 FT OF POTENTIAL ENERGY
WATER FLOW IS CONSTANT, WATER (AMPERES) DOES THE WORK WHILE THE PRESSURE (VOLTAGE) IS DROPPED TO ZERO
12 FT
WATER HAS NO (0 FT) POTENTIAL ENERGY
0 FT
POND

FIGURE 37–8 Electrical flow through a circuit is similar to water flowing over a waterwheel. The more water (amperes in electricity), the greater the amount of work (waterwheel). The amount of water remains constant, yet the pressure (voltage in electricity) drops as the current flows through the circuit.

HIGH RESISTANCE **High resistance** can be caused by any of the following:

- Corroded connections or sockets
- Loose terminals in a connector
- Loose ground connections

If there is high resistance anywhere in a circuit, it may cause the following problems:

1. Slow operation of a motor-driven unit, such as the windshield wipers or blower motor
2. Dim lights
3. "Clicking" of relays or solenoids
4. No operation of a circuit or electrical component

CASE STUDY

The Short-to-Voltage Story

A technician was working on a Chevrolet pickup truck with the following unusual electrical problems:

1. When the brake pedal was depressed, the dash light and the side marker lights would light.
2. The turn signals caused all lights to blink and the fuel gauge needle to bounce up and down.
3. When the brake lights were on, the front parking lights also came on.

NOTE: Using a single-filament bulb (such as a #1156) in the place of a dual-filament bulb (such as a #1157) could also cause many of these same problems.

Because most of the trouble occurred when the brake pedal was depressed, the technician decided to trace all the wires in the brake light circuit. The technician discovered the problem near the exhaust system. A small hole in the tailpipe (after the muffler) directed hot exhaust gases to the wiring harness containing all of the wires for circuits at the rear of the truck. The heat had melted the insulation and caused most of the wires to touch. Whenever one circuit was activated (such as when the brake pedal was applied), the current had a complete path to several other circuits. A fuse did not blow because there was enough resistance in the circuits being energized, so the current (in amperes) was too low to blow any fuses.

Summary:

Complaint—Customer stated that the truck lights were doing strange things when the brake pedal was depressed.

Cause—Melted wires caused by a small hole in the exhaust was found during a visual inspection.

Correction—Performing a wire repair and fixing the exhaust leak corrected the customer concern.

OHM'S LAW

DEFINITION The German physicist George Simon Ohm established that electric pressure (electromotive force; EMF) in volts, electrical resistance in ohms, and the amount of current in amperes flowing through any circuit are all related. **Ohm's law** states:

> It requires 1 volt to push 1 ampere through
> 1 ohm of resistance.

This means that if the voltage is doubled, the number of amperes of current flowing through a circuit also doubles if the resistance of the circuit remains the same.

FORMULAS Ohm's law can also be stated as a simple formula used to calculate one value of an electrical circuit if the other two are known. If, for example, the current (*I*) is unknown but the voltage (*E*) and resistance (*R*) are known, then Ohm's law can be used to find the answer. ● **SEE FIGURE 37–9**.

$$I = \frac{E}{R}$$

where

I = Current in amperes (A)

E = Electromotive force (EMF) in volts (V)

R = Resistance in ohms (Ω), represented by the Greek letter Omega (pronounced oh-MAY-guh).

1. Ohm's law can determine the resistance if the volts and amperes are known: $R = \frac{E}{I}$
2. Ohm's law can determine the *voltage* if the resistance (ohms) and amperes are known: $E = I \times R$
3. Ohm's law can determine the amperes if the resistance and voltage are known: $I = \frac{E}{R}$

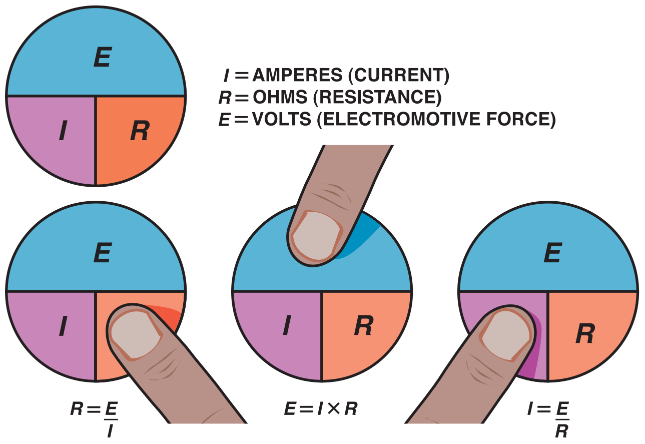


FIGURE 37–9 To calculate one unit of electricity when the other two are known, simply use your finger and cover the unit you do not know. For example, if both voltage (*E*) and resistance (*R*) are known, cover the letter *I* (amperes). Notice that the letter *E* is above the letter *R*, so divide the resistor's value into the voltage to determine the current in the circuit.

VOLTAGE	RESISTANCE	AMPERAGE
Up	Down	Up
Up	Same	Up
Up	Up	Same
Same	Down	Up
Same	Same	Same
Same	Up	Down
Down	Up	Down
Down	Same	Down

CHART 37–1

Ohm's law relationship with the three units of electricity.

NOTE: Before applying Ohm's law, be sure that each unit of electricity is converted into base units. For example, 10 kΩ should be converted to 10,000 Ω and 10 mA should be converted into 0.010 A.

● **SEE CHART 37–1**.

OHM'S LAW APPLIED TO SIMPLE CIRCUITS If a battery with 12 volts is connected to a resistor of 4 ohms, as shown in ● **FIGURE 37–10**, how many amperes flow through the circuit?

Using Ohm's law, we can calculate the number of amperes that flow through the wires and the resistor. Remember, if two factors are known (volts and ohms in this example), the remaining factor (amperes) can be calculated using Ohm's law.

$$I = \frac{E}{R} = \frac{12\text{ V}}{4\ \Omega} = \text{A}$$

The values for the voltage (12) and the resistance (4) were substituted for the variables *E* and *R*, and *I* is thus 3 amperes

$$\left(\frac{12}{4} = 3\right)$$

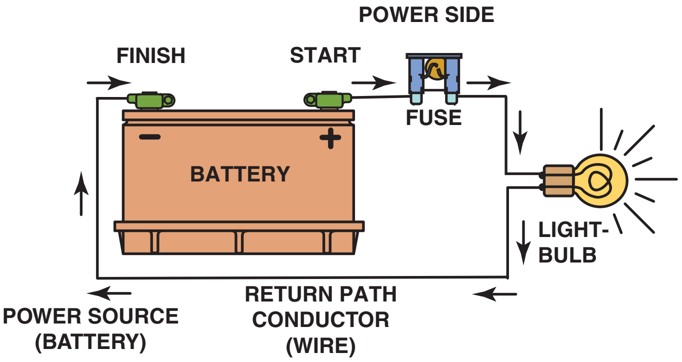


FIGURE 37–10 This closed circuit includes a power source, power-side wire, circuit protection (fuse), resistance (bulb), and return path wire. In this circuit, if the battery has 12 volts and the electrical load has 4 ohms, then the current through the circuit is 3 amperes.

If we want to connect a resistor to a 12 volt battery, we now know that this simple circuit requires 3 amperes to operate. This may help us for two reasons:

1. We can now determine the wire diameter that we need based on the number of amperes flowing through the circuit.
2. The correct fuse rating can be selected to protect the circuit.

WATT'S LAW

BACKGROUND James Watt (1736–1819), a Scottish inventor, first determined the power of a typical horse while measuring the amount of coal being lifted out of a mine. The power of one horse was determined to be 33,000 foot-pounds per minute. Electricity can also be expressed in a unit of power called a watt and the relationship is known as **Watt's law**, which states:

> A **watt** is a unit of electrical power represented by a current of 1 ampere through a circuit with a potential difference of 1 volt.

FORMULAS The symbol for a watt is the capital letter *W*. The formula for watts is

$$W = I \times E$$

Another way to express this formula is to use the letter *P* to represent the unit of power. The formula then becomes

$$P = I \times E$$

NOTE: An easy way to remember this equation is that it spells "pie."

Engine power is commonly rated in watts or kilowatts (1,000 watts equal 1 kilowatt) because 1 horsepower is equal to 746 watts. For example, a 200 horsepower engine can be rated as having the power equal to 149,200 watts or 149.2 kilowatts (kW).

To calculate watts, both the current in amperes and the voltage in the circuit must be known. If any two of these factors are known, then the other remaining factor can be determined by the following equations:

$$P = I \times E \textbf{ (watts equal amperes times voltage)}$$

$$I = \frac{P}{E} \textbf{ (amperes equal watts divided by voltage)}$$

$$E = \frac{P}{I} \textbf{ (voltage equals watts divided by amperes)}$$

For example, the amperage required to operate a 55 watt low beam headlight bulb can be calculated using Watt's law. The vehicle's 12 volt battery supplies the voltage to operate the lamp. Using the formula I = P/E, the calculation is 55/12 = 4.6 amperes.

A Watt's circle can be drawn and used like the Ohm's law circle diagram. ● **SEE FIGURE 37–11**.

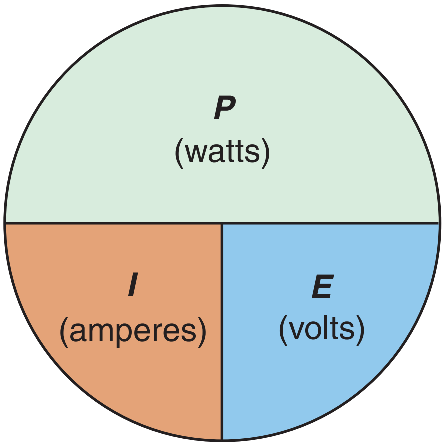


FIGURE 37–11 To calculate one unit when the other two are known, simply cover the unknown unit to see what unit needs to be divided or multiplied to arrive at the solution. The power of electric motors such as starter motors and propulsion (traction) motors used in electric and hybrid electric vehicles are rated in watts.

MAGIC CIRCLE The formulas for calculating any combination of electrical units are shown in ● **FIGURE 37–12**.

It is almost impossible to remember all of these formulas, so this one circle showing all of the formulas is nice to have available if needed.

TECH TIP

Wattage Increases by the Square of the Voltage

The brightness of a lightbulb, such as an automotive headlight or courtesy light, depends on the number of watts available. The watt is the unit by which electrical power is measured. If the battery voltage drops, even slightly, the light becomes noticeably dimmer. The formula for calculating power (P) in watts is $P = I \times E$. This can also be expressed as Watts = Amps × Volts.

According to Ohm's law, $I = \frac{E}{R}$. Therefore, $\frac{E}{R}$ can be substituted for I in the previous formula, resulting in $P = \frac{E}{R} \times E$ or $P = \frac{E^2}{R}$.

E^2 means E multiplied by itself. A small change in the voltage (E) has a big effect on the total brightness of the bulb. (Remember, household lightbulbs are sold according to their wattage.) Therefore, if the voltage to an automotive bulb is reduced, such as by a poor electrical connection, the brightness of the bulb is greatly affected. A poor electrical ground causes a voltage drop. The voltage at the bulb is reduced and the bulb's brightness is reduced.

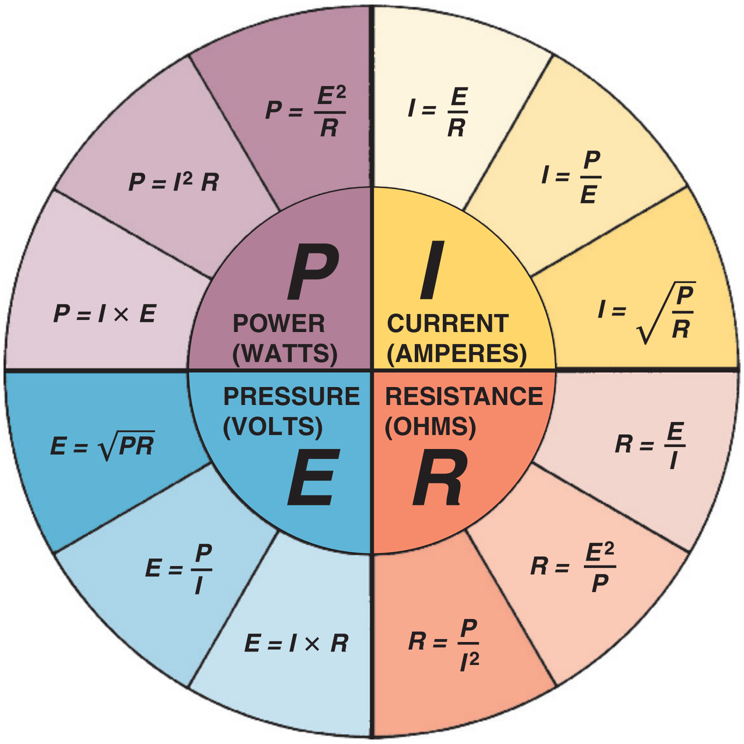


FIGURE 37–12 "Magic circle" of most formulas for problems involving Ohm's law. Each quarter of the "pie" has formulas used to solve for a particular unknown value: current (amperes), in the upper right segment; resistance (ohms), in the lower right; voltage (*E*), in the lower left; and power (watts), in the upper left.

REVIEW QUESTIONS

1. What is included in a complete electrical circuit?
2. What is the difference between a short-to-voltage and a short-to-ground?
3. What is the difference between an electrical open and a short?
4. What is Ohm's law?
5. What happens to current flow (amperes) and wattage if the resistance of a circuit is increased because of a corroded connection?

CHAPTER QUIZ

1. If an insulated (power side) wire gets rubbed through a part of the insulation and the wire conductor touches the steel body of a vehicle, the type of failure would be called a(n) ______________.
   - **a.** short-to-voltage
   - **b.** short-to-ground
   - **c.** open
   - **d.** chassis ground
2. If two insulated (power side) wires were to melt together at the point where the copper conductors touched each other, the type of failure would be called a(n) ______________.
   - **a.** short-to-voltage
   - **b.** short-to-ground
   - **c.** open
   - **d.** floating ground
3. If 12 volts are being applied to a resistance of 3 ohms, ______________ amperes will flow.
   - **a.** 12
   - **b.** 3
   - **c.** 4
   - **d.** 36
4. How many watts are consumed by a lightbulb if 1.2 amperes are measured when 12 volts are applied?
   - **a.** 14.4 watts
   - **b.** 144 watts
   - **c.** 10 watts
   - **d.** 0.10 watt
5. How many watts are consumed by a starter motor if it draws 150 amperes at 10 volts?
   - **a.** 15 watts
   - **b.** 150 watts
   - **c.** 1,500 watts
   - **d.** 15,000 watts
6. High resistance in an electrical circuit can cause ______________.
   - **a.** dim lights
   - **b.** slow motor operation
   - **c.** clicking of relays or solenoids
   - **d.** All of the above
7. If the voltage increases in a circuit, what happens to the current (amperes) if the resistance remains the same?
   - **a.** Increases
   - **b.** Decreases
   - **c.** Remains the same
   - **d.** Cannot be determined
8. If 200 amperes flow from the positive terminal of a battery and operate the starter motor, how many amperes will flow back to the negative terminal of the battery?
   - **a.** Cannot be determined
   - **b.** Zero
   - **c.** One half (about 100 amperes)
   - **d.** 200 amperes
9. What is the symbol for voltage used in calculations?
   - **a.** R
   - **b.** E
   - **c.** EMF
   - **d.** I
10. Which circuit failure is most likely to cause the fuse to blow?
    - **a.** Open
    - **b.** Short-to-ground
    - **c.** Short-to-voltage
    - **d.** High resistance

Chapter 38

SERIES, PARALLEL, AND SERIES-PARALLEL CIRCUITS

LEARNING OBJECTIVES:

After studying this chapter, the reader will be able to:

- Define series circuits.
- Discuss Ohm's law and series circuits.
- Explain Kirchhoff's voltage law.
- Explain series circuit laws.
- Define parallel circuits.
- Discuss Kirchhoff's current law.
- Discuss parallel circuit laws.
- Determine the total resistance of a parallel circuit.
- Define series-parallel circuits.
- Explain how to solve series-parallel problems.

KEY TERMS:

Branches 434 • Combination circuit 437 • Compound circuit 437 • Kirchhoff's current law 434 • Kirchhoff's voltage law 431 • Legs 434 • Parallel circuit 434 • Series circuit 430 • Series-parallel circuits 437 • Shunts 434 • Total circuit resistance 435 • Voltage drop 432

SERIES CIRCUITS

A **series circuit** is a complete circuit that has more than one electrical load where all of the current has only one path to flow through all of the loads. Electrical components, such as fuses and switches, are generally not considered to be included in the determination of a series circuit. The circuit must be continuous or have continuity in order for current to flow through the circuit.

NOTE: Because an electrical load needs both a power and a ground to operate, a break (open) anywhere in a series circuit will cause the current in the circuit to stop.

OHM'S LAW AND SERIES CIRCUITS

Because *all* current flows through all resistances, the total resistance is the sum (addition) of all resistances. ● **SEE FIGURE 38–1.** The total resistance of the circuit shown here is 6 ohms ($1\,\Omega + 2\,\Omega + 3\,\Omega$). The formula for total resistance (R_T) for a series circuit is

$$R_T = R_1 + R_2 + R_3 + \cdots$$

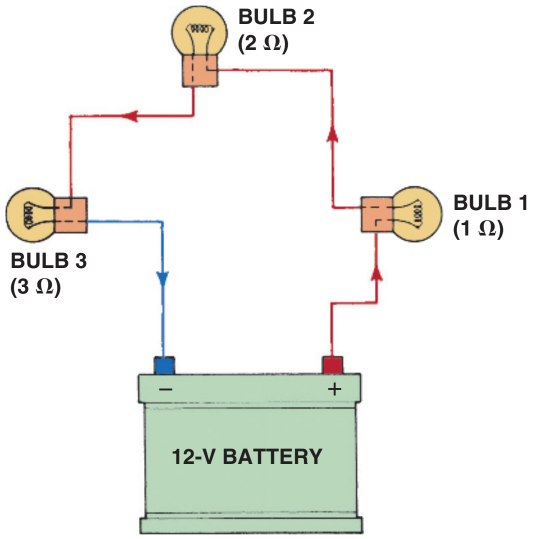


FIGURE 38–1 A series circuit with three bulbs. All current flows through all resistances (bulbs). The total resistance of the circuit is the sum of the total resistance of the bulbs. The bulbs will light dimly because of the increased resistance and the reduction of current flow (amperes) through the circuit.

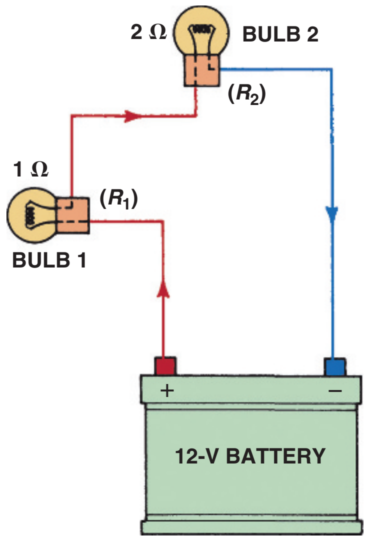


FIGURE 38–2 A series circuit with two bulbs.

TECH TIP

Farsighted Quality of Electricity

Electricity almost seems to act as if it "knows" what resistances are ahead on the long trip through a circuit. If the trip through the circuit has many high-resistance components, very few electrons (amperes) will choose to attempt to make the trip. If a circuit has little or no resistance (e.g., a short circuit), as many electrons (amperes) as possible attempt to flow through the complete circuit. If the flow exceeds the capacity of the fuse or the circuit breaker, the circuit is opened and all current flow stops.

Using Ohm's law to find the current flow, we have

$$I = E/R + 12\ \text{V}/6\ \Omega + 2\ \text{A}$$

Therefore, with a total resistance of 6 ohms using a 12-volt battery in the series circuit shown, 2 amperes of current will flow through the entire circuit. If the amount of resistance in a circuit is reduced, more current will flow.

In ● **FIGURE 38–2**, one resistance has been eliminated and now the total resistance is 3 ohms (1 Ω + 2 Ω). Using Ohm's law to calculate current flow yields 4 amperes.

$$I = E/R = 12\ \text{V}/3\ \Omega = 4\ \text{A}$$

Notice that the current flow was doubled (4 amperes instead of 2 amperes) when the resistance was cut in half (from 6 to 3 ohms).

KIRCHHOFF'S VOLTAGE LAW

The voltage that is applied through a series circuit drops with each resistor in a manner similar to that in which the strength of an athlete drops each time a strenuous physical feat is performed. The greater the resistance, the greater the drop in voltage.

A German physicist, Gustav Robert Kirchhoff (1824–1887), developed laws about electrical circuits. His second law, **Kirchhoff's voltage law**, concerns voltage drops. It states: *The voltage around any closed circuit is equal to the sum (total) of the voltage drops across the resistances.*

APPLYING KIRCHHOFF'S VOLTAGE LAW Kirchhoff states in his second law that the voltage will drop in proportion to the resistance and that the total of all voltage drops will equal the applied voltage. ● **SEE FIGURE 38–3**. Using ● **FIGURE 38–4**, the total resistance of the circuit can be determined by adding the individual resistances (2 Ω + 4 Ω + 6 Ω = 12 Ω). The current through the circuit is determined by using Ohm's law, $I = E/R$ = 12 V/12 Ω = 1 A. Therefore, in the circuit shown, the following values are known:

Resistance = 12 Ω
Voltage = 12 V
Current = 1 A

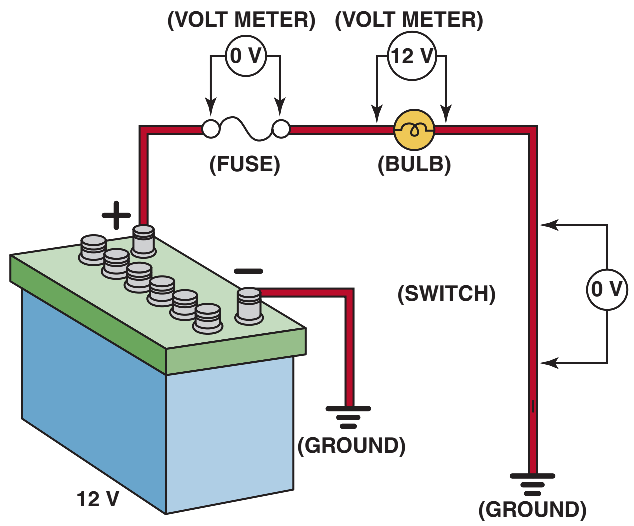


FIGURE 38–3 As current flows through a circuit, the voltage drops in proportion to the amount of resistance in the circuit. Most, if not all, of the resistance should occur across the load, such as the bulb in this circuit. All of the other components and wiring should produce little, if any, voltage drop. If a wire or connection did cause a voltage drop, less voltage would be available to light the bulb and the bulb would be dimmer than normal.

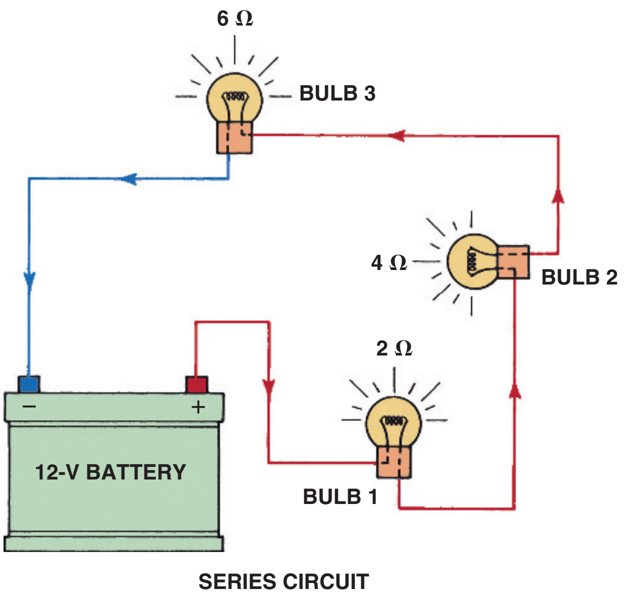


FIGURE 38–4 In a series circuit, the voltage is dropped or lowered by each resistance in the circuit. The higher the resistance, the greater the drop in voltage.

Everything is known *except* the voltage drop caused by each resistance. The **voltage drop** can be determined by using Ohm's law and calculating for voltage (*E*) using the value of each resistance individually:

$$E = I \times R$$

where

E = Voltage
I = Current in the circuit (remember, the current is constant in a series circuit; only the voltage varies)
R = Resistance of only one of the resistances

The voltage drops are as follows:

Voltage drop for bulb 1: $E = I \times R = 1\text{ A} \times 2\ \Omega = 2\text{ V}$
Voltage drop for bulb 2: $E = I \times R = 1\text{ A} \times 4\ \Omega = 4\text{ V}$
Voltage drop for bulb 3: $E = I \times R = 1\text{ A} \times 6\ \Omega = 6\text{ V}$

NOTE: Notice that the voltage drop is proportional to the resistance. In other words, the higher the resistance, the greater the voltage drop. A 6-ohm resistance dropped the voltage three times as much as the voltage drop created by the 2-ohm resistance.

According to Kirchhoff, the sum (addition) of the voltage drops should equal the applied voltage (battery voltage):

$$\textbf{Total of voltage drops} = 2\text{ V} + 4\text{ V} + 6\text{ V} = 12\text{ V} = \textbf{Battery voltage}$$

This illustrates Kirchhoff's second (voltage) law. Another example is illustrated in ● **FIGURE 38–5**.

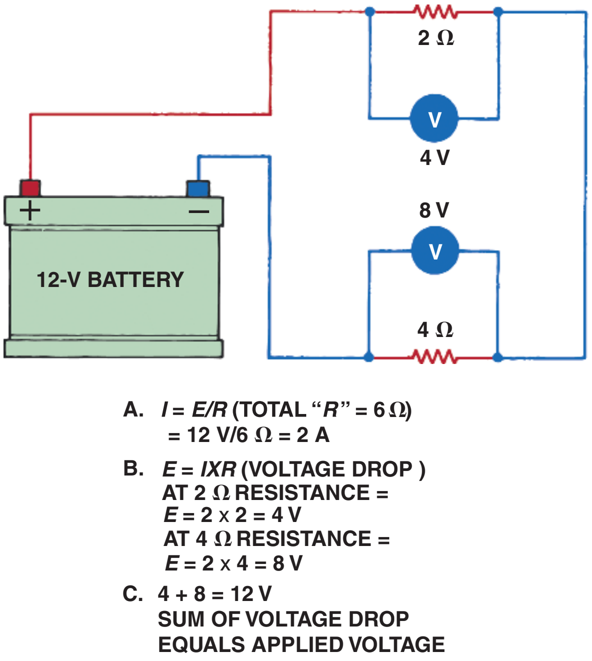


FIGURE 38–5 A voltmeter reads the differences of voltage between the test leads. The voltage read across a resistance is the voltage drop that occurs when current flows through a resistance. A voltage drop is also called an "*IR*" drop because it is calculated by multiplying the current (*I*) through the resistance (electrical load) by the value of the resistance (*R*).

FREQUENTLY ASKED QUESTION

Why Check the Voltage Drop Instead of Measuring the Resistance?

Imagine a wire with all strands cut except for one. An ohmmeter can be used to check the resistance of this wire and the resistance would be low, indicating that the wire was okay. But this one small strand cannot properly carry the current (amperes) in the circuit. A voltage drop test is a better test to determine the resistance in components for following two reasons:

- An ohmmeter can only test a wire or component that has been disconnected from the circuit and is not carrying current. The resistance can, and does, change when current flows.
- A voltage drop test is a dynamic test because as the current flows through a component, the conductor increases in temperature, which in turn increases resistance. This means that a voltage drop test is testing the circuit during normal operation and is therefore the most accurate way of determining circuit conditions.

A voltage drop test is also easier to perform because the resistance does not have to be known, only that the unwanted loss of voltage in a circuit should be less than 3% or less than about 0.14 volts for any 12-volt circuit.

USE OF VOLTAGE DROPS Voltage drops, due to built-in resistance, are used in automotive electrical systems to drop the voltage in the following examples:

1. **Intentional Voltage Drop in Automotive Circuits.** An example of an intentional voltage drop is the blower motor resistor, used in some heater or air-conditioning fans. Speeds are usually controlled by a fan switch sending current through medium 2-, medium 1-, or low-resistance wire resistors. The highest resistance will drop the voltage the most, causing the motor to run at the lowest speed. The speed of the motor changes as current is switched through 1, 2, or 3 resistors in the circuit.
2. **Unintentional Voltage Drop in Automotive Circuits.** Unintentional voltage drop occurs when there is a resistance in a circuit that is not supposed to be there, such as a loose connection or dirty switch contacts.

SERIES CIRCUIT LAWS

Law 1 The total resistance in a series circuit is the sum total of the individual resistances. The resistance values of each electrical load are simply added together.

Law 2 The current is constant throughout the entire circuit. ● **SEE FIGURE 38–6**. If 2 amperes of current leave the battery, 2 amperes of current return to the battery.

Law 3 Although the current (in amperes) is constant, the voltage drops across each resistance in the circuit.

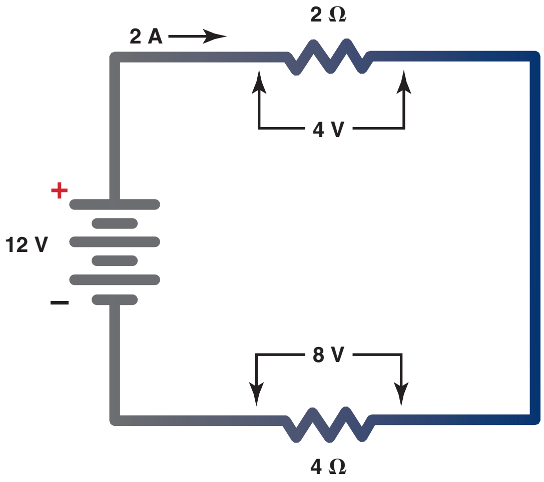


FIGURE 38–6 In this series circuit with a 2-ohm resistor and a 4-ohm resistor, current (2 amperes) is the same throughout even though the voltage drops across each resistor.

The voltage drop across each load is proportional to the value of the resistance compared to the total resistance. For example, if the resistance is one-half of the total resistance, the voltage drop across that resistance will be one-half of the applied voltage. The sum total of all individual voltage drops equals the applied source voltage.

SERIES CIRCUIT EXAMPLES Each of the four examples discussed below includes solving for the following:

- Total resistance in the circuit
- Current flow (amperes) through the circuit
- Voltage drop across each resistance

Example 1:

● **SEE FIGURE 38–7.**

The unknown in this problem is the value of R_2. The total resistance, however, can be calculated using Ohm's law.

$$R_{\text{Total}} = E/I = 12\text{ V}/3\text{ A} = 4\ \Omega$$

Because R_1 is 3 ohms and the total resistance is 4 ohms, the value of R_2 is 1 ohm.

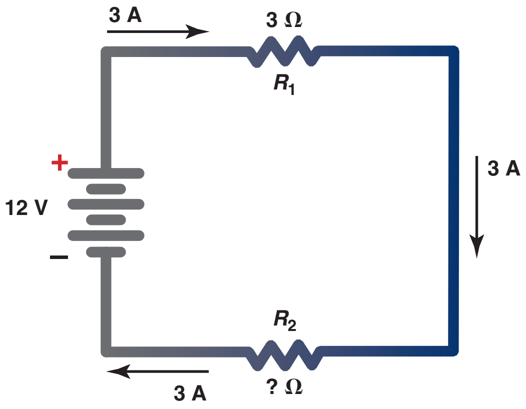


FIGURE 38–7 Example 1.

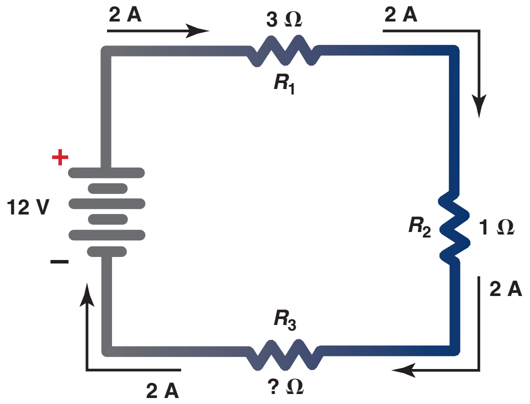


FIGURE 38–8 Example 2.

Example 2:

● **SEE FIGURE 38–8.**

The unknown in this problem is the value of R_3. The total resistance, however, can be calculated using Ohm's law.

$$R_{\text{Total}} = E/I = 12\text{ V}/2\text{ A} = 6\ \Omega$$

The total resistance of R_1 (3 ohms) and R_2 (1 ohm) equals 4 ohms so that the value of R_3 is the difference between the total resistance (6 ohms) and the value of the known resistance (4 ohms).

$$6 - 4 = 2\ \Omega = R_3$$

Example 3:

● **SEE FIGURE 38–9.**

The unknown value in this problem is the voltage of the battery. To solve for voltage, use Ohm's law ($E = I \times R$). The "R" in this problem refers to the total resistance (R_T). The total resistance of a series circuit is determined by adding the values of the individual resistors.

$$R_T = 1\ \Omega + 1\ \Omega + 1\ \Omega$$
$$R_T = 3\ \Omega$$

Placing the value for the total resistance (3 Ω) into the equation results in a battery voltage of 12 volts.

$$E = 4\text{ A} + 3\ \Omega$$
$$E = 12\text{ V}$$

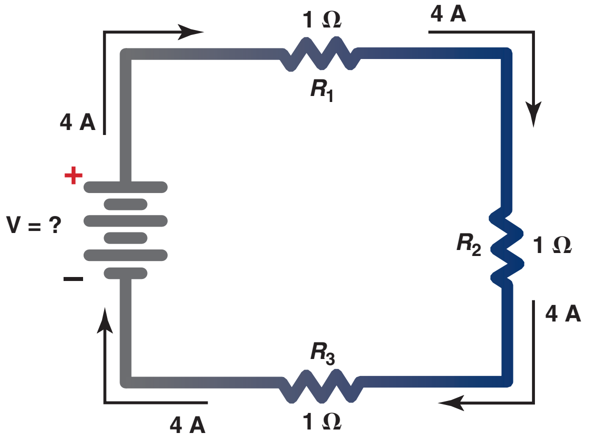


FIGURE 38–9 Example 3.

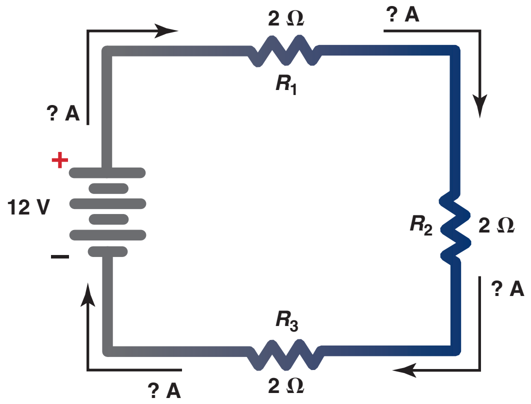


FIGURE 38–10 Example 4.

Example 4:

● **SEE FIGURE 38–10.**

The unknown in this example is the current (amperes) in the circuit. To solve for current, use Ohm's law.

$$I = E/R = 12\text{ V}/6\ \Omega = 2\text{ A}$$

Notice that the total resistance in the circuit (6 ohms) was used in this example, which is the total of the three individual resistors ($2\ \Omega + 2\ \Omega + 2\ \Omega = 6\ \Omega$). The current through the circuit is 2 amperes.

PARALLEL CIRCUITS

A **parallel circuit** is a complete circuit that has more than one path for the current. The separate paths which split and meet at junction points are called **branches**, **legs**, or **shunts**. The current flow through each branch or leg varies, depending on the resistance in that branch. A break or open in one leg or section of a parallel circuit does not stop the current flow through the remaining legs of the parallel circuit.

KIRCHHOFF'S CURRENT LAW

Kirchhoff's current law (his first law) states: *The current flowing into any junction of an electrical circuit is equal to the current flowing out of that junction.* This first law can be illustrated using Ohm's law, as seen in ● **FIGURE 38–11**. Kirchhoff's law states that the amount of current flowing into junction A will equal the current flowing out of junction A.

Because the 6-ohm leg requires 2 amperes and the 3-ohm resistance leg requires 4 amperes, it is necessary that the wire from the battery to junction A be capable of handling 6 amperes. Also notice that the sum of the current flowing *out* of a junction ($2 + 4 = 6$ A) is equal to the current flowing *into* the junction (6 A), proving Kirchhoff's current law.

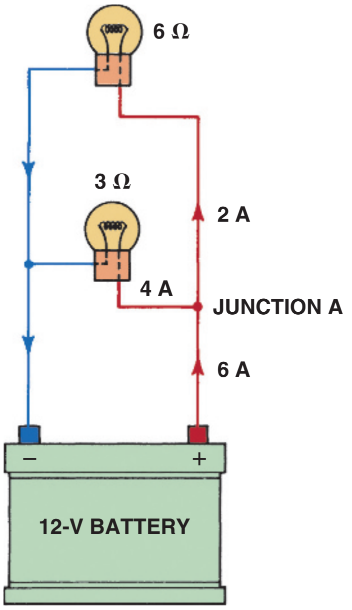


FIGURE 38–11 The amount of current flowing into junction point A equals the total amount of current flowing out of the junction.

TECH TIP

The Path of Least Resistance

There is an old saying that electricity will always take the path of least resistance. This is true, especially if there is a fault, such as in the secondary (high-voltage) section of the ignition system. If there is a path to ground that is lower than the path to the spark plug, the high-voltage spark will take the path of least resistance. In a parallel circuit where there is more than one path for the current to flow, most of the current will flow through the branch with the lower resistance. This does not mean that all of the current will flow through the lowest resistance, because the other path does provide a path to ground, and the amount of current flow through the other branches is determined by the resistance and the applied voltage according to Ohm's law.

Therefore, the only place where electricity takes the path of least resistance is in a series circuit where there are no other paths for the current to flow.

PARALLEL CIRCUIT LAWS

Law 1 The total resistance of a parallel circuit is always less than that of the smallest-resistance leg. This occurs because not all of the current flows through each leg or branch. With many branches, more current can flow from the battery just as more vehicles can travel on a road with five lanes compared to a road with only one or two lanes.

Law 2 The voltage is the same for each leg of a parallel circuit.

Law 3 The sum of the individual currents in each leg will equal the total current. The amount of current flow through a parallel circuit may vary for each leg depending on the resistance of that leg. The current flowing through each leg results in the same voltage drop (from the power side to the ground side) as for every other leg of the circuit. ● **SEE FIGURE 38–12.**

NOTE: A parallel circuit drops the voltage from source voltage to zero (ground) across the resistance in each leg of the circuit.

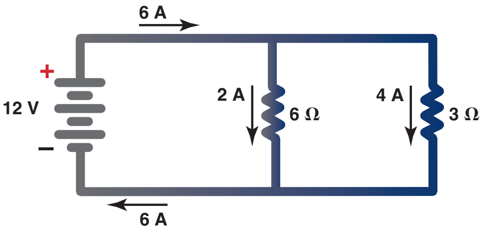


FIGURE 38–12 The current in a parallel circuit splits (divides) according to the resistance in each branch.

DETERMINING TOTAL RESISTANCE IN A PARALLEL CIRCUIT

There are five methods commonly used to determine total resistance in a parallel circuit.

NOTE: Determining the total resistance of a parallel circuit is very important in automotive service. Electronic fuel-injector and diesel engine glow plug circuits are two of the most commonly tested circuits where parallel circuit knowledge is required. Also, when installing extra lighting, the technician must determine the proper gauge wire and protection device.

Method 1 The total *current* (in amperes) can be calculated first by treating each leg of the parallel circuit as a simple circuit. ● **SEE FIGURE 38–13.** Each leg has its own power and ground (−), and therefore, the current through each leg is independent of the current through any other leg.

Current through the 3-Ω resistance =
$$I = E/R = 12\ \text{V}/3\ \Omega = 4\ \text{A}$$
Current through the 4-Ω resistance =
$$I = E/R = 12\ \text{V}/4\ \Omega = 3\ \text{A}$$
Current through the 6-Ω resistance =
$$I = E/R = 12\ \text{V}/6\ \Omega = 2\ \text{A}$$

The total current flowing from the battery is the sum total of the individual currents for each leg. Total current from the battery is, therefore, 9 amperes (4 A + 3 A + 2 A = 9 A).

If **total circuit resistance** (R_T) is needed, Ohm's law can be used to calculate it because voltage (E) and current (I) are now known.

$$R_T = E/I = 12\ \text{V}/9\ \text{A} = 1.33\ \Omega$$

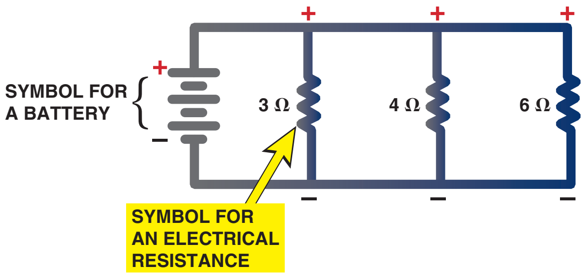


FIGURE 38–13 In a typical parallel circuit, each resistance has power and ground and each leg operates independently of the other legs of the circuit.

Note that the total resistance (1.33 Ω) is smaller than that of the smallest-resistance leg of the parallel circuit. This characteristic of a parallel circuit holds true because not all current flows through all resistances as in a series circuit.

Because the current has alternative paths to ground through the various legs of a parallel circuit, as additional resistances (legs) are added to a parallel circuit, the total current from the battery (power source) *increases.*

Additional current can flow when resistances are added in parallel because each leg of a parallel circuit has its own power and ground and the current flowing through each leg is strictly dependent on the resistance of *that* leg.

Method 2 If only two resistors are connected in parallel, the total resistance (R_T) can be found using the formula $\boldsymbol{R_T = \frac{R_1 \times R_2}{R_1 + R_2}}$. For example, using the circuit in ● **FIGURE 38–14** and substituting 3 ohms for R_1 and 4 amperes for $\boldsymbol{R_2}$, $\boldsymbol{R_T = \frac{(3 \times 4)}{(3 + 4)} = \frac{12}{7} = 1.7\ \Omega}$.

Note that the total resistance (1.7 Ω) is smaller than that of the smallest-resistance leg of the circuit.

NOTE: Which resistor is R_1 and which is R_2 is not important. The position in the formula makes no difference in the multiplication and addition of the resistor values.

This formula can be used for more than two resistances in parallel, but only two resistances can be calculated at a time. After solving for R_T for two resistors, use the value of R_T as R_1 and the additional resistance in parallel as R_2. Then solve for another R_T. Continue the process for all resistance legs of the parallel circuit. However, note that it might be easier to solve for R_T when there are more than two resistances in parallel by using Method 3 or 4.

Method 3 A formula that can be used to find the total resistance for any number of resistances in parallel is $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \cdots$

To solve for R_T for the three resistance legs in ● **FIGURE 38–15**, substitute the values of the resistances for R_1, R_2, and R_3: $1/R_T = 1/3 + 1/4 + 1/6$. The

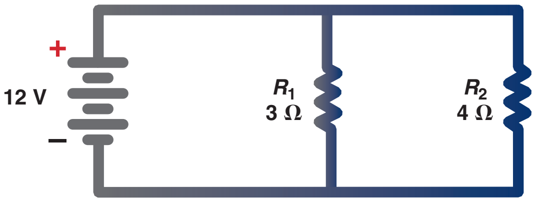


FIGURE 38–14 A schematic showing two resistors in parallel connected to a 12-volt battery.

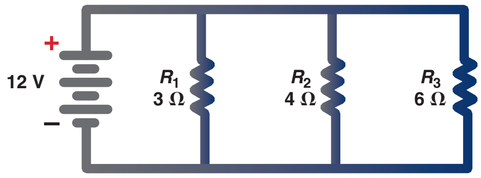


FIGURE 38–15 A parallel circuit with three resistors connected to a 12-volt battery.

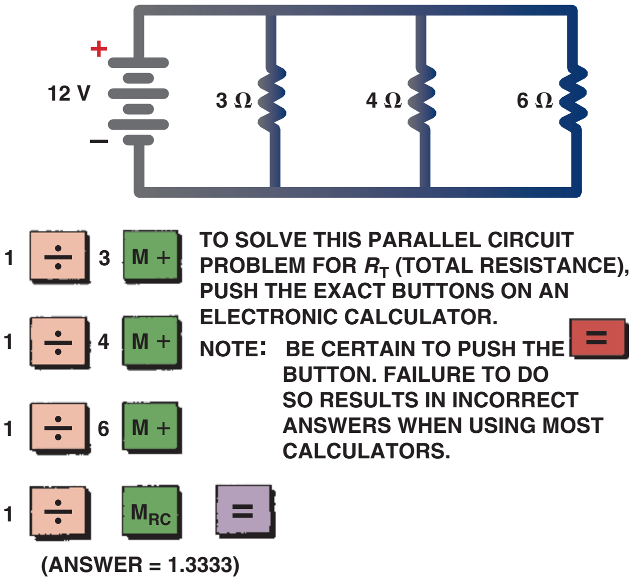
fractions cannot be added together unless they all have the same denominator. The lowest common denominator in this example is 12. Therefore, 1/3 becomes 4/12, 1/4 becomes 3/12, and 1/6 becomes 2/12. $1/R_T = 4/12 + 3/12 + 2/12$ or 9/12. Cross-multiplying $R_T = 12/9 = 1.33\,\Omega$. Note that the result (1.33 Ω) is the same regardless of the method used (see Method 1). The most difficult part of using this method (besides using fractions) is determining the lowest common denominator, especially for circuits containing a wide range of resistance values for the various legs. For an easier method using a calculator, see Method 4.

Method 4 This method uses an electronic calculator, commonly available at very low cost. Instead of determining the lowest common denominator as in Method 3, one can use the electronic calculator to convert the fractions to decimal equivalents. The memory buttons on most calculators can be used to keep a running total of the fractional values. Use ● **FIGURE 38–16** and calculate the total resistance (R_T) by pushing the indicated buttons on the calculator. Also ● **SEE FIGURE 38–17**.

NOTE: This method can be used to find the total resistance of any number of resistances in parallel.

The memory recall (MRC) and equals (=) buttons invert the answer to give the correct value for total resistance (1.33 Ω). The inverse (1/X, or X^{-1}) button can be used with the sum (SUM) button on scientific calculators without using the memory button.

Method 5 This method can be easily used whenever two or more resistances connected in parallel are of the same value. ● **SEE FIGURE 38–18**. To calculate the total resistance (R_T) of equal-value resistors, divide the number of equal resistors into the value of the resistance. R_T = Value of equal resistance/Number of equal resistances $= 12\,\Omega/4 = 3\,\Omega$.

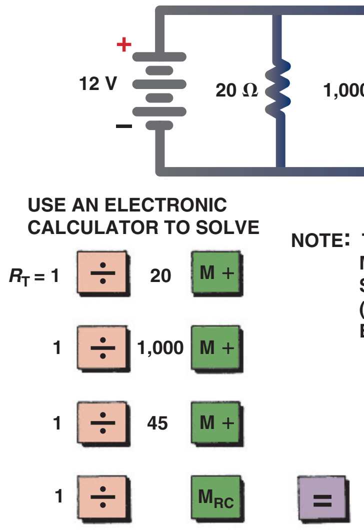


TO SOLVE THIS PARALLEL CIRCUIT PROBLEM FOR R_T (TOTAL RESISTANCE), PUSH THE EXACT BUTTONS ON AN ELECTRONIC CALCULATOR.

NOTE: BE CERTAIN TO PUSH THE = BUTTON. FAILURE TO DO SO RESULTS IN INCORRECT ANSWERS WHEN USING MOST CALCULATORS.

(ANSWER = 1.3333)

FIGURE 38–16 Using an electronic calculator to determine the total resistance of a parallel circuit.



USE AN ELECTRONIC CALCULATOR TO SOLVE

NOTE: THE TOTAL RESISTANCE (R_T) MUST BE LESS THAN THE SMALLEST RESISTANCE (LESS THAN 20 Ω IN THIS EXAMPLE).

FIGURE 38–17 Another example of how to use an electronic calculator to determine the total resistance of a parallel circuit. The answer is 13.45 ohms. Notice that the effective resistance of this circuit is less than the resistance of the lowest branch (20 ohms).

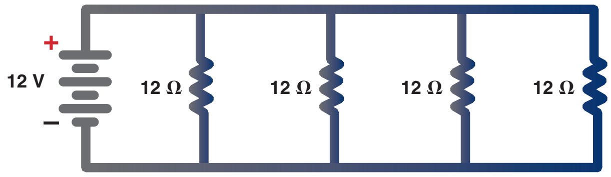


FIGURE 38–18 A parallel circuit containing four 12-ohm resistors. When a circuit has more than one resistor of equal value, the total resistance can be determined by simply dividing the value of the resistance (12 ohms in this example) by the number of equal-value resistors (4 in this example) to get 3 ohms.

NOTE: Since most automotive and light-truck electrical circuits involve multiple use of the same resistance, this method is the most useful. For example, if six additional 12-ohm lights were added to a vehicle, the additional lights would represent just 2 ohms of resistance (12 Ω/6 lights = = 2). Therefore, 6 amperes of additional current would be drawn by the additional lights (I = E/R = 12 V/2 Ω = 6 A).

PARALLEL CIRCUIT EXAMPLES Each of the four examples discussed below includes solving for the following:

- Total resistance
- Current flow (amperes) through each branch as well as total current flow
- Voltage drop across each resistance

Example 1:

● **SEE FIGURE 38–19**.

In this example, the voltage of the battery is unknown and the equation to be used is $E = I \times R$, where R represents the total resistance of the circuit. Using the equation for two resistors in parallel, the total resistance is 6 ohms.

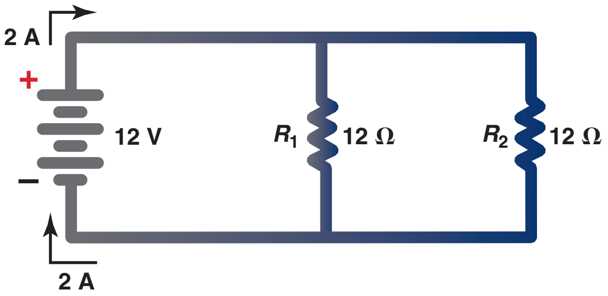


FIGURE 38–19 Example 1.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{12 \times 12}{12 + 12} = \frac{144}{24} = 6\ \Omega$$

Placing the value of the total resistors into the equation results in a value for the battery voltage of 12 volts.

$$\begin{aligned} E &= I \times R \\ E &= 2\text{ A} \times 6\ \Omega \\ E &= 12\text{ V} \end{aligned}$$

Example 2:

● **SEE FIGURE 38–20.**

In this example, the value of R_3 is unknown. Because the voltage (12 volts) and the current (12 A) are known, it is easier to solve for the unknown resistance by treating each branch or leg as a separate circuit. Using Kirchhoff's law, the total current equals the total current flow through each branch. The current flow through R_1 is 3 A ($I = E/R =$ 12 V/4 Ω = 3 A) and the current flow through R_2 is 6 A ($I =$ $E/R =$ 12 V/2 Ω = 6 A). Therefore, the total current through the two known branches equals 9 A (3 A + 6 A = 9 A). Because there are 12 A leaving and returning to the battery, the current flow through R_3 must be 3 A (12 A − 9 A = 3 A).

The resistance must therefore be 4 Ω because the current through the unknown resistance is 3 A ($I = E/R =$ 12 V/4 Ω = 3 A).

Example 3:

● **SEE FIGURE 38–21.**

In this example, the voltage of the battery is unknown. The equation to solve for voltage according to Ohm's law is

$$E = I \times R$$

The R in this equation refers to the total resistance. Because there are four resistors of equal value, the total can be determined by the following equation:

$$R_{\text{Total}} = \text{Value of Resistors/Number of Equal Resistors} = 12\ \Omega/4 = 3\ \Omega$$

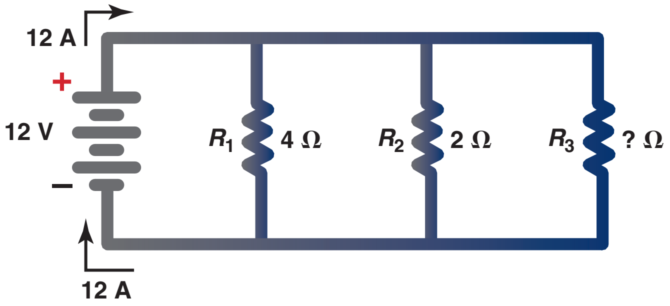


FIGURE 38–20 Example 2.

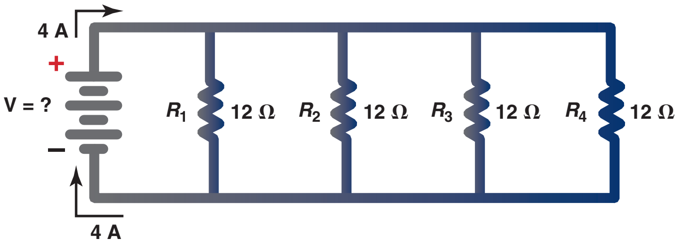


FIGURE 38–21 Example 3.

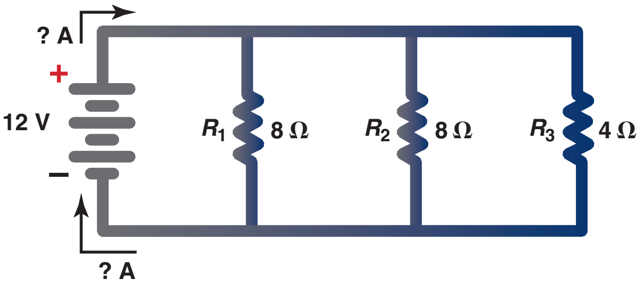


FIGURE 38–22 Example 4.

Inserting the value of the total resistance of the parallel circuit (3 Ω) into Ohm's law results in a battery voltage of 12 V.

$$\begin{aligned} E &= 4\text{ A} \times 3\ \Omega \\ E &= 12\text{ V} \end{aligned}$$

Example 4:

● **SEE FIGURE 38–22.**

The unknown is the amount of current in the circuit. The Ohm's law equation for determining current is

$$I = E/R$$

The R represents the total resistance. Because there are two equal resistances (8 Ω), these two can be replaced by one resistance of 4 Ω (R_{Total} = Value/Number = 8 Ω/2 = 4 Ω).

The total resistance of this parallel circuit containing two 8-ohm resistors and one 4-ohm resistor is 2 ohms. (Two 8-ohm resistors in parallel equals 4 ohms. Then you have two 4-ohm resistors in parallel that equals 2 ohms.) The current flow from the battery is then calculated to be 6 A.

$$I = E/R = 12\text{ V}/2\ \Omega = 6\text{ A}$$

SERIES-PARALLEL CIRCUITS

Series-parallel circuits are a combination of series and parallel segments in one complex circuit. A series-parallel circuit is also called a **compound** or a **combination circuit**. Many automotive circuits include sections that are in parallel and in series.

A series-parallel circuit includes both parallel loads or resistances, plus additional loads or resistances that are electrically connected in series. There are two basic types of series-parallel circuits.

- A circuit where the load is in series with other loads in parallel. ● **SEE FIGURE 38–23.** Flow to the dash lightbulbs, which are wired in parallel.
- A circuit where a parallel circuit contains resistors or loads that are in series with one or more branches.

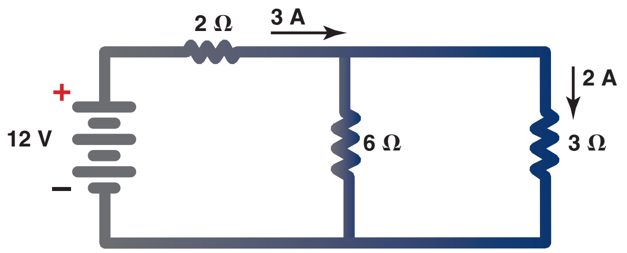


FIGURE 38–23 A series-parallel circuit.

SERIES-PARALLEL CIRCUIT FAULTS If a conventional parallel circuit, such as a taillight circuit, had an electrical fault that increased the resistance in one branch of the circuit, the amount of current flow through that branch will be reduced. The added resistance, due to corrosion or other similar cause, would create a voltage drop. As a result of this drop in voltage, a lower voltage would be applied and the bulb in the taillight would be dimmer than normal. If, however, the added resistance occurred in a part of the circuit that fed both taillights, then both taillights would be dimmer than normal. In this case, the added resistance created a series-parallel circuit that was originally just a simple parallel circuit.

SOLVING SERIES-PARALLEL CIRCUIT PROBLEMS

The key to solving series-parallel circuit problems is to combine or simplify as much as possible. For example, if there are two loads or resistances in series within a parallel branch or leg, the circuit can be made simpler if the two are first added together before attempting to solve the parallel section. ● **SEE FIGURE 38–24.** Ohm's Law can be used to determine an unknown value in a series-parallel circuit. ● **SEE FIGURE 38–25.**

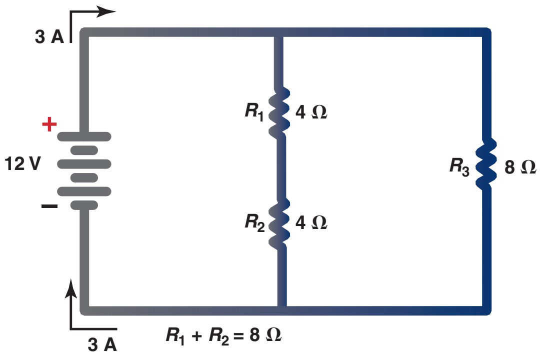


FIGURE 38–24 Solving a series-parallel circuit problem.

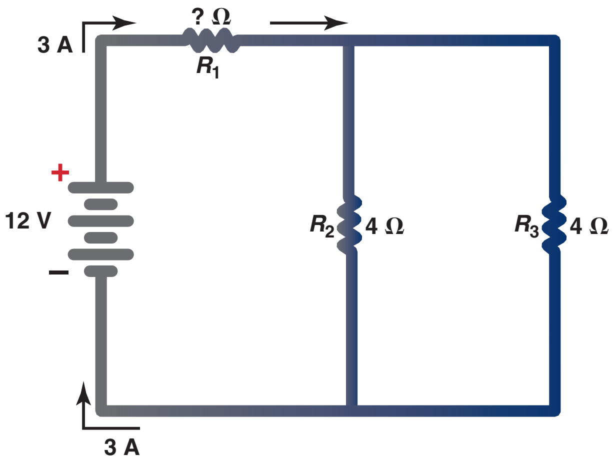


FIGURE 38–25 Find the value of R_1.

REVIEW QUESTIONS

1. What is Kirchhoff's voltage law?
2. What would current (amperes) do if the voltage were doubled in a circuit?
3. Why is the total resistance of a parallel circuit less than the smallest resistance?
4. What would be the effect of an open circuit in one leg of a parallel portion of a series-parallel circuit?
5. What would be the effect of an open circuit in a series portion of a series-parallel circuit?

CHAPTER QUIZ

1. The amperage in a series circuit __________.
   a. is the same anywhere in the circuit
   b. varies in the circuit due to the different resistances
   c. is high at the beginning of the circuit and decreases as the current flows through the resistance
   d. is always less returning to the battery than leaving the battery
2. The sum of the voltage drops in a series circuit equals the __________.
   a. amperage
   b. resistance
   c. source voltage
   d. wattage
3. If the resistance and the voltage are known, what is the formula for finding the current (amperes)?
   a. $E = I \times R$
   b. $I = E \times R$
   c. $R = E \times I$
   d. $I = E/R$
4. A series circuit has three resistors of 4 ohms each. The voltage drop across each resistor is 4 volts. Technician A says that the source voltage is 12 volts. Technician B says that the total resistance is 18 ohms. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

5. If a 12-volt battery is connected to a series circuit with three resistors of 2, 4, and 6 ohms, how much current will flow through the circuit?
   a. 1 ampere
   b. 2 amperes
   c. 3 amperes
   d. 4 amperes

6. A series circuit has two 10-ohm bulbs. A third bulb is added in series. Technician A says that the three bulbs will be dimmer than when only two bulbs were in the circuit. Technician B says that the current in the circuit will increase. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Technician A says that the sum of the voltage drops in a series circuit should equal the source voltage. Technician B says that the current (amperes) varies depending on the value of the resistance in a series circuit. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. Two bulbs are connected in parallel to a 12-volt battery. One bulb has a resistance of 6 ohms and the other bulb has a resistance of 2 ohms. Technician A says that only the 2-ohm bulb will light because all of the current will flow through the path with the least resistance and no current will flow through the 6-ohm bulb. Technician B says that the 6-ohm bulb will be dimmer than the 2-ohm bulb. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Calculate the total resistance and current in a parallel circuit with three resistors of 4, 8, and 16 ohms, using any one of the five methods (calculator suggested). What is the total resistance and current?
   a. 27 ohms (0.4 ampere)
   b. 14 ohms (0.8 ampere)
   c. 4 ohms (3.0 amperes)
   d. 2.3 ohms (5.3 amperes)

10. When solving series-parallel circuit calculations it is best to ___________ the resistances first.
    a. reduce
    b. combine
    c. eliminate
    d. subtract

Chapter 39

CIRCUIT TESTERS AND DIGITAL METERS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss how to safely set up and use a fused jumper wire.
- Discuss how to safely set up and use a test light.
- Discuss how to safely set up and use a logic probe.
- Describe the uses of digital multimeters.
- Describe the uses of inductive ammeters.
- Discuss diode check and frequency.
- Describe the prefixes used with electrical units.
- Describe how to read digital meters.

KEY TERMS:

AC/DC clamp-on DMM 446 • DMM 442 • DVOM 442 • High-impedance test meter 442 • IEC 451 • Inductive ammeter 446 • Kilo (k) 447 • LED test light 441 • Logic probe 441 • Mega (M) 447 • Meter accuracy 450 • Meter resolution 450 • Milli (m) 447 • OL 444 • RMS 448 • Test light 441

FUSED JUMPER WIRE

DEFINITION A fused jumper wire is used to check a circuit by bypassing the switch or to provide a power or ground to a component. A fused jumper wire, also called a test lead, can be purchased or made by the service technician. ● **SEE FIGURE 39–1**.

It should include the following features:

- **Fuse.** A typical fused jumper wire has a blade-type fuse that can be easily replaced. A 10 ampere fuse (red color) is often the value used.
- **Alligator clip ends.** Alligator clips at the ends allow the fused jumper wire to be clipped to a ground or power source, while the other end is attached to the power side or ground side of the unit being tested.
- **Good-quality insulated wire.** Most purchased jumper wire is about 14-gauge stranded copper wire with a flexible rubberized insulation to allow it to move easily, even in cold weather.

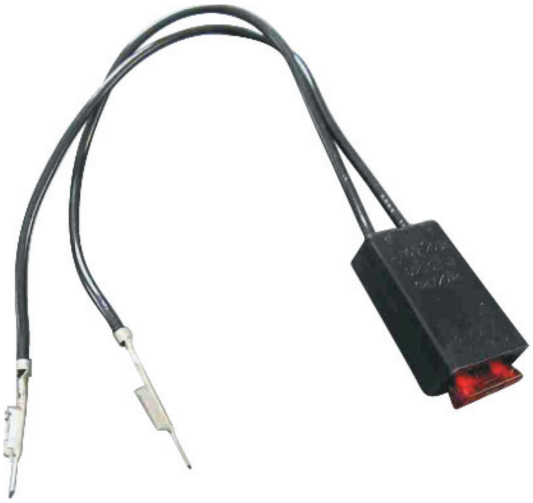


FIGURE 39–1 A technician-made fused jumper lead, which is equipped with a red 10 ampere fuse. This fused jumper wire uses terminals for testing circuits at a connector instead of alligator clips.

USES OF A FUSED JUMPER WIRE A fused jumper wire can be used to help diagnose a component or circuit by performing the following procedures:

- **Supply power or ground.** If a component, such as a horn, does not work, a fused jumper wire can be used to supply a temporary power and/or ground. Start by unplugging the electrical connector from the device and connect a fused jumper lead to the power terminal. Another fused jumper wire may be needed to provide the ground. If the unit works, the problem is in the power-side or ground-side circuit.

CAUTION: Never use a fused jumper wire to bypass any resistance or load in the circuit. The increased current flow could damage the wiring and could blow the fuse on the jumper lead.

TEST LIGHTS

NONPOWERED TEST LIGHT A 12 volt test light is one of the simplest testers that can be used to detect electricity. A **test light** is simply a lightbulb with a probe and a ground wire attached. ● **SEE FIGURE 39–2**.

It is used to detect battery voltage potential at various test points. Battery voltage cannot be seen or felt and can be detected only with test equipment.

The ground clip is connected to a clean ground on either the negative terminal of the battery, or a clean metal part of the body, and the probe touched to terminals or components. If the test light comes on, this indicates that voltage is available. ● **SEE FIGURE 39–3**.

A purchased test light should be labeled a "12 volt test light." Do not purchase a test light designed for household current (110 or 220 volts), as it does not light with 12 to 14 volts.

USES OF A 12 VOLT TEST LIGHT A 12 volt test light can be used to check the following:

- **Electrical power.** If the test light comes on, there is power available. It does not, however, indicate the voltage level, or if there is enough current available to operate an electrical load. This only indicates that there is enough voltage and current to light the test light (about 0.25 ampere).
- **Grounds.** A test light can be used to check for grounds by attaching the clip of the test light to the positive terminal of the battery or to any 12 volt electrical terminal. The tip of the test light can then be used to touch the ground wire. If there is a ground connection, the test light comes on.

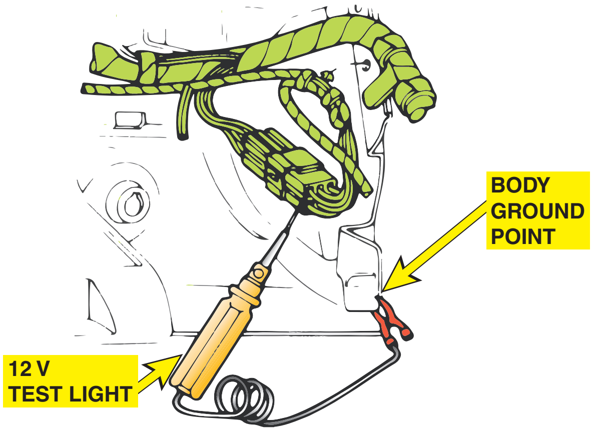


FIGURE 39–2 A 12 volt test light is attached to a good ground while probing for power.

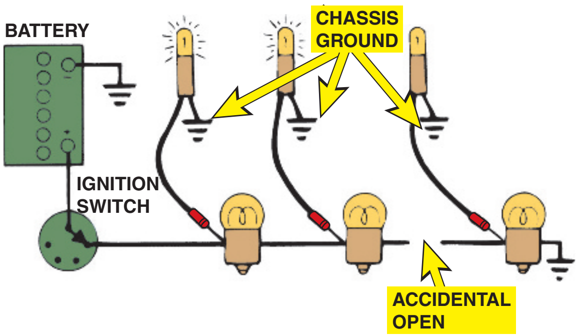


FIGURE 39–3 A test light can be used to locate an open in a circuit. Note that the test light is grounded at a different location than the circuit itself.

HIGH-IMPEDANCE TEST LIGHT A high-impedance test light has a high internal resistance and, therefore, draws very low current in order to light. High-impedance test lights are safe to use on computer circuits because they do not affect the circuit current in the same way as conventional 12 volt test lights when connected to a circuit. There are two types of high-impedance test lights.

- Some test lights use an electronic circuit to limit the current flow to avoid causing damage to electronic devices.
- An **LED test light** uses a light-emitting diode (LED), instead of a standard automotive bulb, for a visual indication of voltage. An LED test light requires only about 25 milliamperes (0.025 ampere) to light; therefore, it can be used on electronic circuits, as well as on standard circuits.

LOGIC PROBE

PURPOSE AND FUNCTION A **logic probe** is an electronic device that lights up a red (usually) LED if the probe is touched to battery voltage. If the probe is touched to ground, a green (usually) LED lights. ● **SEE FIGURE 39–4**.

A logic probe can "sense" the difference between high- and low-voltage levels, which explains the name *logic*.

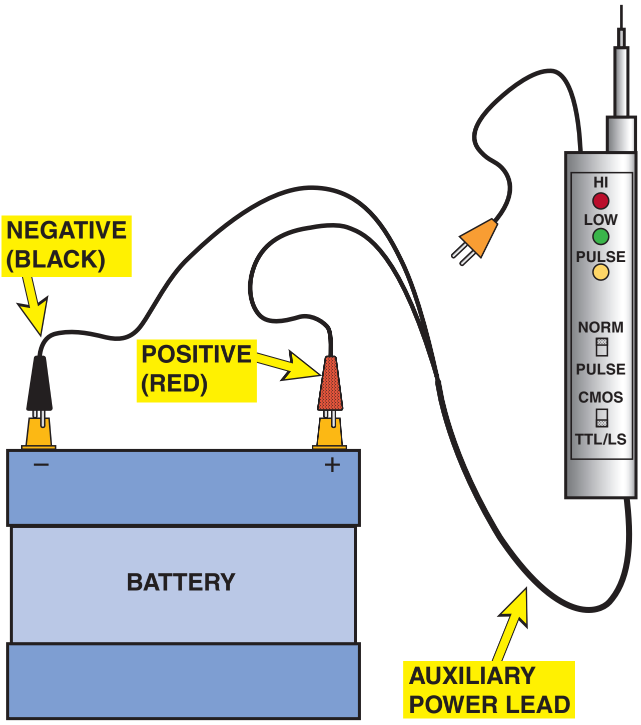


FIGURE 39–4 A logic probe connected to the vehicle battery. When the tip probe is connected to a circuit, it can check for power, ground, or a pulse.

- A typical logic probe can also light another light (often amber color) when a change in voltage occurs.
- Some logic probes flash the red light when a pulsing voltage signal is detected.
- Some flash the green light when a pulsing ground signal is detected.

This feature is helpful when checking for a variable voltage output from a computer or ignition sensor.

USING A LOGIC PROBE A logic probe must first be connected to a power and ground source, such as the vehicle battery. This connection powers the probe and gives it a reference low (ground).

Most logic probes also make a distinctive sound for each high- and low-voltage level. This makes troubleshooting easier when probing connectors or component terminals. A sound (usually a beep) is heard when the probe tip is touched to a changing voltage source. The changing voltage also usually lights the pulse light on the logic probe. Therefore, the probe can be used to check components, such as

- Pickup coils
- Hall-effect sensors
- Magnetic sensors

DIGITAL MULTIMETERS

TERMINOLOGY **Digital multimeter (DMM)** and **digital volt-ohm-meter (DVOM)** are terms commonly used for electronic **high-impedance test meters**. *High impedance* means that the electronic internal resistance of the meter is high enough to prevent excessive current draw from any circuit being tested. Most meters today have a minimum of 10 million ohms (10 megohms) of resistance. This high internal resistance between the meter leads is present only when measuring volts. The high resistance in the meter itself reduces the amount of current flowing through the meter when it is being used to measure voltage, leading to more accurate test results because the meter does not change the load on the circuit. High-impedance meters are required for measuring computer circuits.

CAUTION: Analog (needle-type) meters are almost always lower than 10 megohms and should not be used to measure any computer or electronic circuit. Connecting an analog meter to a computer circuit could damage the computer or other electronic modules.

A high-impedance meter can be used to measure any automotive circuit within the ranges of the meter. ● **SEE FIGURE 39–5**.

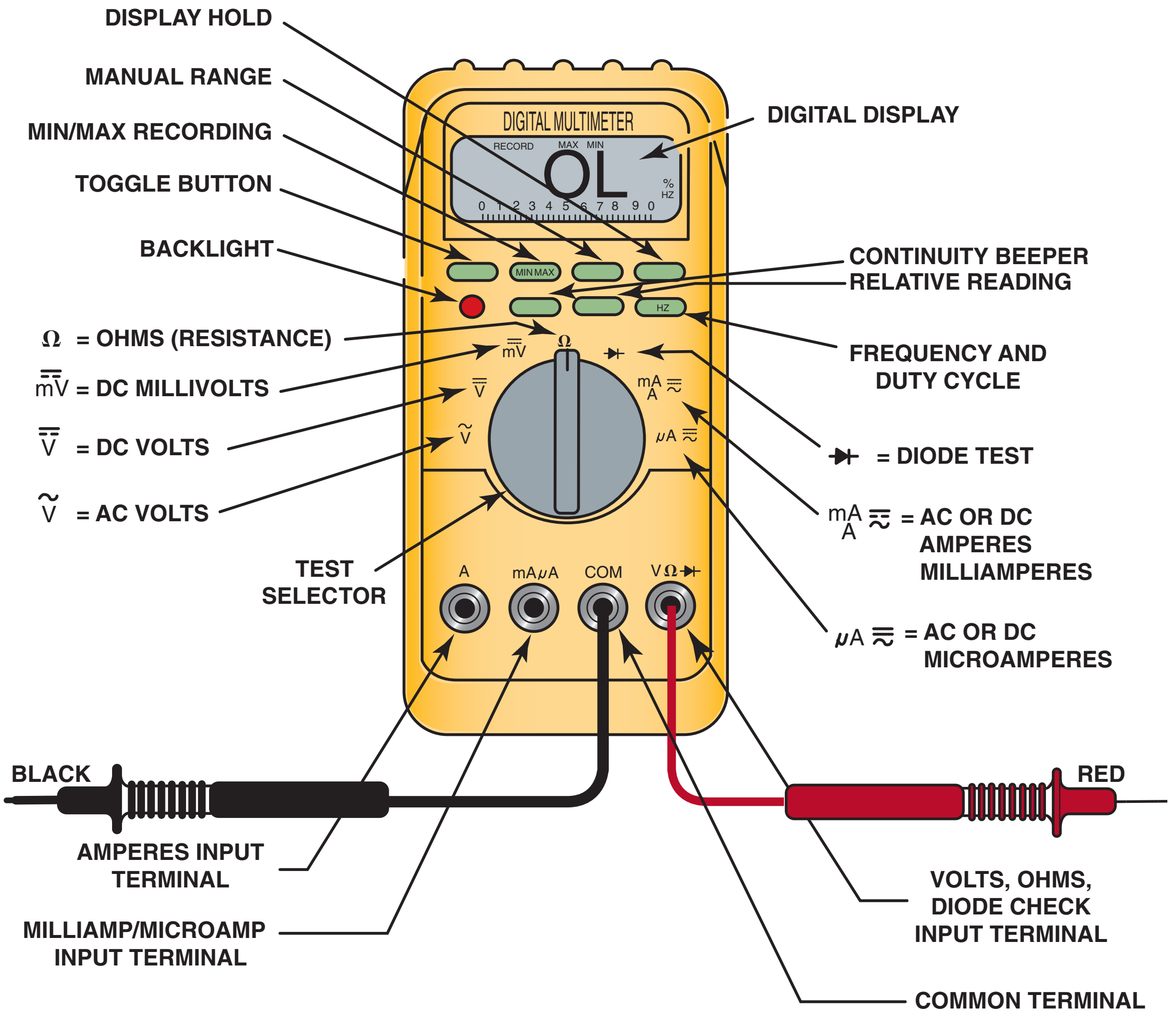

DISPLAY HOLD
MANUAL RANGE
MIN/MAX RECORDING
TOGGLE BUTTON
BACKLIGHT
Ω = OHMS (RESISTANCE)
m$\overline{\text{V}}$ = DC MILLIVOLTS
$\overline{\text{V}}$ = DC VOLTS
$\tilde{\text{V}}$ = AC VOLTS
TEST SELECTOR
DIGITAL MULTIMETER
RECORD
MAX MIN
OL
% HZ
0 1 2 3 4 5 6 7 8 9 0
MIN MAX
HZ
A
mAμA
COM
VΩ
DIGITAL DISPLAY
CONTINUITY BEEPER
RELATIVE READING
FREQUENCY AND DUTY CYCLE
= DIODE TEST
mA A = AC OR DC AMPERES MILLIAMPERES
μA = AC OR DC MICROAMPERES
BLACK
RED
AMPERES INPUT TERMINAL
MILLIAMP/MICROAMP INPUT TERMINAL
VOLTS, OHMS, DIODE CHECK INPUT TERMINAL
COMMON TERMINAL

FIGURE 39–5 Typical digital multimeter. The black meter lead is always placed in the COM terminal. The red meter test lead should be in the volt-ohm terminal, except when measuring current in amperes.

SYMBOL	MEANING
AC	Alternating current or voltage
DC	Direct current or voltage
V	Volts
mV	Millivolts (1/1,000 volts)
A	Ampere (amps), current
mA	Milliampere (1/1,000 amps)
%	Percent (for duty-cycle readings only)
Ω	Ohms, resistance
kΩ	Kilohm (1,000 ohms), resistance
MΩ	Megohm (1,000,000 ohms), resistance
Hz	Hertz (cycles per second), frequency
kHz	Kilohertz (1,000 cycles/sec.), frequency
ms	Milliseconds (1/1,000 sec.) for pulse-width measurements

CHART 39–1

Common symbols and abbreviations used on digital meters.

The common abbreviations for the units that many meters can measure are often confusing. ● **SEE CHART 39–1** for the most commonly used symbols and their meanings.

MEASURING VOLTAGE A voltmeter measures the *pressure* or potential of electricity in units of volts. A voltmeter is connected to a circuit in parallel. Voltage can be measured by selecting either AC or DC volts.

- **DC volts (DCV).** This setting is the most common for automotive use. Use this setting to measure battery voltage and voltage to all lighting and accessory circuits.
- **AC volts (ACV).** This setting is used to check for unwanted AC voltage from alternators and some sensors.
- **Range.** The range is automatically set for most meters, but can be manually ranged, if needed.

● **SEE FIGURES 39–6 AND 39–7**.

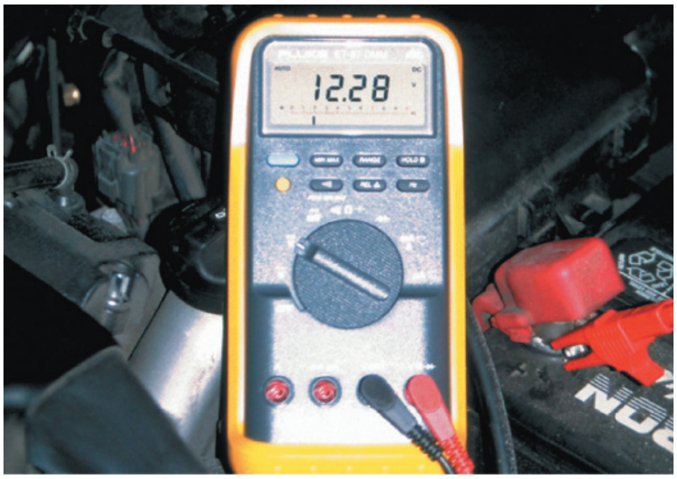
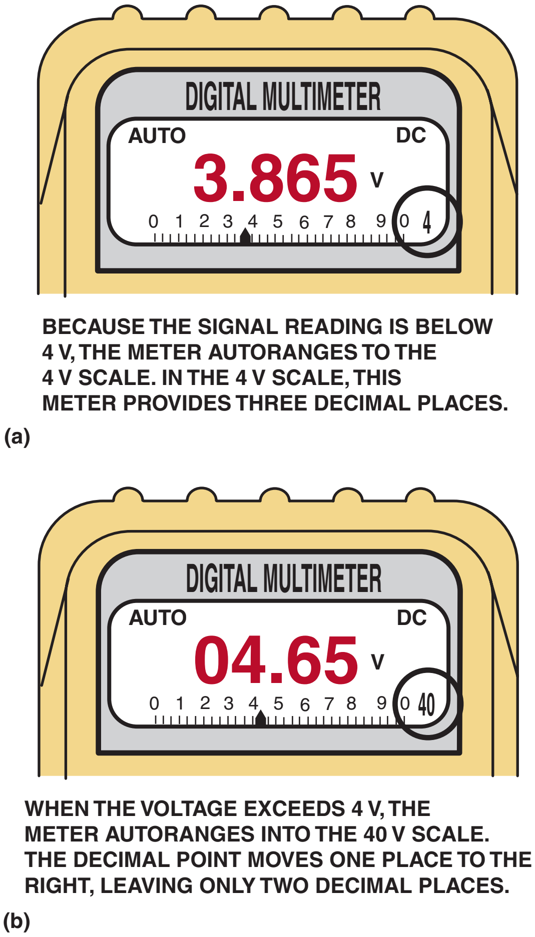


FIGURE 39–6 Typical digital multimeter (DMM) set to read DC volts.



BECAUSE THE SIGNAL READING IS BELOW 4 V, THE METER AUTORANGES TO THE 4 V SCALE. IN THE 4 V SCALE, THIS METER PROVIDES THREE DECIMAL PLACES.

WHEN THE VOLTAGE EXCEEDS 4 V, THE METER AUTORANGES INTO THE 40 V SCALE. THE DECIMAL POINT MOVES ONE PLACE TO THE RIGHT, LEAVING ONLY TWO DECIMAL PLACES.

FIGURE 39–7 A typical autoranging digital multimeter automatically selects the proper scale to read the voltage being tested. The scale selected is usually displayed on the meter face. (a) Note that the display indicates "4," meaning that this range can read up to 4 volts. (b) The range is now set to the 40 volt scale, meaning that the meter can read up to 40 volts on the scale. Any reading above this level causes the meter to reset to a higher scale. If not set on autoranging, the meter display indicates OL if a reading exceeds the limit of the scale selected.

MEASURING RESISTANCE An ohmmeter measures the resistance in ohms of a component or circuit section when no current is flowing through the circuit. An ohmmeter contains a battery (or other power source) and is connected in series with the component or wire being measured. When the leads are connected to a component, current flows through the test leads and the difference in voltage (voltage drop) between the leads is measured as resistance. Note the following facts about using an ohmmeter:

- Zero ohms on the scale means that there is no resistance between the test leads, thus indicating continuity or a continuous path for the current to flow in a closed circuit.
- Infinity means no connection, as in an open circuit.
- Ohmmeters have no required polarity, even though red and black test leads are used for resistance measurement.

CAUTION: The circuit must be electrically open with no current flowing when using an ohmmeter. If current is flowing when an ohmmeter is connected, the reading is incorrect and the meter can be destroyed.

Different meters have different ways of indicating infinite resistance, or a reading higher than the scale allows. Examples of an over-limit display include

- **OL**, meaning **over limit** or overload
- Flashing or solid number 1
- Flashing or solid number 3 on the left side of the display

Check the meter instructions for the exact display used to indicate an open circuit or over-range reading. ● **SEE FIGURES 39–8 AND 39–9**.

To summarize, open and zero readings are as follows:

0.00 Ω = Zero resistance (component or circuit has continuity)

OL = An open circuit or reading is higher than the scale selected (no current flows)

MEASURING AMPERES An ammeter measures the flow of *current* through a complete circuit in units of amperes. The ammeter has to be installed in the circuit (in series) so that it can measure all the current flow in that circuit, just as a water flow meter measures the amount of water flow (cubic feet per minute, for example). ● **SEE FIGURE 39–10**.

CAUTION: An ammeter must be installed in series with the circuit to measure the current flow in the circuit. If a meter set to read amperes is connected in parallel, such as across a battery, the meter or the leads may

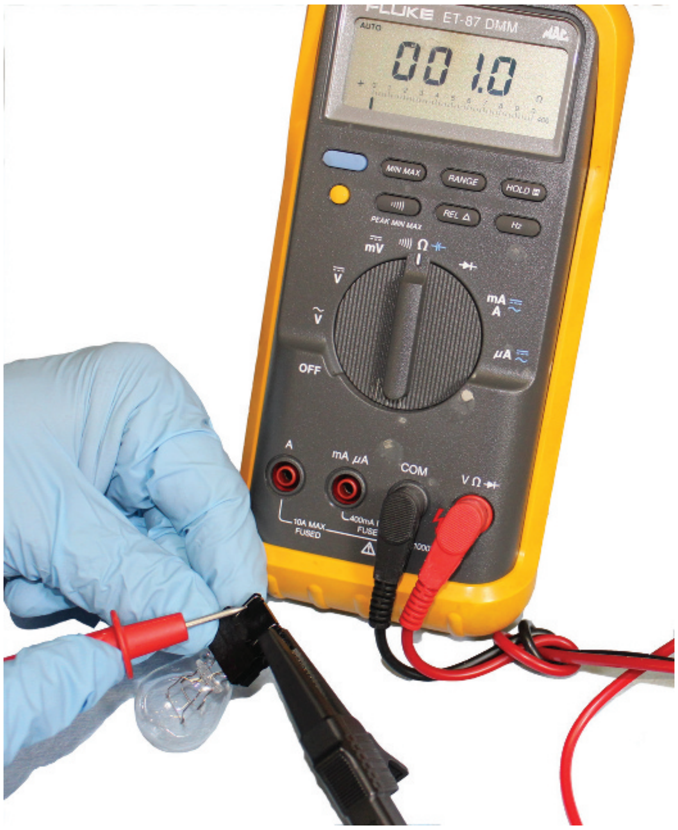

FLUKE ET-87 DMM
AUTO
00 1.0
MIN MAX
RANGE
HOLD
REL Δ
PEAK MIN MAX
Hz
mV
Ω
V
OFF
mA A
μA
A
mA μA
COM
V Ω
10A MAX FUSED
400mA FUSE

FIGURE 39–8 Using a digital multimeter set to read ohms (Ω) to test this lightbulb. The meter reads the resistance of the filament.

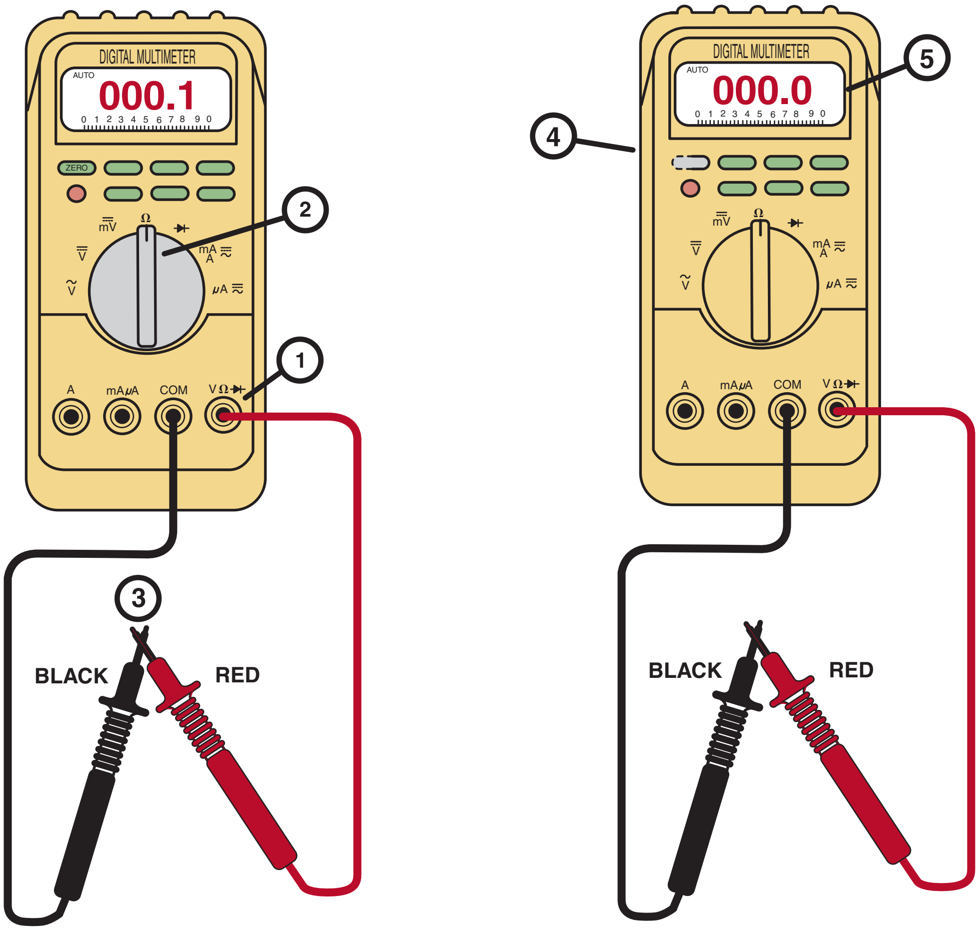

DIGITAL MULTIMETER
AUTO
000.1
0 1 2 3 4 5 6 7 8 9 0
ZERO
mV
Ω
V
mA A
μA
A
mAμA
COM
V Ω
1
2
3
BLACK
RED
DIGITAL MULTIMETER
AUTO
000.0
0 1 2 3 4 5 6 7 8 9 0
4
5
mV
Ω
V
mA A
μA
A
mAμA
COM
V Ω
BLACK
RED

FIGURE 39–9 Many digital multimeters can have the display indicate zero to compensate for test lead resistance. (1) Connect leads in the V Ω and COM meter terminals. (2) Select the Ω scale. (3) Touch the two meter leads together. (4) Push the “zero” or “relative” button on the meter. (5) The meter display now indicates zero ohms of resistance.

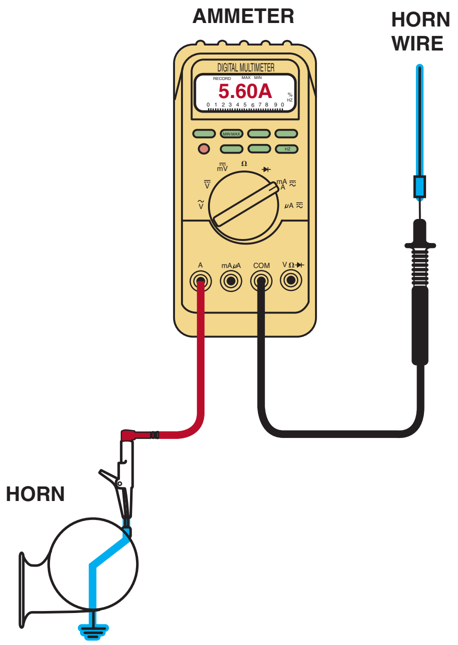


FIGURE 39–10 Measuring the current flow required by a horn requires that the ammeter be connected to the circuit in series and the horn button be depressed by an assistant.

FREQUENTLY ASKED QUESTION

How Much Voltage Does an Ohmmeter Apply?

Most digital meters that are set to measure ohms (resistance) apply 0.3 to 1 volt to the component being measured. The voltage comes from the meter itself to measure the resistance. Two things are important to remember about an ohmmeter:

1. The component or circuit must be disconnected from any electrical circuit while the resistance is being measured.
2. Because the meter itself applies a voltage (even though it is relatively low), a meter set to measure ohms can damage electronic circuits. Computer or electronic chips can be easily damaged if subjected to only a few milliamperes of current, similar to the amount an ohmmeter applies when a resistance measurement is being performed.

be destroyed, or the fuse blows, by the current available across the battery. Some digital multimeters (DMMs) beep if the unit selection does not match the test lead connection on the meter. However, in a noisy shop, this beep sound may be inaudible.

Digital meters require that the meter leads be moved to the ammeter terminals. Most digital meters have an ampere scale that can accommodate a maximum of 10 amperes. See the Tech Tip "Fuse Your Meter Leads!"

FREQUENTLY ASKED QUESTION

What Does "CE" Mean on Many Meters?

The "CE" means that the meter meets the newest European Standards and the CE mark stands for Conformité Europeenne, which is French for "European Conformity."

TECH TIP

Fuse Your Meter Leads!

Most digital meters include an ammeter capability. When reading amperes, the leads of the meter must be changed from volts or ohms (V or Ω) to amperes (A), milliamperes (mA), or microamperes (μA).

A common problem may occur the next time voltage is measured. Although the technician may switch the selector to read volts, often the leads are not switched back to the volt or ohm position. Because the ammeter lead position results in zero ohms of resistance to current flow through the meter, the meter or the fuse inside the meter is destroyed if the meter is connected to a battery. Many meter fuses are expensive and difficult to find.

To avoid this problem, simply solder an inline 10 ampere blade-fuse holder into one meter lead. ● **SEE FIGURE 39–11**.

Do not think that this technique is for beginners only. Experienced technicians often get in a hurry and forget to switch the lead. A blade fuse is faster, easier, and less expensive to replace than a meter fuse, or the meter itself. Also, if the soldering is done properly, the addition of an inline fuse holder and fuse does not increase the resistance of the meter leads.

WARNING

Do not use a meter equipped with an external add-on fuse when testing a high-voltage circuit to prevent possible shock hazard.

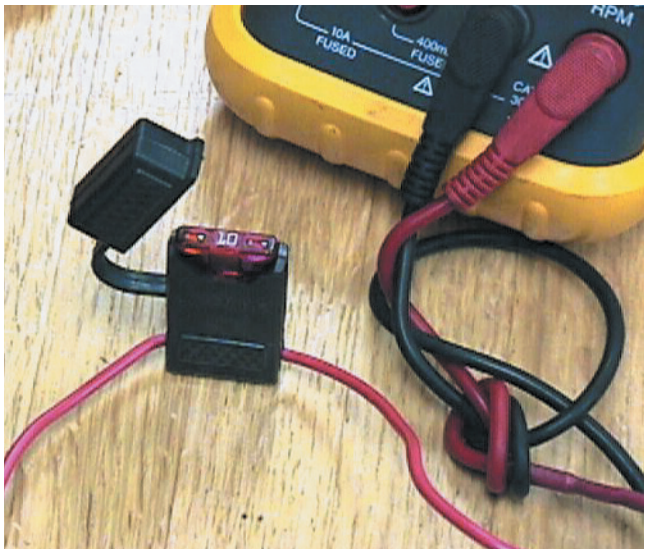


FIGURE 39–11 Note the blade-type fuse holder soldered in series with one of the meter leads. A 10 ampere fuse helps protect the internal meter fuse (if equipped), and the meter itself, from damage that may result from excessive current flow, if accidentally used incorrectly.

INDUCTIVE AMMETERS

OPERATION **Inductive ammeters** do not make physical contact with the circuit. They measure the strength of the magnetic field surrounding the wire carrying the current, and use a Hall-effect sensor to measure current. The Hall-effect sensor detects the strength of the magnetic field that surrounds the wire carrying an electrical current. ● **SEE FIGURE 39–12**.

This means that the meter probe surrounds the wire(s) carrying the current and measures the strength of the magnetic field that surrounds any conductor carrying a current.

AC/DC CLAMP-ON DIGITAL MULTIMETERS An **AC/DC clamp-on digital multimeter (DMM)** is a useful meter for automotive diagnostic work. ● **SEE FIGURE 39–13**.

The major advantage of the clamp-on-type meter is that there is no need to break the circuit to measure current (amperes). Simply clamp the jaws of the meter around the power lead(s) or ground lead(s) of the component being measured and read the display. Most clamp-on meters can also measure alternating current, which is helpful in the diagnosis of an alternator problem. Volts, ohms, frequency, and temperature can also be measured with the typical clamp-on DMM, but use conventional meter leads. The inductive clamp is only used to measure amperes.

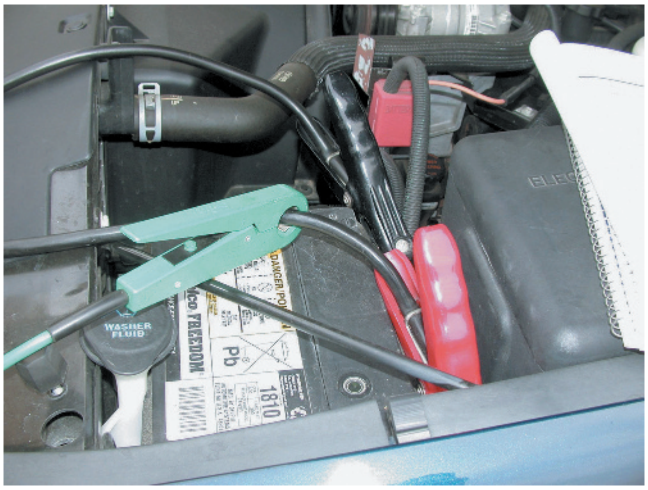


FIGURE 39–12 An inductive ammeter clamp is used with all starting and charging testers to measure the current flow through the battery cables.

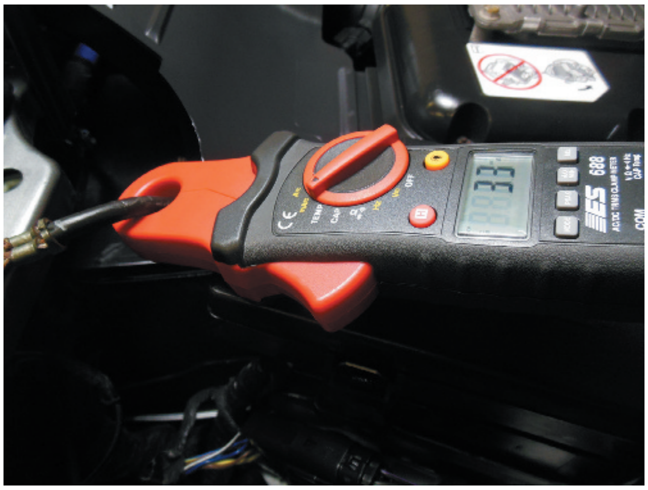


FIGURE 39–13 A typical mini clamp-on-type digital multimeter. This meter is capable of measuring alternating current (AC) and direct current (DC) without requiring that the circuit be disconnected to install the meter in series. The jaws are simply placed over the wire and current flow through the circuit is displayed.

TECH TIP

Over-Limit Display Does Not Mean the Meter Is Reading "Nothing"

The meaning of the over-limit display on a digital meter often confuses beginning technicians. When asked what the meter is reading when an over limit (OL) is displayed on the meter face, the response is often, "Nothing." Many meters indicate over limit or over load, which simply means that the reading is over the maximum that can be displayed for the selected range. For example, the meter displays OL if 12 volts are being measured, but the meter has been set to read a maximum of 4 volts.

Autoranging meters adjust the range to match what is being measured. Here OL means a value higher than the meter can read (unlikely on the voltage scale for automobile usage), or infinity when measuring resistance (ohms). Therefore, OL means infinity when measuring resistance or an open circuit is being indicated. The meter reads 00.0 if the resistance is zero, so "nothing" in this case indicates continuity (zero resistance), whereas OL indicates infinite resistance. Therefore, when talking with another technician about a meter reading, make sure you know exactly what the reading on the face of the meter means. Also be sure that you are connecting the meter leads correctly. ● **SEE FIGURE 39–14**.

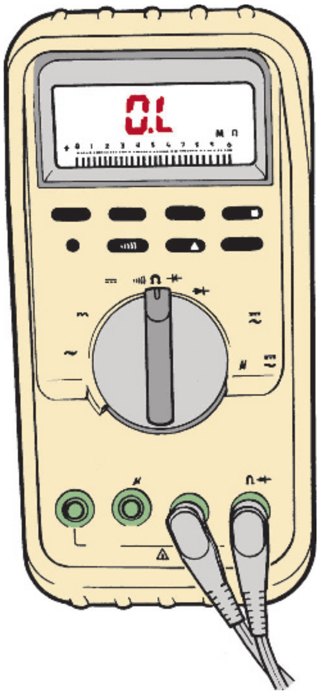


FIGURE 39–14 Typical digital multimeter showing OL (over limit) on the readout with the ohms (Ω) unit selected. This usually means that the unit being measured is open (infinite resistance) and has no continuity.

DIODE CHECK, DUTY CYCLE, AND FREQUENCY

DIODE CHECK Diode check is a meter function that can be used to check diodes, including light-emitting diodes (LEDs).

The meter is able to test diodes in the following way:

- The meter applies roughly a 3 volt DC signal to the text leads.
- The voltage is high enough to cause a diode to work and the meter displays
  1. 0.4 to 0.7 volt when testing silicon diodes, such as those found in alternators
  2. 1.5 to 2.3 volts when testing LEDs, such as those found in some lighting applications

DUTY CYCLE Duty cycle is the amount of time, by percentage, that a signal is on compared to being off.

- 100% indicates that a device is being commanded on all of the time.
- 50% indicates that a device is being commanded on half of the time.
- 25% indicates that a device is being commanded on just 25% of the time.

Duty cycle is used to measure the on time for fuel injectors and other computer-controlled solenoid and devices.

FREQUENCY Frequency is a measure of how many times per second a signal changes. Frequency is measured in a unit called hertz, formerly termed “cycles per second.”

Frequency measurements are used when checking the following:

- Mass airflow (MAF) sensors for proper operation
- Ignition primary pulse signals when diagnosing a no-start condition
- Checking a wheel speed sensor

ELECTRICAL UNIT PREFIXES

DEFINITIONS Electrical units are measured in numbers such as 12 volts, 150 amperes, and 470 ohms. Large units over 1,000 may be expressed in kilo units. **Kilo (k)** means 1,000. ● **SEE FIGURE 39–15**.

4,700 ohms = 4.7 kilohms (kΩ)

If the value is over 1 million (1,000,000), the prefix **mega (M)** is often used. For example:

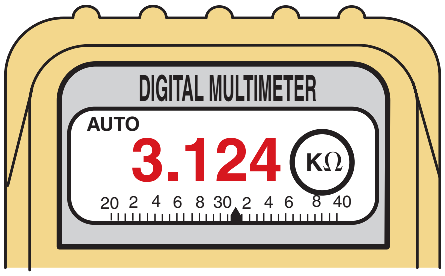
1,100,000 volts = 1.1 megavolts (MV)

4,700,000 ohms = 4.7 megohms (MΩ)

Sometimes a circuit conducts so little current that a smaller unit of measure is required. Small units of measure expressed in 1/1,000 are prefixed by **milli (m)**. To summarize:

mega (M) = 1,000,000 (decimal point six places to the right = 1,000,000)

kilo (k) = 1,000 (decimal point three places to the right = 1,000)



THE SYMBOL ON THE RIGHT SIDE OF THE DISPLAY INDICATES WHAT RANGE THE METER HAS BEEN SET TO READ.

Ω = OHMS

IF THE ONLY SYMBOL ON THE DISPLAY IS THE OHMS SYMBOL, THE READING ON THE DISPLAY IS EXACTLY THE RESISTANCE IN OHMS.

kΩ = KILOHMS = OHMS TIMES 1,000

A "K" IN FRONT OF THE OHMS SYMBOL MEANS "KILOHMS"; THE READING ON THE DISPLAY IS IN KILOHMS. YOU HAVE TO MULTIPLY THE READING ON THE DISPLAY BY 1,000 TO GET THE RESISTANCE IN OHMS.

MΩ = MEGOHMS = OHMS TIMES 1,000,000

AN "M" IN FRONT OF THE OHMS SYMBOL MEANS "MEGOHMS"; THE READING ON THE DISPLAY IS IN MEGOHMS. YOU HAVE TO MULTIPLY THE READING ON THE DISPLAY BY 1,000,000 TO GET THE RESISTANCE IN OHMS.

FIGURE 39–15 Always look at the meter display when a measurement is being made, especially if using an autoranging meter.

milli (m) = 1/1,000 (decimal point three places to the left = 0.001)

NOTE: Lowercase *m* equals a small unit (milli), whereas a capital *M* represents a large unit (mega).

● **SEE CHART 39–2**.

PREFIXES The prefixes can be confusing because most digital meters can express values in more than one unit, especially if the meter is autoranging. For example, an ammeter reading may show 36.7 mA on autoranging. When the scale is changed to amperes (“A” in the window of the display), the number displayed is 0.037 A. Note that the resolution of the value is reduced.

TO/ FROM	MEGA	KILO	BASE	MILLI
Mega	0 places	3 places to the right	6 places to the right	9 places to the right
Kilo	3 places to the left	0 places	3 places to the right	6 places to the right
Base	6 places to the left	3 places to the left	0 places	3 places to the right
Milli	9 places to the left	6 places to the left	3 places to the left	0 places

CHART 39–2

A conversion chart showing the decimal point location for the various prefixes.

TECH TIP

Think of Money

Digital meter displays can often be confusing. The display for a battery measured as 12 1/2 volts is 12.50 V, just as $12.50 is 12 dollars and 50 cents. A 1/2 volt reading on a digital meter is displayed as 0.50 V, just as $0.50 is half of a dollar.

It is more confusing when low values are displayed. For example, if a voltage reading is 0.063 volt, an autoranging meter displays 63 millivolts (63 mV), or 63/1,000 of a volt, or $63 of $1,000. (It takes 1,000 mV to equal 1 volt.) Think of millivolts as one-tenth of a cent, with 1 volt being $1.00. Therefore, 630 millivolts are equal to $0.63 of $1.00 (630 tenths of a cent, or 63 cents).

To avoid confusion, try to manually range the meter to read base units (whole volts). If the meter is ranged to base-unit volts, 63 millivolts is displayed as 0.063, or maybe just 0.06, depending on the display capabilities of the meter.

NOTE: Always check the face of the meter display for the unit being measured. To best understand what is being displayed on the face of a digital meter, select a manual scale and move the selector until *whole units appear*, such as "A" for amperes instead of "mA" for milliamperes.

HOW TO READ DIGITAL METERS

STEPS TO FOLLOW Getting to know and use a digital meter takes time and practice. The first step is to read, understand, and follow all safety and operational instructions that come with the meter. Use of the meter usually involves the following steps:

Step 1 **Select the proper unit of electricity for what is being measured.** This unit could be volts, ohms (resistance), or amperes (amount of current flow). If the meter is not autoranging, select the proper scale for the anticipated reading. For example, if a 12 volt battery is being measured, select a meter reading range that is higher than the voltage, but not too high. A 20 or 30 volt range accurately shows the voltage of a 12 volt battery. If a 1,000 volt scale is selected, a 12 volt reading may not be accurate.

Step 2 **Place the meter leads into the proper input terminals.**

- The black lead is inserted into the common (COM) terminal. This meter lead usually stays in this location for all meter functions.
- The red lead is inserted into the volt, ohm, or diode check terminal, usually labeled "VΩ" when voltage, resistance, or diodes are being measured.
- When current flow in amperes is being measured, most digital meters require that the red test lead be inserted in the ammeter terminal, usually labeled "A" or "mA."

CAUTION: If the meter leads are inserted into ammeter terminals, even though the selector is set to volts, the meter may be damaged, or an internal fuse may blow, if the test leads touch both terminals of a battery.

Step 3 Measure the component being tested. Carefully note the decimal point and the unit on the face of the meter.

- **Meter lead connections.** If the meter leads are connected to a battery backward (red to the battery negative, for example), the display still shows the correct reading, but a negative sign (–) is displayed in front of the number. The correct polarity is not important when measuring resistance (ohms), except where indicated, such as measuring a diode.
- **Autorange.** Many meters automatically default to the autorange position and the meter displays the value in the most readable scale. The meter can be manually ranged to select other levels, or to lock in a scale for a value that is constantly changing.

  If a 12 volt battery is measured with an autoranging meter, the correct reading of 12.0 is given. "AUTO" and "V" should show on the face of the meter. For example, if a meter is manually set to the 2 kilohm scale, the highest that the meter reads is 2,000 ohms. If the reading is over 2,000 ohms, the meter displays OL. ● **SEE CHART 39–3**.

Step 4 Interpret the reading. This is especially difficult on autoranging meters, where the meter itself selects the proper scale. The following are two examples of different readings.

Example 1: A voltage drop is being measured. The specifications indicate a maximum voltage drop of 0.2 volt. The meter reads "AUTO" and "43.6 mV." This reading means that the voltage drop is 0.0436 volt, or 43.6 mV, which is far lower than the 0.2 volt (200 mV). Because the number showing on the meter face is much larger than the specifications, many beginner technicians believe that the voltage drop is excessive.

NOTE: Pay attention to the units displayed on the meter face and convert to whole units.

Example 2: A spark plug wire is being measured. The reading should be less than 10,000 ohms for each foot in length, if the wire is okay. The wire being tested is 3 foot long (maximum allowable resistance is 30,000 ohms). The meter reads "AUTO" and "14.85 kΩ." This reading is equivalent to 14,850 ohms.

NOTE: When converting from kilohms to ohms, make the decimal point a comma.

Because this reading is well below the specified maximum allowable, the spark plug wire is okay.

RMS VERSUS AVERAGE Alternating-current voltage waveforms can be true sinusoidal or nonsinusoidal. A true sine wave pattern measurement is the same for both **root-mean-square (RMS)** and average-responding meters. RMS and averaging are two methods used to measure the true effective rating of a signal that is constantly changing. ● **SEE FIGURE 39–16**.

	VOLTAGE BEING MEASURED					
	0.01 V (10 mV)	**0.150 V (150 mV)**	**1.5 V**	**10.0 V**	**12.0 V**	**120 V**
Scale Selected	**Voltmeter displays:**					
200 mV	10.0	150.0	OL	OL	OL	OL
2 V	0.100	0.150	1.500	OL	OL	OL
20 V	0.1	1.50	1.50	10.00	12.00	OL
200 V	00.0	01.5	01.5	10.0	12.0	120.0
2 kV	00.00	00.00	000.1	00.10	00.12	0.120
Autorange	10.0 mV	15.0 mV	1.50	10.0	12.0	120.0
	RESISTANCE BEING MEASURED					
	10 OHMS	**100 OHMS**	**470 OHMS**	**1 KILOHM**	**220 KILOHMS**	**1 MEGOHM**
Scale Selected	**Ohmmeter displays:**					
400 ohms	10.0	100.0	OL	OL	OL	OL
4 kilohms	010	100	0.470 k	1000	OL	OL
40 kilohms	00.0	0.10 k	0.47 k	1.00 k	OL	OL
400 kilohms	000.0	00.1 k	00.5 k	0.10 k	220.0 k	OL
4 megohms	00.00	0.01 M	0.05 M	00.1 M	0.22 M	1.0 M
Autorange	10.0	100.0	470.0	1.00 k	220 k	1.00 M
	CURRENT BEING MEASURED					
	50 mA	**150 mA**	**1.0 A**	**7.5 A**	**15.0 A**	**25.0 A**
Scale Selected	**Ammeter displays:**					
40 mA	OL	OL	OL	OL	OL	OL
400 mA	50.0	150	OL	OL	OL	OL
4 A	0.05	0.00	1.00	OL	OL	OL
40 A	0.00	0.000	01.0	7.5	15.0	25.0
Autorange	50.0 mA	150.0 mA	1.00	7.5	15.0	25.0

CHART 39–3

Sample meter readings, using manually set and autoranging selection on the digital meter control.

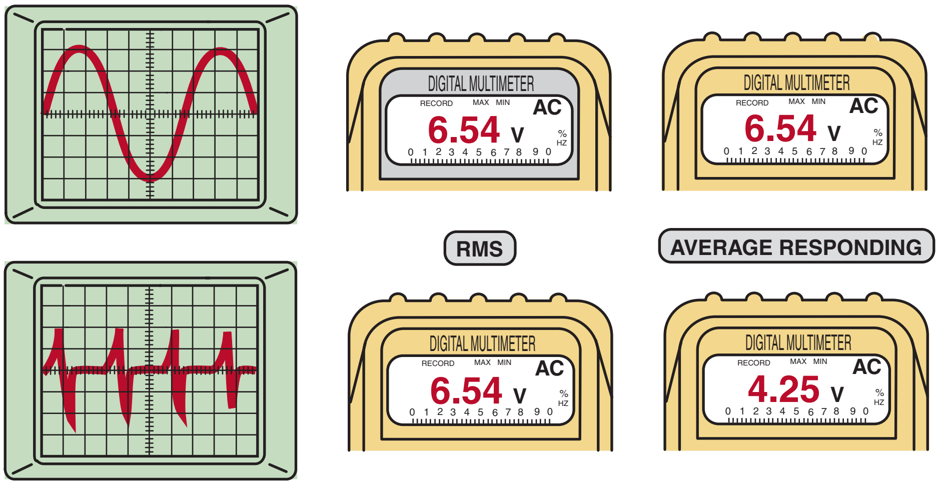

DIGITAL MULTIMETER
RECORD
MAX MIN
AC
6.54 V
% Hz
0 1 2 3 4 5 6 7 8 9 0
DIGITAL MULTIMETER
6.54 V
RMS
AVERAGE RESPONDING
DIGITAL MULTIMETER
6.54 V
DIGITAL MULTIMETER
4.25 V

FIGURE 39–16 When reading AC voltage signals, a true RMS meter (such as a Fluke 87) provides a different reading than an average-responding meter (such as a Fluke 88). The only place this difference is important is when a reading is to be compared with a specification.

Only true RMS meters are accurate when measuring nonsinusoidal AC waveforms, which are seldom used in automotive applications.

RESOLUTION, DIGITS, AND COUNTS

Meter resolution refers to how small or fine a measurement the meter can make. By knowing the resolution of a DMM, you can determine whether the meter could measure down to only 1 volt, or down to 1 millivolt (1/1,000 of a volt).

The terms *digits* and *counts* are used to describe a meter's resolution. DMMs are grouped by the number of counts or digits they display.

- A 3 1/2-digit meter can display three full digits ranging from 0 to 9, and one "half" digit that displays only a 1 or is left blank. A 3 1/2-digit meter displays up to 1,999 counts of resolution.
- A 4 1/2-digit meter can display up to 19,000 counts of resolution. It is more precise to describe a meter by counts of resolution than by 3 1/2 or 4 1/2 digits. Some 3 1/2-digit meters have enhanced resolution of up to 3,200 or 4,000 counts.

Meters with more counts offer better resolution for certain measurements. For example, a 1,999-count meter is not able to measure down to a tenth of a volt when measuring 200 volts or more. ● **SEE FIGURE 39–17**.

However, a 3,200-count meter displays a tenth of a volt, up to 320 volts. Digits displayed to the far right of the display may at times flicker or constantly change. This is called *digit rattle* and represents a changing voltage being measured on the ground (COM terminal of the meter lead). High-quality meters are designed to reject this unwanted voltage.

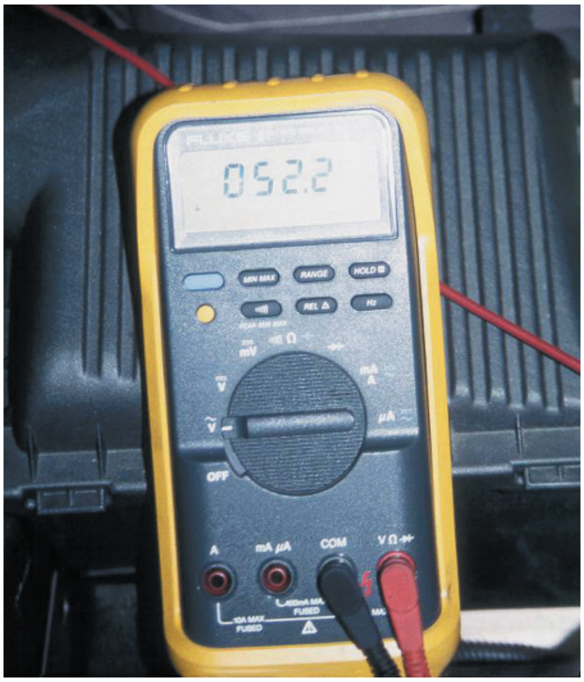


FIGURE 39–17 This meter display shows 052.2 AC volts. Notice that the zero beside the 5 indicates that the meter can read over 100 volts AC with a resolution of 0.1 volt.

TECH TIP

Purchase a Digital Meter That Works for Automotive Use

Try to purchase a digital meter that is capable of reading the following:

- DC volts
- AC volts
- DC amperes (up to 10 A or more is helpful)
- Ohms (Ω) up to 40 MΩ (40 million ohms)
- Diode check

Additional features for advanced automotive diagnosis include

- Frequency (hertz, abbreviated Hz)
- Temperature probe (°F and/or °C)
- Pulse width (millisecond, abbreviated ms)
- Duty cycle (%)

ACCURACY

Meter accuracy is the largest allowable error that occurs under specific operating conditions. In other words, it is an indication of how close the DMM's displayed measurement is to the actual value of the signal being measured.

Accuracy for a DMM is usually expressed as a percent of reading. An accuracy of ±1% of reading means that for a displayed reading of 100.0 V, the actual value of the voltage could be anywhere between 99.0 and 101.0 V. Thus, the lower the percent of accuracy is, the better.

- Unacceptable = 1.00%
- Okay = 0.50% (1/2%)
- Good = 0.25% (1/4%)
- Excellent = 0.10% (1/10%)

For example, if a battery had 12.6 volts, a meter could read between the following, based on its accuracy.

±0.1% high = 12.61
low = 12.59
±0.25% high = 12.63
low = 12.57
±0.50% high = 12.66
low = 12.54
±1.00% high = 12.73
low = 12.47

Before you purchase a meter, check the accuracy. Accuracy is usually indicated on the specifications sheet for the meter.

SAFETY TIP

Meter Usage on Hybrid-Electric Vehicles

Many hybrid-electric vehicles use system voltage as high as 650 volts DC. Be sure to follow all vehicle manufacturer's testing procedures. If a voltage measurement is needed, be sure to use a meter and test leads that are designed to insulate against high voltages. The **International Electrotechnical Commission (IEC)** has several categories of voltage standards for meter and meter leads. These categories are ratings for overvoltage protection and are rated CAT I, CAT II, CAT III, and CAT IV. The higher the category rating, the greater the protection against voltage spikes caused by high-energy circuits. Under each category, there are various energy and voltage ratings.

CAT I	Typically, a CAT I meter is used for low-energy voltage measurements, such as at wall outlets in the home. Meters with a CAT I rating are usually rated at 300 to 800 volts.
CAT II	This higher rated meter is typically used for checking higher energy level voltages at the fuse panel in the home. Meters with a CAT II rating are usually rated at 300 to 600 volts.
CAT III	This minimum-rated meter should be used for hybrid vehicles. The CAT III category is designed for high-energy levels and voltage measurements at the service pole at the transformer. Meters with this rating are usually rated at 600 to 1,000 volts.
CAT IV	CAT IV meters are for clamp-on meters only. If a clamp-on meter also has meter leads for voltage measurements, that part of the meter is rated as CAT III.

NOTE: Always use the highest CAT rating meter, especially when working with hybrid vehicles. A CAT III, 600 volt meter is safer than a CAT II, 1,000 volt meter because of the energy level of the CAT ratings.

Therefore, for best personal protection, use only meters and meter leads that are CAT III or CAT IV rated when measuring voltage on a hybrid vehicle. ● **SEE FIGURES 39–18 AND 39–19**.

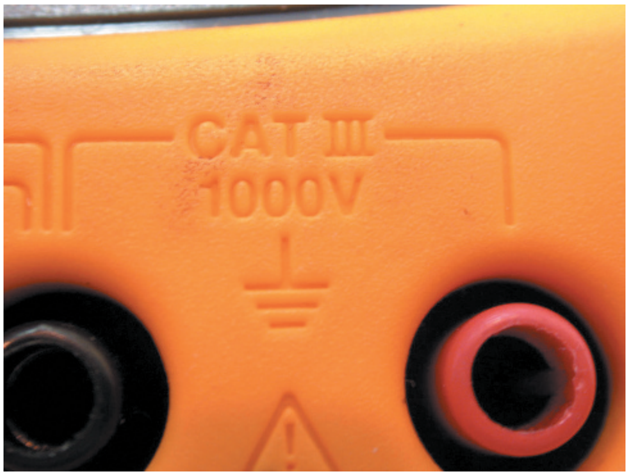


FIGURE 39–18 Be sure to use only a meter that is CAT III rated when taking electrical voltage measurements on a hybrid vehicle.

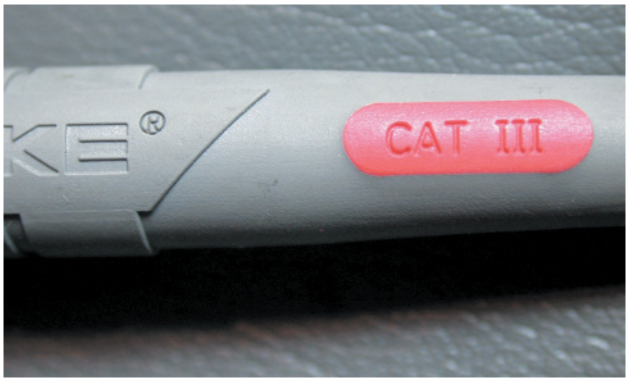
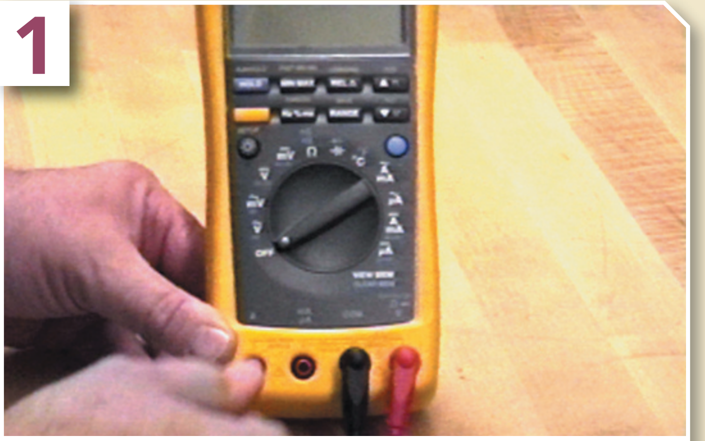


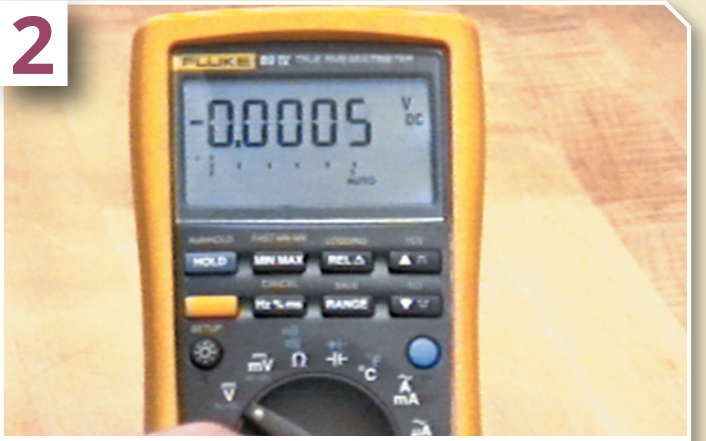
FIGURE 39–19 Always use meter leads that are CAT III rated on a meter that is also CAT III rated, to maintain the protection needed when working on hybrid vehicles.

DIGITAL METER USAGE

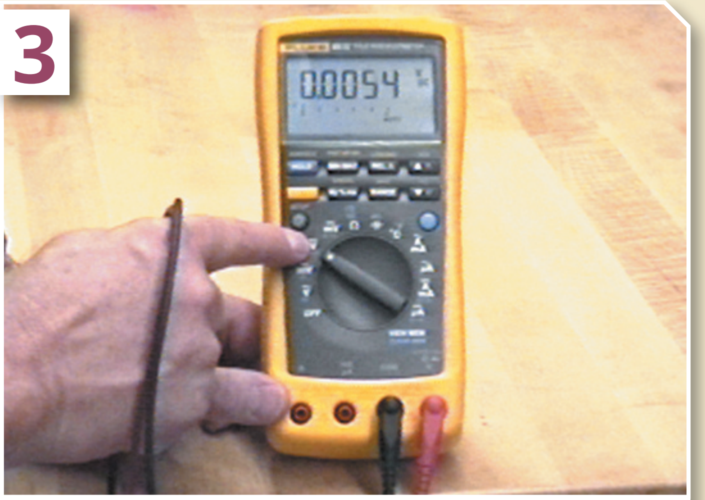
1


For most electrical measurements, the black meter lead is inserted in the terminal labeled “COM” and the red meter lead is inserted into the terminal labeled “V.”

2

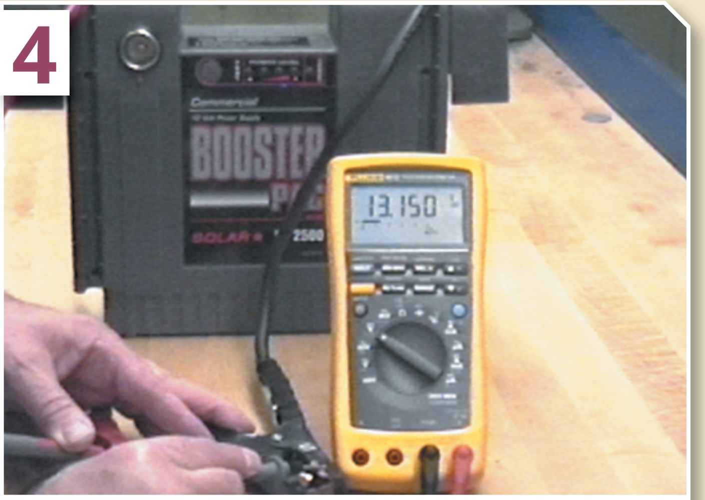

FLUKE
-0.0005
V DC
HOLD
MIN MAX
REL Δ
RANGE
To use a digital meter, turn the power switch and select the unit of electricity to be measured. In this case, the rotary switch is turned to select DC volts V.

3

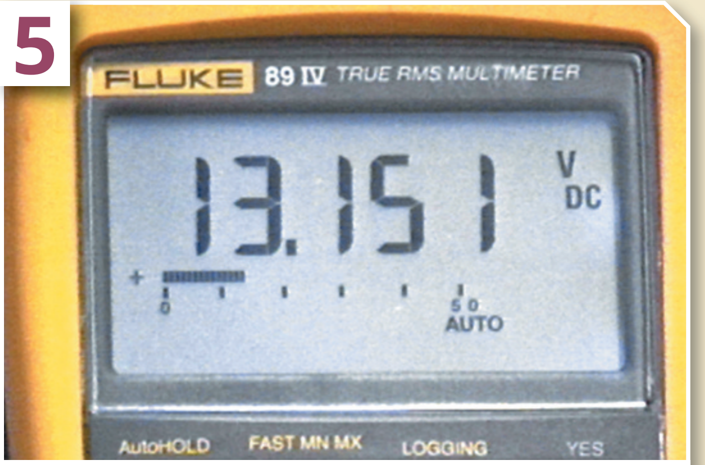


For most automotive electrical use, such as measuring battery voltage, select DC volts.

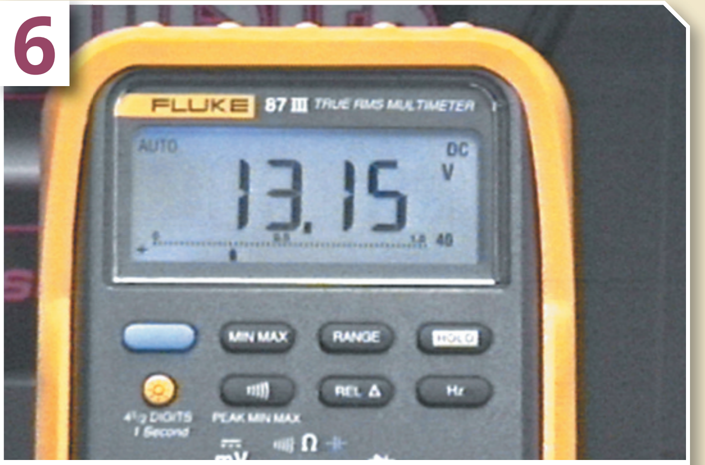
4


BOOSTER PAC
SOLAR
2500
13.150
Connect the red meter lead to the positive (+) terminal of a battery and the black meter lead to the negative (−) terminal. The meter reads the voltage difference between the leads.

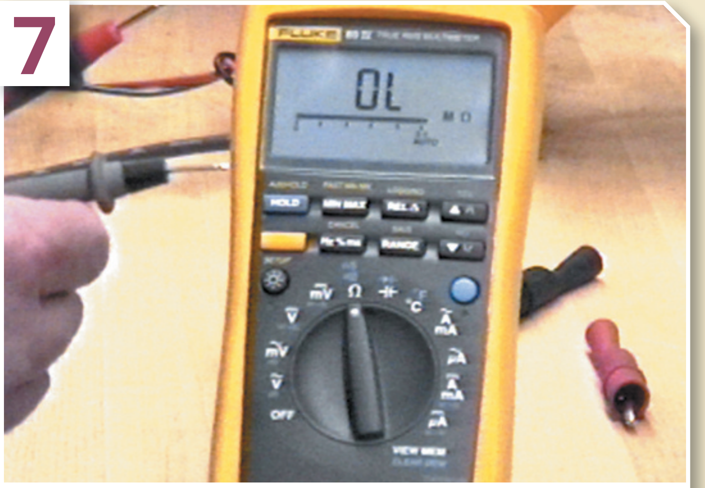
5


FLUKE 89 IV TRUE RMS MULTIMETER
13.151
V DC
AUTO
AutoHOLD
FAST MN MX
LOGGING
YES
This jump-start battery unit measures 13.151 volts with the meter set on autoranging on the DC voltage scale.

6

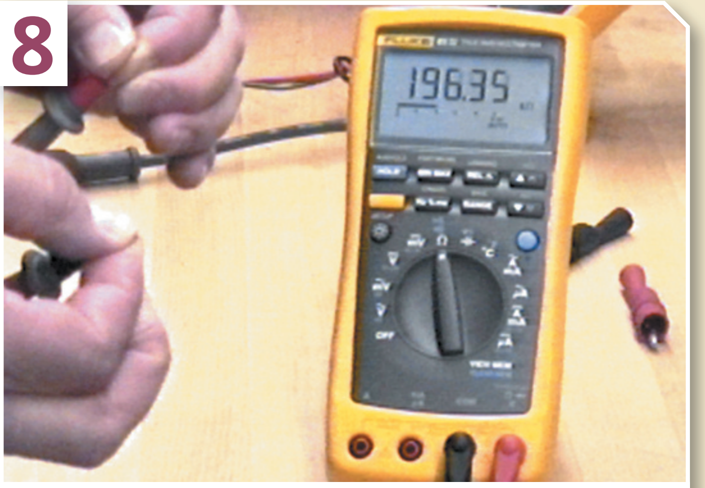

FLUKE 87 III TRUE RMS MULTIMETER
AUTO
DC V
13.15
MIN MAX
RANGE
HOLD
REL Δ
Hz
PEAK MIN MAX
Another meter (Fluke 87 III) displays four digits when measuring the voltage of the battery jump-start unit.

7



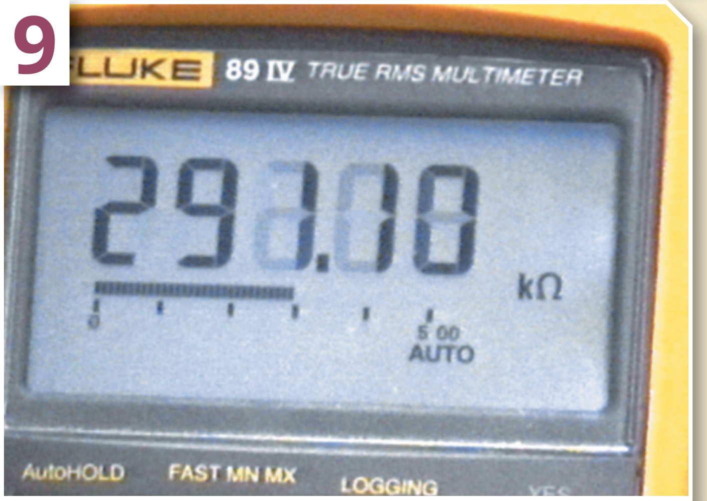
To measure resistance, turn the rotary dial to the ohm (Ω) symbol. With the meter leads separated, the meter display reads OL (over limit).

8



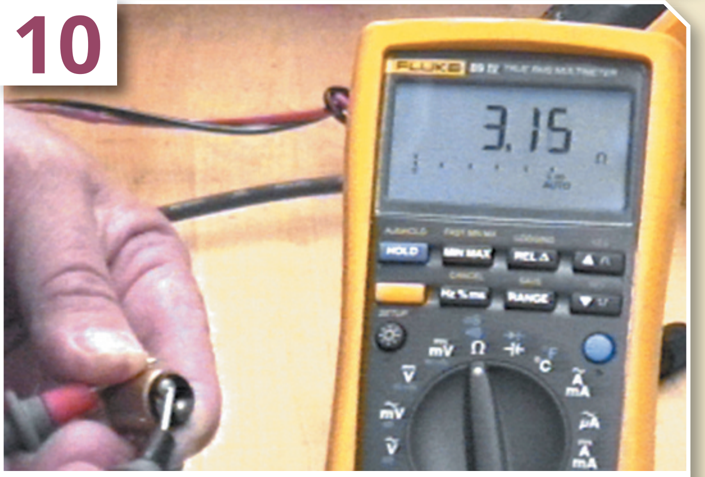
The meter can read your own body resistance if you grasp the meter lead terminals with your fingers. The reading on the display indicates 196.35 kΩ.

9


FLUKE
89 IV TRUE RMS MULTIMETER
kΩ
0
5 00
AUTO
AutoHOLD
FAST MN MX
LOGGING

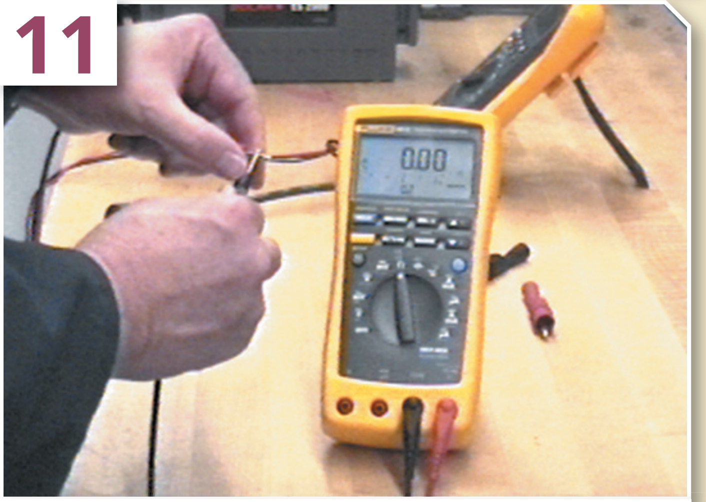
When measuring anything, be sure to read the symbol on the meter face. In this case, the meter reading is 291.10 kΩ.

10



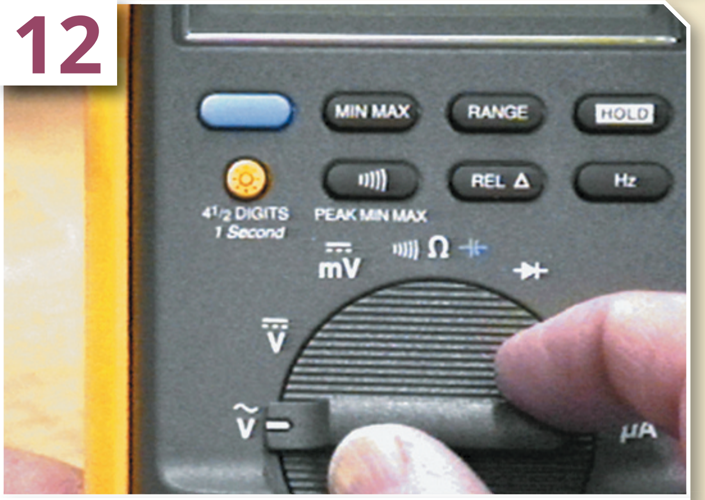
A meter set on ohms can be used to check the resistance of a lightbulb filament. In this case, the meter reads 3.15 ohms. If the bulb were bad (filament open), the meter displays OL.

11



A digital meter set to read ohms should measure 0.00, as shown, when the meter leads are touched together.

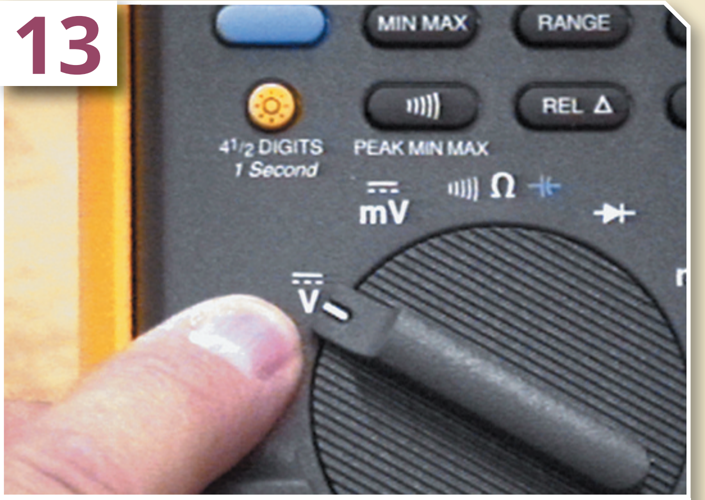
12


MIN MAX
RANGE
HOLD
REL Δ
Hz
4½ DIGITS
1 Second
PEAK MIN MAX
mV
Ω
V
V
µA

The large letter V means volts and the wavy symbol over the V means that the meter measures alternating-current (AC) voltage, if this position is selected.

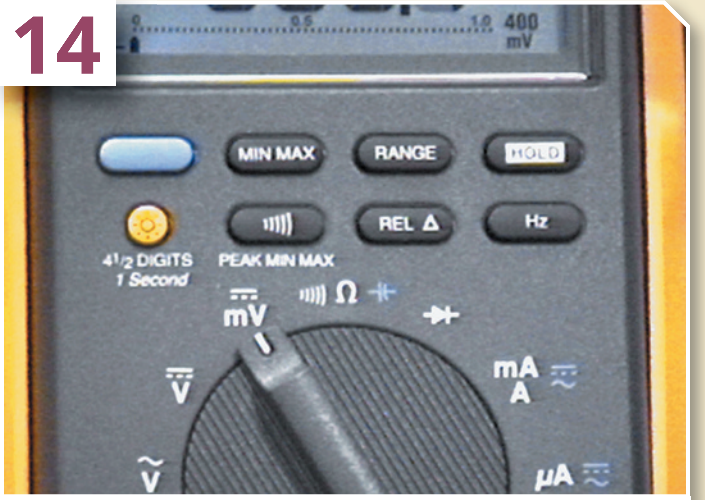
DIGITAL METER USAGE

13


MIN MAX
RANGE
REL Δ
4½ DIGITS
1 Second
PEAK MIN MAX
mV
Ω
V

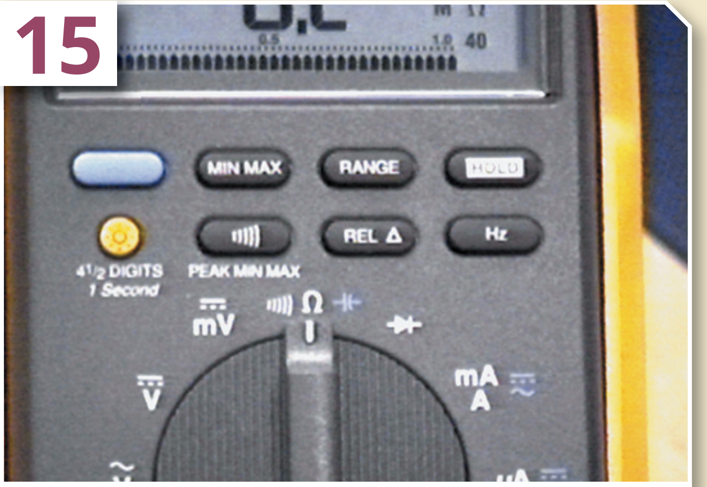
The next symbol is a V with a dotted and a straight line overhead. This symbol stands for direct-current (DC) volts. This position is most used for automotive service.

14


400
mV
MIN MAX
RANGE
HOLD
REL Δ
Hz
4½ DIGITS
1 Second
PEAK MIN MAX
mV
Ω
V
mA
A
µA

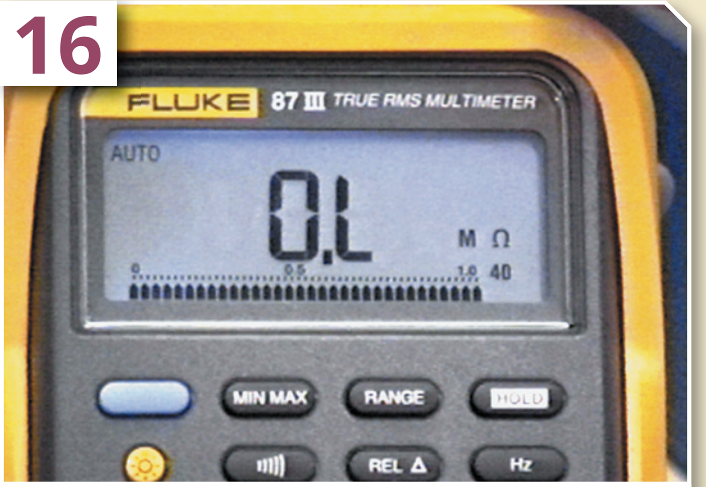
The symbol mV indicates millivolts or 1/1,000 of a volt (0.001). The solid and dashed line above the mV means DC mV.

15


40
MIN MAX
RANGE
HOLD
REL Δ
Hz
4½ DIGITS
1 Second
PEAK MIN MAX
mV
Ω
V
mA
A

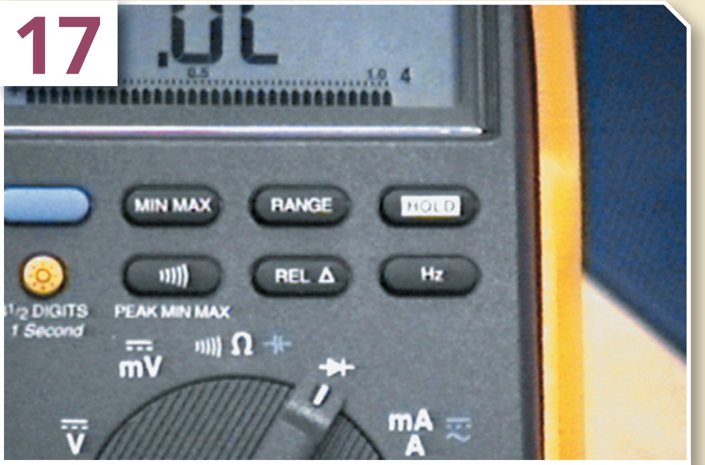
The rotary switch is turned to Ω (ohms) unit of resistance measure. The symbol to the left of the Ω symbol is the beeper or continuity indicator.

16


FLUKE
87 III TRUE RMS MULTIMETER
AUTO
0.L
M Ω
40
MIN MAX
RANGE
HOLD
REL Δ
Hz

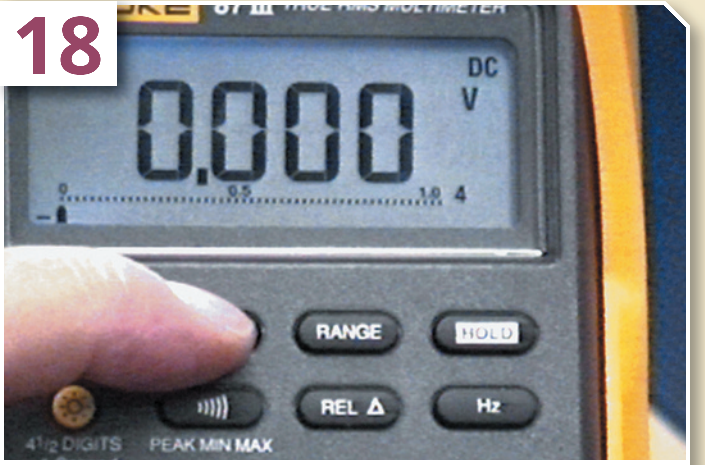
Notice that AUTO is in the upper left and the MΩ is in the lower right. MΩ means megohms or that the meter is set to read in millions of ohms.

17


.0L
4
MIN MAX
RANGE
HOLD
REL Δ
Hz
½ DIGITS
1 Second
PEAK MIN MAX
mV
Ω
V
mA
A

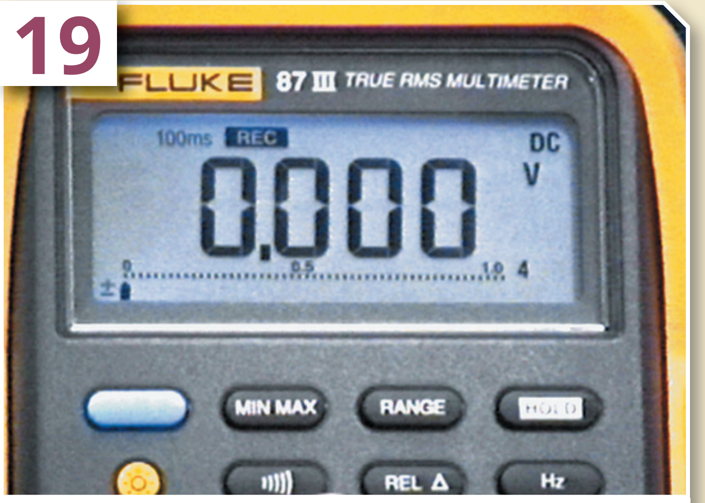
The symbol shown is that of a diode. In this position, the meter applies a voltage to a diode and the meter reads the voltage drop across the junction of a diode.

18


DC
V
0.000
4
RANGE
HOLD
REL Δ
Hz
4½ DIGITS
PEAK MIN MAX

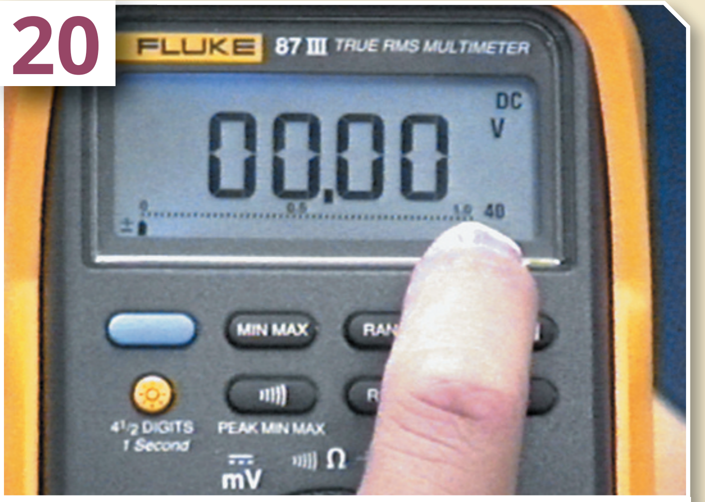
One of the most useful features of this meter is the MIN/MAX feature. By pushing the MIN/MAX button, the meter is able to display the highest (MAX) and the lowest (MIN) reading.

19



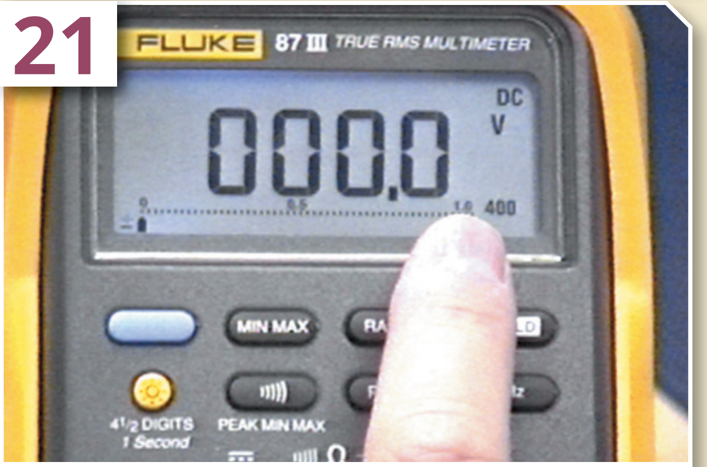
Pushing the MIN/MAX button puts the meter into record mode. Note the 100 ms and "rec" on the display. In this position, the meter is capturing any voltage change that lasts 100 ms (0.1 sec.) or longer.

20



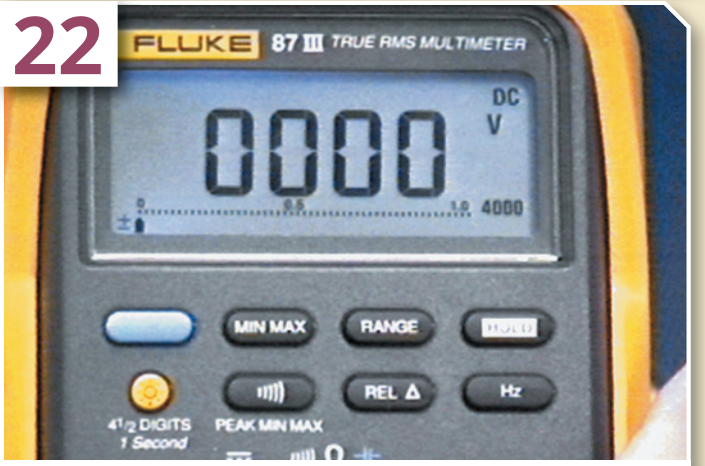
To increase the range of the meter, touch the range button. Now the meter is set to read voltage up to 40 volt DC.

21



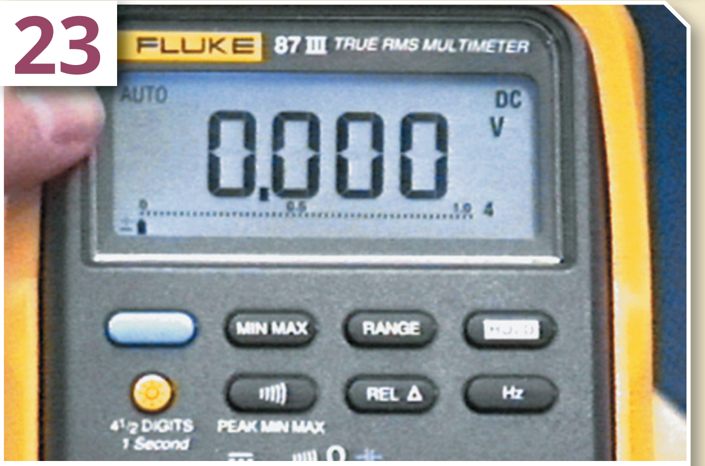
Pushing the range button one more time changes the meter scale to the 400 volt range. Notice that the decimal point has moved to the right.

22



Pushing the range button again changes the meter to the 4,000 volt range. This range is not suitable to use in automotive applications.

23



By pushing and holding the range button, the meter resets to autorange. Autorange is the preferred setting for most automotive measurements, except when using MIN/MAX record mode.

REVIEW QUESTIONS

1. Why should high-impedance meters be used when measuring voltage on computer-controlled circuits?
2. How is an ammeter connected to an electrical circuit?
3. Why must an ohmmeter be connected to a disconnected circuit or component?
4. How is a diode tested using a digital meter?
5. What is meant when a meter reads "OL" when measuring ohms?

CHAPTER QUIZ

1. A fused jumper wire can be used to _________.
   a. bypass a switch
   b. replace an electrical load
   c. bypass a resistance in the circuit
   d. Any of the above
2. A test light can be used to check for _________
   a. power
   b. ground
   c. Either a or b
   d. Nether a nor b
3. A logic probe can used to check for _________.
   a. pulsating power or ground
   b. power
   c. ground
   d. Any of the above
4. A digital multimeter can be used to check _________.
   a. diodes
   b. frequency
   c. voltage
   d. All of the above
5. When testing a diode with the multimeter set on "Diode Check," a reading of 0.6 volt is obtained. This indicates that the diode being tested is a _________.
   a. tungsten bulb
   b. light-emitting diode
   c. silicon diode
   d. bad diode
6. If a digital meter face shows 0.93 when set to read kΩ, the reading means _________.
   a. 93 ohms
   b. 930 ohms
   c. 9,300 ohms
   d. 93,000 ohms
7. A reading of 432 shows on the face of the meter set to the millivolt scale. The reading means _________.
   a. 0.432 volt
   b. 4.32 volts
   c. 43.2 volts
   d. 4,320 volts
8. What could happen if the meter leads were connected to the positive and negative terminals of the battery while the meter and leads were set to read amperes?
   a. Could blow an internal fuse or damage the meter
   b. Would read volts instead of amperes
   c. Would display OL
   d. Would display 0.00
9. The highest amount of resistance that can be read by the meter set to the 2k scale is _________.
   a. 2,000 ohms
   b. 200 ohms
   c. 200k (200,000 ohms)
   d. 20,000,000 ohms
10. An inductive ammeter can measure _________ by clamping the probe over the wire(s).
   a. voltage
   b. frequency
   c. wire gauge size
   d. current

Chapter

40

DIGITAL STORAGE OSCILLOSCOPES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Compare the different types of oscilloscopes.
- Explain scope setup and adjustments.
- Define AC voltage.
- Describe the use of DC or AC coupling when displaying waveforms on an oscilloscope.
- Explain how to interpret pulse trains on a scope.
- Explain how to interpret channels on a scope.
- Explain how to interpret triggers on a scope.
- Explain how to use a scope.
- Discuss graphing multimeters and scan tools.

KEY TERMS:

AC coupling 459 • BNC connector 462 • Cathode ray tube (CRT) 457 • Channel 461 • DC coupling 459 • Digital storage oscilloscope (DSO) 457 • Division 458 • Duty cycle 460 • External trigger 461 • Frequency 460 • GMM 462 • Graticule 457 • Hertz 460 • Oscilloscope (scope) 457 • Pulse train 459 • Pulse width 460 • PWM 460 • Time base 458 • Trigger level 461 • Trigger slope 461

TYPES OF OSCILLOSCOPES

TERMINOLOGY An **oscilloscope** (usually called a **scope**) is a visual voltmeter with a timer that shows when a voltage changes. The following are two types of oscilloscopes:

- An *analog scope* uses a **cathode ray tube (CRT)**, similar to some television screens, to display voltage patterns. The scope screen displays the electrical signal constantly.
- A *digital scope* commonly uses a liquid crystal display (LCD), but a CRT may also be used on some digital scopes. A digital scope takes samples of the signals that can be stopped or stored and is, therefore, called a **digital storage oscilloscope,** or **DSO.**

A digital scope does not capture each change in voltage but instead captures voltage levels over time and stores them as dots. Each dot is a voltage level. The scope displays the waveforms using the thousands of dots (each representing a voltage level) and electrically connects the dots to create a waveform.

A DSO can be connected to a sensor output signal wire and can record over a long period of time the voltage signals. It can be replayed, and a technician can see if any faults were detected. This feature makes a DSO the perfect tool to help diagnose intermittent problems.

A digital storage scope, however, can sometimes miss faults called glitches that may occur between samples captured by the scope. This is why a DSO with a high "sampling rate" is preferred. Sampling rate means that a scope can capture voltage changes that occur over a very short period of time. Some digital storage scopes have a capture rate of 25 million (25,000,000) samples per second. This means that the scope can capture a glitch (fault) that lasts just 40 nano (0.00000040) seconds.

A scope has been called "a voltmeter with a clock."

- The voltmeter part means that a scope can capture and display changing voltage levels.
- The clock part means that the scope can display these changes in voltage levels within a specific time period and, with a DSO, it can be replayed so that any faults can be seen and studied.

OSCILLOSCOPE DISPLAY GRID A typical scope face usually has eight or ten grids vertically (up and down) and ten grids horizontally (left to right). The transparent scale (grid), used for reference measurements, is called a **graticule**. This arrangement is commonly 8 × 10 or 10 × 10 divisions. ● **SEE FIGURE 40–1**.

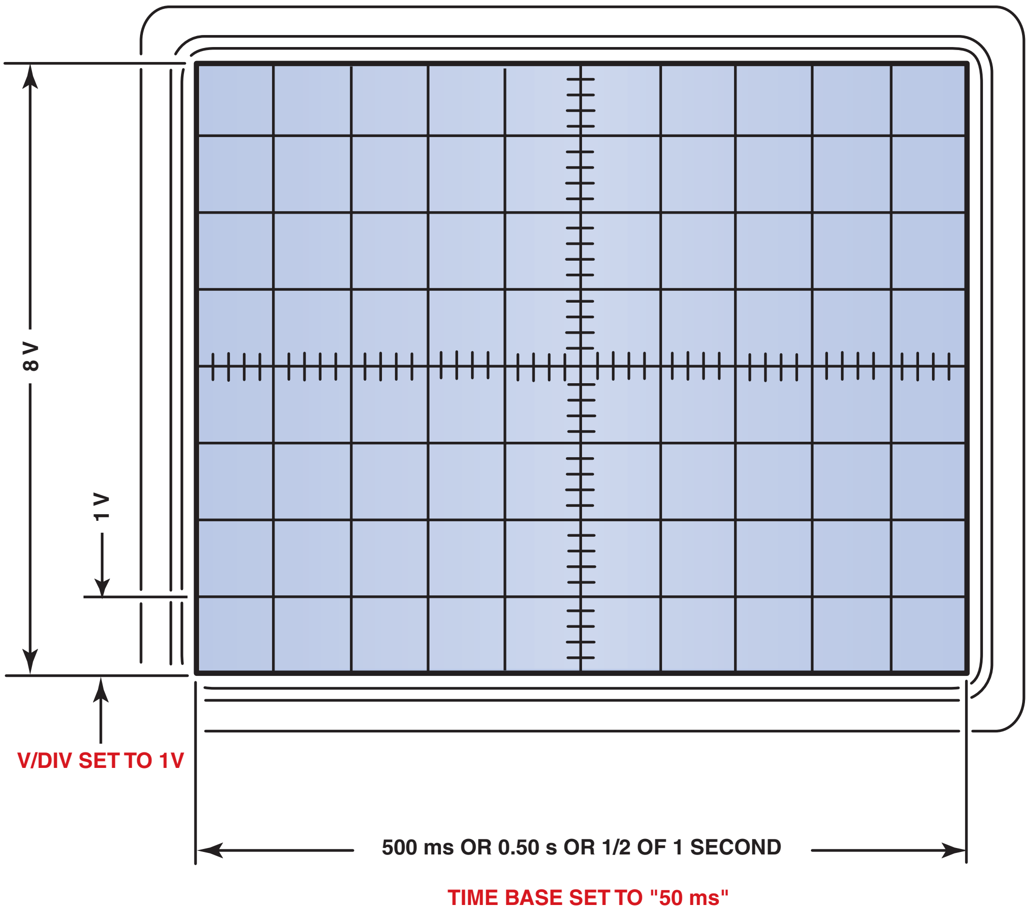


FIGURE 40–1 A scope display allows technicians to take measurements of voltage patterns. In this example, each vertical division is 1 volt and each horizontal division is set to represent 50 milliseconds.

NOTE: These numbers originally referred to the metric dimensions of the graticule in centimeters. Therefore, an 8 × 10 display is 8 cm (80 mm or 3.14 inch) high and 10 cm (100 mm or 3.90 inch) wide.

- Voltage is displayed on a scope starting with zero volts at the bottom and higher voltage being displayed vertically.
- The scope illustrates time left to right. The pattern starts on the left and sweeps across the screen from left to right.

SCOPE SETUP AND ADJUSTMENTS

SETTING THE TIME BASE Most scopes use 10 graticules from left to right on the display. Setting the **time base** means setting how much time is displayed in each block, called a **division**. For example, if the scope is set to read 2 seconds per division (referred to as *s/div*), the total time displayed is 20 seconds (2 × 10 divisions = 20 sec.). The time base should be set to an amount of time that allows two to four events to be displayed. Milliseconds (0.001 sec.) are commonly used in scopes when adjusting the time base. Sample time is milliseconds per division (indicated as *ms/div*) and total time. ● **SEE CHART 40–1**.

NOTE: Increasing the time base reduces the number of samples per second.

MILLISECONDS PER DIVISION (MS/DIV)	TOTAL TIME DISPLAYED
1 ms	10 ms (0.010 sec.)
10 ms	100 ms (0.100 sec.)
50 ms	500 ms (0.500 sec.)
100 ms	1 sec. (1.000 sec.)
500 ms	5 sec. (5.0 sec.)
1,000 ms	10 sec. (10.0 sec.)

CHART 40–1

The time base is milliseconds (ms) and total time of an event that can be displayed.

The horizontal scale is divided into 10 divisions (sometimes called *grats*). If each division represents 1 second of time, then the total time period displayed on the screen is 10 seconds. The time per division is selected so that several events of the waveform are displayed. Time per division settings can vary greatly in automotive use, including

- MAP/MAF sensors: 2 ms/div (20 ms total)
- Network (CAN) communications network: 2 ms/div (20 ms total)
- Throttle position (TP) sensor: 100 ms per division (1 sec. total)

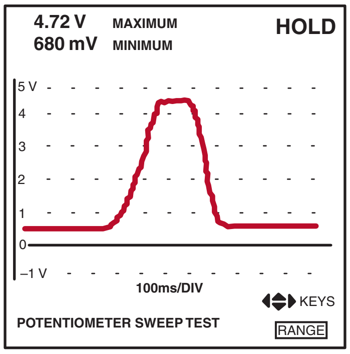


FIGURE 40–2 The digital storage oscilloscope (DSO) displays the entire waveform of a throttle position (TP) sensor from idle to wide-open throttle and returns to idle. The display also indicates the maximum (4.72 V) and minimum (680 mV or 0.68 V) readings. The display does not show anything until the throttle is opened because the scope has been set up to start displaying a waveform only after a certain voltage level has been reached. This voltage is called the trigger or trigger point.

- Fuel injector: 2 ms/div (20 ms total)
- Oxygen sensor: 1 sec. per division (10 sec. total)
- Primary ignition: 10 ms/div (100 ms total)
- Secondary ignition: 10 ms/div (100 ms total)
- Voltage measurements: 5 ms/div (50 ms total)

The total time displayed on the screen allows comparisons to see if the waveform is consistent or is changing. Multiple waveforms shown on the display at the same time also allow for measurements to be seen more easily. ● **SEE FIGURE 40–2** for an example of a throttle position sensor waveform created by measuring the voltage output as the throttle is depressed and then released.

VOLTS PER DIVISION The volts per division, abbreviated *V/div*, should be set so that the entire anticipated waveform can be viewed. Examples include

Throttle position (TP) sensor: 1 V/div (8 V total)
Battery, starting and charging: 2 V/div (16 V total)
Oxygen sensor: 200 mV/div (1.6 V total)

Notice from the examples that the total voltage to be displayed exceeds the voltage range of the component being tested. This ensures that all the waveform is displayed. It also allows for some unexpected voltage readings. For example, an oxygen sensor should read between 0 V and 1 V (1,000 mV). By setting the V/div to 200 mV, up to 1.6 V (1,600 mV) is displayed.

AC VOLTAGE

DEFINITION Whereas direct current (DC) flows in one direction, alternating current (AC) voltage changes direction continuously. The voltage varies over time and the waveform is a sine wave. ● **SEE FIGURE 40–3**.

DC AND AC COUPLING

DC COUPLING **DC coupling** is the most used position on a scope because it allows the scope to display both AC and DC voltage signals present in the circuit. The AC part of the signal rides on top of the DC component. For example, if the engine is running and the charging voltage is 14.4 volt DC, this is displayed as a horizontal line on the screen. Any AC ripple voltage leaking past the alternator diodes is displayed as an AC signal on top of the horizontal DC voltage line. Therefore, both components of the signal can be observed at the same time.

AC COUPLING When the **AC coupling** position is selected, a capacitor is placed into the meter lead circuit, which effectively blocks all DC voltage signals, but allows the AC portion of the signal to pass and be displayed. AC coupling can be used to show output signal waveforms from sensors, such as

- Distributor pickup coils
- Magnetic wheel speed sensors
- Magnetic crankshaft position sensors
- Magnetic camshaft position sensors
- The AC ripple from an alternator. ● **SEE FIGURE 40–4**.
- Magnetic vehicle speed sensors

NOTE: Check the instructions from the scope manufacturer for the recommended settings to use. Sometimes it is necessary to switch from DC coupling to AC coupling, or from AC coupling to DC coupling, to properly see some waveforms.

PULSE TRAINS

DEFINITION Scopes can show all voltage signals. Among the most commonly found in automotive applications is a DC voltage that varies up and down and does not go below zero, like an AC voltage. A DC voltage that turns on and off in a series of pulses is called a **pulse train**. Pulse trains differ from an AC signal in that they do not go below zero. An alternating voltage goes above and below zero voltage. Pulse train signals can vary in several ways. ● **SEE FIGURE 40–5**.

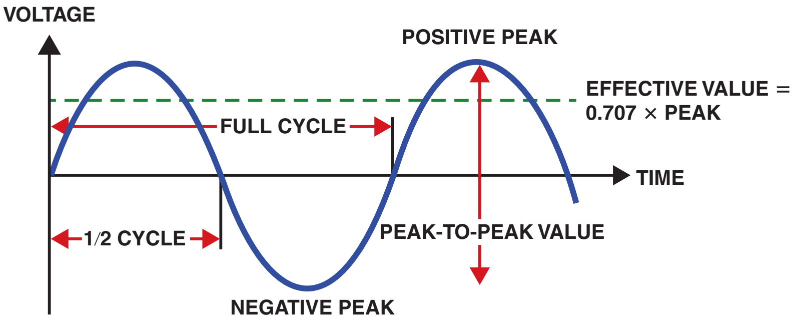


FIGURE 40–3 AC voltage varies over time from positive voltage to negative voltage. The effective value (0.707 of peak) is the level of DC required to deliver the same power.

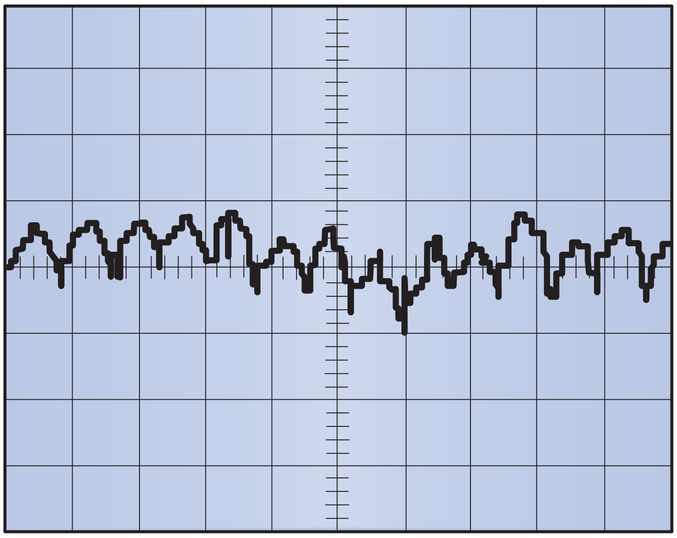


FIGURE 40–4 Ripple voltage is created from the AC voltage from an alternator. Some AC ripple voltage is normal, but if the AC portion exceeds 0.5 volt, then a bad diode is the most likely cause. Excessive AC ripple can cause many electrical and electronic devices to work incorrectly.

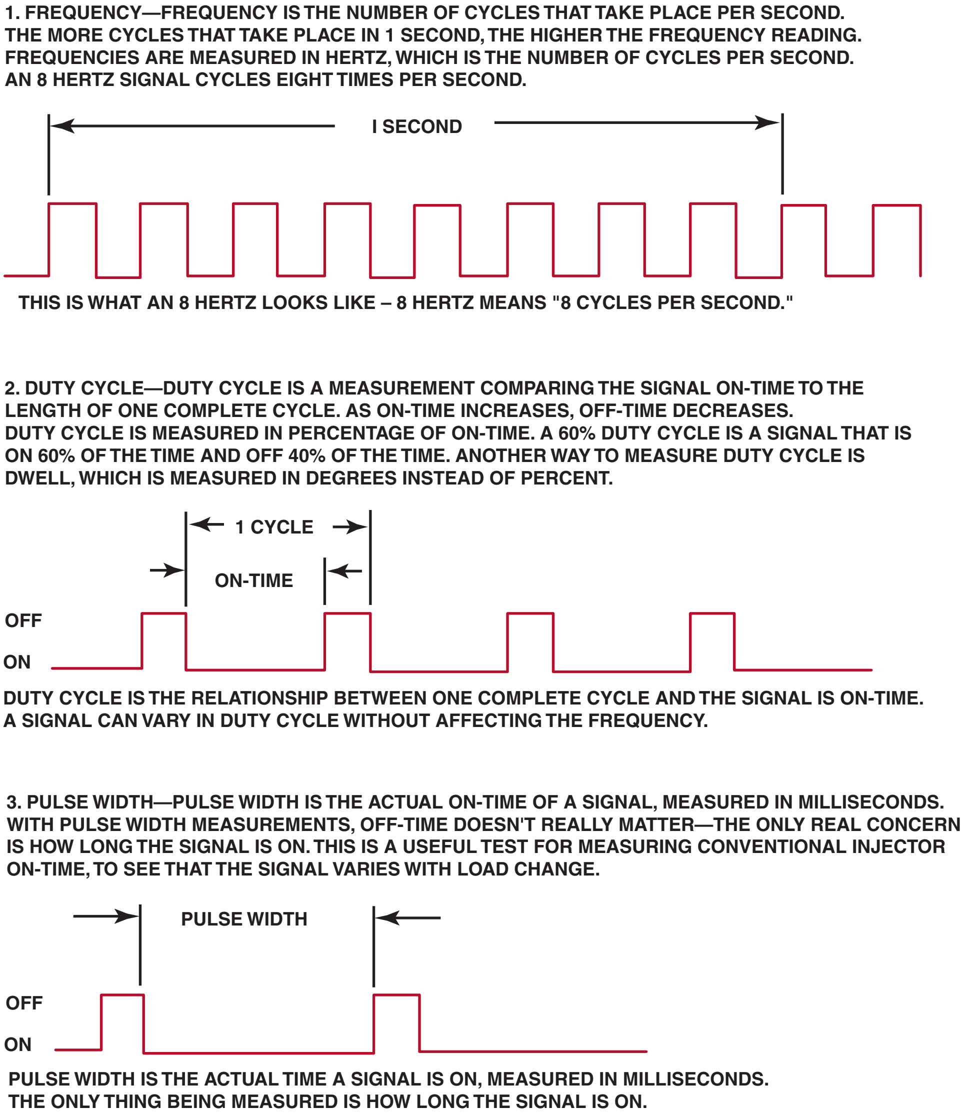
FREQUENCY **Frequency** is the number of cycles per second measured in **hertz**. The engine revolutions per minute (RPM) is an example of a signal that can occur at various frequencies. At low engine speed, the ignition pulses occur fewer times per second (lower frequency) than when the engine is operated at higher engine speeds (RPM).

DUTY CYCLE **Duty cycle** refers to the percentage of on-time of the signal during one complete cycle. As on-time increases, the amount of time the signal is off decreases and is usually measured in percentage. Duty cycle is also called **pulse-width modulation (PWM)** and can be measured in degrees. ● **SEE FIGURE 40–6**.

PULSE WIDTH The **pulse width** is a measure of the actual on-time measured in milliseconds. Fuel injectors are usually controlled by varying the pulse width. ● **SEE FIGURE 40–7**.

NUMBER OF CHANNELS

DEFINITION Scopes are available that allow the viewing of more than one sensor or event at the same time on the display. The number of events, which require leads for each, is called a



1. FREQUENCY—FREQUENCY IS THE NUMBER OF CYCLES THAT TAKE PLACE PER SECOND. THE MORE CYCLES THAT TAKE PLACE IN 1 SECOND, THE HIGHER THE FREQUENCY READING. FREQUENCIES ARE MEASURED IN HERTZ, WHICH IS THE NUMBER OF CYCLES PER SECOND. AN 8 HERTZ SIGNAL CYCLES EIGHT TIMES PER SECOND.

THIS IS WHAT AN 8 HERTZ LOOKS LIKE – 8 HERTZ MEANS "8 CYCLES PER SECOND."

2. DUTY CYCLE—DUTY CYCLE IS A MEASUREMENT COMPARING THE SIGNAL ON-TIME TO THE LENGTH OF ONE COMPLETE CYCLE. AS ON-TIME INCREASES, OFF-TIME DECREASES. DUTY CYCLE IS MEASURED IN PERCENTAGE OF ON-TIME. A 60% DUTY CYCLE IS A SIGNAL THAT IS ON 60% OF THE TIME AND OFF 40% OF THE TIME. ANOTHER WAY TO MEASURE DUTY CYCLE IS DWELL, WHICH IS MEASURED IN DEGREES INSTEAD OF PERCENT.

DUTY CYCLE IS THE RELATIONSHIP BETWEEN ONE COMPLETE CYCLE AND THE SIGNAL IS ON-TIME. A SIGNAL CAN VARY IN DUTY CYCLE WITHOUT AFFECTING THE FREQUENCY.

3. PULSE WIDTH—PULSE WIDTH IS THE ACTUAL ON-TIME OF A SIGNAL, MEASURED IN MILLISECONDS. WITH PULSE WIDTH MEASUREMENTS, OFF-TIME DOESN'T REALLY MATTER—THE ONLY REAL CONCERN IS HOW LONG THE SIGNAL IS ON. THIS IS A USEFUL TEST FOR MEASURING CONVENTIONAL INJECTOR ON-TIME, TO SEE THAT THE SIGNAL VARIES WITH LOAD CHANGE.

PULSE WIDTH IS THE ACTUAL TIME A SIGNAL IS ON, MEASURED IN MILLISECONDS. THE ONLY THING BEING MEASURED IS HOW LONG THE SIGNAL IS ON.

FIGURE 40–5 A pulse train is any electrical signal that turns on and off, or goes high and low in a series of pulses. Ignition module and fuel-injector pulses are examples of a pulse train signal.

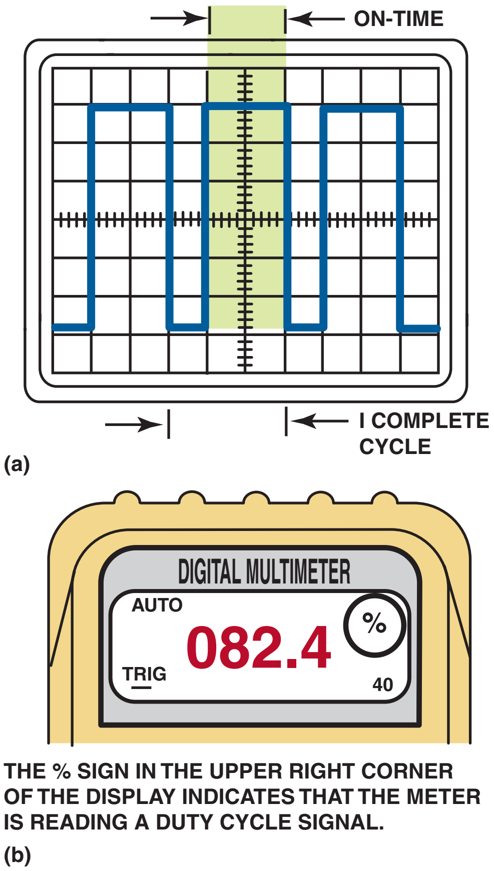

ON-TIME
I COMPLETE CYCLE
(a)
DIGITAL MULTIMETER
AUTO
082.4
%
TRIG
40
THE % SIGN IN THE UPPER RIGHT CORNER OF THE DISPLAY INDICATES THAT THE METER IS READING A DUTY CYCLE SIGNAL.
(b)

FIGURE 40–6 (a) A scope representation of a complete cycle, showing both on-time and off-time. (b) A meter display, indicating the on-time duty cycle in percentage (%). Note the trigger and negative (–) symbol. This indicates that the meter started recording the percentage of on-time when the voltage dropped (start of on-time).

channel. A channel is an input to a scope. Commonly available scopes include

- **Single channel.** A single-channel scope is capable of displaying only one sensor signal waveform at a time.
- **Two channel.** A two-channel scope can display the waveform from two separate sensors or components at the same time. This feature is very helpful when testing the camshaft and crankshaft position sensors on an engine to see if they are properly timed. ● **SEE FIGURE 40–8**.
- **Four channel.** A four-channel scope allows the technician to view up to four different sensors or actuators on one display.

NOTE: Often the capture speed of the signals is slowed when using more than one channel.

TRIGGERS

EXTERNAL TRIGGER

An **external trigger** is when the waveform starts when a signal is received from another external source, rather than from the signal pickup lead. A common example of an external trigger comes from the probe clamp around the cylinder #1 spark plug wire to trigger the start of an ignition pattern.

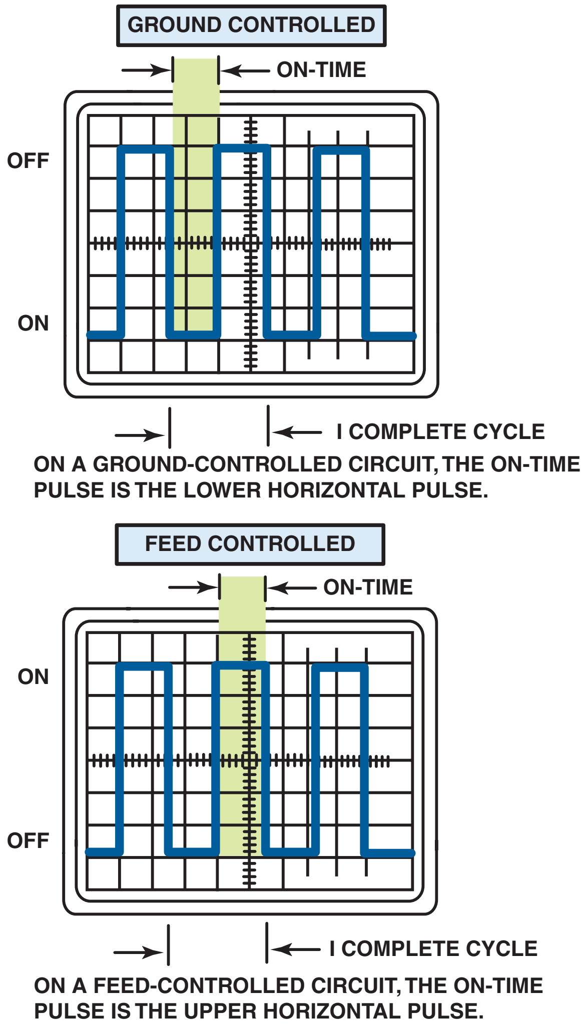

GROUND CONTROLLED
ON-TIME
OFF
ON
I COMPLETE CYCLE
ON A GROUND-CONTROLLED CIRCUIT, THE ON-TIME PULSE IS THE LOWER HORIZONTAL PULSE.
FEED CONTROLLED
ON-TIME
ON
OFF
I COMPLETE CYCLE
ON A FEED-CONTROLLED CIRCUIT, THE ON-TIME PULSE IS THE UPPER HORIZONTAL PULSE.

FIGURE 40–7 Most automotive computer systems control the device by opening and closing the ground to the component.

TRIGGER LEVEL

Trigger level is the voltage that must be detected by the scope before the pattern is displayed. A scope starts displaying a voltage signal only when it is triggered or is told to start. The trigger level must be set to start the display. If the pattern starts at 1 volt, then the trace begins displaying on the left side of the screen *after* the trace has reached 1 volt.

TRIGGER SLOPE

The **trigger slope** is the voltage direction that a waveform must have in order to start the display. Most often, the trigger to start a waveform display is taken from the signal itself. Besides trigger voltage level, most scopes can be adjusted to trigger only when the voltage rises past the trigger-level voltage. This is called a *positive slope*. When the voltage falling past the higher level activates the trigger, this is called a *negative slope*.

The scope display indicates both a positive and a negative slope symbol. For example, if a waveform, such as a magnetic sensor used for crankshaft position or wheel speed, starts moving upward, a positive slope should be selected. If a negative slope is selected, the waveform does not start showing until the voltage reaches the trigger level in a downward direction. A negative slope should be used when a fuel-injector circuit is being analyzed. In this circuit, the computer provides the ground and the voltage level drops when the computer commands the injector on. Sometimes the technician needs to change from negative to positive, or positive to negative, trigger if a waveform is not being shown correctly. ● **SEE FIGURE 40–9**.

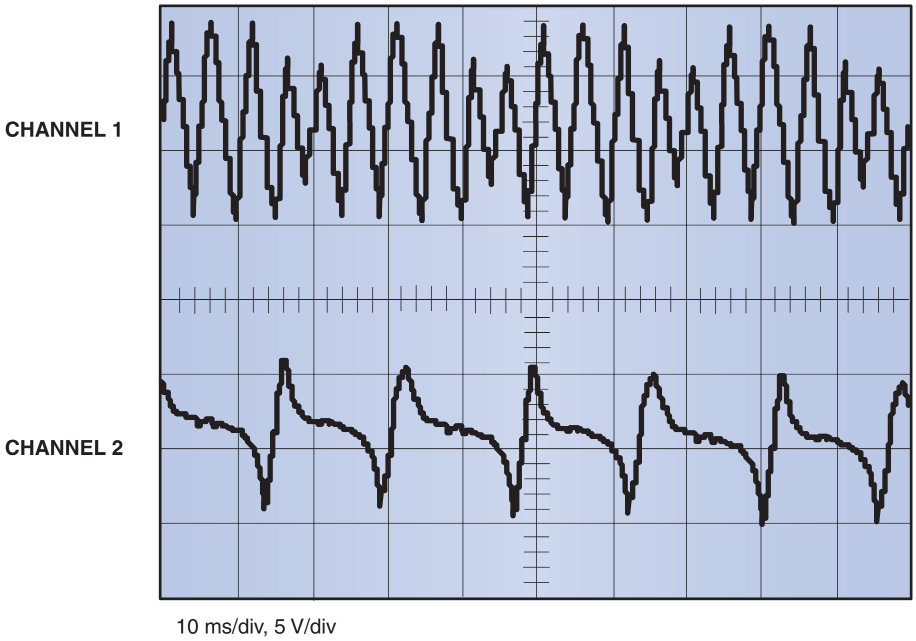


FIGURE 40–8 A two-channel scope being used to compare two signals on the same vehicle.

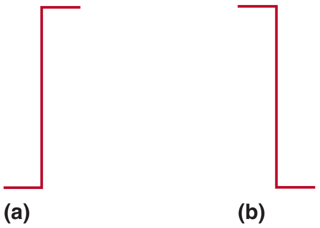


FIGURE 40–9 (a) A symbol for a positive trigger—a trigger occurs at a rising (positive) edge of the signal (waveform). (b) A symbol for a negative trigger—a trigger occurs at a falling (negative) edge of the signal (waveform).

USING A SCOPE

USING SCOPE LEADS Most scopes use leads that attach to the scope through a **BNC connector**, which is a miniature standard coaxial cable connector. BNC is an international standard that is used in the electronics industry. If using a BNC connector, be sure to connect one lead to a good clean, metal engine ground. The probe of the scope lead attaches to the circuit or component being tested. Many scopes use one ground lead and then each channel has its own signal pickup lead.

MEASURING BATTERY VOLTAGE WITH A SCOPE One of the easiest things to measure and observe on a scope is battery voltage. A lower voltage can be observed on the scope display as the engine is started, and a higher voltage should be displayed after the engine starts. ● **SEE FIGURE 40–10**.

An analog scope displays rapidly and cannot be set to show or freeze a display. Therefore, even though an analog scope shows all voltage signals, it is easy to miss a momentary glitch on an analog scope.

CAUTION: Check the instructions for the scope being used before attempting to scope household AC circuits. Some scopes, such as the Snap-On MODIS, are not designed to measure high-voltage AC circuits.

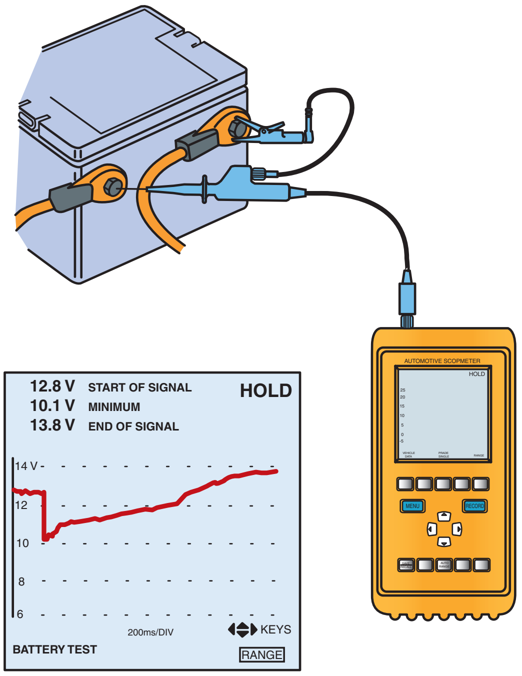


FIGURE 40–10 Constant battery voltage is represented by a flat horizontal line. In this example, the engine was started and the battery voltage dropped to about 10 V, as shown on the left side of the scope display. When the engine started, the alternator started to charge the battery and the voltage is shown as climbing.

GRAPHING MULTIMETERS AND SCAN TOOLS

GRAPHING MULTIMETER A **graphing multimeter**, abbreviated **GMM**, is a cross between a digital meter and a digital storage oscilloscope. A graphing multimeter displays the voltage levels at two places:

- On a display screen
- In a digital readout

It is usually not capable of capturing very short duration faults or glitches that are likely captured with a digital storage oscilloscope. ● **SEE FIGURE 40–11**.

GRAPHING SCAN TOOLS Many scan tools are capable of displaying the voltage levels captured by the scan tool through the data link connector (DLC) on a screen. This feature is helpful where changes in voltage levels are difficult to detect by looking at numbers that are constantly changing. Read and follow the instructions for the scan tool being used.

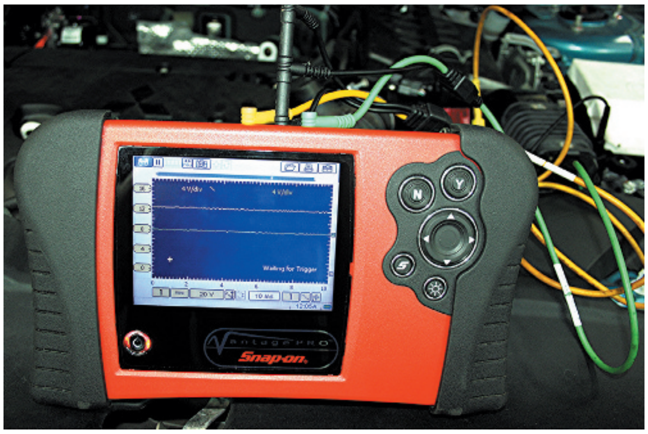


FIGURE 40–11 A typical graphing multimeter that can be used as a digital meter, plus it can show the voltage levels on the display screen.

REVIEW QUESTIONS

1. What are the differences between an analog and a digital oscilloscope?
2. What is the difference between DC coupling and AC coupling?
3. Why are DC signals that change called pulse trains?
4. What is the difference between an oscilloscope and a graphing multimeter?
5. What is the difference between a positive trigger and a negative trigger?

CHAPTER QUIZ

1. Technician A says an analog scope can store the waveform for viewing later. Technician B says that the trigger level has to be set on most scopes to be able to view a changing waveform. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. An oscilloscope display is called a _________.
   - **a.** grid
   - **b.** graticule
   - **c.** division
   - **d.** box
3. A signal showing the voltage of a battery displayed on a digital storage oscilloscope (DSO) is being discussed. Technician A says that the display shows one horizontal line above the zero line. Technician B says that the display shows a line sloping upward from zero to the battery voltage level. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Setting the time base to 50 milliseconds per division allows the technician to view a waveform how long in duration?
   - **a.** 50 ms
   - **b.** 200 ms
   - **c.** 400 ms
   - **d.** 500 ms
5. A throttle position sensor waveform is going to be observed. At what setting should the volts per division be set to see the entire waveform from 0 to 5 volts?
   - **a.** 0.5 V/div
   - **b.** 1.0 V/div
   - **c.** 2.0 V/div
   - **d.** 5.0 V/div
6. Two technicians are discussing the DC coupling setting on a DSO. Technician A says that the position allows both the DC and AC signals of the waveform to be displayed. Technician B says that this setting allows just the DC part of the waveform to be displayed. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Voltage signals (waveforms) that do not go below zero are called _________.
   - **a.** AC signals
   - **b.** pulse trains
   - **c.** pulse width
   - **d.** DC-coupled signals
8. To view more than one waveform at the same time, what type of DSO is needed?
   - **a.** Single channel
   - **b.** Two channel
   - **c.** Four channel
   - **d.** Either b or c
9. Oscilloscopes use what type of lead connector?
   - **a.** Banana plugs
   - **b.** Double banana plugs
   - **c.** Single conductor plugs
   - **d.** BNC
10. A waveform can be displayed on a _________.
    - **a.** graphing multimeter (GMM)
    - **b.** DMM
    - **c.** scan tool
    - **d.** Either a or c

Chapter

41

AUTOMOTIVE WIRING AND WIRE REPAIR

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain automotive wiring and wire gauge systems.
- Explain the purpose of ground wires.
- Explain the purpose of battery cables.
- Explain the purpose of jumper cables.
- Describe how fuses, fusible links, circuit breakers, and PTC devices protect circuits and wiring.
- List the steps for removing a terminal from a connector.
- List the steps for performing each method of wire repair.
- Explain the types of electrical conduit.

KEY TERMS:

Adhesive-lined heat shrink tubing 473 • American wire gauge (AWG) 464 • Auto link 468 • Battery cables 466 • Braided ground straps 465 • Circuit breakers 469 • Cold solder joint 473 • CPA 471 • Crimp-and-seal connectors 473 • Fuse link 468 • Fuses 466 • Fusible link 469 • Heat shrink tubing 473 • Jumper cables 466 • Lock tang 471 • Metric wire gauge 464 • Pacific fuse element 468 • PTC circuit protectors 469 • Rosin-core solder 472 • Terminal 471

AUTOMOTIVE WIRING

DEFINITION AND TERMINOLOGY Most automotive wire is made from strands of copper covered by plastic insulation. Copper is an excellent conductor of electricity that is reasonably priced and very flexible.

AMERICAN WIRE GAUGE Wiring is sized and purchased according to gauge size as assigned by the **American wire gauge (AWG)** system. AWG numbers can be confusing because as the gauge number *increases*, the size of the conductor wire *decreases*. Therefore, a 14-gauge wire is smaller than a 10-gauge wire. The *greater* the amount of current (in amperes) that is flowing through a wire, the *larger the diameter (smaller gauge number)* that is required. ● **SEE CHART 41–1**, which compares the AWG number to the actual wire diameter in inches. The diameter refers to the diameter of the metal conductor and does not include the insulation.

The following are general applications for the most commonly used wire gauge sizes. Always check the installation instructions or the manufacturer's specifications for wire gauge size before replacing any automotive wiring.

- 20 to 22 gauge: radio speaker wires
- 18 gauge: small bulbs and short leads
- 16 gauge: taillights, gas gauge, turn signals, windshield wipers
- 14 gauge: horn, radio power lead, headlights, accessory power socket, brake lights
- 12 gauge: headlight switch to fuse box, rear window defogger, power windows and locks
- 10 gauge: alternator to battery
- 4, 2,or 0 (1/0) gauge: battery cables

METRIC WIRE GAUGE Most manufacturers indicate on the wiring diagrams the **metric wire gauge** sizes measured in square millimeters (mm^2)of cross-sectional area. ● **CHART 41–2** gives conversions or comparisons between metric gauge and AWG sizes. Notice that the metric wire size increases with size (area), whereas the AWG size gets smaller with larger size wire.

WIRE SIZE VS WIRE LENGTH The AWG number should be decreased (wire size increased) with increased lengths of wire. ● **SEE CHART 41–3**. For example, a trailer may require 14-gauge wire to light all the trailer lights, but if the wire required is over 25-feet long, 12-gauge wire should be used.

WIRE GAUGE DIAMETER TABLE	
AMERICAN WIRE GAUGE (AWG)	**WIRE DIAMETER IN INCHES**
20	0.03196118
18	0.040303
16	0.0508214
14	0.064084
12	0.08080810
10	0.10189
8	0.128496
6	0.16202
5	0.18194
4	0.20431
3	0.22942
2	0.25763
1	0.2893
0	0.32486
00	0.3648

CHART 41–1

American wire gauge (AWG) number and the actual conductor diameter in inches.

METRIC SIZE (MM^2)	AWG SIZE
0.5	20
0.8	18
1.0	16
2.0	14
3.0	12
5.0	10
8.0	8
13.0	6
19.0	4
32.0	2
52.0	0

CHART 41–2

Metric wire size in square millimeters (mm^2) conversion chart to American wire gauge (AWG).

GROUND WIRES

PURPOSE AND FUNCTION All vehicles use ground wires between the engine and body and/or between the body and the negative terminal of the battery. The two types of ground wires are the following:

- Insulated copper wire
- Braided ground straps

Braided ground straps are uninsulated. It is not necessary to insulate a ground strap because it does not matter if it touches metal, as it already attaches to ground. Braided ground straps

12 V	RECOMMENDED WIRE GAUGE (AWG) (FOR LENGTH IN FEET)*						
AMPS	**3′**	**5′**	**7′**	**10′**	**15′**	**20′**	**25′**
5	18	18	18	18	18	18	18
7	18	18	18	18	18	18	16
10	18	18	18	18	16	16	16
12	18	18	18	18	16	16	14
15	18	18	18	18	14	14	12
18	18	18	16	16	14	14	12
20	18	18	16	16	14	12	10
22	18	18	16	16	12	12	10
24	18	18	16	16	12	12	10
30	18	16	16	14	10	10	10
40	18	16	14	12	10	10	8
50	16	14	12	12	10	10	8
100	12	12	10	10	6	6	4
150	10	10	8	8	4	4	2
200	10	8	8	6	4	4	2

* When mechanical strength is a factor, use the next larger wire gauge.

CHART 41–3

Recommended AWG wire size increases as the length increases because all wires have internal resistance. The longer the wire is, the greater the resistance. The larger the diameter is, the lower the resistance.

FREQUENTLY ASKED QUESTION

Why Is There a Ground Strap on My Exhaust System?

The ground strap is only there to dissipate static electricity. Static electricity is created when the flow of the exhaust gases travels through the system. Using a ground strap connected to the exhaust system helps prevent the static charge from building up, which could cause a spark to jump to the body or frame of the vehicle.

The exhaust is insulated electrically from the rest of the vehicle by rubber hangers and gaskets at the exhaust manifold, causing the entire exhaust system to be electrically isolated from chassis ground.

If a vehicle is equipped with a ground strap, be sure that it is connected at both ends to help ensure long exhaust system life. If static electricity is allowed to discharge from the exhaust system to the body or frame of the vehicle, the resulting arcing points can cause rust or corrosion, shortening the life of the exhaust system.

If a new exhaust system is installed, be sure to reattach the ground strap. Most vehicles also use a ground strap connected to the fuel filler tube for the same reason.

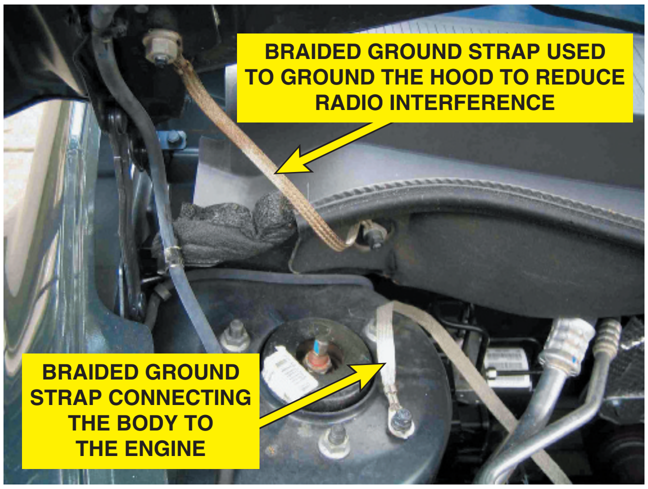

BRAIDED GROUND STRAP USED TO GROUND THE HOOD TO REDUCE RADIO INTERFERENCE
BRAIDED GROUND STRAP CONNECTING THE BODY TO THE ENGINE

FIGURE 41–1 All lights and accessories ground to the body of the vehicle. Body ground wires, such as this one, are needed to conduct all of the current from these components back to the negative terminal of the battery. The body ground wire connects the body to the engine. Most battery negative cables attach to the engine.

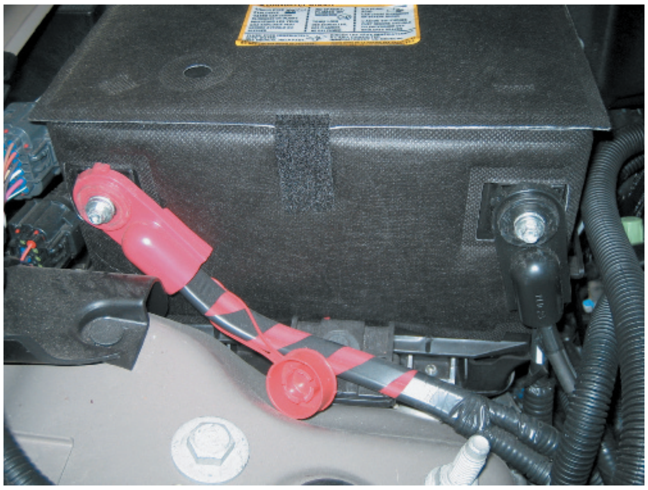


FIGURE 41–2 Battery cables are designed to carry heavy starter current and are, therefore, usually 4 gauge or larger wire. Note that this battery has a thermal blanket covering to help protect the battery from high underhood temperatures. The wiring is also covered with a plastic conduit called split-loom tubing.

are more flexible than stranded wire. Because the engine moves slightly on its mounts, the braided ground strap must be able to flex without breaking. ● **SEE FIGURE 41–1**.

SKIN EFFECT The braided strap also dampens out some radio-frequency interference that otherwise might be transmitted through standard stranded wiring, due to the skin effect.

The *skin effect* is the term used to describe how high-frequency AC electricity flows through a conductor. Direct current flows through a conductor, but alternating current tends to travel through the outside (skin) of the conductor. Because of the skin effect, most audio (speaker) cable is constructed of many small-diameter copper wires, instead of fewer larger strands, because the smaller wire has a greater surface area and results in less resistance to the flow of AC voltage.

NOTE: Body ground wires are necessary to provide a circuit path for the lights and accessories that ground to the body and flow to the negative battery terminal.

BATTERY CABLES

DEFINITION **Battery cables** are the largest wires used in the automotive electrical system. The cables are usually 4-gauge, 2-gauge, or 1-gauge wires (19 mm^2 or larger). ● **SEE FIGURE 41–2**.

Wires larger than 1 gauge are called 0 gauge (pronounced "ought"). Larger cables are labeled 2/0 or 00 (2 ought) and 3/0 or 000 (3 ought). Electrical systems that are 6 volts require battery cables two sizes larger than those used for 12 volt electrical systems because the lower voltage used in antique vehicles resulted in twice the amount of current (amperes) to supply the same electrical power.

JUMPER CABLES

DEFINITION **Jumper cables** are 4- to 2/0-gauge electrical cables with large clamps attached and are used to connect the discharged battery of one vehicle to the good battery of another vehicle. Good-quality jumper cables are necessary to prevent excessive voltage drops caused by cable resistance. Aluminum wire jumper cables should not be used because, even though aluminum is a good electrical conductor (although not as good as copper), it is less flexible and can crack and break when bent or moved repeatedly. The size should be 6 gauge or larger.

1/0 AWG welding cable can be used to construct an excellent set of jumper cables using welding clamps on both ends. Welding cable is usually constructed of many very fine strands of wire, which allow for easier bending of the cable as the strands of fine wire slide against each other inside the cable.

NOTE: Always check the wire gauge of any battery cables or jumper cables and do not rely on the outside diameter of the wire. Many lower-cost jumper cables use smaller gauge wire, but may use thick insulation to make the cable look as if it is the correct size wire.

FUSES AND CIRCUIT PROTECTION DEVICES

CONSTRUCTION **Fuses** should be used in every circuit to protect the wiring from overheating and damage caused by excessive current flow as a result of a short circuit or other malfunction. The symbol for a fuse is a wavy line between two points: –∿–

A fuse is constructed of a fine tin conductor inside a glass, plastic, or ceramic housing. The tin is designed to melt and open the circuit if excessive current flows through the fuse. Each fuse is rated according to its maximum current-carrying capacity.

Many fuses are used to protect more than one circuit of the automobile. ● **SEE FIGURE 41–3**.

A typical example is the fuse for the accessory socket that also protects many other circuits, such as those for the courtesy lights, clock, and other circuits. A fault in one of these circuits can cause this fuse to melt, which prevents the operation of all other circuits that are protected by the fuse.

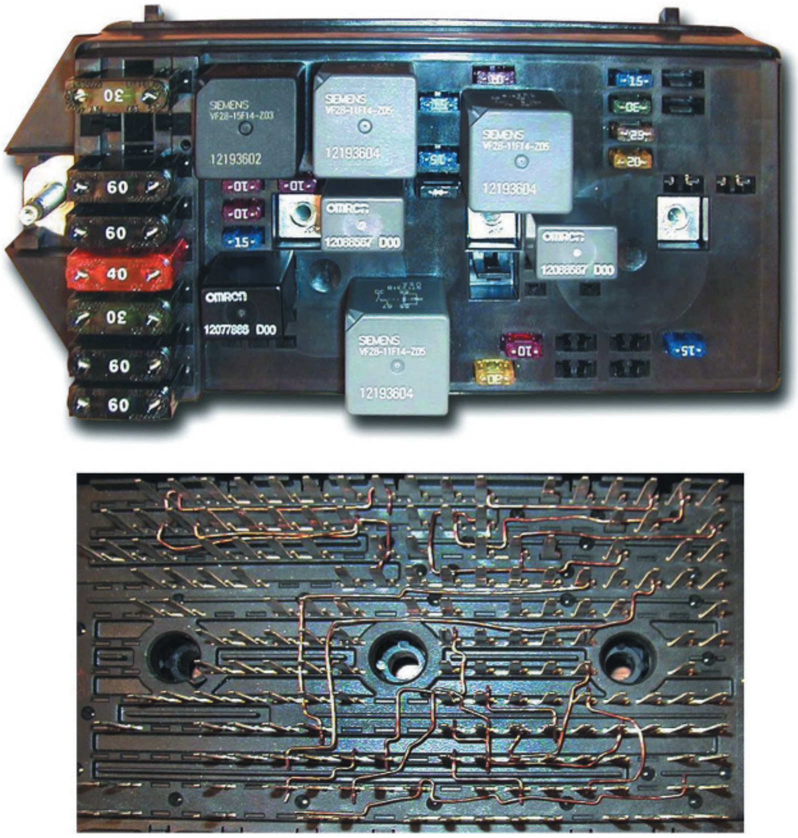


FIGURE 41–3 A typical Underhood Electrical Center (UHEC). Most are referred to as an "intelligent power distribution box" or a "smart junction box," because underneath (lower figure) are wires that join the circuits from the maxi fuses to other fuses and to or from relays. Because of these interconnected circuits, if there is a fault due to a collision or water intrusion, most experts suggest replacing the entire assembly rather than trying to repair the assembly. Always check service information for the exact procedures to follow when working with an underhood fuse panel.

NORMAL CURRENT IN THE CIRCUIT (AMPERES)	FUSE RATING (AMPERES)
7.5	10
16	20
24	30

CHART 41–4

The fuse rating should be 20% higher than the maximum current in the circuit to provide the best protection for the wiring and the component being protected.

FUSE RATINGS

Fuses are used to protect the wiring and components in the circuit from damage if an excessive amount of current flows. The fuse rating is normally about 20% higher than the normal current in the circuit. ● **SEE CHART 41–4** for a typical fuse rating based on the normal current in the circuit. In other words, the normal current flow should be about 80% of the fuse rating.

BLADE FUSES

Colored blade-type fuses are also referred to as ATO fuses and have been used since 1977. The color of the plastic of blade fuses indicates the maximum current flow, measured in amperes.

● **SEE CHART 41–5** for the color and the amperage rating of blade fuses.

Each fuse has an opening in the top of its plastic portion to allow access to its metal contacts for testing purposes. ● **SEE FIGURE 41–4**.

AMPERAGE RATING	COLOR
1	Dark green
2	Gray
2.5	Purple
3	Violet
4	Pink
5	Tan
6	Gold
7.5	Brown
9	Orange
10	Red
14	Black
15	Blue
20	Yellow
25	White
30	Green

CHART 41–5

The amperage rating and the color of the blade fuse are standardized.

MINI FUSES

To save space, many vehicles use mini (small) blade fuses. Not only do they save space, but they also allow the vehicle design engineer to fuse individual circuits, instead of grouping many different components on one fuse. This improves

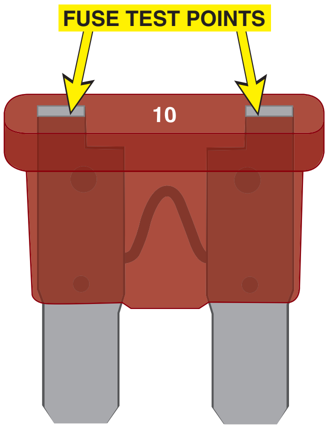


FIGURE 41–4 Blade-type fuses can be tested through openings in the plastic at the top of the fuse.

AMPERAGE RATING	COLOR
5	Tan
7.5	Brown
10	Red
15	Blue
20	Yellow
25	Natural
30	Green

CHART 41–6

Mini fuse amperage rating and colors.

AMPERAGE RATING	COLOR
20	Yellow
30	Green
40	Amber
50	Red
60	Blue
70	Brown
80	Natural

CHART 41–7

Maxi fuse amperage rating and colors.

customer satisfaction because if one component fails, it only affects that circuit, without stopping electrical power to several other circuits, as well. This makes troubleshooting much easier, too, because each circuit is separate. ● **SEE CHART 41–6** for the amperage rating and corresponding fuse color for mini fuses.

MAXI FUSES Maxi fuses are a large version of blade fuses and are used to replace fusible links in many vehicles. Maxi fuses are rated up to 80 amperes or more. ● **SEE CHART 41–7** for the amperage rating and corresponding color for maxi fuses.

● **SEE FIGURE 41–5** for a comparison of the various sizes of blade-type fuses.

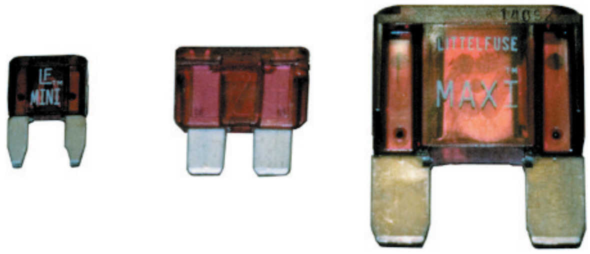


FIGURE 41–5 Three sizes of blade-type fuses: mini on the left, standard or ATO type in the center, and maxi on the right.

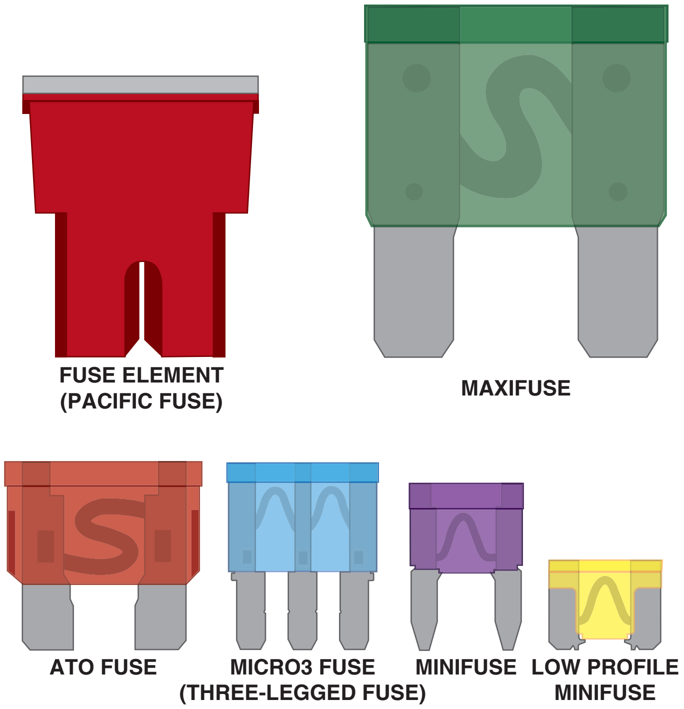


FIGURE 41–6 A comparison of the various types of protective devices used in most vehicles.

PACIFIC FUSE ELEMENT First used in the late 1980s, **Pacific fuse elements** (also called a **fuse link** or **auto link**) are used to protect wiring from a direct short-to-ground. The housing contains a short link of wire sized for the rated current load. The transparent top allows inspection of the link inside. ● **SEE FIGURE 41–6**.

TESTING FUSES It is important to test the condition of a fuse if the circuit being protected by the fuse does not operate. Most blown fuses can be detected quickly because the center conductor is melted. Fuses can also fail and open the circuit because of a poor connection in the fuse itself or in the fuse holder. Therefore, just because a fuse "looks okay" does not mean that it *is* okay. All fuses should be tested with a test light. The test light should be connected to first one side of the fuse and then the other. A test light should light on both sides. If the test light only lights on one side, the fuse is blown or open. If the test light does not light on either side of the fuse, then that circuit is not being supplied power. ● **SEE FIGURE 41–7**. An ohmmeter can be used to test fuses.

CAUTION: Only use name-brand fuses purchased from a known source. Some off-brand or no-brand fuses have been found to not blow until exposed to current levels far exceeding their rating. Fuses that do not blow at the designed rating could cause wiring to overheat and may even cause a fire.

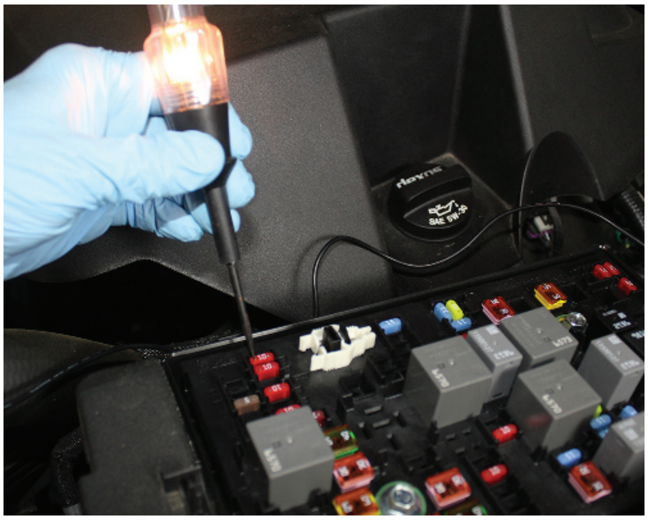


FIGURE 41–7 To test a fuse, use a test light to check for power at the power side of the fuse. The ignition switch and lights may have to be on before some fuses receive power. If the fuse is good, the test light should light on both sides (power side and load side) of the fuse.

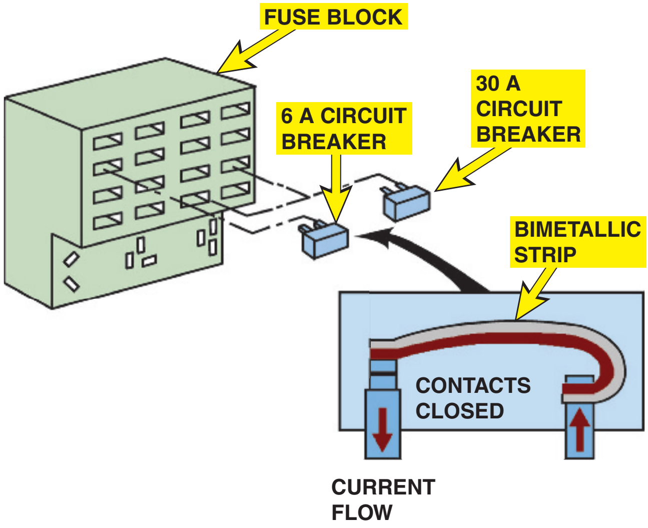


FIGURE 41–8 Typical blade circuit breaker fits into the same space as a blade fuse. If excessive current flows through the bimetallic strip, the strip bends and opens the contacts and stops current flow. When the circuit breaker cools, the contacts close again, completing the electrical circuit.

CIRCUIT BREAKERS

Circuit breakers are used to prevent harmful overload (excessive current flow) in a circuit by opening the circuit and stopping the current flow to prevent overheating, and possible fire, caused by hot wires or electrical components. **Circuit breakers** are mechanical units made of two different metals (bimetallic) that deform when heated, and open a set of contact points that work in the same manner as an “off” switch. ● **SEE FIGURE 41–8**.

Cycling-type circuit breakers, therefore, are reset when the current stops flowing, which causes the bimetallic strip to cool and the circuit to close again. A circuit breaker is used in circuits that could affect the safety of passengers if a conventional nonresetting fuse were used. The headlight circuit is an excellent example of the use of a circuit breaker, rather than a fuse. A short or grounded circuit anywhere in the headlight circuit could cause excessive current flow and, therefore, the opening of the circuit. Obviously, a sudden loss of headlights at night could have disastrous results. A circuit breaker opens and closes the circuit rapidly, thereby protecting the circuit from overheating and also providing sufficient current flow to maintain at least partial headlight operation.

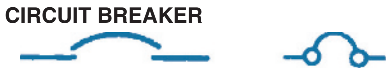


FIGURE 41–9 Electrical symbols used to represent circuit breakers.

Circuit breakers are also used in other circuits where conventional fuses could not provide for the surges of high current commonly found in those circuits. ● **SEE FIGURE 41–9** for the electrical symbols used to represent a circuit breaker.

Examples are the circuits for the following accessories:

1. Power seats
2. Power door locks
3. Power windows

PTC CIRCUIT PROTECTORS

Positive temperature coefficient (PTC) circuit protectors are solid state (without moving parts). Like all other circuit-protection devices, PTCs are installed in series in the circuit being protected. If excessive current flows, the temperature and resistance of the PTC increase.

This increased resistance reduces current flow (amperes) in the circuit and may cause the electrical component in the circuit not to function correctly. For example, when a PTC circuit protector is used in a power window circuit, the increased resistance causes the operation of the power window to be much slower than normal.

Unlike circuit breakers or fuses, PTC circuit-protection devices do *not* open the circuit, but rather provide a very high resistance between the protector and the component. ● **SEE FIGURE 41–10**.

In other words, voltage is available to the component. This fact has led to a lot of misunderstanding about how these circuit-protection devices actually work. It is even more confusing when the circuit is opened and the PTC circuit protector cools down. When the circuit is turned back on, the component may operate normally for a short time; however, the PTC circuit protector again get hot because of too much current flow. The resistance again increases to limit current flow.

The protective devices are often located in a power distribution center. ● **SEE FIGURE 41–11**.

FUSIBLE LINKS

A **fusible link** is a type of fuse that consists of a short length (6 to 9 inches long) of standard copper-strand wire covered with a special nonflammable insulation. This wire is usually four wire numbers smaller than the wire of the circuits it protects. For example, a 12-gauge circuit is protected by a 16-gauge fusible link. The special thick insulation over the wire may make it look larger than other wires of the same gauge number. ● **SEE FIGURE 41–12**.

If excessive current flow (caused by a short-to-ground or a defective component) occurs, the fusible link melts in half and opens the circuit to prevent a fire hazard. Some fusible links are identified with “fusible link” tags at the junction between the fusible link and the standard chassis wiring, which represent only the junction. Fusible links are the backup system for circuit protection. All current, except the current used by the starter motor, flows through fusible links and then through individual circuit

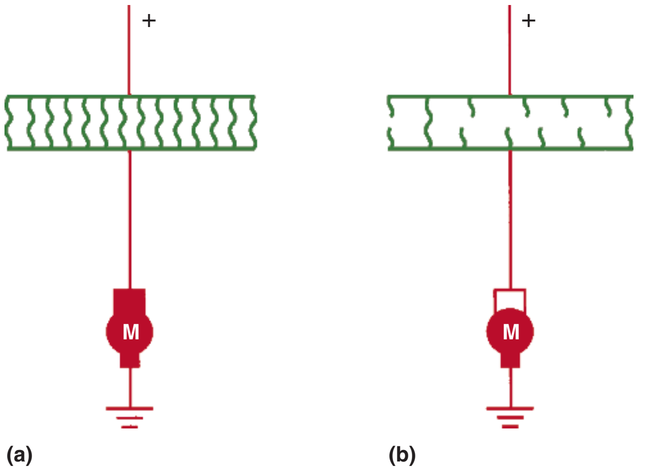


FIGURE 41–10 (a) The normal operation of a PTC circuit protector, such as in a power window motor circuit showing the many conducting paths. With normal current flow, the temperature of the PTC circuit protector remains normal. (b) When current exceeds the amperage rating of the PTC circuit protector, the polymer material that makes up the electronic circuit protector increases in resistance. As shown, a high-resistance electrical path still exists, even though the motor stops operating, as a result of the very low current flow through the very high resistance. The circuit protector does not reset or cool down until voltage is removed from the circuit.

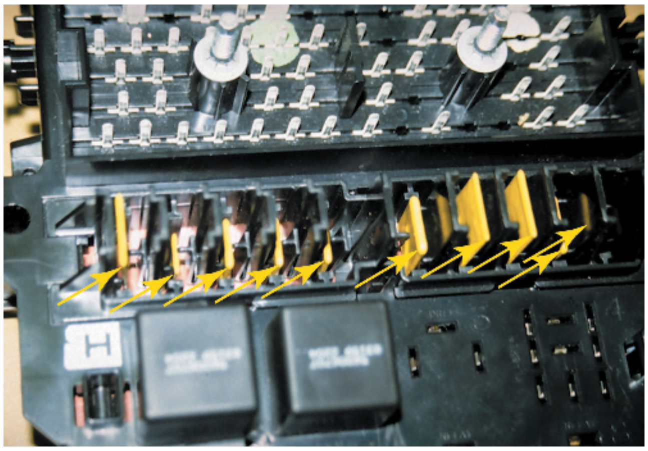


FIGURE 41–11 PTC circuit protectors are used extensively in the power distribution center of this Chrysler vehicle.

fuses. It is possible that a fusible link melts and does not blow a fuse. Fusible links are installed as close to the battery as possible so that they can protect the wiring and circuits coming directly from the battery.

MEGA FUSES Many newer vehicles are equipped with mega fuses instead of fusible links to protect high-amperage circuits. Circuits often controlled by mega fuses include

- Charging circuit
- HID headlights
- Heated front or rear glass
- Multiple circuits usually protected by mega fuses
- Mega fuse rating for vehicles, including 80, 100, 125, 150, 175, 225, 250, and 300 amperes

● **SEE FIGURE 41–13.**

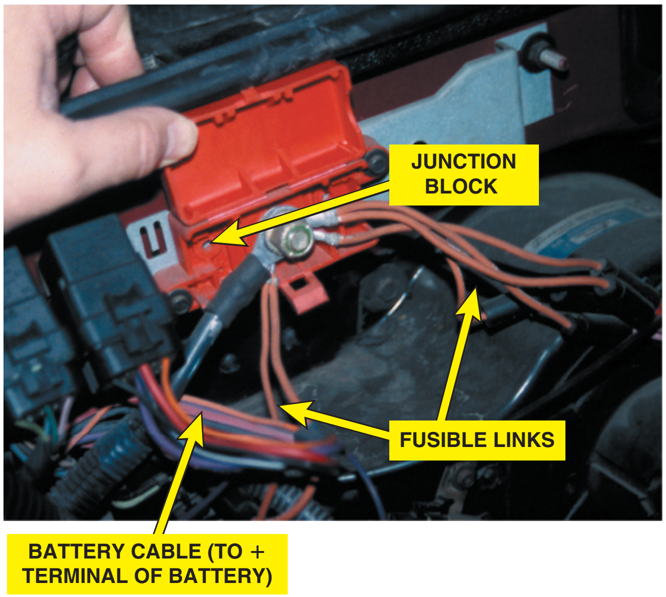


FIGURE 41–12 Fusible links are usually located close to the battery and are attached to a junction block.

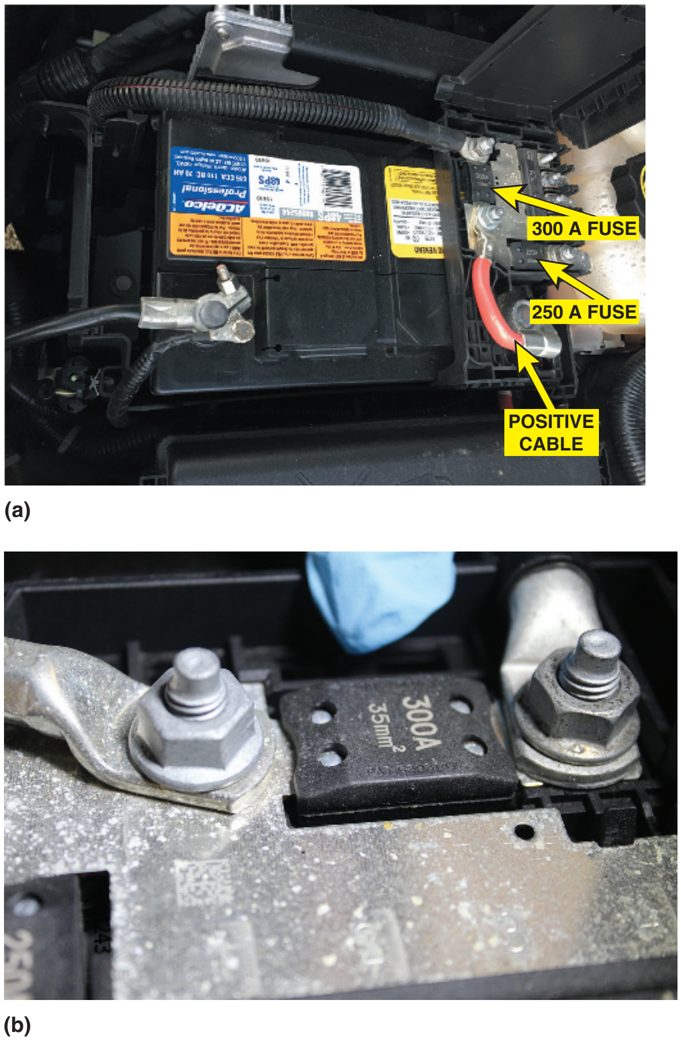


FIGURE 41–13 (a) Several maxi fuses are used on this Chevrolet to protect all the circuits, including the 300 ampere fuse that is connected directly to the positive battery cable. (b) A close-up of the 300 ampere maxi fuse showing the marking that it is a 35 square millimeter (35 mm^2) conductor being used to protect most of the electrical circuits at the battery.

TECH TIP

Find the Root Cause

If a mega fuse or fusible link fails, find the root cause before replacing it. A mega fuse can fail due to vibration or physical damage as a result of a collision or corrosion. Check to see if the fuse itself is loose and can be moved by hand. If loose, simply replace the mega fuse. If a fusible link or mega fuse has failed due to excessive current, check for evidence of a collision or any other reason that could cause an excessive amount of current to flow. This inspection should include each electrical component being supplied current from the fusible link. After being sure that the root cause has been found and corrected, replace the fusible link or mega fuse.

TECH TIP

Look for the "Green Crud"

Corroded connections are a major cause of intermittent electrical problems and open circuits. The usual sequence of conditions is as follows:

1. **Heat causes expansion.** This heat can be from external sources, such as connectors being too close to the exhaust system. Another possible source of heat is a poor connection at the terminal, causing a voltage drop and heat due to the electrical resistance.
2. **Condensation occurs when a connector cools.** The moisture from condensation causes rust and corrosion.
3. **Water gets into the connector.** If corroded connectors are noticed, the terminal should be cleaned and the condition of the electrical connection to the wire terminal end(s) confirmed. Many vehicle manufacturers recommend using a dielectric silicone or lithium-based grease inside connectors to prevent moisture from getting into and attacking the connector.

CHECKING FUSIBLE LINKS AND MEGA FUSES Fusible links and mega fuses are usually located near where electrical power is sent to other fuses or circuits, such as

- Starter solenoid battery terminals
- Power distribution centers
- Output terminals of alternators
- Positive terminals of the battery

Fusible links can melt and not show any external evidence of damage. To check a fusible link, gently pull on each end to see if it stretches. If the insulation stretches, then the wire inside has melted and the fusible link must be replaced after determining what caused the link to fail.

Another way to check a fusible link is to use a test light or a voltmeter and check for available voltage at both ends of the fusible link. If voltage is available at only one end, then the link is electrically open and should be replaced.

REPLACING A FUSIBLE LINK If a fusible link is found to be melted, perform the following step:

STEP 1 Determine why the fusible link failed and repair the fault.

STEP 2 Check service information for the exact length, gauge, and type of fusible link required.

STEP 3 Replace the fusible link with the specified fusible link wire and according to the instructions found in the service information.

CAUTION: Always use the *exact* length of fusible link wire required because, if it is too short, it does not have enough resistance to generate the heat needed to melt the wire and protect the circuits or components. If the wire is too long, it could melt during normal operation of the circuits it is protecting. Fusible link wires are usually longer than 6 inches and shorter than 9 inches.

TERMINALS AND CONNECTORS

DEFINITIONS A **terminal** is a metal fastener attached to the end of a wire, which makes the electrical connection. The term *connector* usually refers to the plastic portion that snaps or connects together, making the mechanical connection. Wire terminal ends usually snap into, and are held by, a connector. Male and female connectors can then be snapped together, completing an electrical connection. Connectors exposed to the environment are also equipped with a weather-tight seal. ● **SEE FIGURE 41–14**.

Terminals are retained in connectors by the use of a **lock tang**. Removing a terminal from a connector includes the following steps:

STEP 1 Release the **connector position assurance (CPA)**, if equipped, that keeps the latch of the connector from releasing accidentally.

STEP 2 Separate the male and female connector by opening the lock. ● **SEE FIGURE 41–15**.

STEP 3 Release the secondary lock, if equipped. ● **SEE FIGURE 41–16**.

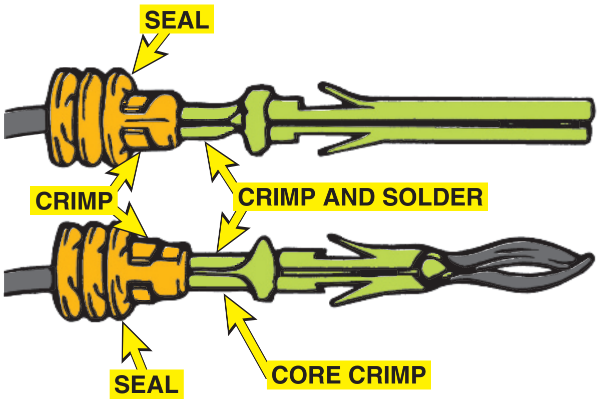


FIGURE 41–14 Some terminals have seals attached to help seal the electrical connections.

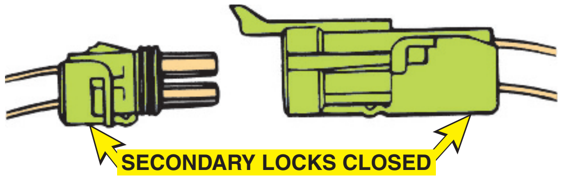


FIGURE 41–15 Separate a connector by opening the lock and pulling the two apart.

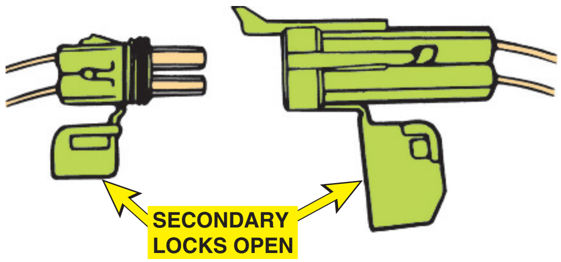


FIGURE 41–16 The secondary locks help retain the terminals in the connector.

STEP 4 Using a pick, look for the slot in the plastic connector where the lock tang is located, depress the lock tang, and gently remove the terminal from the connector. ● **SEE FIGURE 41–17**.

WIRE REPAIR

SOLDER Many manufacturers recommend that all wiring repairs be soldered. Solder is an alloy of tin and lead used to make a good electrical contact between two wires or connections in an electrical circuit. However, a flux must be used to help clean the area and to help make the solder flow. Therefore, solder is made with a resin (rosin) contained in the center, called **rosin-core solder**.

CAUTION: Never use acid-core solder to repair electrical wiring as the acid causes corrosion.

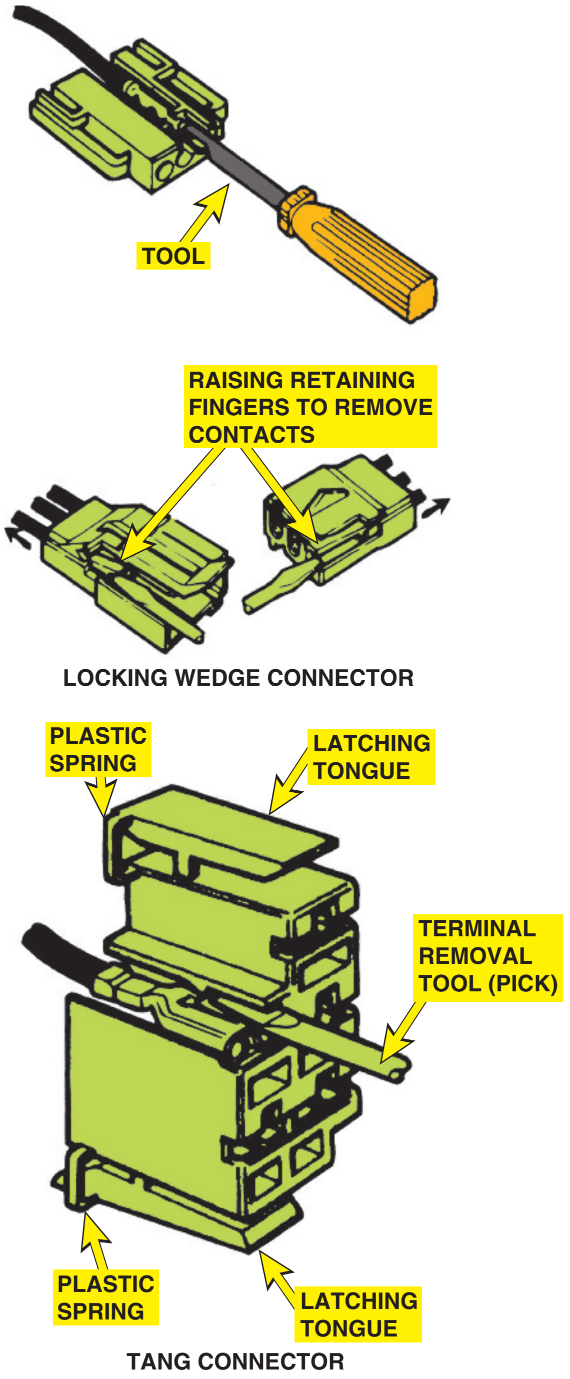
● **SEE FIGURE 41–18**.

An acid-core solder is also available, but should only be used for soldering sheet metal. Solder is available with various percentages of tin and lead in the alloy. Ratios are used to identify these various types of solder, with the first number denoting the percentage of tin in the alloy and the second number giving the percentage of lead. The most commonly used solder is 50/50, which means that 50% of the solder is tin and the other 50% is lead. The percentages of each alloy primarily determine the melting point of the solder.

- 60/40 solder (60% tin/40% lead) melts at 361°F (183°C).
- 50/50 solder (50% tin/50% lead) melts at 421°F (216°C).
- 40/60 solder (40% tin/60% lead) melts at 460°F (238°C).

NOTE: The melting points stated here can vary, depending on the purity of the metals used.

Because of the lower melting point, 60/40 solder is the most highly recommended solder to use, followed by 50/50.


TOOL
RAISING RETAINING FINGERS TO REMOVE CONTACTS
PLASTIC SPRING
LATCHING TONGUE
TERMINAL REMOVAL TOOL (PICK)
PLASTIC SPRING
LATCHING TONGUE

LOCKING WEDGE CONNECTOR

TANG CONNECTOR

FIGURE 41–17 Use a small removal tool, sometimes called a pick, to release terminals from the connector.

SOLDERING GUNS When soldering wires, be sure to heat the wires (not the solder) using

- An electric soldering gun or soldering pencil (60 to 150 watt rating)
- Butane-powered tool that uses a flame to heat the tip (about 60 watt rating) ● **SEE FIGURE 41–19**.

SOLDERING PROCEDURE Soldering a wiring splice includes the following steps:

STEP 1 While touching the soldering gun to the splice, apply solder to the junction of the gun and the wire.

STEP 2 The solder starts to flow. Do not move the soldering gun.

Radio Shack®
Cat. No. 64-009
.032
8 OZ.
60/40
LIGHT DUTY
Rosin Core Solder

FIGURE 41–18 Always use rosin-core solder for electrical or electronic soldering. Also, use small-diameter solder for small soldering irons. Use large-diameter solder only for large-diameter (large-gauge) wire and higher-wattage soldering irons (guns).

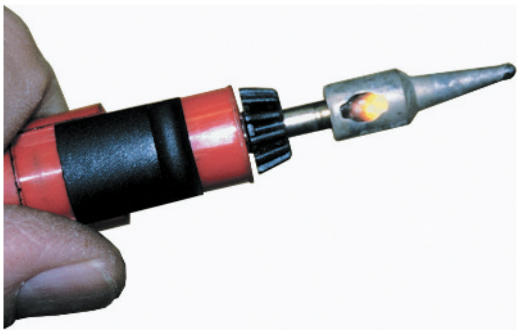


FIGURE 41–19 A butane-powered soldering tool. The cap has a built-in striker to light a converter in the tip of the tool. This handy soldering tool produces the equivalent of 60 watts of heat. It operates for about 1/2 hour on one charge from a commonly available butane refill dispenser.

STEP 3 Just keep feeding more solder into the splice as it flows into and around the strands of the wire.

STEP 4 After the solder has flowed throughout the splice, remove the soldering gun and the solder from the splice and allow the solder to cool slowly.

The solder should have a shiny appearance. Dull-looking solder may be caused by not reaching a high enough temperature, which results in a **cold solder joint**. Reheating the splice and allowing it to cool often restores the shiny appearance.

CRIMPING TERMINALS

Terminals can be crimped to create a good electrical connection if the proper type of crimping tool is used. Most vehicle manufacturers recommend that a W-shaped crimp be used to force the strands of the wire into a tight space. ● **SEE FIGURE 41–20**.

Most vehicle manufacturers also specify that all hand-crimped terminals or splices be soldered. ● **SEE FIGURE 41–21**.

HEAT SHRINK TUBING

Heat shrink tubing is usually made from polyvinyl chloride (PVC) or polyolefin and shrinks to about half of its original diameter when heated; this is usually called a 2:1 shrink ratio. Heat shrink by itself does not provide protection against corrosion because the ends of the tubing are not sealed against moisture. Chrysler Corporation recommends that all wire repairs that may be exposed to the elements be repaired and sealed, using **adhesive-lined heat shrink tubing**. The tubing is usually made from flame-retardant flexible polyolefin with an internal layer of special thermoplastic adhesive. When heated, this tubing shrinks to one-third of its original diameter (3:1 shrink ratio) and the adhesive melts and seals the ends of the tubing. ● **SEE FIGURE 41–22**.

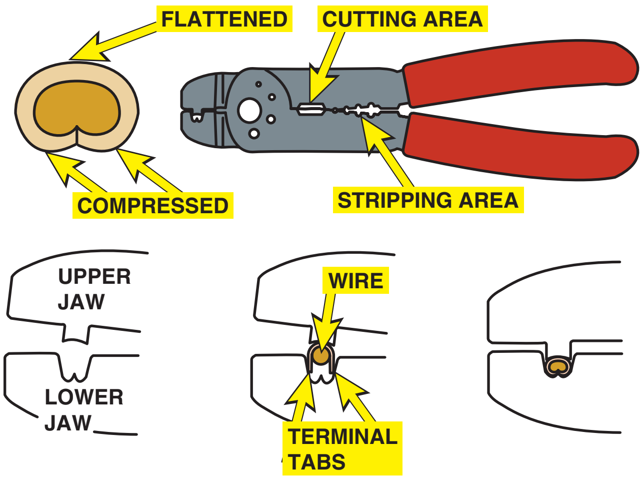


FIGURE 41–20 Notice that to create a good crimp the open part of the terminal is placed in the jaws of the crimping tool toward the anvil or the W-shape part.

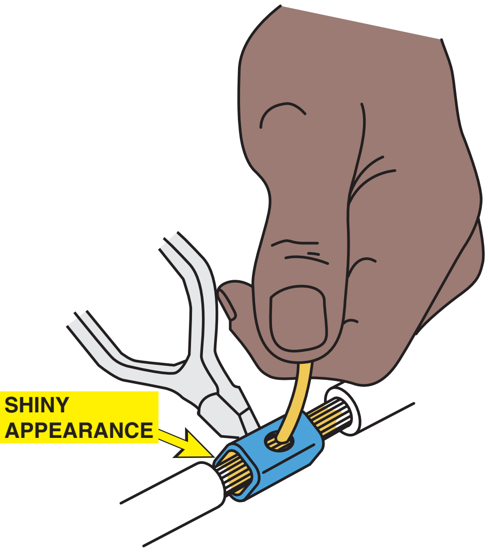


FIGURE 41–21 All hand-crimped splices or terminals should be soldered to be assured of a good electrical connection.

CRIMP-AND-SEAL CONNECTORS

General Motors Corporation recommends the use of crimp-and-seal connectors as the method for wire repair. **Crimp-and-seal connectors** contain a sealant and shrink tubing in one piece and are *not* simply butt connectors. ● **SEE FIGURE 41–23**.

The usual procedure specified for making a wire repair using a crimp-and-seal connector is as follows:

STEP 1 Strip the insulation from the ends of the wire (about 5/16 inch or 8 mm).

STEP 2 Select the proper size of crimp-and-seal connector for the gauge of wire being repaired. Insert the wires into the splice sleeve and crimp.

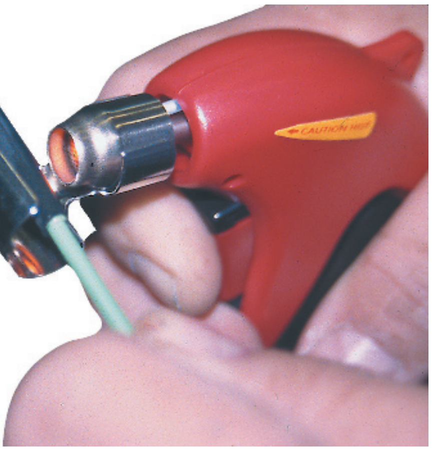


FIGURE 41–22 A butane torch especially designed for use on heat shrink applies heat without an open flame, which could cause damage.

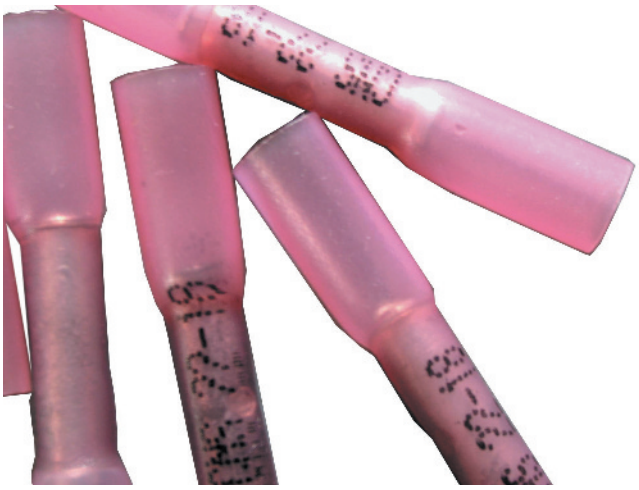


FIGURE 41–23 A typical crimp-and-seal connector. This type of connector is first lightly crimped to retain the ends of the wires and then it is heated. The tubing shrinks around the wire splice, and thermoplastic glue melts on the inside to provide an effective weather-resistant seal.

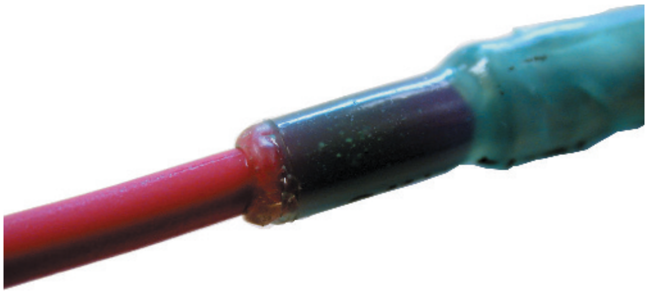


FIGURE 41–24 Heating the crimp-and-seal connector melts the glue and forms an effective seal against moisture.

NOTE: Use only the specified crimping tool to help prevent the pliers from creating a hole in the cover.

STEP 3 Apply heat to the connector until the sleeve shrinks down around the wire and a small amount of sealant is observed around the ends of the sleeve, as shown in ● **FIGURE 41–24**.

FREQUENTLY ASKED QUESTION

What Method of Wire Repair Should I Use?

Good question. Vehicle manufacturers recommend all wire repairs performed under the hood, or where the repair could be exposed to the elements, be weatherproof. The most commonly recommended methods include the following:

- **Crimp-and-seal connector.** These connectors are special and are not like low-cost insulated-type crimp connectors. This type of connector is recommended by General Motors and others and is sealed using heat after the mechanical crimp has secured the wire ends together.
- **Solder and adhesive-lined heat shrink tubing.** This method is recommended by Chrysler and it uses the special heat shrink that has glue inside that melts when heated to form a sealed connection. Regular heat shrink tubing can be used inside a vehicle, but should not be used where it can be exposed to the elements.
- **Solder and electrical tape.** This is acceptable to use inside the vehicle where the splice is not exposed to the outside elements. It is best to use a crimp and seal, even on the inside of the vehicle, for best results.

FREQUENTLY ASKED QUESTION

What Is in Lead-Free Solder?

Lead is an environmental and health concern and all vehicle manufacturers are switching to lead-free solder. Lead-free solder does not contain lead, but usually a very high percentage of tin. Several formulations of lead-free solder include the following:

- 95% tin; 5% antimony (melting temperature 450°F (245°C))
- 97% tin; 3% copper (melting temperature 441°F (227°C))
- 96% tin; 4% silver (melting temperature 443°F (228°C))

ELECTRICAL CONDUIT

DEFINITION Electrical conduit covers and protects wiring. The color used on electrical convoluted conduit tells the technician a lot if some information is known, such as the following:

- **Black conduit with a green or blue stripe.** This conduit is designed for high temperatures and is used under the hood and near hot engine parts. Do not replace high-temperature conduit with low-temperature conduit that does not have a stripe when performing wire repairs. ● **SEE FIGURE 41–25**.
- **Blue or yellow conduit.** This color conduit is used to cover wires that have voltages ranging from 12 to 42 volts.

Circuits that use this high voltage usually are for the electric power steering. While 42 volts does not represent a shock hazard, an arc is maintained if a line circuit is disconnected. Use caution around these circuits. ● **SEE FIGURE 41–26**.

- **Orange conduit.** This color conduit is used to cover wiring that carries high-voltage current above 60 volts. These circuits are found in hybrid-electric vehicles (HEVs). An electric shock from these wires can be fatal, so extreme caution has to be taken when working on or near the components that have orange conduit. Follow the vehicle manufacturer's instruction for de-powering the high-voltage circuits before work begins on any of the high-voltage components. ● **SEE FIGURE 41–27**.

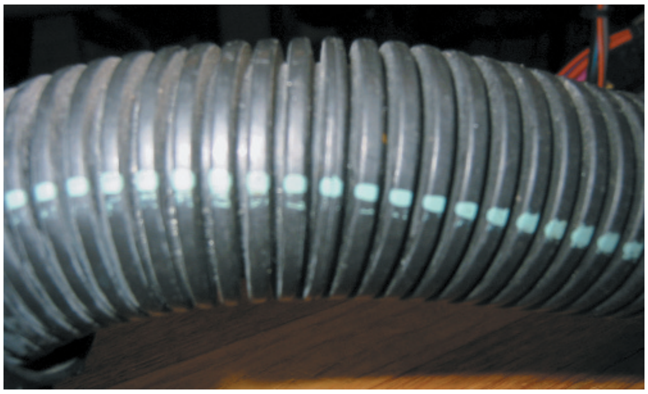


FIGURE 41–25 Conduit that has a paint stripe is constructed of plastic that can withstand high underhood temperatures.

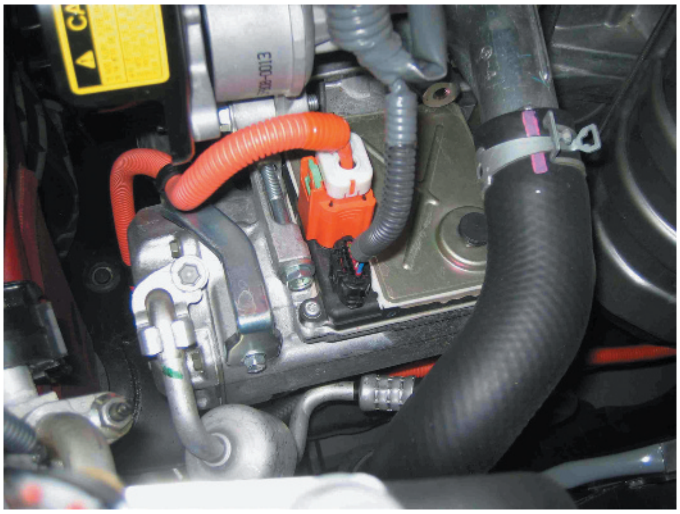
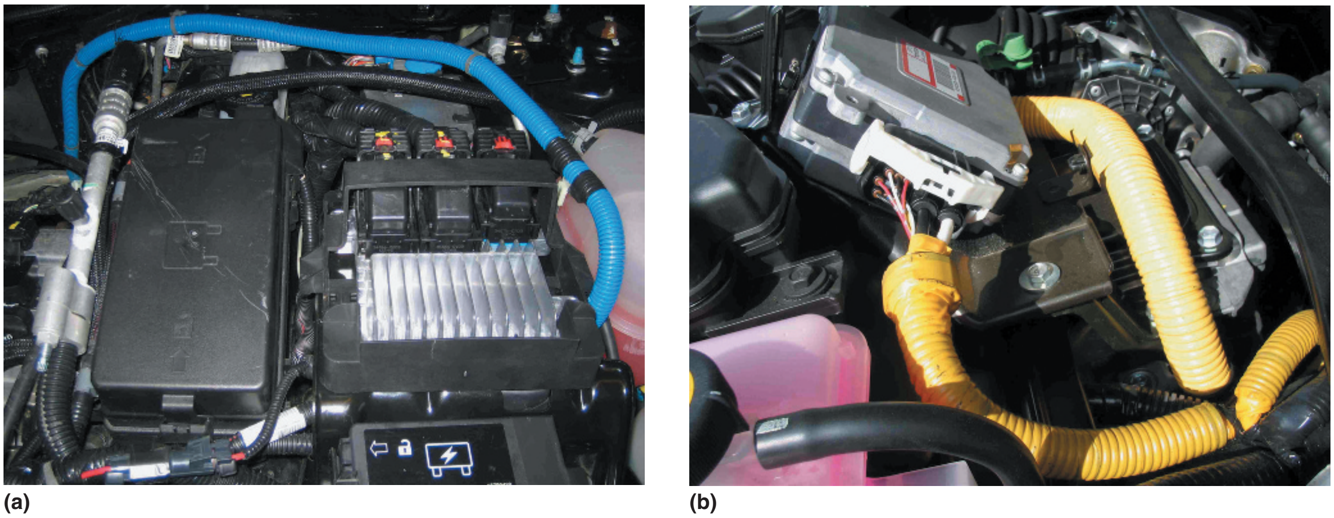


FIGURE 41–27 Always follow the vehicle manufacturer's instructions, which include the use of linesman's (high-voltage) gloves, if working on circuits that are covered in orange conduit.



(a)

(b)

FIGURE 41–26 (a) Blue conduit is used to cover circuits that carry up to 42 volts. (b) Yellow conduit can also be used to cover 42 volt wiring.

REVIEW QUESTIONS

1. What is the difference between the American wire gauge (AWG) system and the metric system?
2. What is the difference between a wire and a cable?
3. What is the difference between a terminal and a connector?
4. How do fuses, PTC circuit protectors, circuit breakers, and fusible links protect a circuit?
5. How should a wire repair be done if the repair is under the hood where it is exposed to the outside?

CHAPTER QUIZ

1. The higher the AWG number, ____________.
   - **a.** the smaller the wire diameter
   - **b.** the larger the wire diameter
   - **c.** the thicker the insulation
   - **d.** the more strands in the conductor core
2. Battery cables and jumper cables are ____________.
   - **a.** higher AWG number than standard wiring
   - **b.** larger diameter wire compared to regular wires used for electrical accessories
   - **c.** lower AWG number than standard wiring
   - **d.** Both b and c
3. Which statement is true about fuse ratings?
   - **a.** The fuse rating should be less than the maximum current for the circuit.
   - **b.** The fuse rating should be higher than the normal current for the circuit.
   - **c.** Of the fuse rating, 80% should equal the current in the circuit.
   - **d.** Both b and c
4. Which statement(s) is/are true about wire, terminals, and connectors?
   - **a.** Wire is called a lead, and the metal end is a connector.
   - **b.** A connector is usually a plastic piece where terminals lock in.
   - **c.** A lead and a terminal are the same thing.
   - **d.** Both a and c
5. The type of solder that should be used for electrical work is ____________.
   - **a.** rosin core
   - **b.** acid core
   - **c.** 60/40 with no flux
   - **d.** 50/50 with acid paste flux
6. A technician is performing a wire repair on a circuit under the hood of the vehicle. Technician A says to use solder and adhesive-lined heat shrink tubing or a crimp-and-seal connector. Technician B says to solder and use electrical tape. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Two technicians are discussing fuse testing. Technician A says that a test light should light on both test points of the fuse if it is okay. Technician B says the fuse is defective if a test light only lights on one side of the fuse. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Many ground straps are uninsulated and braided because ____________.
   - **a.** they are more flexible to allow movement of the engine without breaking the wire
   - **b.** they are less expensive than conventional wire
   - **c.** they help dampen radio-frequency interference (RFI)
   - **d.** Both a and c
9. What causes a fuse to blow?
   - **a.** A decrease in circuit resistance
   - **b.** An increase in the current flow through the circuit
   - **c.** A sudden decrease in current flow through the circuit
   - **d.** Both a and b
10. A vehicle has some wiring covered with orange conduit. This indicates a ____________ circuit.
    - **a.** 42-volt
    - **b.** 12 to 16-volt
    - **c.** variable voltage
    - **d.** high-voltage

Chapter 42

WIRING SCHEMATICS AND CIRCUIT TESTING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe what information wiring schematics include.
- Interpret wiring schematics.
- Explain the procedure to identify relay terminals.
- Explain how to locate an open circuit.
- Describe how to check for common power or ground.
- Discuss circuit troubleshooting.
- Explain the different methods to locate a short circuit.
- Explain the procedure to troubleshoot an electrical problem.

KEY TERMS:

Coil 484 • DPDT 482 • DPST 482 • Gauss gauge 489 • Momentary switch 482 • N.C. 482 • N.O. 482 • Poles 482 • Relay 482 • Short circuit 488 • SPDT 482 • SPST 482 • Terminal 478 • Throws 482 • Tone generator tester 489 • Wiring schematic 477

WIRING SCHEMATICS AND SYMBOLS

TERMINOLOGY The service manuals of automotive manufacturers include wiring schematics of every electrical circuit in a vehicle. A **wiring schematic**, sometimes called a *diagram*, shows electrical components and wiring using symbols and lines to represent components and wires. A typical wiring schematic may include all of the circuits combined on several large foldout sheets, or they may be broken down to show individual circuits. All circuit schematics or diagrams include the following:

- Power-side wiring of the circuit
- All splices
- Connectors
- Wire size
- Wire color
- Trace color (if any)
- Circuit number
- Electrical components
- Ground return paths
- Fuses and switches

CIRCUIT INFORMATION Many wiring schematics include numbers and letters near components and wires that may confuse readers of the schematic. Most letters used near or on a wire identify the color or colors of the wire.

- The first color or color abbreviation is the color of the wire insulation.
- The second color (if mentioned) is the color of the stripe or tracer on the base color. ● **SEE FIGURE 42–1**.

Wires with different color tracers are indicated by a slash (/) between them. For example, GRN/WHT means a green wire with a white stripe or tracer. ● **SEE CHART 42–1**.

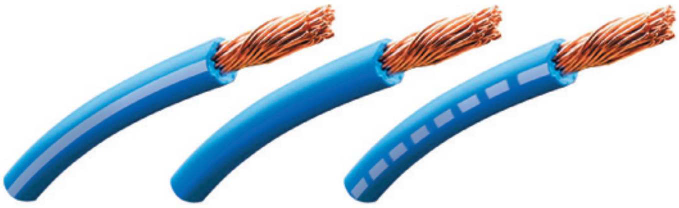


FIGURE 42–1 The center wire is a solid color wire, meaning that the wire has no other identifying tracer or stripe color. The two end wires could be labeled "BLU/WHT," indicating a blue wire with a white tracer or stripe.

ABBREVIATION	COLOR
BRN	Brown
BLK	Black
GRN	Green
WHT	White
PPL	Purple
PNK	Pink
TAN	Tan
BLU	Blue
YEL	Yellow
ORN	Orange
DK BLU	Dark blue
LT BLU	Light blue
DK GRN	Dark green
LT GRN	Light green
RED	Red
GRY	Gray
VIO	Violet

CHART 42–1

Typical abbreviations used on schematics to show wire color. Some vehicle manufacturers use two letters to represent a wire color. Check service information for the color abbreviations used.

WIRE SIZE Wire size is shown on all schematics. ● **FIGURE 42–2** illustrates a rear side-marker bulb circuit diagram where "0.8" indicates the metric wire gauge size in square millimeters (mm^2) and "PPL" indicates a solid purple wire.

The wire diagram also shows that the color of the wire changes at number C210. This stands for "connector #210" and is used for reference purposes. The symbol for the connection can vary depending on the manufacturer. The color change from purple (PPL) to purple with a white tracer (PPL/WHT) is not important except for knowing where the wire changes color in the circuit. The wire gauge has remained the same on both sides of the connection (0.8 mm^2 or 18 gauge). The ground circuit is the "0.8 BLK" wire. ● **FIGURE 42–3** shows many of the electrical and electronic symbols that are used in wiring and circuit diagrams.

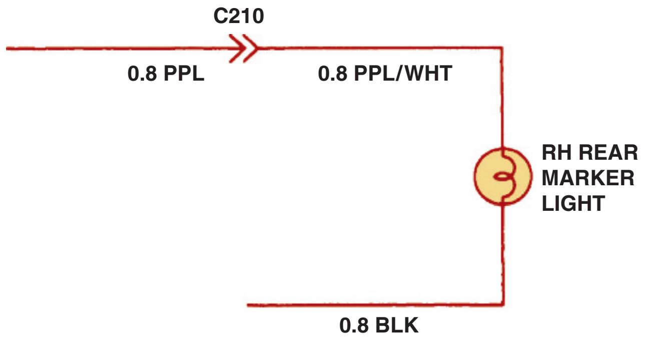


FIGURE 42–2 Typical section of a wiring diagram. Notice that the wire color changes at connection C210. The "0.8" represents the metric wire size in square millimeters.

TECH TIP

Read the Arrows

Wiring diagrams indicate connections by symbols that look like arrows. ● **SEE FIGURE 42–4**.

Do *not* read these "arrows" as pointers showing the direction of current flow. Also observe that the power side (positive side) of the circuit is usually the female end of the connector. If a connector becomes disconnected, it is difficult for the circuit to become shorted to ground or to another circuit because the wire is recessed inside the connector.

SCHEMATIC SYMBOLS

BATTERY The plates of a battery are represented by long and short lines. ● **SEE FIGURE 42–5**.

The longer line represents the positive plate of a battery and the shorter line represents the negative plate. Therefore, each pair of short and long lines represents one cell of a battery. Because each cell of a typical automotive lead–acid battery has 2.1 volts, a battery symbol showing a 12 volt battery should have six pairs of lines. However, most battery symbols simply use two or three pairs of long and short lines and list the voltage of the battery next to the symbol. As a result, the battery symbols are shorter and yet clear because the voltage is stated. The positive terminal of the battery is often indicated with a plus sign (+), representing the positive post of the battery, and is placed next to the long line of the end cell. The negative terminal of the battery is represented by a negative sign (–) and is placed next to the shorter cell line. The negative battery terminal is connected to ground. ● **SEE FIGURE 42–6**.

WIRING Electrical wiring is shown as straight lines and with a few numbers and/or letters to indicate the following:

- **Wire size.** This can be either AWG, such as 18 gauge, or in square millimeters, such as 0.8 mm^2.
- **Circuit numbers.** Each wire in part of a circuit is labeled with the circuit number to help the service technician trace the wiring and to provide an explanation of how the circuit should work.
- **Wire color.** Most schematics also indicate an abbreviation for the color of the wire and place it next to the wire. Many wires have two colors: a solid color and a stripe color. In this case, the solid color is listed, followed by a slash (/) and the color of the stripe. For example, Red/Wht indicates a red wire with a white tracer. ● **SEE FIGURE 42–7**.
- **Terminals.** The metal part attached at the end of a wire is called a **terminal**. A symbol for a terminal is shown in ● **FIGURE 42–8**.
- **Splices.** When two wires are electrically connected, the junction is shown with a black dot. The identification of the splice is an "S" followed by three numbers, such as S103. ● **SEE FIGURE 42–9**. When two wires cross in a schematic that are not electrically connected, one of the wires is shown as going over the other wire and does not connect. ● **SEE FIGURE 42–10**.

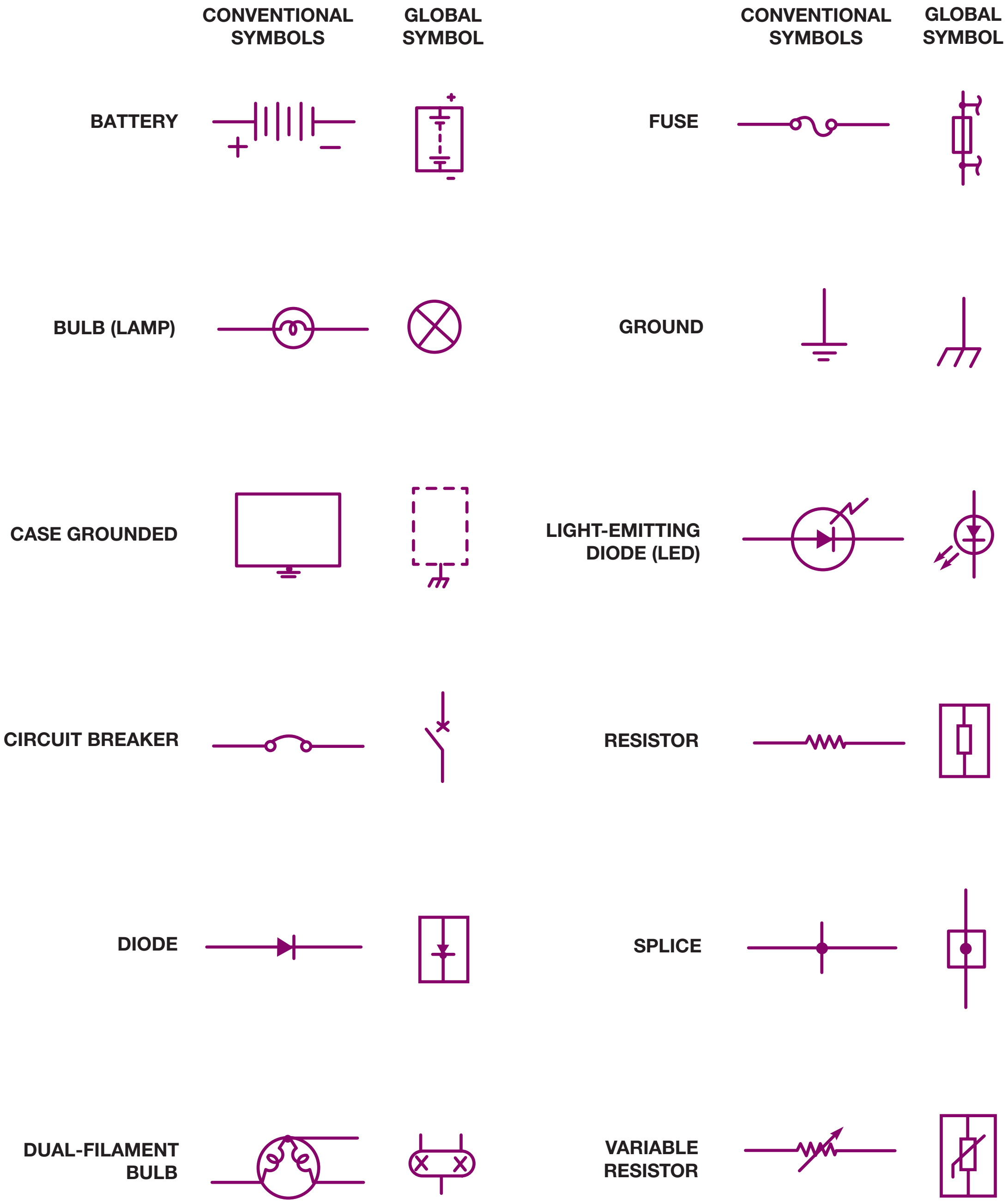

CONVENTIONAL SYMBOLS
GLOBAL SYMBOL
CONVENTIONAL SYMBOLS
GLOBAL SYMBOL
BATTERY
+
−
+
−
FUSE
BULB (LAMP)
GROUND
CASE GROUNDED
LIGHT-EMITTING DIODE (LED)
CIRCUIT BREAKER
RESISTOR
DIODE
SPLICE
DUAL-FILAMENT BULB
VARIABLE RESISTOR

FIGURE 42–3 Typical electrical and electronic symbols used in automotive wiring and circuit diagrams. Both the conventional and the global symbols are shown side by side to make reading schematics easier. The global symbols are used by many vehicle manufacturers.

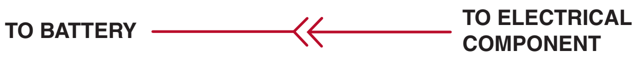

TO BATTERY
TO ELECTRICAL COMPONENT

FIGURE 42–4 In this typical connector, note that the positive terminal is usually a female connector.

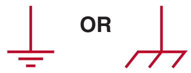


FIGURE 42–6 The ground symbol on the left represents an earth ground. The ground symbol on the right represents a chassis ground.

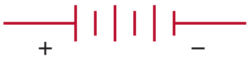


FIGURE 42–5 The symbol for a battery. The positive plate of a battery is represented by the longer line and the negative plate by the shorter line. The voltage of the battery is usually stated next to the symbol.

- **Connectors.** An electrical connector is a plastic part that contains one or more terminals. Although the terminals provide the electrical connection in a circuit, it is the plastic connector that keeps the terminals together mechanically.
- **Location.** Connections are usually labeled “C” followed by three numbers. The three numbers indicate the general

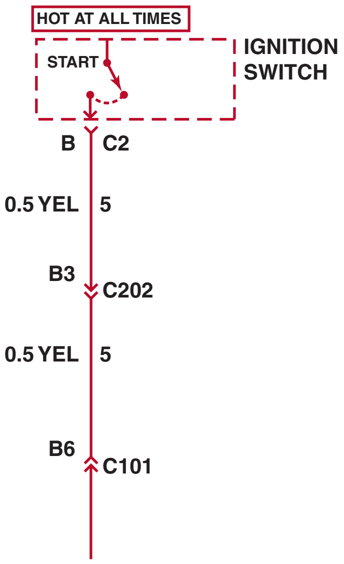

HOT AT ALL TIMES
START
IGNITION SWITCH
B
C2
0.5 YEL
5
B3
C202
0.5 YEL
5
B6
C101

FIGURE 42–7 Starting at the top, the wire from the ignition switch is attached to terminal B of connector C2, the wire is 0.5 mm² (20-gauge AWG), and is yellow. The circuit number is 5. The wire enters connector C202 at terminal B3.

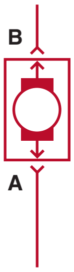


FIGURE 42–8 The electrical terminals are usually labeled with a letter or number.

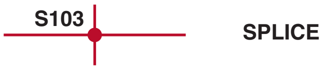

S103
SPLICE

FIGURE 42–9 Two wires that cross at the dot indicate that the two are electrically connected.

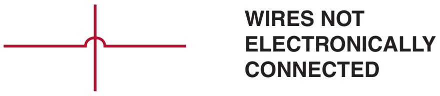

WIRES NOT
ELECTRONICALLY
CONNECTED

FIGURE 42–10 Wires that cross, but do not electrically contact each other, are shown with one wire bridging over the other.

location of the connector. Normally, the connector number represents the general area of the vehicle, including:

100–199	Under the hood
200–299	Under the dash
300–399	Passenger compartment
400–499	Rear package or trunk area
500–599	Left-front door
600–699	Right-front door
700–799	Left-rear door
800–899	Right-rear door

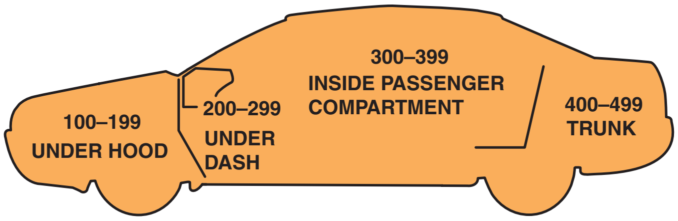

100–199
UNDER HOOD
200–299
UNDER
DASH
300–399
INSIDE PASSENGER
COMPARTMENT
400–499
TRUNK

FIGURE 42–11 Connectors (C), grounds (G), and splices (S) are followed by a number, generally indicating the location in the vehicle. For example, G209 is a ground connection located under the dash.

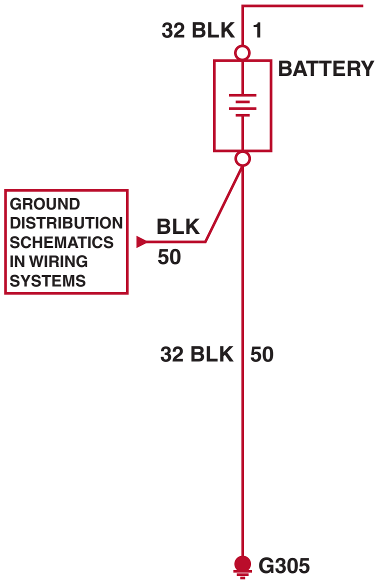

32 BLK
1
BATTERY
GROUND
DISTRIBUTION
SCHEMATICS
IN WIRING
SYSTEMS
BLK
50
32 BLK
50
G305

FIGURE 42–12 The ground for the battery is labeled G305, indicating the ground connector is located in the passenger compartment of the vehicle. The ground wire is black (BLK), the circuit number is 50, and the wire is 32 mm² (2-gauge AWG).

Even-numbered connectors are on the right (passenger side) of the vehicle and odd-numbered connectors are on the left (driver's side) of the vehicle. For example, C102 is a connector located under the hood (between 100 and 199) on the right side of the vehicle (even number 102). ● **SEE FIGURE 42–11**.

- **Grounds and splices.** These are also labeled using the same general format as connectors. Therefore, a ground located in the passenger compartment could be labeled G305 (*G* means "ground" and "305" means that it is located in the passenger compartment). ● **SEE FIGURE 42–12**.

ELECTRICAL COMPONENTS Most electrical components have their own unique symbol that shows the basic function or parts.

BULBS Lightbulbs often use a filament, which heats and gives off light when electrical current flows. The symbol used for a lightbulb is a circle with a filament inside. A dual-filament bulb, such as is used for taillights and brake light/turn signals, is shown with two filaments. ● **SEE FIGURE 42–13**.

ELECTRIC MOTORS An electric motor symbol shows a circle with the letter *M* in the center and two electrical connections, one at the top and the other at the bottom. ● **SEE FIGURE 42–14** for an example of a cooling fan motor.

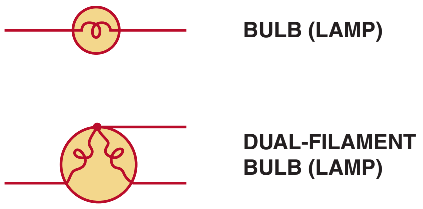


FIGURE 42–13 The symbol for lightbulbs shows the filament inside a circle, which represents the glass ampoule of the bulb.

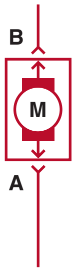


FIGURE 42–14 An electric motor symbol shows a circle with the letter *M* in the center and two black sections that represent the brushes of the motor. This symbol is used even though the motor is a brushless design.

RESISTORS Although resistors are usually part of another component, the symbol appears on many schematics and wiring diagrams. A resistor symbol is a jagged line representing resistance to current flow. If the resistor is variable, such as a thermistor, an arrow is shown running through the symbol of a fixed resistor. A potentiometer is a three-wire variable resistor, shown with an arrow pointing toward the resistance part of a fixed resistor. ● **SEE FIGURE 42–15**.

A two-wire rheostat is usually shown as part of another unit, such as a fuel-level sensing unit. ● **SEE FIGURE 42–16**.

CAPACITORS Capacitors are usually part of an electronic component, but not a replaceable component, unless the vehicle is an older model. Many older vehicles used capacitors to reduce radio interference and were installed inside alternators or were attached to wiring connectors. ● **SEE FIGURE 42–17**.

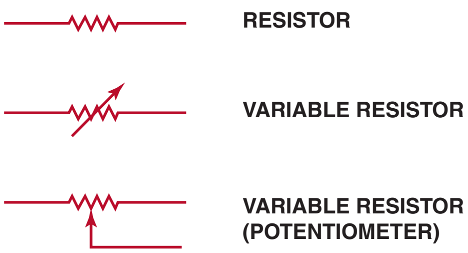


FIGURE 42–15 Resistor symbols vary, depending on the type of resistor.

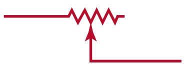


FIGURE 42–16 A rheostat uses only two wires—one is connected to a voltage source and the other is attached to the movable arm.

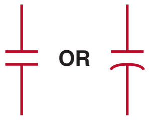


FIGURE 42–17 Symbols used to represent capacitors. If one of the lines is curved, this indicates that the capacitor being used has a polarity, while the one without a curved line can be installed in the circuit without concern about polarity.

ELECTRIC HEATED UNIT Electric grid-type rear window defoggers and heated outside mirrors are shown with a square box–type symbol. ● **SEE FIGURE 42–18**.

BOXED COMPONENTS If a component is shown in a box using a solid line, the box is the entire component. If a box uses dashed lines, it represents part of a component. A commonly used dashed-line box is a fuse panel. Often, just one or two fuses are shown in a dashed-line box. This means that a fuse panel has more fuses than shown. ● **SEE FIGURES 42–19 AND 42–20**.

SEPARATE REPLACEABLE PART Often components are shown on a schematic that cannot be replaced, but are part of a complete assembly. When looking at a schematic of General Motors vehicles, the following is shown:

- If a part name is underlined, it is a replaceable part.
- If a part is not underlined, it is not available as a replaceable part, but is included with other components shown and sold as an assembly.
- If the case itself is grounded, the ground symbol is attached to the component as shown in ● **FIGURE 42–21**.

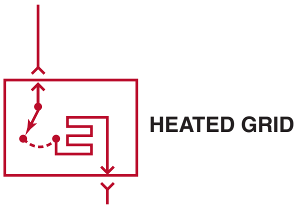


FIGURE 42–18 The grid-like symbol represents an electrically heated element.

FIGURE 42–19 A dashed outline represents a portion (part) of a component.

FIGURE 42–20 A solid box represents an entire component.

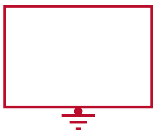


FIGURE 42–21 This symbol represents a component that is case grounded.

SWITCHES Electrical switches are drawn on a wiring diagram in their normal position. This can be one of two possible positions:

- **Normally open.** The switch is not connected to its internal contacts and no current flows. This type of switch is labeled **N.O**.
- **Normally closed.** The switch is electrically connected to its internal contacts and current flows through the switch. This type of switch is labeled **N.C**.

Other switches can use more than two contacts.

The **poles** refer to the number of circuits completed by the switch and the **throws** refer to the number of output circuits. A **single-pole, single-throw (SPST)** switch has only two positions, on or off. A **single-pole, double-throw (SPDT)** switch has three terminals, one wire in and two wires out. A headlight dimmer switch is an example of a typical SPDT switch. In one position, the current flows to the low-filament headlight; in the other, the current flows to the high-filament headlight.

NOTE: A SPDT switch is not an on or off type of switch, but instead directs power from the source to either the high-beam lamps or the low-beam lamps.

There are also **double-pole, single-throw (DPST)** switches and **double-pole, double-throw (DPDT)** switches. ● **SEE FIGURE 42–22**.

NOTE: All switches are shown on schematics in their normal position. This means that the headlight switch is shown normally off, as are most other switches and controls.

MOMENTARY SWITCH A **momentary switch** is a switch primarily used to send a voltage signal to a module or controller to request that a device be turned on or off. The switch makes momentary contact and returns to the open position. A horn switch is a commonly used momentary switch. The symbol that represents a momentary switch uses two dots for the contact with a switch above them. A momentary switch can be either normally open or normally closed. ● **SEE FIGURE 42–23**.

A momentary switch, for example, can be used to lock or unlock a door or to turn the air conditioning on or off. If the device is currently operating, the signal from the momentary switch turns it off, and if it is off, the switch signals the module to turn it on. The major advantage of momentary switches is that they can be lightweight and small because the switch does not carry any heavy electrical current, just a small voltage signal. Most momentary switches use a membrane constructed of foil and plastic.

TECH TIP

Color-Coding Is Key to Understanding

Whenever diagnosing an electrical problem, it is common practice to print out the schematic of the circuit and take it to the vehicle. A meter is then used to check for voltage at various parts of the circuit to help determine whether there is a fault. The diagnosis can be made easier if the parts of the circuit are first color-coded using markers or color pencils.

The colors represent voltage conditions in various parts of a circuit. Once the circuit has been color-coded, it can be tested using the factory wire colors as a guide. ● **SEE FIGURE 42–24**.

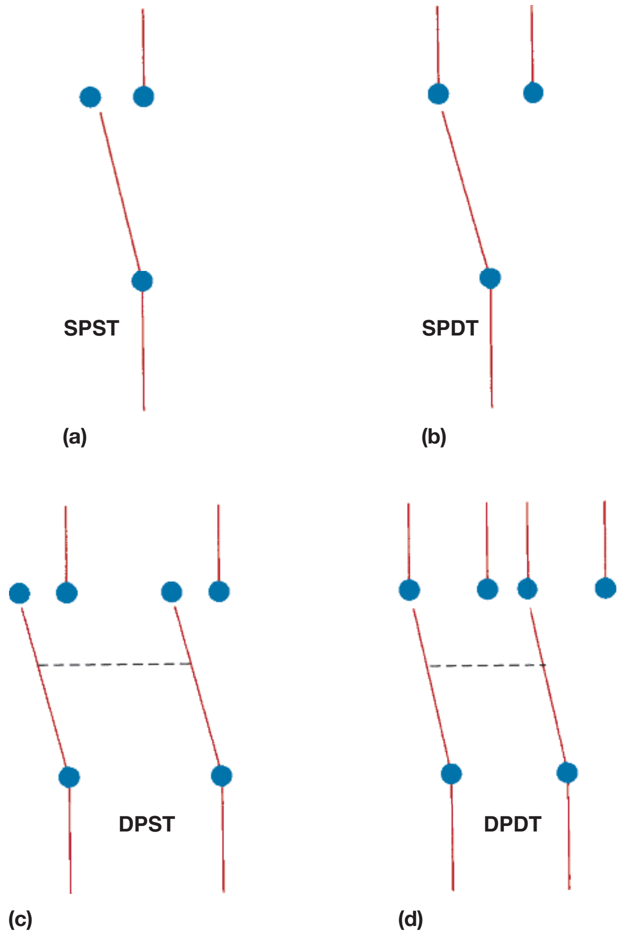


FIGURE 42–22 (a) A symbol for a single-pole, single-throw (SPST) switch. This type of switch is normally open (N.O.) because nothing is connected to the terminal that the switch is contacting in its normal position. (b) A single-pole, double-throw (SPDT) switch has three terminals. (c) A double-pole, single-throw (DPST) switch has two positions (off and on) and can control two separate circuits. (d) A double-pole, double-throw (DPDT) switch has six terminals—three for each pole. Note: Both (c) and (d) also show a dotted line between the two arms indicating that they are mechanically connected, called a "ganged switch."

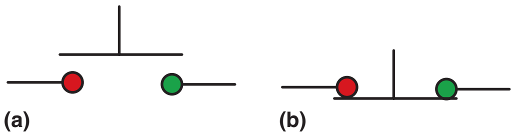


FIGURE 42–23 (a) A symbol for a normally open (N.O.) momentary switch. (b) A symbol for a normally closed (N.C.) momentary switch.

RELAY TERMINAL IDENTIFICATION

DEFINITION A **relay** is a magnetic switch that uses a movable armature to control a high-amperage circuit by using a low-amperage electrical switch.

ISO RELAY TERMINAL IDENTIFICATION Most automotive relays adhere to common terminal identification. The primary source for this common identification comes from the standards

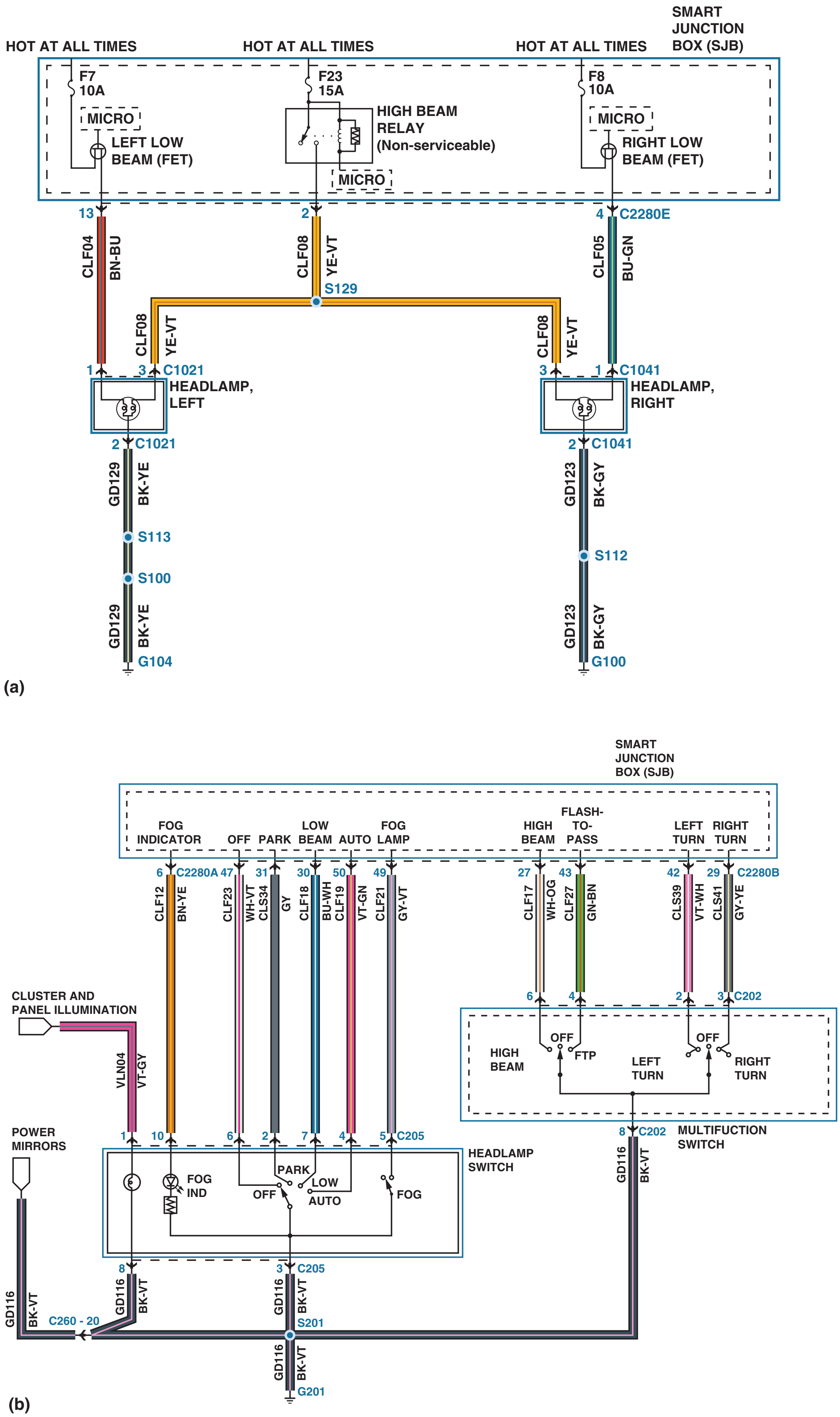

SMART JUNCTION BOX (SJB)
HOT AT ALL TIMES
HOT AT ALL TIMES
HOT AT ALL TIMES
F7 10A
F23 15A
F8 10A
MICRO
LEFT LOW BEAM (FET)
HIGH BEAM RELAY (Non-serviceable)
MICRO
MICRO
RIGHT LOW BEAM (FET)
13
2
4
C2280E
CLF04
BN-BU
CLF08
YE-VT
S129
CLF05
BU-GN
CLF08
YE-VT
CLF08
YE-VT
1
3
C1021
HEADLAMP, LEFT
3
1
C1041
HEADLAMP, RIGHT
2
C1021
2
C1041
GD129
BK-YE
S113
S100
GD129
BK-YE
G104
GD123
BK-GY
S112
GD123
BK-GY
G100
(a)
SMART JUNCTION BOX (SJB)
FOG INDICATOR
OFF
PARK
LOW BEAM
AUTO
FOG LAMP
HIGH BEAM
FLASH-TO-PASS
LEFT TURN
RIGHT TURN
6
C2280A
47
31
30
50
49
27
43
42
29
C2280B
CLF12
BN-YE
CLF23
WH-VT
CLS34
GY
CLF18
BU-WH
CLF19
VT-GN
CLF21
GY-VT
CLF17
WH-OG
CLF27
GN-BN
CLS39
VT-WH
CLS41
GY-YE
6
4
2
3
C202
OFF
FTP
OFF
HIGH BEAM
LEFT TURN
RIGHT TURN
8
C202
MULTIFUCTION SWITCH
GD116
BK-VT
CLUSTER AND PANEL ILLUMINATION
VLN04
VT-GY
POWER MIRRORS
1
10
6
2
7
4
5
C205
HEADLAMP SWITCH
FOG IND
PARK
OFF
LOW
AUTO
FOG
8
3
C205
GD116
BK-VT
GD116
BK-VT
S201
GD116
BK-VT
C260 - 20
GD116
BK-VT
G201
(b)

FIGURE 42–24 (a) A typical headlight circuit showing the colors of the wires. (b) A more complex circuit using colored pencils to indicate where there is voltage in the circuit will help diagnose the system if there is a fault.

established by the International Standards Organization (ISO). Knowing this terminal information helps in the correct diagnosis and troubleshooting of any circuit containing a relay. ● **SEE FIGURES 42–25 AND 42–26**.

Relays are found in many circuits because they are capable of being controlled by computers, yet are able to handle enough current to power motors and accessories. Relays include the following components and terminals.

RELAY OPERATION

1. **Coil** (terminals 85 and 86)
    - A coil provides the magnetic pull to a movable armature (arm).
    - The resistance of most relay coils ranges from 50 to 150 ohms, but is usually between 60 and 100 ohms.
    - The ISO identification of the coil terminals are 86 and 85. The terminal number 86 represents the power to the relay coil and the terminal labeled 85 represents the ground side of the relay coil.
    - The relay coil can be controlled by supplying either power or ground to the relay coil winding.
    - The coil winding represents the *control circuit,* which uses low current to control the higher current through the other terminals of the relay. ● **SEE FIGURE 42–27**.

TECH TIP

Divide the Circuit in Half

When diagnosing any circuit that has a relay, start testing at the relay and divide the circuit in half.

- **High-current portion:** Remove the relay and check that there are 12 volts at the terminal 30 socket. If there is, the power side is okay. Use an ohmmeter and check between terminal 87 socket and ground. If the load circuit has continuity, there should be some resistance. If OL, the circuit is electrically open.
- **Control circuit (low current):** With the relay removed from the socket, check that there are 12 volts to terminal 86 with the ignition on and the control switch on. If not, check service information to see if power should be applied to terminal 86, and continue troubleshooting the switch power and related circuit.
- **Check the relay itself:** Use an ohmmeter and measure for continuity and resistance.
    - Between terminals 85 and 86 (coil), there should be 60 to 100 ohms. If not, replace the relay.
    - Between terminals 30 and 87 (high-amperage switch controls), there should be continuity (low ohms) when there is power applied to terminal 85 and a ground applied to terminal 86 that operates the relay. If OL is displayed on the meter set to read ohms, the circuit is open, which requires that the relay be replaced.
    - Between terminals 30 and 87a (if equipped), with the relay turned off, there should be low resistance (less than 5 ohms).

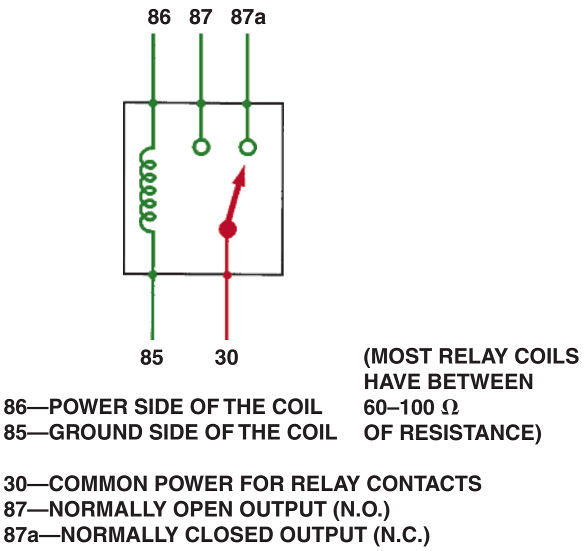

86 87 87a
85 30
(MOST RELAY COILS HAVE BETWEEN 60–100 Ω OF RESISTANCE)
86—POWER SIDE OF THE COIL
85—GROUND SIDE OF THE COIL
30—COMMON POWER FOR RELAY CONTACTS
87—NORMALLY OPEN OUTPUT (N.O.)
87a—NORMALLY CLOSED OUTPUT (N.C.)

FIGURE 42–25 A relay uses a movable arm to complete a circuit whenever there is a power at terminal 86 and a ground at terminal 85. A typical relay only requires about 1/10 ampere through the relay coil. The movable arm then closes the contacts (#30 to #87) and can relay 30 amperes or more.

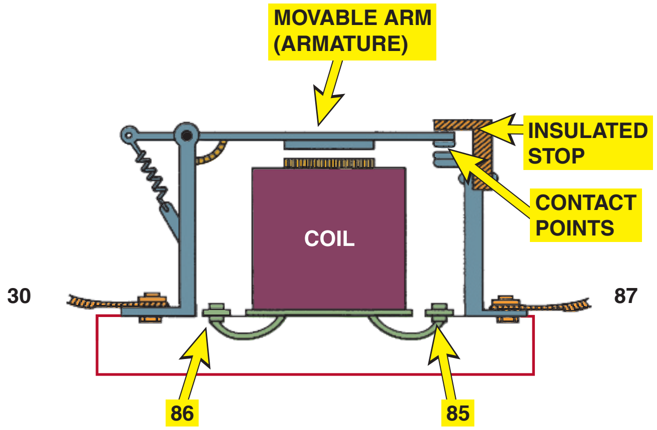


FIGURE 42–26 A cross-sectional view of a typical four-terminal relay. Current flowing through the coil (terminals 86 and 85) causes the movable arm (called the armature) to be drawn toward the coil magnet. The contact points complete the electrical circuit connected to terminals 30 and 87.

2. **Armature and contact points** (terminals 30, 87, and 87a)
    - The higher amperage current flow through a relay flows through terminals 30 and 87, and often 87a.
    - Terminal 30 is usually where power is applied to a relay. Check service information for the exact operation of the relay being tested.
    - When the relay is at rest without power and ground to the coil, the armature inside the relay electrically connects terminals 30 and 87a if the relay has five terminals. When there is power at terminal 85 and a ground at terminal 86 of the relay, a magnetic field is created in the coil winding, which draws the armature of the relay toward the coil. The armature, when energized electrically, connects terminals 30 and 87.

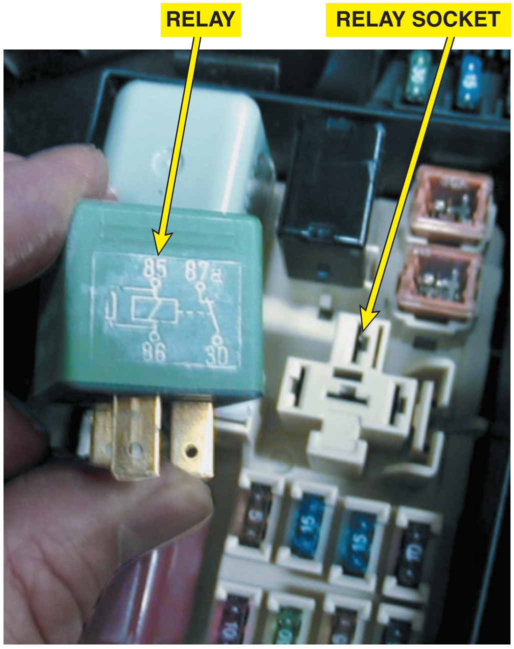


FIGURE 42–27 A typical relay showing the schematic of the wiring in the relay.

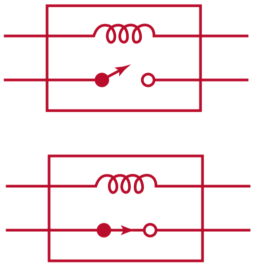


FIGURE 42–28 All schematics are shown in their normal, nonenergized position.

The maximum current through the relay is determined by the resistance of the circuit, and relays are designed to safely handle the designed current flow. ● **SEE FIGURES 42–28 AND 42–29**.

RELAY VOLTAGE SPIKE CONTROL Relays contain a coil and, when power is removed, the magnetic field surrounding the coil collapses, creating a voltage to be induced in the coil winding. This induced voltage can be as high as 100 volts or more and can cause problems with other electronic devices in the vehicle. For example, the short high-voltage surge can be heard as a "pop" in the radio. To reduce the induced voltage, some relays contain a diode connected across the coil. ● **SEE FIGURE 42–30**.

When the current flows through the coil, the diode is not part of the circuit because it is installed to block current. However, when the voltage is removed from the coil, the resulting voltage induced in the coil windings has a reversed polarity to the applied voltage. Therefore, the voltage in the coil is applied to the coil in a forward direction through the diode, which conducts the current back into the winding. As a result, the induced voltage spike is eliminated.

Most relays use a resistor connected in parallel with the coil winding. The use of a resistor, typically about 400 to 600 ohms, reduces the voltage spike by providing a path for the voltage created in the coil to flow back through the coil windings when the coil circuit is opened. ● **SEE FIGURE 42–31**.

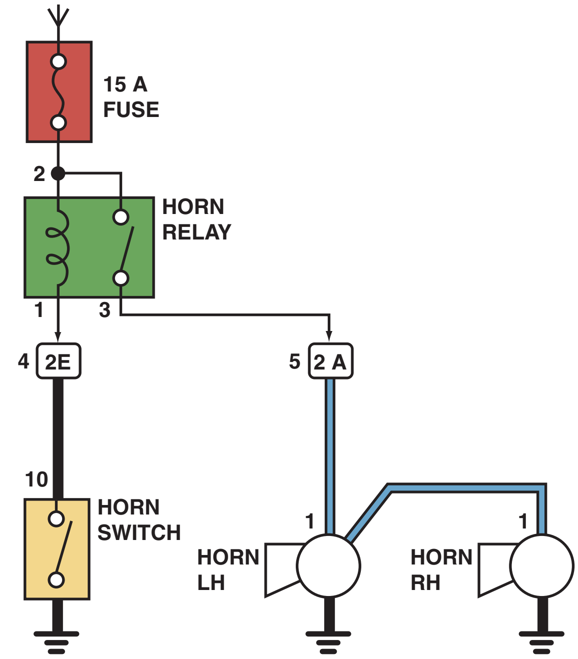


FIGURE 42–29 A horn circuit. Note that the relay contacts supply the heavy current to operate the horn when the horn switch simply completes a low-current circuit to ground, causing the relay contacts to close.

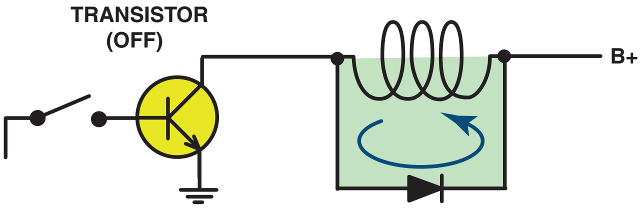


FIGURE 42–30 When the relay or solenoid coil current is turned off, the stored energy in the coil flows through the clamping diode and effectively reduces voltage spike.

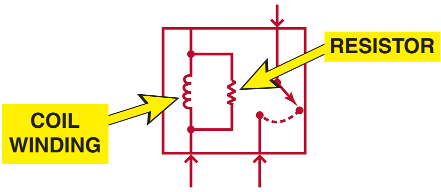


FIGURE 42–31 A resistor used in parallel with the coil windings is a common spike reduction method used in many relays.

FREQUENTLY ASKED QUESTION

What Is the Difference between a Relay and a Solenoid?

Often, these terms are used differently among vehicle manufacturers, which can lead to some confusion.

Relay: A relay is an electromagnetic switch that uses a movable arm. Because a relay uses a movable arm, it is generally limited to current flow not exceeding 30 amperes.

Solenoid: A solenoid is an electromagnetic switch that uses a movable core. Because of this type of design, a solenoid is capable of handling 200 amperes or more. It is used in the starter motor circuit and other high-amperage applications, such as in the glow plug circuit of diesel engines.

LOCATING AN OPEN CIRCUIT

TERMINOLOGY An open circuit is a break in the electrical circuit that prevents current from flowing and operating an electrical device. Examples of open circuits include the following:

- Blown (open) lightbulbs
- Cut or broken wires
- Disconnected or partially disconnected electrical connectors
- Electrically open switches
- Loose or broken ground connections or wires
- Blown fuse

PROCEDURE TO LOCATE AN OPEN CIRCUIT The typical procedure for locating an open circuit involves the following steps:

STEP 1 **Perform a thorough visual inspection.** Check the following:

- Look for evidence of a previous repair. Often, an electrical connector or ground connection can be accidentally left disconnected.
- Look for evidence of recent body damage or body repairs. Movement due to a collision can cause metal to move, which can cut wires or damage connectors or components.

STEP 2 **Print out the schematic.** Trace the circuit and check for voltage at certain places. This helps pinpoint the location of the open circuit.

STEP 3 **Check everything that does and does not work.** Often, an open circuit affects more than one component. Check the part of the circuit that is common to the other components that do not work.

STEP 4 **Check for voltage.** Voltage is present up to the location of the open circuit fault. For example, if there is battery voltage at the positive terminal and the negative (ground) terminal of a two-wire lightbulb socket with the bulb plugged in, the ground circuit is open.

COMMON POWER OR GROUND

When diagnosing an electrical problem that affects more than one component or system, check the electrical schematic for a common power source or a common ground. ● **SEE FIGURE 42–32** for an example of lights being powered by one fuse (power source).

- Underhood light
- Inside lighted mirrors
- Dome light
- Left-side courtesy light
- Right-side courtesy light

If a customer complains about one or more of the items listed, check the fuse and the common part of the circuit that feeds all of the affected lights. Check for a common ground if several components that seem unrelated are not functioning correctly.

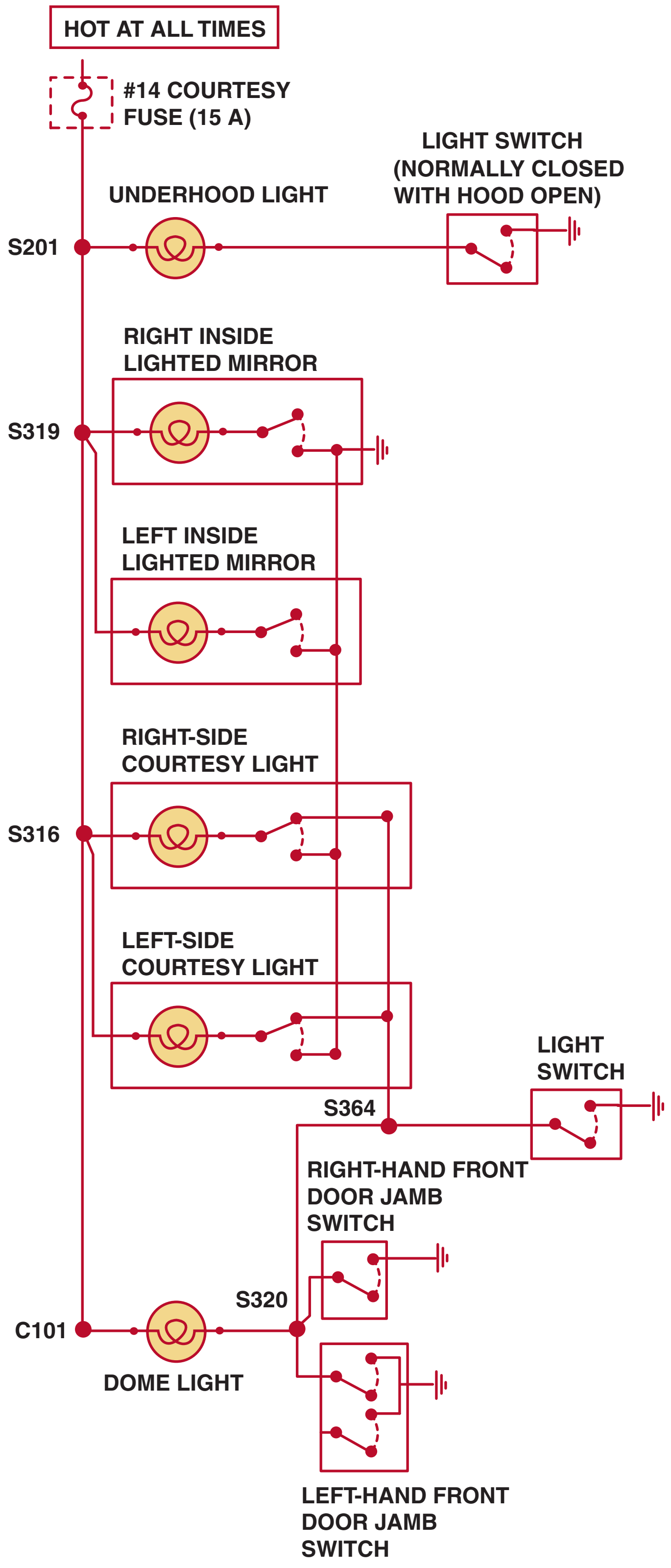

HOT AT ALL TIMES
#14 COURTESY FUSE (15 A)
LIGHT SWITCH (NORMALLY CLOSED WITH HOOD OPEN)
UNDERHOOD LIGHT
S201
RIGHT INSIDE LIGHTED MIRROR
S319
LEFT INSIDE LIGHTED MIRROR
RIGHT-SIDE COURTESY LIGHT
S316
LEFT-SIDE COURTESY LIGHT
LIGHT SWITCH
S364
RIGHT-HAND FRONT DOOR JAMB SWITCH
S320
C101
DOME LIGHT
LEFT-HAND FRONT DOOR JAMB SWITCH

FIGURE 42–32 A typical wiring diagram showing multiple switches and bulbs powered by one fuse.

CIRCUIT TROUBLESHOOTING

PROCEDURE Follow these steps when troubleshooting wiring problems:

STEP 1 Verify the malfunction. If, for example, the backup lights do not operate, make certain that the ignition is on (key on, engine off), with the gear selector in reverse, and check for operation of the backup lights.

TECH TIP

Do It Right—Install a Relay

Often the owners of vehicles, especially owners of pickup trucks and sport utility vehicles (SUVs), want to add additional electrical accessories or lighting. It is tempting in these cases to simply splice into an existing circuit. However, when another circuit or component is added, the current that flows through the newly added component is also added to the current for the original component. This additional current can easily overload the fuse and wiring. Do not simply install a larger amperage fuse; the wire gauge size was not engineered for the additional current and could overheat.

The solution is to install a relay, which uses a small coil to create a magnetic field that causes a movable arm to switch on a higher current circuit. The typical relay coil has 50 to 150 ohms (usually 60 to 100 ohms) of resistance and requires just 0.24 to 0.08 ampere when connected to a 12 volt source. This small additional current is not enough to overload the existing circuit. ● **SEE FIGURE 42–33** for an example of how additional lighting can be added.

STEP 2 Check everything else that does or does not operate correctly. For example, if the taillights are also not working, the problem could be a loose or broken ground connection in the trunk area that is shared by both the backup lights and the taillights.

STEP 3 Check the fuse for the backup lights. ● **SEE FIGURE 42–34.**

STEP 4 Check for voltage at the backup light socket. This can be done using a test light or a voltmeter.

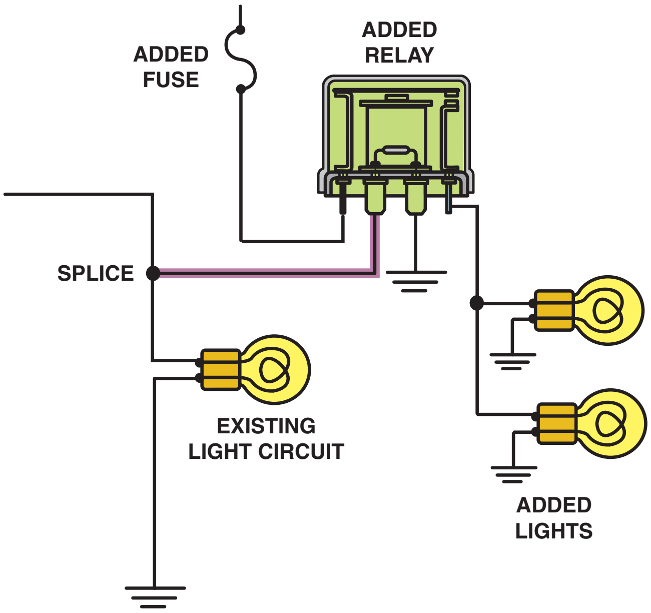


FIGURE 42–33 To add additional lighting, simply tap into an existing light wire and connect a relay. Whenever the existing light is turned on, the coil of the relay is energized. The arm of the relay then connects power from another circuit (fuse) to the auxiliary lights without overloading the existing light circuit.

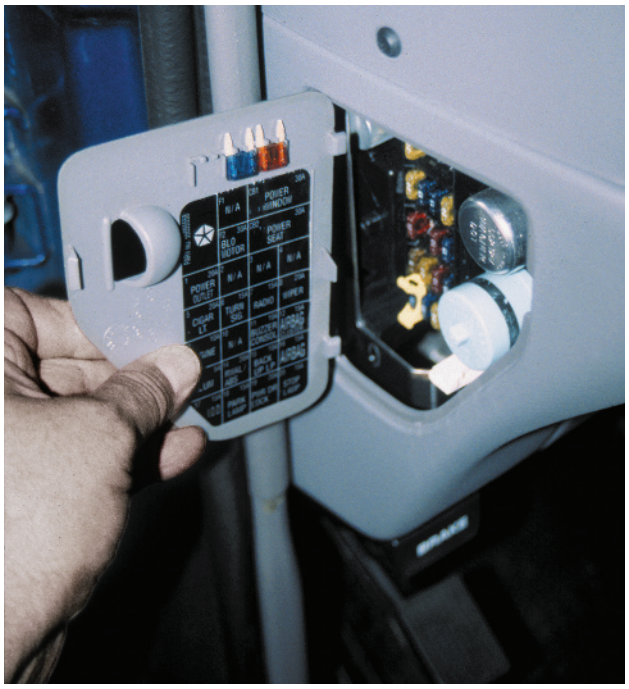


FIGURE 42–34 Always check the simple things first. Check the fuse for the circuit you are testing. Maybe a fault in another circuit controlled by the same fuse could have caused the fuse to blow. Use a test light to check that both sides of the fuse have voltage.

CASE STUDY

The Electric Mirror Fault Story

A customer noticed that the electric mirrors stopped working. The service technician checked all electrical components in the vehicle and discovered that the interior lights were also not working.

The interior lights were not mentioned by the customer as being a problem most likely because the driver only used the vehicle in daylight hours.

The service technician found the interior light and power accessory fuse blown. Replacing the fuse restored the proper operation of the electric outside mirror and the interior lights. However, what caused the fuse to blow? A visual inspection of the dome light, next to the electric sunroof, showed an area where a wire was bare. Evidence showed the bare wire had touched the metal roof, which could cause the fuse to blow. The technician covered the bare wire with a section of vacuum hose and then taped the hose with electrical tape to complete the repair.

Summary:

Complaint—The electric power mirrors stopped working.
Cause—A blown fuse due to a fault in the wiring at the dome light.
Correction—Repaired the wiring at the dome light, which restored the proper operation of the electric mirrors that shared the same fuse as the dome light.

If voltage is available at the socket, the problem is either a defective bulb or a poor ground at the socket or a ground wire connection to the body or frame. If no voltage is available at the socket, consult a wiring diagram for the type of vehicle being tested. The wiring diagram should show all of the wiring and components included in the circuit. For example, the backup light current must flow through the fuse and ignition switch to the gear selector switch before traveling to the rear backup light socket. As stated in the second step, the fuse used for the backup lights may also be used for other vehicle circuits.

The wiring diagram can be used to determine all other components that share the same fuse. If the fuse is blown (open circuit), the cause can be a short in any of the circuits sharing the same fuse. Because the backup light circuit current must be switched on and off by the gear selector switch, an open in the switch can also prevent the backup lights from functioning.

LOCATING A SHORT CIRCUIT

TERMINOLOGY A short circuit usually blows a fuse, and a replacement fuse often also blows in the attempt to locate the source of the short circuit. A **short circuit** is an electrical connection to another wire or to ground before the current flows through some or all of the resistance in the circuit. A short-to-ground always blows a fuse and usually involves a wire on the power side of the circuit coming in contact with metal. Therefore, a thorough visual inspection should be performed around areas involving heat or movement, especially if there is evidence of a previous collision or previous repair that may not have been properly completed.

A short-to-voltage may or may not cause the fuse to blow and usually affects another circuit. Look for areas of heat or movement where two power wires could come in contact with each other. Several methods can be used to locate the short.

FREQUENTLY ASKED QUESTION

Where to Start?

The common question is where does a technician start the troubleshooting when using a wiring diagram (schematic)?

HINT 1 If the circuit contains a relay, start your diagnosis at the relay. The entire circuit can be tested at the terminals of the relay.

HINT 2 The easiest first step is to locate the unit on the schematic that is not working or not working correctly.

- **a.** Trace where the unit gets its ground connection.
- **b.** Trace where the unit gets its power connection.

Often a ground is used by more than one component. Therefore, ensure that everything else is working correctly. If not, the fault may lie at the common ground (or power) connection.

HINT 3 Divide the circuit in half by locating a connector or a part of the circuit that can be accessed easily. Then check for power and ground at this midpoint. This step could save you time.

HINT 4 Use a fused jumper wire to substitute a ground or a power source to replace a suspected switch or section of wire.

FUSE REPLACEMENT METHOD Disconnect one component at a time and then replace the fuse. If the new fuse blows, continue the process until you determine the location of the short. This method uses many fuses and is *not* a preferred method for finding a short circuit.

CIRCUIT BREAKER METHOD Another method is to connect an automotive circuit breaker to the contacts of the fuse holder with alligator clips. Circuit breakers are available that plug directly into the fuse panel, replacing a blade-type fuse. The circuit breaker alternately opens and closes the circuit, protecting the wiring from possible overheating damage, while still providing current flow through the circuit.

NOTE: A heavy-duty (HD) flasher can also be used in place of a circuit breaker to open and close the circuit. Wires and terminals must be made to connect the flasher unit where the fuse normally plugs in.

All components included in the defective circuit should be disconnected one at a time until the circuit breaker stops clicking. The unit that was disconnected and stopped the circuit breaker clicking is the unit causing the short circuit. If the circuit breaker continues to click with all circuit components unplugged, the problem is in the wiring *from* the fuse panel *to* any one of the units in the circuit. Visual inspection of all the wiring or further disconnecting is necessary to locate the problem.

TEST LIGHT METHOD To use the test light method, simply remove the blown fuse and connect a test light to the terminals of the fuse holder (polarity does not matter). If there is a short circuit, current flows from the power side of the fuse holder through the test light and on to ground through the short circuit, and the test light lights. Unplug the connectors or components protected by the fuse until the test light goes out. The circuit that was disconnected, which caused the test light to go out, is the circuit that is shorted.

BUZZER METHOD The buzzer method is similar to the test light method, but uses a buzzer to replace a fuse and act as an electrical load. The buzzer sounds if the circuit is shorted and stops when the part of the circuit that is grounded is unplugged.

OHMMETER METHOD The fifth method uses an ohmmeter connected to the fuse holder and ground. This is the recommended method of finding a short circuit, as an ohmmeter indicates low ohms when connected to a short circuit. However, an ohmmeter should never be connected to an operating circuit. The correct procedure for locating a short using an ohmmeter is as follows:

1. Connect one lead of an ohmmeter (set to a low scale) to a good clean metal ground and the other lead to the circuit (load) side of the fuse holder.

CAUTION: Connecting the lead to the power side of the fuse holder causes current to flow through and damages the ohmmeter.

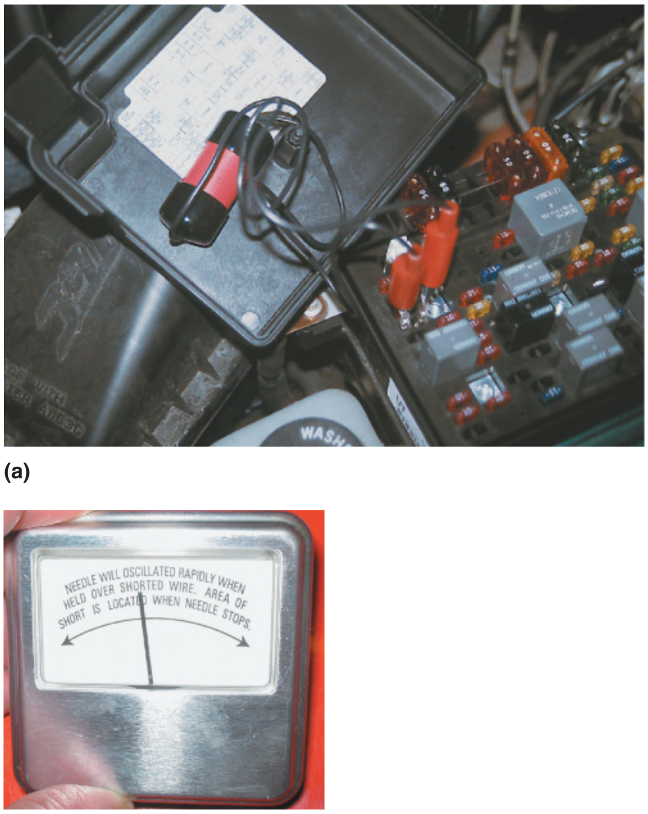
2. The ohmmeter reads zero, or almost zero, ohms if the circuit or a component in the circuit is shorted.
3. Disconnect one component in the circuit at a time and watch the ohmmeter. If the ohmmeter reading shoots to a high value or infinity, the component just unplugged was the source of the short circuit.

4. If all of the components have been disconnected and the ohmmeter still reads low ohms, disconnect electrical connectors until the ohmmeter reads high ohms. The location of the short-to-ground is between the ohmmeter and the disconnected connector.

NOTE: Some meters, such as the Fluke 87, can be set to beep (alert) when the circuit closes or when the circuit opens—a very useful feature.

GAUSS GAUGE METHOD If a short circuit blows a fuse, a special pulsing circuit breaker (similar to a flasher unit) can be installed in the circuit in place of the fuse. Current flows through the circuit until the circuit breaker opens the circuit. As soon as the circuit breaker opens the circuit, it closes again. This on-and-off current flow creates a pulsing magnetic field around the wire carrying the current. A **Gauss gauge** is a handheld meter that responds to weak magnetic fields. It is used to observe this pulsing magnetic field, which is indicated on the gauge as needle movement. This pulsing magnetic field registers on the Gauss gauge, even through the metal body of the vehicle. A needle-type compass can also be used to observe the pulsing magnetic field. ● **SEE FIGURES 42–35 AND 42–36.**

CIRCUIT TRACER An electronic tone generator tester can be used to locate a short-to-ground or an open circuit. Similar to test equipment used to test telephone and cable television lines, a **tone generator tester** generates a tone that can be heard through a receiver (probe). ● **SEE FIGURE 42–37.**


NEEDLE WILL OSCILLATED RAPIDLY WHEN HELD OVER SHORTED WIRE. AREA OF SHORT IS LOCATED WHEN NEEDLE STOPS

(a)

(b)

FIGURE 42–35 (a) After removing the blown fuse, a pulsing circuit breaker is connected to the terminals of the fuse. (b) The circuit breaker causes current to flow, then stop, then flow again, through the circuit up to the point of the short-to-ground. By observing the Gauss gauge, the location of the short is indicated near where the needle stops moving due to the magnetic field created by the flow of current through the wire.

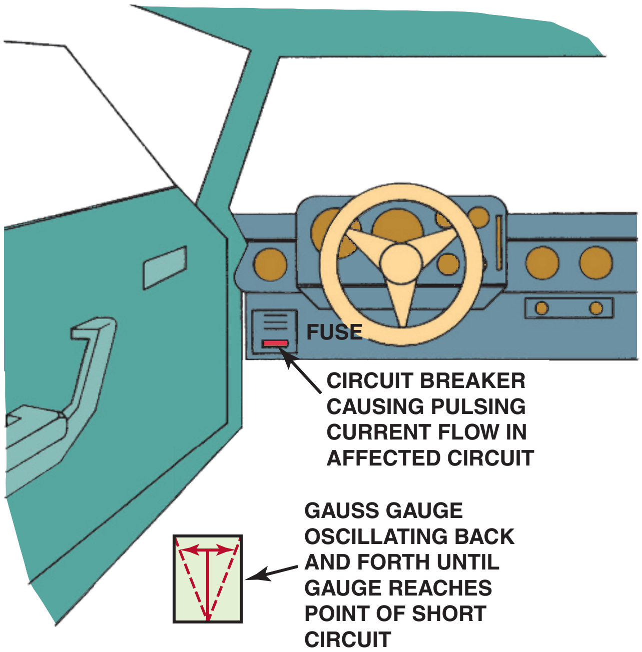

FUSE
CIRCUIT BREAKER CAUSING PULSING CURRENT FLOW IN AFFECTED CIRCUIT
GAUSS GAUGE OSCILLATING BACK AND FORTH UNTIL GAUGE REACHES POINT OF SHORT CIRCUIT

FIGURE 42–36 A Gauss gauge can be used to determine the location of a short circuit even behind a metal panel.

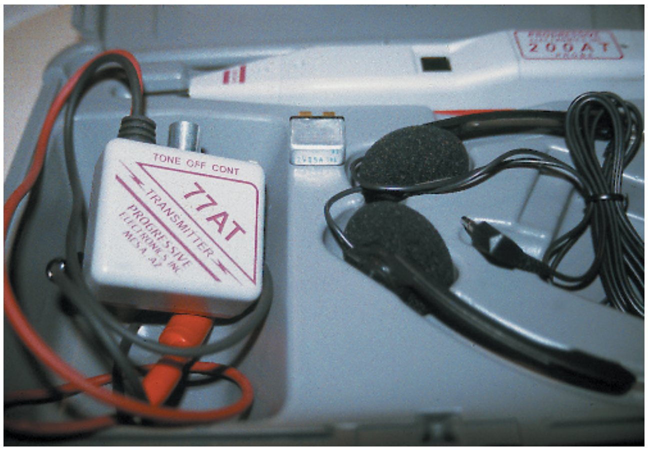

TONE OFF CONT
77AT
TRANSMITTER
PROGRESSIVE ELECTRONICS INC. MESA AZ
200AT

FIGURE 42–37 A tone generator–type tester used to locate open circuits and circuits that are shorted-to-ground. Included with this tester is a transmitter (tone generator), receiver probe, and headphones for use in noisy shops.

TECH TIP

Heat or Movement

Electrical shorts are commonly caused either by movement, which causes the insulation around the wiring to be worn away, or by heat melting the insulation. When checking for a short circuit, first check the wiring that is susceptible to heat, movement, and damage.

1. **Heat.** Wiring near heat sources, such as the exhaust system, cigarette lighter, or alternator
2. **Wire movement.** Wiring that moves, such as in areas near the doors, trunk, or hood
3. **Damage.** Wiring subject to mechanical injury, such as in the trunk, where heavy objects can move around and smash or damage wiring can also occur as a result of an accident or a previous repair

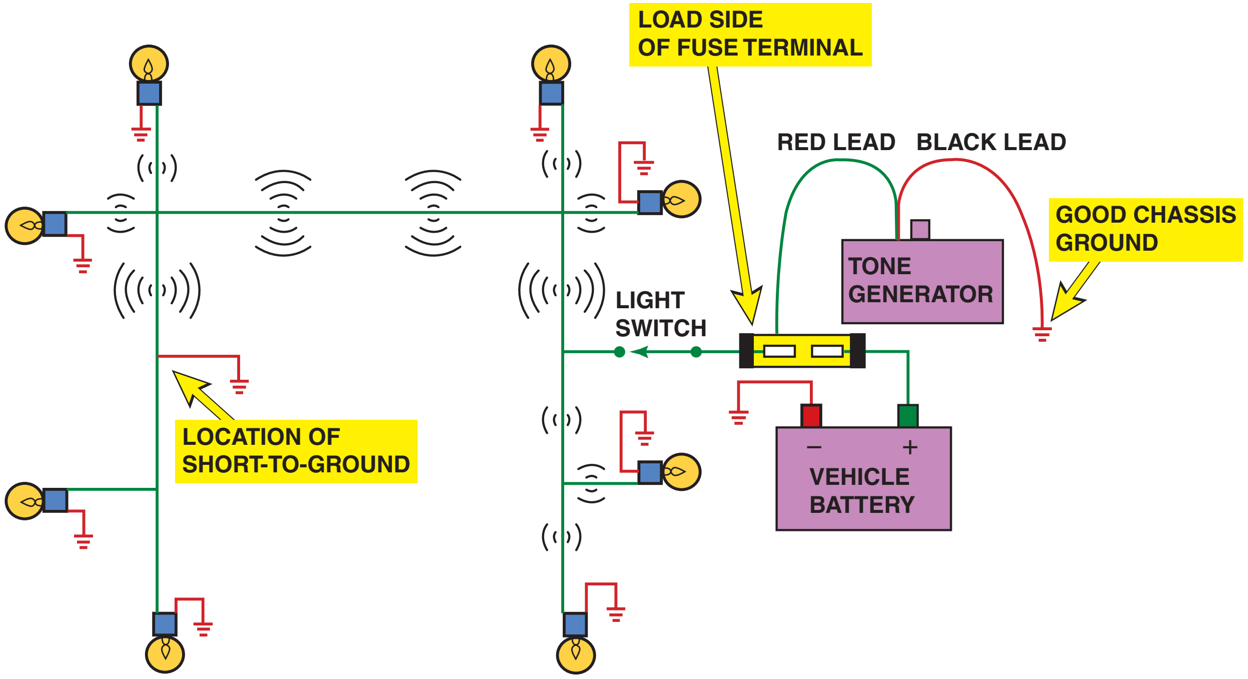


FIGURE 42–38 To check for a short-to-ground using a tone generator, connect the black transmitter lead to a good chassis ground and the red lead to the load side of the fuse terminal. Turn the transmitter on and check for tone signal with the receiver. Using a wiring diagram, follow the strongest signal to the location of the short-to-ground. There is no signal beyond the fault, either a short-to-ground, as shown, or an open circuit.

The tone is generated as long as there is a continuous electrical path along the circuit. The signal stops if there is a short-to-ground or an open in the circuit. ● **SEE FIGURE 42–38**.

TECH TIP

Electrical Troubleshooting Guide

When troubleshooting any electrical component, remember the following hints to identify the problem faster and more easily:

1. For a device to work, it must have two things: power and ground. Often more than one circuit shares a single ground connector.
2. If there is no power to a device, an open power side (blown fuse, etc.) is indicated. Often more than one circuit is being protected by each fuse.
3. If there is power on both sides of a device, an open ground is indicated.
4. If a fuse blows immediately, a grounded power-side wire is indicated.
5. Most electrical faults result from heat or movement.
6. Most noncomputer–controlled devices operate by opening and closing the power side of the circuit (power-side switch).
7. Most computer-controlled devices operate by opening and closing the ground side of the circuit (ground-side switch).

STEP-BY-STEP TROUBLESHOOTING PROCEDURE

Knowing what should be done and when it should be done is a major concern for many technicians trying to repair an electrical problem. The following field-tested procedure provides a step-by-step guide for troubleshooting an electrical fault:

STEP 1 Determine the customer concern (complaint) and get as much information as possible from the customer or service advisor.
- **a.** When did the problem start?
- **b.** Under what conditions does the problem occur?
- **c.** Have there been any recent previous repairs to the vehicle that could have created the problem?

STEP 2 Verify the customer's concern by actually observing the fault.

STEP 3 Perform a thorough visual inspection and be sure to check everything that does and does not work.

STEP 4 Check for technical service bulletins (TSBs).

STEP 5 Locate the wiring schematic for the circuit being diagnosed.

STEP 6 Check the factory service information and follow the troubleshooting procedure.
- **a.** Determine how the circuit works.
- **b.** Determine which part of the circuit is good, based on what works and what does not work.
- **c.** Isolate the problem area.

TECH TIP

Wiggle Test

Intermittent electrical problems are common, yet difficult to locate. To help locate these hard-to-find problems, try operating the circuit and start wiggling the wires and connections that control the circuit. If in doubt where the wiring goes, try moving all the wiring starting at the battery. Pay particular attention to wiring running near the battery or the windshield washer container. Corrosion can cause wiring to fail, and battery acid fumes and alcohol-based windshield washer fluid can start or contribute to the problem. If you notice any change in the operation of the device being tested while wiggling the wiring, look closer in the area you were wiggling until you locate and correct the actual problem.

CASE STUDY

Shocking Experience

A customer complained that after driving for a while, they got a shock whenever they grabbed the door handle when exiting the vehicle. The customer thought that there must be an electrical fault and that the shock was coming from the vehicle itself. In a way, the shock was caused by the vehicle, but it was not a fault. The service technician sprayed the cloth seats with an antistatic spray and the problem did not reoccur. Obviously, a static charge was being created by the movement of the driver's clothing on the seats and then discharged when the driver touched the metal door handle. ● **SEE FIGURE 42–39**.

Summary:

Complaint—Vehicle owner complained that they got shocked when the door handle was touched.

Cause—Static electricity was found to be the cause, not a fault with the vehicle.

Correction—The seats and carpet were sprayed with an antistatic spray and this corrected the concern.

Part No. Q3X1
Anti-Static Spray
WARNING

FIGURE 42–39 Antistatic spray can be used by customers to prevent being shocked when they touch a metal object like the door handle.

NOTE: Split the circuit in half to help isolate the problem and start at the relay (if the circuit has a relay).

STEP 7 Determine the root cause and repair the vehicle.

STEP 8 Verify the repair and complete the work order by listing the three Cs (complaint, cause, and correction).

REVIEW QUESTIONS

1. What do the circuit numbers shown on schematics usually mean?
2. What do the terminal numbers on an ISO relay mean?
3. What is used to control voltage spikes inside a relay?
4. How can a tone generator be used to locate a short circuit?
5. What is the difference between a relay and a solenoid?

CHAPTER QUIZ

1. On a wiring diagram, S110 with a "0.8 BRN/BLK" means ___________.

a. circuit #.8, spliced under the hood

b. a connector with 0.8 mm^2 wire

c. a splice of a brown with black stripe, wire size being 0.8 mm^2 (18-gauge AWG)

d. Both a and b

2. Where is connector C250?

a. Under the hood

b. Under the dash

c. In the passenger compartment

d. In the trunk

3. All switches illustrated in schematics are ___________.

a. shown in their normal position

b. always shown in their on position

c. always shown in their off position

d. shown in their on position except for lighting switches

4. When testing a relay using an ohmmeter, which two terminals should be touched to measure the coil resistance?

a. 87 and 30

b. 86 and 85

c. 87a and 87

d. 86 and 87

5. Technician A says that a good relay should measure between 60 and 100 ohms across the coil terminals. Technician B says that OL should be displayed on an ohmmeter when touching terminals 30 and 87. Which technician is correct?

a. Technician A only

b. Technician B only

c. Both Technicians A and B

d. Neither Technician A nor B

6. Which relay terminal is the normally closed (N.C.) terminal?

a. 30
c. 87

b. 85
d. 87a

7. Technician A says that there is often more than one circuit being protected by each fuse. Technician B says that more than one circuit often shares a single ground connector. Which technician is correct?

a. Technician A only

b. Technician B only

c. Both Technicians A and B

d. Neither Technician A nor B

8. Two technicians are discussing finding a short-to-ground using a test light. Technician A says that the test light, connected in place of the fuse, lights when the circuit that has the short is disconnected. Technician B says that the test light should be connected to the positive (+) and negative (−) terminals of the battery during this test. Which technician is correct?

a. Technician A only

b. Technician B only

c. Both Technicians A and B

d. Neither Technician A nor B

9. A short circuit can be located using a ___________.

a. test light

b. gauss gauge

c. tone generator

d. Any of the above

10. For an electrical device to operate, it must have ___________.

a. power and a ground

b. a switch and a fuse

c. a ground and fusible link

d. a relay to transfer the current to the device

Chapter

43

CAPACITANCE AND CAPACITORS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain capacitance.
- Explain the construction and operation of capacitors.
- Explain factors of capacitance.
- Explain the uses of capacitors.
- Discuss capacitors connected in series and parallel.

KEY TERMS:

Capacitance 493 • Condenser 494 • Dielectric 494 • Farads 496 • Leyden jar 493

CAPACITANCE

DEFINITION **Capacitance** is the ability of an object or surface to store an electrical charge. Around 1745, Ewald Christian von Kliest and Pieter van Musschenbroek independently discovered capacitance in an electric circuit. While engaged in separate studies of electrostatics, they discovered that an electric charge could be stored for a period of time. They used a device, now called a **Leyden jar**, for their experimentation, which consisted of a glass jar filled with water, with a nail piercing the stopper and dipping into the water. ● **SEE FIGURE 43–1**.

The two scientists connected the nail to an electrostatic charge. After disconnecting the nail from the source of the charge, they felt a shock by touching the nail, demonstrating that the device had stored the charge.

In 1747, John Bevis lined both the inside and outside of the jar with foil. This created a capacitor with two conductors (the inside and outside metal foil layers) equally separated by the insulating glass. The Leyden jar was also used by Benjamin Franklin to store the charge from lightning, as well as in other experiments. The natural phenomenon of lightning includes capacitance,

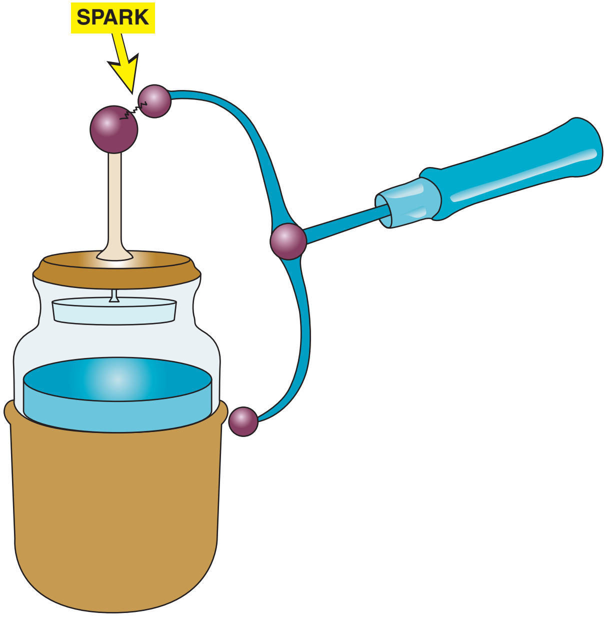


FIGURE 43–1 A Leyden jar can be used to store an electrical charge.

because huge electrical fields develop between cloud layers or between clouds and the earth prior to a lightning strike.

NOTE: Capacitors are also called condensers. This term developed because electric charges collect, or condense, on the plates of a capacitor, much like water vapor collects and condenses on a cold bottle or glass.

CAPACITOR CONSTRUCTION AND OPERATION

CONSTRUCTION A capacitor (also called a condenser) consists of two conductive plates with an insulating material between them. The insulating material is commonly called a **dielectric**. This substance is a poor conductor of electricity and can include air, mica, ceramic, glass, paper, plastic, or any similar nonconductive material. The dielectric constant is the relative strength of a material against the flow of electrical current. The higher the number is, the better are the insulating properties. ● **SEE CHART 43–1**.

OPERATION When a capacitor is placed in a closed circuit, the voltage source (battery) forces electrons around the circuit. Because electrons cannot flow through the dielectric of the capacitor, excess electrons collect on what becomes the negatively charged plate. At the same time, the other plate loses electrons and, therefore, becomes positively charged. ● **SEE FIGURE 43–2**.

MATERIAL	DIELECTRIC CONSTANT
Vacuum	1
Air	1.00059
Polystyrene	2.5
Paper	3.5
Mica	5.4
Flint glass	9.9
Methyl alcohol	35
Glycerin	56.2
Pure water	81

CHART 43–1

The higher the dielectric constant is, the better are the insulating properties between the plates of the capacitor.

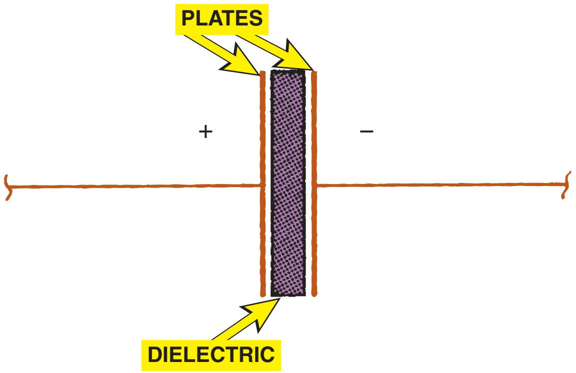


FIGURE 43–2 This simple capacitor is made of two plates separated by an insulating material, called a dielectric.

Current continues until the voltage charge across the capacitor plates becomes the same as the source voltage. At that time, the negative plate of the capacitor and the negative terminal of the battery are at the same negative potential. ● **SEE FIGURE 43–3**.

The positive plate of the capacitor and the positive terminal of the battery are also at equal positive potentials. There is a voltage charge across the battery terminals and an equal voltage charge across the capacitor plates. The circuit is in balance, and there is no current. An electrostatic field now exists between the capacitor plates because of their opposite charges. It is this field that stores energy. In other words, a charged capacitor is similar to a charged battery. ● **SEE FIGURE 43–4**.

If the circuit is opened, the capacitor holds its charge until it is connected into an external circuit through which it can discharge. When the charged capacitor is connected to an external circuit, it discharges. After discharging, both plates of the capacitor are neutral because all the energy from a circuit stored in a capacitor is returned when it is discharged. ● **SEE FIGURE 43–5**.

Theoretically, a capacitor holds its charge indefinitely. Actually, the charge slowly leaks off the capacitor through the dielectric. The better the dielectric, the longer the capacitor holds its charge. To avoid an electrical shock, any capacitor should be treated as if it were charged until it is proven to be discharged. To safely discharge a capacitor, use a test light with the clip attached to a good ground, and touch the pigtail or terminal with the point of the test light. ● **SEE FIGURE 43–6** for the symbol for capacitors as used in electrical schematics.

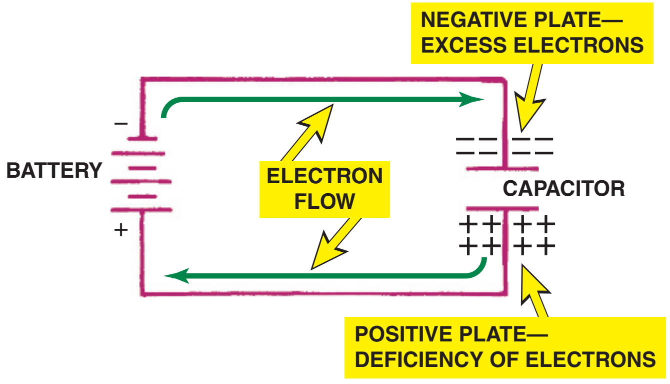


FIGURE 43–3 As the capacitor is charging, the battery forces electrons through the circuit.

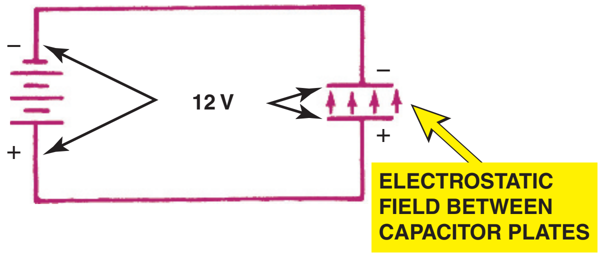


FIGURE 43–4 When the capacitor is charged, there is equal voltage across the capacitor and the battery. An electrostatic field exists between the capacitor plates. No current flows in the circuit.

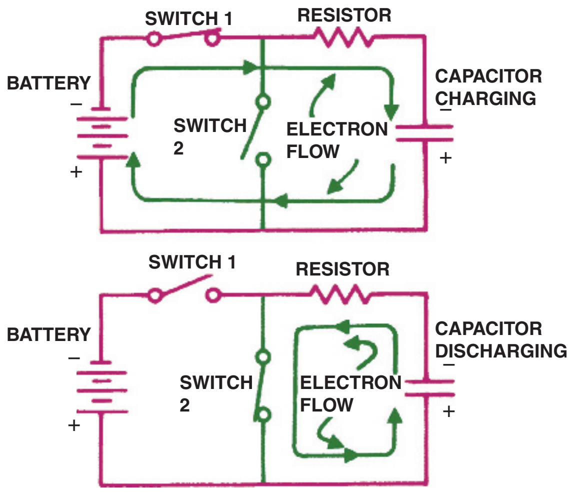


FIGURE 43–5 The capacitor is charged through one circuit (top) and discharged through another (bottom).

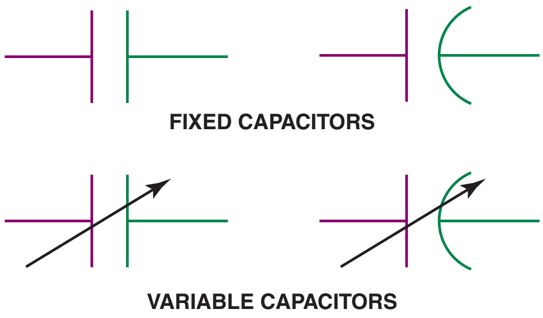


FIGURE 43–6 Capacitor symbols as shown in electrical diagrams. The negative plate is often shown curved.

FACTORS OF CAPACITANCE

Capacitance is governed by three factors:

- The surface area of the plates
- The distance between the plates
- The dielectric material

FREQUENTLY ASKED QUESTION

What Are "Points and Condenser"?

Points and condenser are used in point-type ignition systems.

Points. A set of points use one stationary contact and a movable contact that is opened by a cam lobe inside the ignition distributor. When the points are closed, current flows through the primary windings of the ignition coil and creates a strong magnetic field. As the engine rotates, the distributor can open the contact points, which opens the circuit to the coil. The stored magnetic field in the coil collapses and generates a high-voltage arc from the secondary winding of the coil. It is this spark that is sent to the spark plugs that ignites the air–fuel mixture inside the engine.

Condenser. The condenser (capacitor) is attached to the points and the case of the condenser is grounded. When the points start to open, the charge built up in the primary winding of the coil likely starts to arc across the opening points. To prevent the points from arcing and to increase how rapidly the current is turned off, the condenser stores the current temporarily.

Points and condenser were used in vehicles and small gasoline engines until the mid-1970s. ● **SEE FIGURE 43–7**.

The larger the surface area of the plates is, the greater the capacitance because more electrons collect on a larger plate area than on a small one. The closer the plates are to each other, the greater the capacitance because a stronger electrostatic field exists between charged bodies that are close together. The insulating qualities of the dielectric material also affect capacitance. The capacitance of a capacitor is higher if the dielectric is a very good insulator.

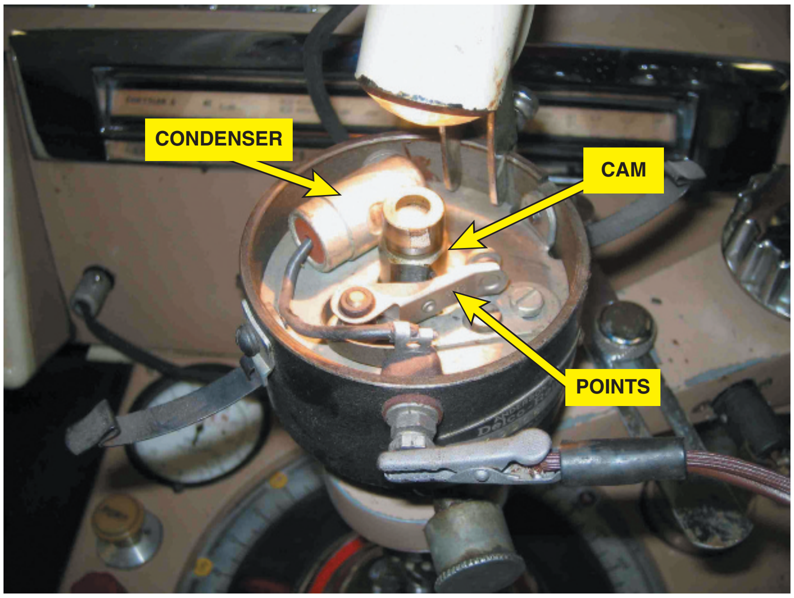


FIGURE 43–7 A point-type distributor shown with the condenser from an old vehicle being tested on a distributor machine.

MEASUREMENT OF CAPACITANCE Capacitance is measured in **farads**, which is named after Michael Faraday (1791–1867), an English physicist. The symbol for farads is the letter *F*. If a charge of 1 coulomb is placed on the plates of a capacitor and the potential difference between them is 1 volt, the capacitance is defined to be 1 farad, or 1 F. One coulomb is equal to the charge of 6.25×10^{18} electrons. One farad is an extremely large quantity of capacitance. Microfarads (0.000001 farad), or μF, are more commonly used.

The capacitance of a capacitor is proportional to the quantity of charge that can be stored in it for each volt difference in potential.

USES FOR CAPACITORS

SPIKE SUPPRESSION A capacitor can be used in parallel to a coil to reduce the resulting voltage spike that occurs when the circuit is opened. The energy stored to the magnetic field of the coil is rapidly released at this time. The capacitor acts to absorb the high voltage produced and stop it from interfering with other electronic devices, such as automotive radio and video equipment.

NOISE FILTERING Interference in a sound system or radio is usually due to alternating current (AC) voltage created somewhere in the vehicle, such as in the alternator. A capacitor does the following:

- Blocks the flow of direct current (DC)
- Allows AC to pass

By connecting a capacitor (condenser) to the power lead of the radio or sound system amplifier, the AC voltage passes through the capacitor to the ground, where the other end of the capacitor is connected. Therefore, the capacitor provides a path for the AC without affecting the DC power circuit. ● **SEE FIGURE 43–8**.

Because a capacitor stores a voltage charge, it opposes or slows any voltage change in a circuit. Therefore, capacitors are often used as voltage "shock absorbers." You sometimes find a capacitor attached to one terminal of an ignition coil. In this application, the capacitor absorbs and dampens changes in ignition voltage that interfere with radio reception.

SUPPLEMENTAL POWER SOURCE A capacitor can be used to supply electrical power for short bursts in an audio system to help drive the speakers. Woofers and subwoofers require a lot of electrical current that often cannot be delivered by the amplifier itself. ● **SEE FIGURE 43–9**.

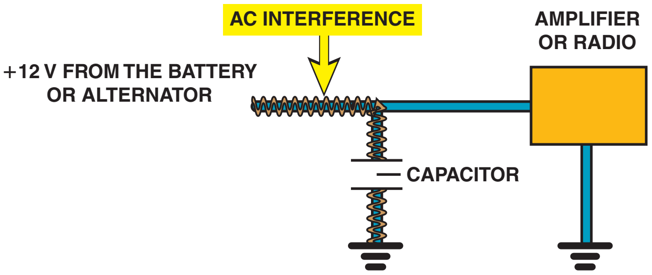


FIGURE 43–8 A capacitor blocks direct current (DC), but passes alternating current (AC). A capacitor makes a very good noise suppressor because most of the interference is AC, and the capacitor conducts this AC to ground before it can reach the radio or amplifier.

FIGURE 43–9 A 1 farad capacitor used to boost the power to large speakers.

TIMER CIRCUITS Capacitors are used in electronic circuits as part of a timer, to control window defoggers, interior lighting, pulse wipers, and automatic headlights. The capacitors store energy and are allowed to discharge through a resistance load. The greater the capacity of the capacitor and the higher the resistance load, the longer the time it takes for the capacitor to discharge.

COMPUTER MEMORY In most cases, the main memory of a computer is a high-speed random-access memory (RAM). One type of main memory called dynamic random-access memory (DRAM) is the most commonly used type of RAM. A single memory chip is made up of several million memory cells. In a DRAM chip, each memory cell consists of a capacitor. When a capacitor is electrically charged, it is said to store the binary digit 1, and when discharged, it represents 0.

CAPACITORS IN CIRCUITS

CAPACITORS IN PARALLEL Capacitance can be increased in a circuit by connecting capacitors in parallel. For example, if a greater boost is needed for a sound system, then additional capacitors should be connected in parallel because their value adds together. ● **SEE FIGURE 43–10**.

Connecting two or more capacitors in parallel in effect increases plate size. Increasing plate area makes it possible to store more charge, and therefore, creates greater capacitance. To determine total capacitance of several parallel capacitors, simply add up their individual values. The following is the formula for calculating total capacitance in a circuit containing capacitors in parallel:

$$C_T = C_1 + C_2 + C_3 \cdots$$

For example, 200 μF + 200 μF = 400 μF when connected in parallel.

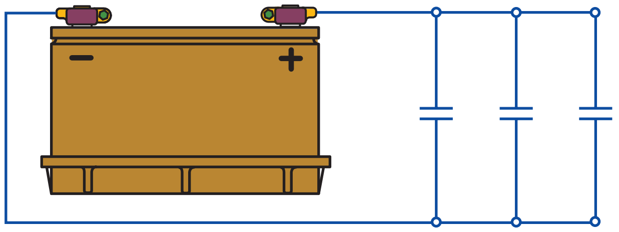


FIGURE 43–10 Capacitors in parallel effectively increase the capacitance.

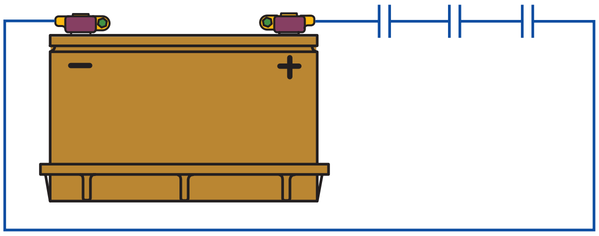


FIGURE 43–11 Capacitors in series decrease the capacitance.

CAPACITORS IN SERIES Capacitance in a circuit can be decreased by placing capacitors in series, as shown in ● **FIGURE 43–11**.

We know that capacitance of a capacitor can be decreased by placing the plates further apart. Connecting two or more capacitors in series in effect increases the distance between the plates and thickness of the dielectric, decreasing the amount of capacitance.

Following is the formula for calculating total capacitance in a circuit containing two capacitors in series:

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

For example, $\frac{220\ \mu\text{F} \times 220\ \mu\text{F}}{220\ \mu\text{F} + 220\ \mu\text{F}} = \frac{48{,}400}{440} = 110\ \mu\text{F}$

NOTE: Capacitors are often used to reduce radio interference or to improve the performance of a high-power sound system. Additional capacitance can, therefore, be added by attaching another capacitor in parallel.

REVIEW QUESTIONS

1. How does a capacitor store an electrical charge?
2. How should two capacitors be electrically connected if greater capacitance is needed?
3. How can a capacitor be used as a power source?
4. How can a capacitor be used as a noise filter?
5. Why is a large capacitor used in some high-powered sound systems?

CHAPTER QUIZ

1. A capacitor _________.
   a. stores electrons
   b. passes AC
   c. blocks DC
   d. All of the above
2. Capacitors are often used as "suppression capacitors." What does a capacitor suppress?
   a. Excessive current
   b. Voltage fluctuations
   c. Resistance
   d. Noise
3. Capacitors are commonly used as a ___________.
   a. voltage supply
   b. timer
   c. noise filter
   d. All of the above
4. A charged capacitor acts like a ___________.
   a. switch
   b. battery
   c. resistor
   d. coil
5. The unit of measurement for capacitor rating is the _________.
   a. ohm
   b. volt
   c. farad
   d. ampere
6. Two technicians are discussing the operation of a capacitor. Technician A says that a capacitor can create electricity. Technician B says that a capacitor can store electricity. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Capacitors block the flow of ___________ current but allow ___________ current to pass.
   a. strong; weak
   b. AC; DC
   c. DC; AC
   d. weak; strong
8. To increase the capacity, what could be done?
   a. Connect another capacitor in series
   b. Connect another capacitor in parallel
   c. Add a resistor between two capacitors
   d. Both a and b
9. A capacitor can be used in what components?
   a. Computer memory
   b. Radio
   c. Speaker
   d. All of the above
10. A capacitor used for spike protection is normally placed in ___________ to the load or circuit.
   a. series
   b. parallel
   c. either series or parallel
   d. parallel with a resistor in series

Chapter

44

MAGNETISM AND ELECTROMAGNETISM

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Define magnetism and explain the concepts of magnetic induction, permeability, and reluctance.
- Explain how an electromagnet works.
- Explain how electromagnetism is used in relays and solenoids.
- Discuss electromagnetic induction.
- Describe how an ignition coil works.
- Describe ways to reduce electromagnetic interference.

KEY TERMS:

Ampere-turns 502 • Counter electromotive force (CEMF) 505 • Electromagnetic interference (EMI) 507 • Flux density 499 • Flux lines 499 • Ignition control module (ICM) 507 • Left-hand rule 501 • Lenz's law 504 • Magnetic flux 499 • Magnetic induction 499 • Magnetism 498 • Mutual induction 505 • Permeability 499 • Pole 499 • Relay 502 • Reluctance 500 • Residual magnetism 499 • Turns ratio 506

FUNDAMENTALS OF MAGNETISM

DEFINITION **Magnetism** is a form of energy that is caused by the motion of electrons in some materials. It is recognized by the attraction it exerts on other materials. Like electricity, magnetism cannot be seen. It can be explained in theory, however, because it is possible to see the results of magnetism and recognize the actions that it causes. Magnetite is the most naturally occurring magnet. Naturally magnetized pieces of magnetite, called *lodestone*, attract and hold small pieces of iron. ● **SEE FIGURE 44–1**.

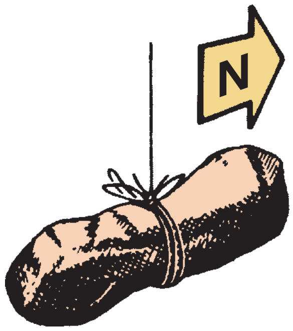


FIGURE 44–1 A freely suspended natural magnet (lodestone) points toward the magnetic north pole.

TECH TIP

A Cracked Magnet Becomes Two Magnets

Magnets are commonly used in vehicle crankshaft, camshaft, and wheel speed sensors. If a magnet is struck and cracks or breaks, the result is two smaller-strength magnets. Because the strength of the magnetic field is reduced, the sensor output voltage is also reduced. A typical problem occurs when a magnetic crankshaft sensor becomes cracked, resulting in a no-start condition. Sometimes the cracked sensor works well enough to start an engine that is cranking at normal speeds, but does not work when the engine is cold. ● **SEE FIGURE 44–2**.

Many other materials can be artificially magnetized to some degree, depending on their atomic structure. Soft iron is very easy to magnetize, whereas some materials, such as aluminum, glass, wood, and plastic, cannot be magnetized at all.

LINES OF FORCE The lines that create a field of force around a magnet are believed to be caused by the way groups of atoms are aligned in the magnetic material. In a bar magnet, the lines

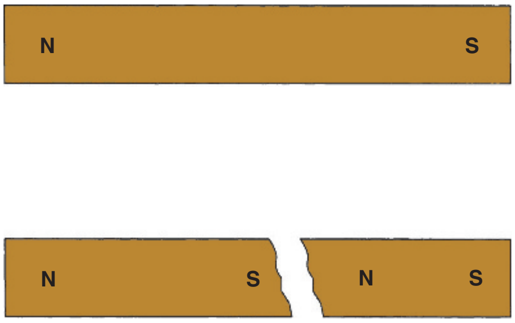


FIGURE 44–2 If a magnet breaks or is cracked, it becomes two weaker magnets.

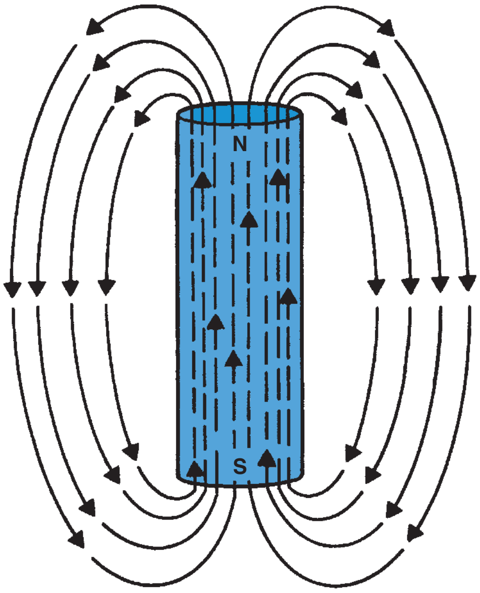


FIGURE 44–3 Magnetic lines of force leave the north pole and return to the south pole of a bar magnet.

are concentrated at both ends of the bar and form closed, parallel loops in three dimensions around the magnet. Force does not flow along these lines the way electrical current flows, but the lines *do* have direction. They come out of the north end, or **pole**, of the magnet and enter at the other end. ● **SEE FIGURE 44–3**.

The opposite ends of a magnet are called its north and south poles. In reality, they should be called the "north-seeking" and "south-seeking" poles because they seek the earth's North Pole and South Pole, respectively.

The more lines of force that are present, the stronger the magnet becomes. The magnetic lines of force, also called **magnetic flux** or **flux lines**, form a magnetic field. The terms *magnetic field, lines of force, flux,* and *flux lines* are used interchangeably.

Flux density refers to the number of flux lines per unit area. A magnetic field can be measured using a Gauss gauge, named for German scientist Johann Carl Friedrick Gauss (1777–1855).

Magnetic lines of force can be seen by spreading fine iron filings or dust on a piece of paper laid on top of a magnet. A magnetic field can also be observed by using a compass. A compass is simply a thin magnet or magnetized iron needle balanced on a pivot. The needle rotates to point toward the opposite pole of a magnet. The needle can be very sensitive to small magnetic fields. Because it is a small magnet, a compass usually has one north end (marked N) and one south end (marked S). ● **SEE FIGURE 44–4**.

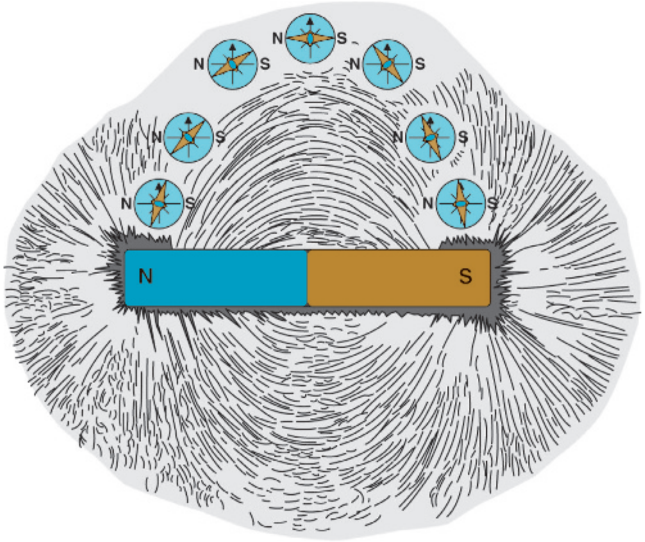


FIGURE 44–4 Iron filings and a compass can be used to observe the magnetic lines of force.

MAGNETIC INDUCTION If a piece of iron or steel is placed in a magnetic field, it also becomes magnetized. This process of creating a magnet by using a magnetic field is called **magnetic induction**.

If the metal is then removed from the magnetic field, and it retains some magnetism, this is called **residual magnetism**.

ATTRACTING OR REPELLING The poles of a magnet are called north (N) and south (S) because when a magnet is suspended freely, the poles tend to point toward the earth's North Pole and South Pole. Magnetic flux lines exit from the north pole and bend around to enter the south pole. An equal number of lines exit and enter, so magnetic force is equal at both poles of a magnet. Flux lines are concentrated at the poles and, therefore, magnetic force (flux density) is stronger at the ends.

Magnetic poles behave like positively and negatively charged particles. When unlike poles are placed close together, the lines exit from one magnet and enter the other. The two magnets are pulled together by flux lines. If like poles are placed close together, the curving flux lines meet head-on, forcing the magnets apart. Therefore, like poles of a magnet repel and unlike poles attract. ● **SEE FIGURE 44–5**.

PERMEABILITY Magnetic flux lines cannot be insulated. There is no known material through which magnetic force does not pass, if the force is strong enough. However, some materials allow the force to pass through more easily than others. This degree of passage is called **permeability**. Iron allows magnetic flux lines to pass through much more easily than air, so iron is highly permeable.

An example of this characteristic is the use of a reluctor wheel in magnetic-type camshaft position (CMP) and crankshaft position (CKP) sensors. The teeth on a reluctor cause the magnetic field to increase as each tooth gets closer to the sensor, and decrease as the tooth moves away, thus creating an AC voltage signal. ● **SEE FIGURE 44–6**.

RELUCTANCE Although there is no absolute insulation for magnetism, certain materials resist the passage of magnetic force. This can be compared to resistance without an electrical circuit.

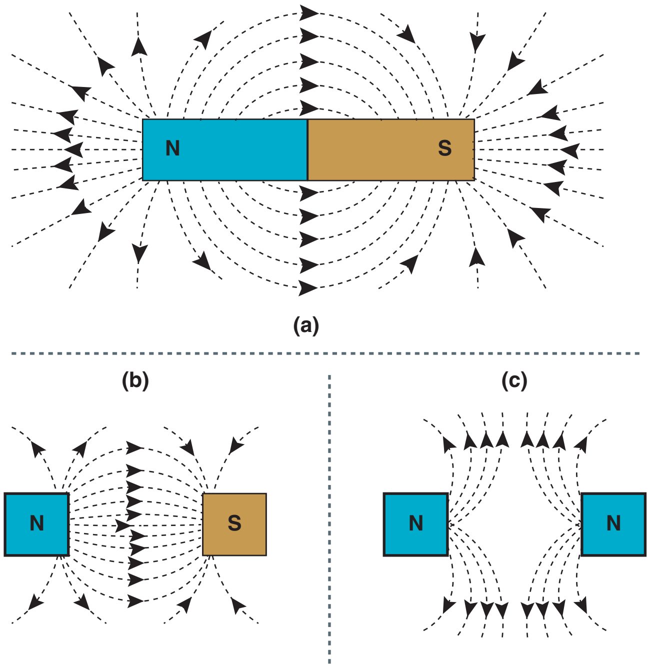


FIGURE 44–5 (a) Magnetic lines of force spread out from around an isolated magnet. (b) Opposite poles attract. (c) Similar poles repel.

Air does not allow easy passage, so air has a high **reluctance**. Magnetic flux lines tend to concentrate in permeable materials and avoid materials with high reluctance. As with electricity, magnetic force follows the path of least resistance.

ELECTROMAGNETISM

DEFINITION Scientists did not discover that current-carrying conductors also are surrounded by a magnetic field until 1820. These fields may be made many times stronger than those surrounding conventional magnets. Also, the magnetic field strength around a conductor may be controlled by changing the current.

- As current increases, more flux lines are created and the magnetic field expands.
- As current decreases, the magnetic field contracts. The magnetic field collapses when the current is shut off.
- The interaction and relationship between magnetism and electricity is known as electromagnetism.

CREATING AN ELECTROMAGNET An easy way to create an electromagnet is to wrap a nail with 20 turns of insulated wire and connect the ends to the terminals of a 1.5 volt dry cell battery. When energized, the nail becomes a magnet and is able to pick up tacks or other small steel objects.

STRAIGHT CONDUCTOR The magnetic field surrounding a straight, current-carrying conductor consists of several concentric cylinders of flux that are the length of the wire. The amount

TECH TIP

Magnetize a Steel Needle

A piece of steel can be magnetized by rubbing a magnet in one direction along the steel. This causes the atoms to line up in the steel, so it acts like a magnet. The steel often does not remain magnetized, whereas the true magnet is permanently magnetized.

When soft iron or steel is used, such as a paper clip, it loses its magnetism quickly. The atoms in a magnetized needle can be disturbed by heating it or by dropping the needle on a hard object, which causes the needle to lose its magnetism. Soft iron is used inside ignition coils because it does not keep its magnetism.

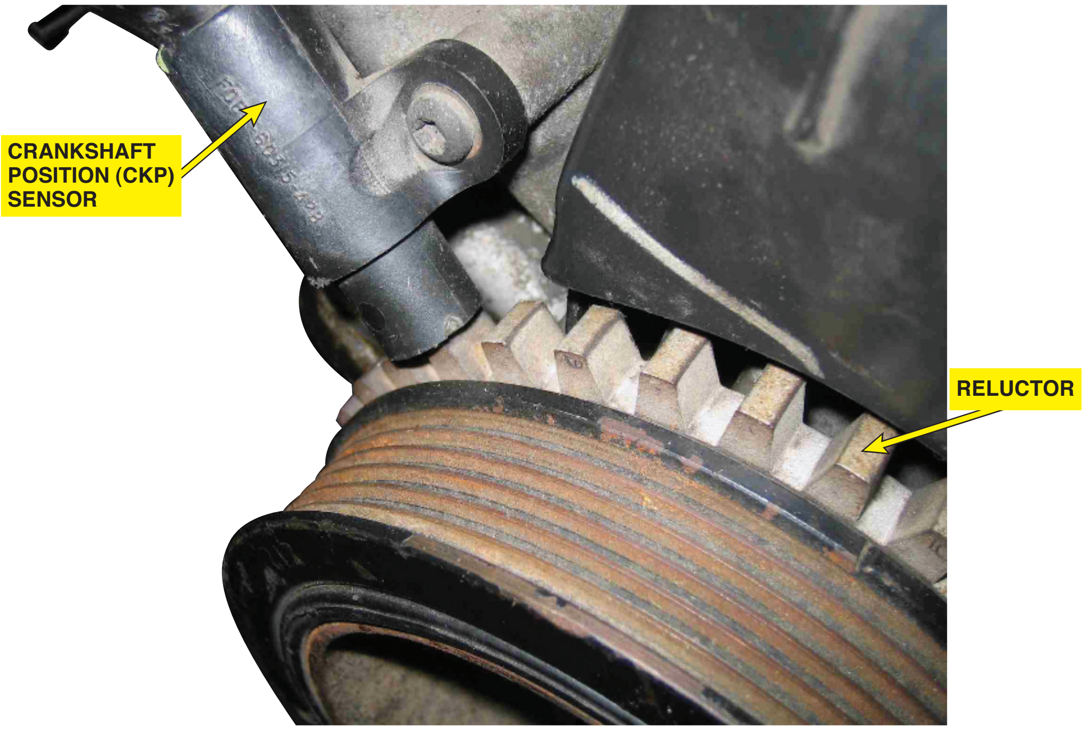


FIGURE 44–6 A crankshaft position sensor and reluctor (notched wheel).

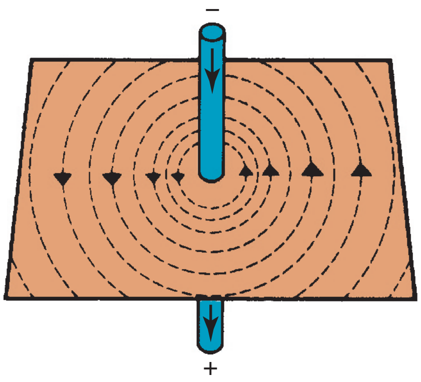


FIGURE 44–7 A magnetic field surrounds a straight, current-carrying conductor.

of current flow (amperes) determines how many flux lines (cylinders) there are and how far out they extend from the surface of the wire. ● **SEE FIGURE 44–7**.

LEFT-HAND AND RIGHT-HAND RULES Magnetic flux cylinders have direction, just as the flux lines surrounding a bar magnet have direction. The **left-hand rule** is a simple way to determine this direction. When you grasp a conductor with your left hand so that your thumb points in the direction of electron flow (– to +) through the conductor, your fingers curl around the wire in the direction of the magnetic flux lines. ● **SEE FIGURE 44–8**.

Most automotive circuits use the conventional theory of current (+ to –) and, therefore, the right-hand rule is used to determine the direction of the magnetic flux lines. ● **SEE FIGURE 44–9**.

FIELD INTERACTION The cylinders of flux surrounding current-carrying conductors interact with other magnetic fields. In the following illustrations, the cross symbol (+) indicates current moving inward, or away from you. It represents the tail of an arrow. The dot symbol (·) represents an arrowhead and indicates current moving outward. If two conductors carry current in opposite directions, their magnetic fields also carry current in opposite directions (according to the left-hand rule). If they are placed side by side, then the opposing flux lines between the conductors create a strong magnetic field. Current-carrying conductors tend to move out of a strong field into a weak field, so the conductors move away from each other. ● **SEE FIGURE 44–10**.

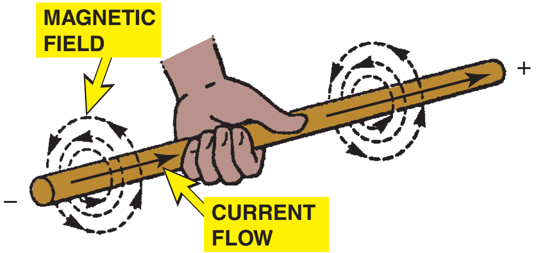


FIGURE 44–8 The left-hand rule for magnetic field direction is used with the electron flow theory.

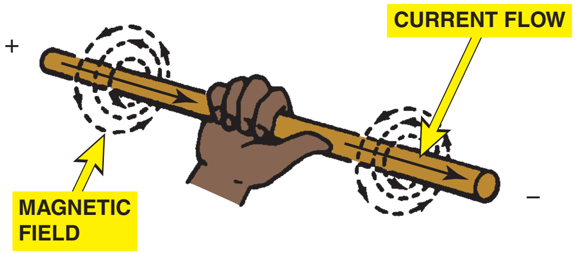


FIGURE 44–9 The right-hand rule for magnetic field direction is used with the conventional theory of electron flow.

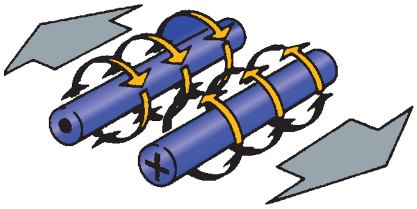


FIGURE 44–10 Conductors with opposing magnetic fields move apart into weaker fields.

If the two conductors carry current in the same direction, their fields are in the same direction. The flux lines between the two conductors cancel each other out, leaving a very weak field between them. The conductors are drawn into this weak field, and they tend to move toward each other.

MOTOR PRINCIPLE Electric motors, such as vehicle starter motors, use this magnetic field interaction to convert electrical energy into mechanical energy. If two conductors carrying current in opposite directions are placed between strong north and south poles, the magnetic field of the conductor interacts with the magnetic fields of the poles. The counterclockwise field of the top conductor adds to the fields of the poles and creates a strong field beneath the conductor. The conductor then tries to move up to get out of this strong field. The clockwise field of the lower conductor adds to the field of the poles and creates a strong field above the conductor. The conductor then tries to move down to get out of this strong field. These forces cause the center of the motor, where the conductors are mounted, to turn clockwise. ● **SEE FIGURE 44–11**.

COIL CONDUCTOR If several loops of wire are made into a coil, then the magnetic flux density is strengthened. Flux lines around a coil are the same as the flux lines around a bar magnet. ● **SEE FIGURE 44–12**.

TECH TIP

Electricity and Magnetism

Electricity and magnetism are closely related because any electrical current flowing through a conductor creates a magnetic field. Any conductor moving through a magnetic field creates an electrical current. This relationship can be summarized as follows:

- Electricity creates magnetism.
- Magnetism creates electricity.

From a service technician's point of view, this relationship is important because wires carrying current should always be routed as the factory intended to avoid causing interference with another circuit or electronic component. This is especially important when installing or servicing spark plug wires, which carry high voltages and can cause high electromagnetic interference.

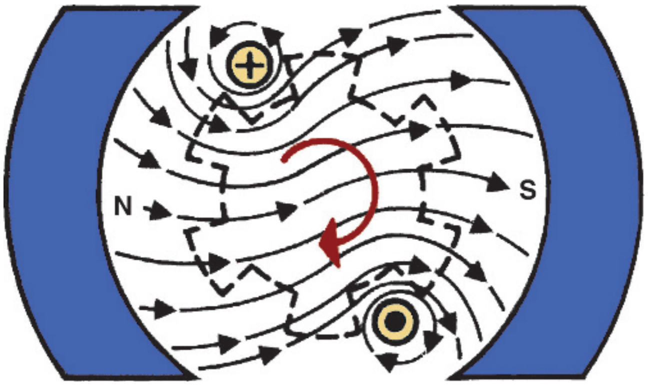


FIGURE 44–11 Electric motors use the interaction of magnetic fields to produce mechanical energy.

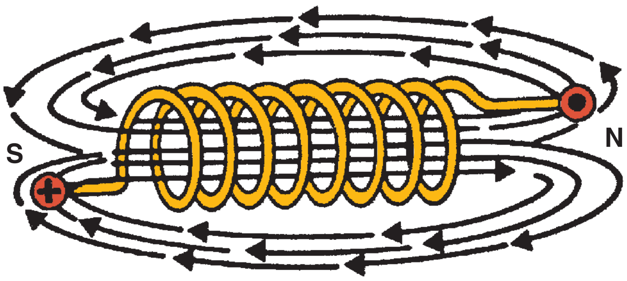


FIGURE 44–12 The magnetic lines of flux surrounding a coil look like those surrounding a bar magnet.

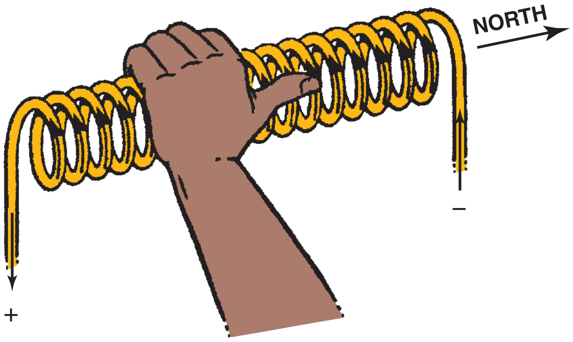


FIGURE 44–13 The left-hand rule for coils is shown.

They exit from the north pole and enter at the south pole. Use the left-hand rule to determine the north pole of a coil, as shown in ● **FIGURE 44–13**.

Grasp the coil with your left hand so that your fingers point in the direction of electron flow; your thumb points toward the north pole of the coil.

ELECTROMAGNETIC STRENGTH The magnetic field surrounding a current-carrying conductor can be strengthened (increased) in three ways:

- Place a soft iron core in the center of the coil.
- Increase the number of turns of wire in the coil.
- Increase the current flow through the coil windings.

Because soft iron is highly permeable, magnetic flux lines pass through it easily. If a piece of soft iron is placed inside a coiled conductor, the flux lines concentrate in the iron core, rather than pass through the air, which is less permeable. The concentration of force greatly increases the strength of the magnetic field inside the coil. Increasing the number of turns in a coil and/or increasing the current flow through the coil results in greater field strength and is proportional to the number of turns. The magnetic field strength is often expressed in the units called **ampere-turns**. Coils with an iron core are called electromagnets. ● **SEE FIGURE 44–14**.

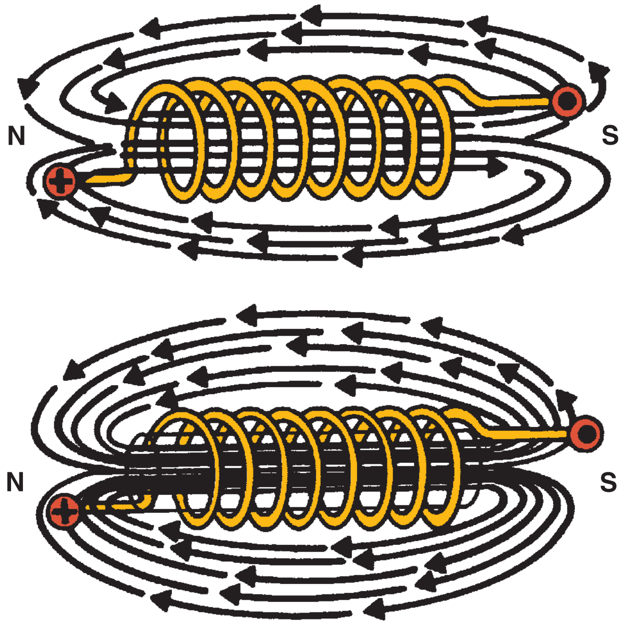


FIGURE 44–14 An iron core concentrates the magnetic lines of force surrounding a coil.

USES OF ELECTROMAGNETISM

RELAYS As mentioned in Chapter 42, a **relay** is a control device that allows a small amount of current to control a large amount of current in another circuit. A simple relay contains an electromagnetic coil in series with a battery and a switch. Near the electromagnet is a movable flat arm, called an *armature*, of some material that is attracted by a magnetic field. ● **SEE FIGURE 44–15**.

The armature pivots at one end and is held a small distance away from the electromagnet by a spring (or by the spring steel of the movable arm itself). A contact point, made of a good conductor, is attached to the free end of the armature. Another contact point is fixed a small distance away. The two contact points are wired in series with an electrical load and the battery.

When the switch is closed, the following occurs:

1. Current travels from the battery through a coil, creating an electromagnet.
2. The magnetic field created by the current attracts the armature, pulling it down until the contact points close.
3. Closing the contacts allows current in the heavy current circuit from the battery to the load.

When the switch is open, the following occurs:

1. The electromagnet loses its magnetism when the current is shut off.
2. Spring pressure lifts the arm backup.

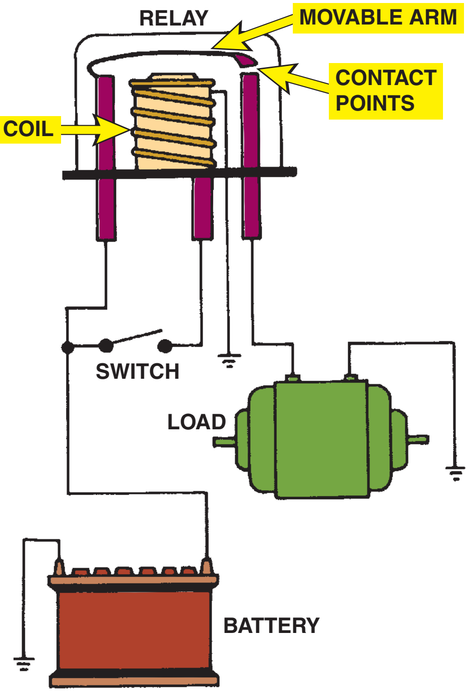


FIGURE 44–15 An electromagnetic switch that has a movable arm is referred to as a relay.

FREQUENTLY ASKED QUESTION

Solenoid or Relay?

Often, either term is used to describe the same part in service information. ● **SEE CHART 44–1** for a summary of the differences.

3. The heavy current circuit is broken by the opening of the contact points.

Relays may also be designed with normally closed contacts that open when current passes through the electromagnetic coil.

SOLENOID A solenoid is an example of an electromagnetic switch. A solenoid uses a movable core rather than a movable arm and is generally used in higher-amperage applications. A solenoid can be a separate unit or attached to a starter, such as a starter solenoid. ● **SEE FIGURE 44–16.**

ELECTROMAGNETIC INDUCTION

PRINCIPLES INVOLVED Electricity can be produced by using the relative movement of an electrical conductor and a magnetic field. The following three items are necessary to produce electricity (voltage) from magnetism:

1. Electrical conductor (usually a coil of wire)
2. Magnetic field
3. Movement of either the conductor or the magnetic field

Therefore:

- Electricity creates magnetism.
- Magnetism can create electricity.

Magnetic flux lines create an electromotive force, or voltage, in a conductor if either the flux lines or the conductor is moving. This movement is called *relative motion*. This process is called induction, and the resulting electromotive force is called *induced voltage*. This creation of a voltage (electricity) in a conductor by a moving magnetic field is called electromagnetic induction. ● **SEE FIGURE 44–17.**

VOLTAGE INTENSITY Voltage is induced when a conductor cuts across magnetic flux lines. The amount of the voltage depends on the rate at which the flux lines are broken. The more flux lines that are broken per unit of time, the greater the induced voltage. If a single conductor breaks 1 million flux lines per second, 1 volt is induced.

There are four ways to increase induced voltage:

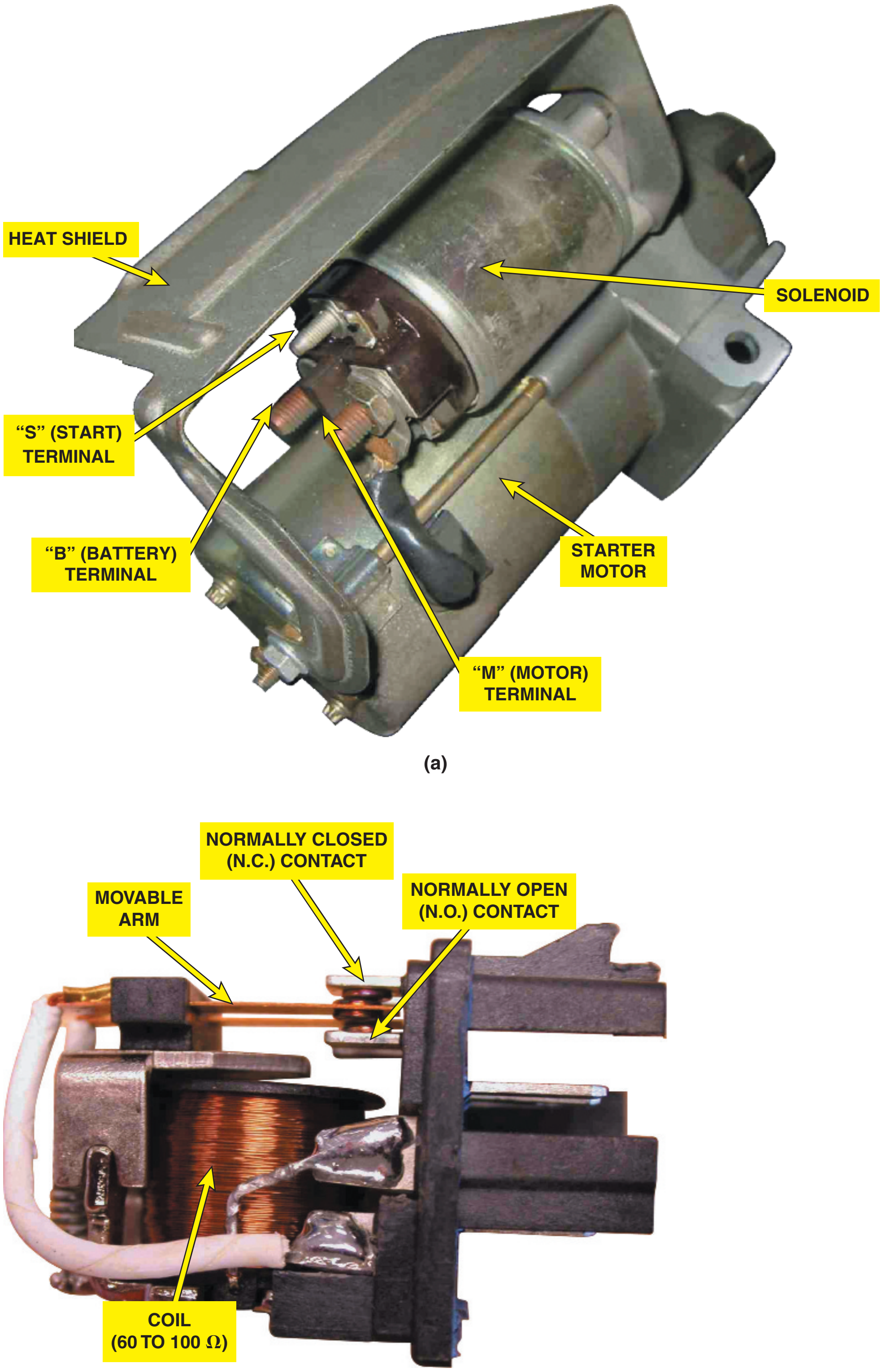
- Increase the strength of the magnetic field, so there are more flux lines.
- Increase the number of conductors that are breaking the flux lines.
- Increase the speed of the relative motion between the conductor and the flux lines so that more lines are broken per time unit.
- Increase the angle between the flux lines and the conductor to a maximum of 90 degrees. There is no voltage induced if the conductors move parallel to, and do not break, any flux lines.

Maximum voltage is induced if the conductors break flux lines at 90 degrees. Induced voltage varies proportionately at angles between 0 and 90 degrees. ● **SEE FIGURE 44–18.**

	CONSTRUCTION	AMPERAGE RATING (AMPERE)	USES	CALLED IN SERVICE INFORMATION
Relay	Uses a movable arm Coil: 60–100 ohms requiring 0.12–0.20 ampere to energize	1–30	Lower current switching, lower cost, more commonly used	Electromagnetic switch or relay
Solenoid	Uses a movable core Coil(s): 0.2–0.6 ohm requiring 20–60 amperes to energize	30–400	Higher cost, used in starter motor circuits and other high-amperage applications	Solenoid, relay, or electromagnetic switch

CHART 44–1

Comparison between a relay and a solenoid.


HEAT SHIELD
SOLENOID
"S" (START) TERMINAL
"B" (BATTERY) TERMINAL
STARTER MOTOR
"M" (MOTOR) TERMINAL
NORMALLY CLOSED (N.C.) CONTACT
MOVABLE ARM
NORMALLY OPEN (N.O.) CONTACT
COIL (60 TO 100 Ω)

(a)

(b)

FIGURE 44–16 (a) A starter with attached solenoid. All the current needed by the starter flows through the two large terminals of the solenoid and through the solenoid contacts inside. (b) A relay is designed to carry lower current, compared to a solenoid, and uses a movable arm.

Voltage can be induced electromagnetically and can be measured. Induced voltage creates current. The direction of induced voltage (and the direction in which current moves) is called *polarity* and depends upon the direction of the flux lines, as well as the direction of relative motion.

LENZ'S LAW An induced current moves so that its magnetic field opposes the motion that induced the current. This principle is called **Lenz's law**. The relative motion of a conductor and a magnetic field is opposed by the magnetic field of the current it has induced.

SELF-INDUCTION When current begins to flow in a coil, the flux lines expand as the magnetic field forms and strengthens. As current increases, the flux lines continue to expand, cutting across the wires of the coil and actually inducing another voltage within the same coil. Following Lenz's law, this self-induced voltage tends to *oppose* the current that produces it. If the current continues to increase, the second voltage opposes the increase. When the current stabilizes, the counter voltage is no longer induced because there are no more expanding flux lines (no relative motion). When current to the coil is shut

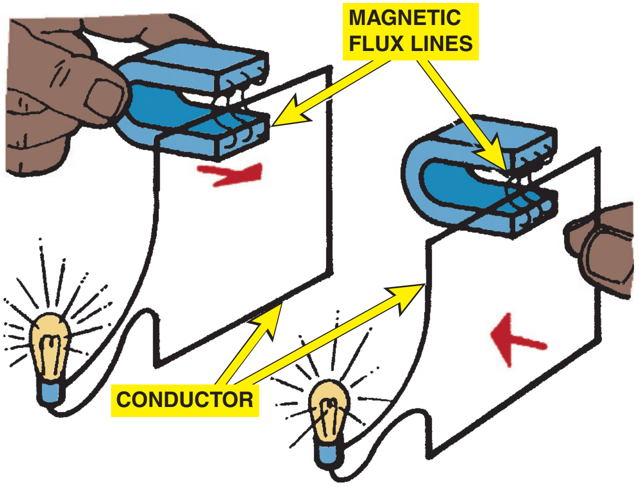

MAGNETIC FLUX LINES
CONDUCTOR

FIGURE 44–17 Voltage can be induced by the relative motion between a conductor and magnetic lines of force.

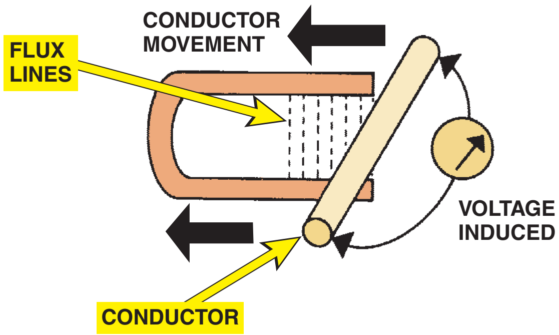

FLUX LINES
CONDUCTOR MOVEMENT
VOLTAGE INDUCED
CONDUCTOR

FIGURE 44–18 Maximum voltage is induced when conductors cut across the magnetic lines of force (flux lines) at a 90-degree angle.

off, the collapsing magnetic flux lines self-induce a voltage in the coil that tries to maintain the original current. The self-induced voltage *opposes* and *slows* the *decrease* in the original current. The self-induced voltage that opposes changes in current flow in an inductor is called **counter electromotive force (CEMF)**.

MUTUAL INDUCTION When two coils are close together, energy may be transferred from one to the other by magnetic coupling, called mutual induction. **Mutual induction** means that the expansion or collapse of the magnetic field around one coil induces a voltage in the second coil.

IGNITION COILS

IGNITION COIL WINDINGS Ignition coils use two windings and are wound on the same iron core:

- One coil winding is connected to a battery through a switch and is called the *primary winding*.
- The other coil winding is connected to an external circuit and is called the *secondary winding*.

When the switch is open, there is no current in the primary winding. There is no magnetic field and, therefore, no voltage in the secondary winding. When the switch is closed, current is introduced and a magnetic field builds up around both windings. The primary winding thus changes electrical energy from the battery into magnetic energy of the expanding field. As the field expands, it cuts across the secondary winding and induces a voltage in it. A meter connected to the secondary circuit shows current. ● **SEE FIGURE 44–19**.

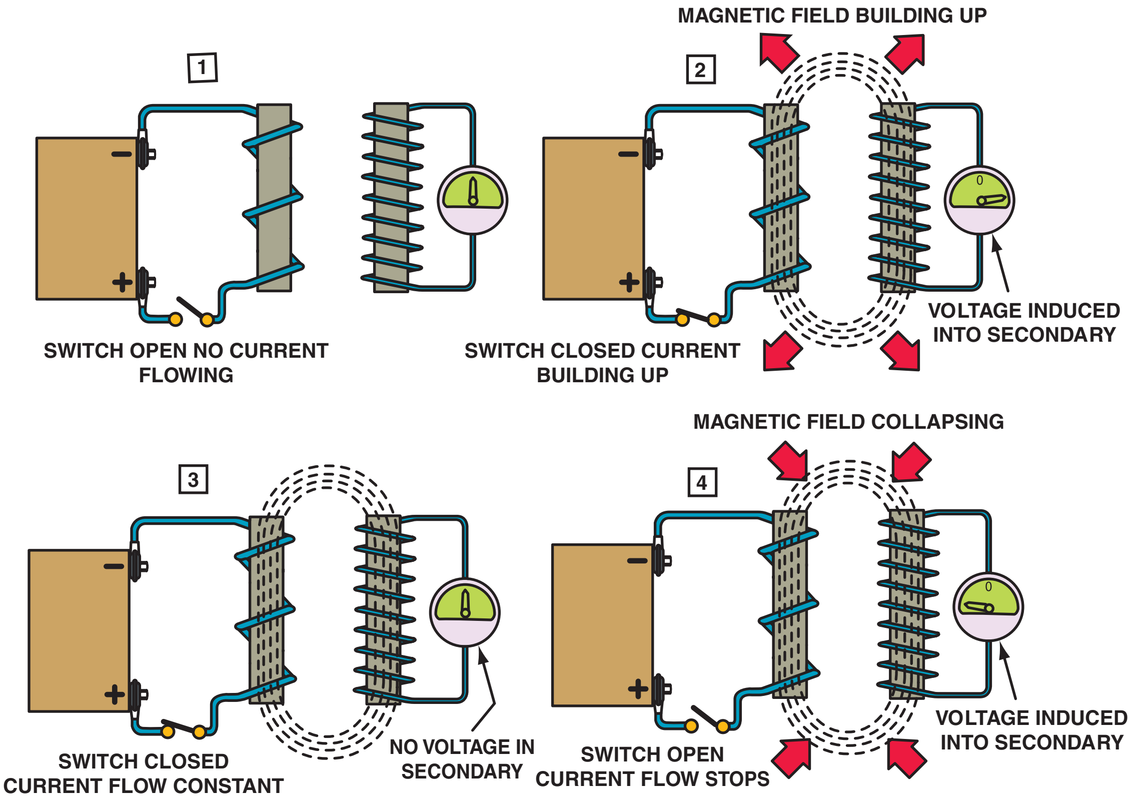

MAGNETIC FIELD BUILDING UP
1
2
SWITCH OPEN NO CURRENT FLOWING
SWITCH CLOSED CURRENT BUILDING UP
VOLTAGE INDUCED INTO SECONDARY
MAGNETIC FIELD COLLAPSING
3
4
SWITCH CLOSED CURRENT FLOW CONSTANT
NO VOLTAGE IN SECONDARY
SWITCH OPEN CURRENT FLOW STOPS
VOLTAGE INDUCED INTO SECONDARY

FIGURE 44–19 Mutual induction occurs when the expansion or collapse of a magnetic field around one coil induces a voltage in a second coil.

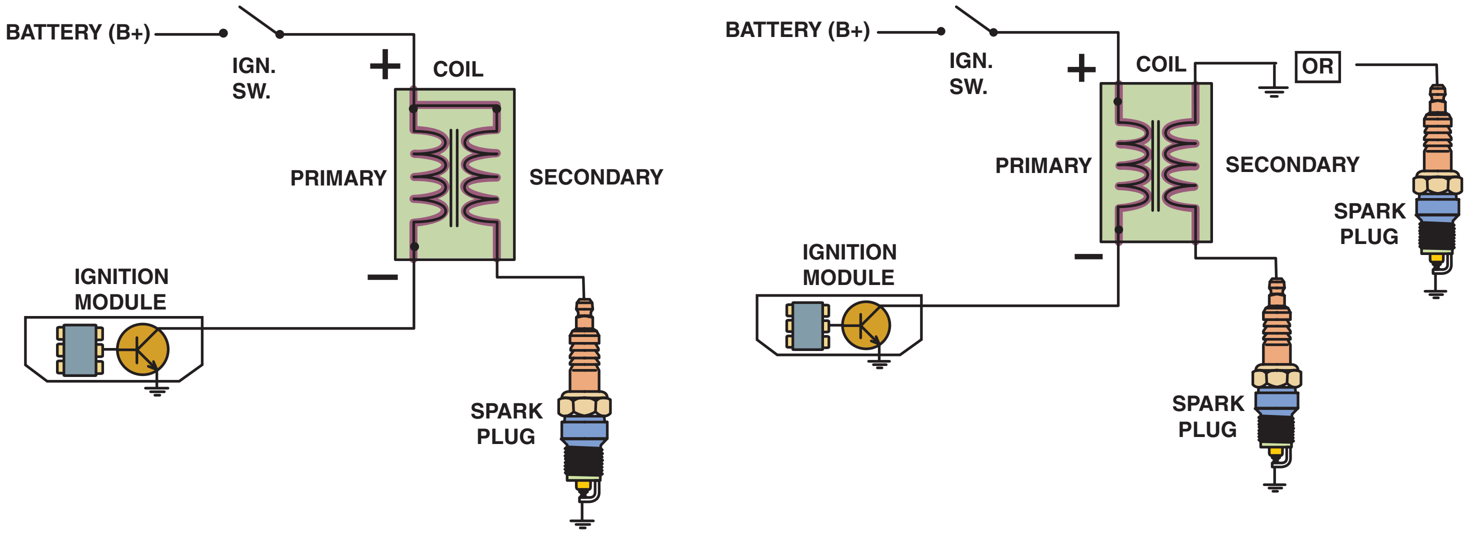


FIGURE 44–20 Some ignition coils are electrically connected, called "married" (left figure), whereas others use separated primary and secondary windings, called "divorced" (right figure).

When the magnetic field has expanded to its full strength, it remains steady as long as the same amount of current exists. The flux lines have stopped their cutting action. There is no relative motion and no voltage in the secondary winding, as shown on the meter.

When the switch is opened, primary current stops and the field collapses. As it does, flux lines cut across the secondary winding, but in the opposite direction. This induces a secondary voltage with current in the opposite direction, as shown on the meter.

Mutual induction is used in ignition coils. In an ignition coil, low-voltage primary current induces a very high secondary voltage because of the different number of turns in the primary and secondary windings. Because the voltage is increased, an ignition coil is also called a *step-up transformer*.

- **Electrically connected windings.** Many ignition coils contain two separate, but electrically connected, windings of copper wire. This type of coil is called a "married" type and is used in older distributor-type ignition systems and in many coil-on-plug (COP) designs.
- **Electrically insulated windings.** Other coils are true transformers in which the primary and secondary windings are not electrically connected. This type of coil is often called a "divorced" type and is used in all waste-spark-type ignition systems.

● **SEE FIGURE 44–20**.

IGNITION COIL CONSTRUCTION The center of an ignition coil contains a core of laminated soft iron (thin strips of soft iron). This core increases the magnetic strength of the coil. Surrounding the laminated core are approximately 20,000 turns of fine wire (approximately 42 gauge). These windings are called the secondary coil windings. Surrounding the secondary windings are approximately 150 turns of heavy wire (approximately 21 gauge). These windings are called the primary coil windings. The secondary winding has about 100 times the number of turns of the primary winding, referred to as the **turns ratio** (approximately 100:1). In many coils, these windings are surrounded with a thin metal shield and insulating paper and placed into a metal container. The metal container and shield help retain the magnetic field produced in the coil windings. The primary and secondary windings produce heat because of the electrical resistance in the turns of wire. Many coils contain oil to help cool the ignition coil. Other coil designs include the following:

- **Air-cooled, epoxy-sealed E coil.** The *E coil* is so named because the laminated, soft iron core is E shaped, with the coil wire turns wrapped around the center "finger" of the E and the primary winding wrapped inside the secondary winding. ● **SEE FIGURE 44–21**.
- **Spool design.** Used mostly for coil-on-plug design, the coil windings are wrapped around a nylon or plastic spool or bobbin. ● **SEE FIGURE 44–22**.

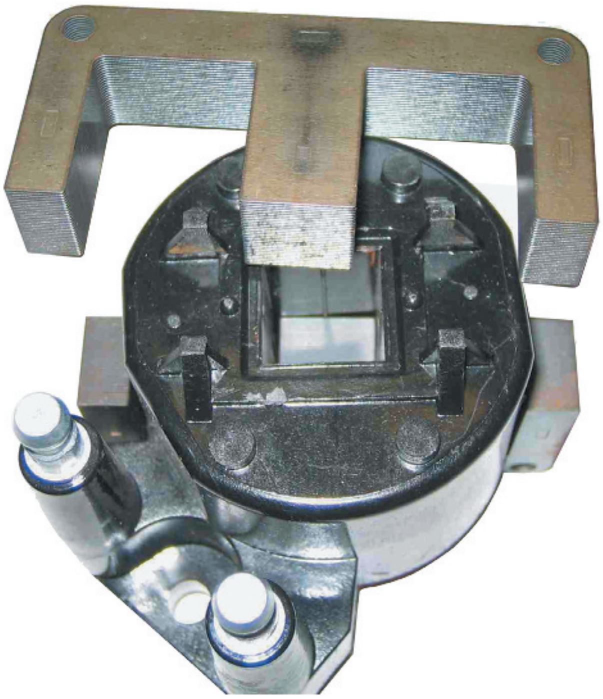


FIGURE 44–21 A GM waste-spark ignition coil showing the section of laminations that is shaped like the letter *E*. These mild steel laminations improve the efficiency of the coil.

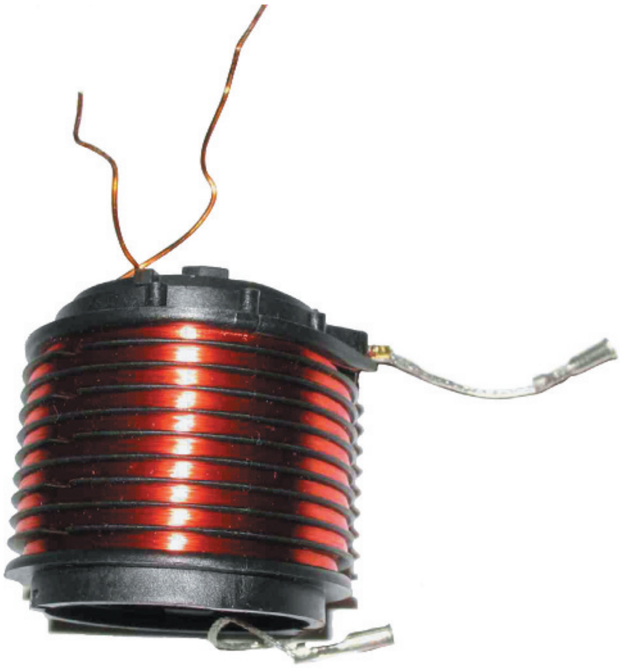


FIGURE 44–22 The coil-on-plug (COP) design typically uses a bobbin-type coil.

IGNITION COIL OPERATION The negative terminal is attached to an **ignition control module (ICM**, or igniter), which opens and closes the primary ignition circuit by opening or closing the ground return path of the circuit. When the ignition switch is on, voltage should be available at *both* the positive terminal and the negative terminal of the coil if the primary windings of the coil have continuity.

A spark is created by the following sequence of events:

- A magnetic field is created in the primary winding of the coil when there are 12 volts applied to the primary coil winding and the ignition control module grounds the other end on the coil.
- When the ignition control module (or powertrain control module) opens the ground circuit, the stored magnetic field collapses and creates a high voltage (up to 40,000 volts or more) in the secondary winding.
- The high-voltage pulse then flows to the spark plug and creates a spark at the ground electrode inside the engine that ignites the air–fuel mixture inside the cylinder.

ELECTROMAGNETIC INTERFERENCE

DEFINITION Until the advent of onboard computers, **electromagnetic interference (EMI)** was not a source of real concern to automotive engineers. The problem was mainly one of *radio-frequency interference* (RFI), caused primarily by the use of secondary ignition cables. Using spark plug wires that contained a high-resistance, nonmetallic core made of carbon, linen, or fiberglass strands impregnated with graphite mostly solved RFI from the secondary ignition system. RFI is a part of electromagnetic interference, which deals with interference that affects radio reception. All electronic devices used in vehicles are affected by EMI/RFI.

HOW EMI IS CREATED Whenever there is current in a conductor, an electromagnetic field is created. When current stops and starts, as in a spark plug cable or a switch that opens and closes, the field strength changes. Each time this happens, it creates an electromagnetic signal wave. If it happens rapidly enough, the resulting high-frequency signal waves, or EMI, interfere with radio and television transmission or with other electronic systems, such as those under the hood. This is an undesirable side effect of the phenomenon of electromagnetism.

Static electric charges caused by friction of the tires with the road, or the friction of engine drive belts contacting their pulleys, also produce EMI. Drive axles, driveshafts, and clutch or brake-lining surfaces are other sources of static electric charges.

There are four ways of transmitting EMI, all of which can be found in a vehicle:

- Conductive coupling is actual physical contact through circuit conductors.
- Capacitive coupling is the transfer of energy from one circuit to another through an electrostatic field between two conductors.
- Inductive coupling is the transfer of energy from one circuit to another as the magnetic fields between two conductors form and collapse.
- Electromagnetic radiation is the transfer of energy by the use of radio waves from one circuit or component to another.

EMI SUPPRESSION DEVICES There are four general ways in which EMI is reduced.

- **Resistance suppression.** Adding resistance to a circuit to suppress RFI works only for high-voltage systems. This has been done by the use of resistance spark plug cables, resistor spark plugs, and the silicone grease used on the distributor cap and rotor of some electronic ignitions.
- **Suppression capacitors and coils.** Capacitors are installed across many circuits and switching points to absorb voltage fluctuations. Among other applications, they are used across the following:
  - The primary circuit of some electronic ignition modules
  - The output terminal of most alternators
  - The armature circuit of some electric motors

Coils reduce current fluctuations resulting from self-induction. They are often combined with capacitors to act as EMI filter circuits for windshield wiper and electric fuel pump motors. Filters also may be incorporated in wiring connectors.

- **Shielding.** The circuits of onboard computers are protected to some degree from external electromagnetic waves by their metal housings.
- **Ground wires or straps.** Ground wires or braided straps between the engine and chassis of an automobile help suppress EMI conduction and radiation by providing a low-resistance circuit ground path. Such suppression ground straps are often installed between rubber-mounted components and body parts. On some models, ground straps are installed between body parts, such as between the hood and a fender panel, where no electrical circuit exists. The strap has no other job than to suppress EMI. Without it, the sheet-metal body and hood could function as a large capacitor. The space between the fender and hood could form an electrostatic field and couple with the computer circuits in the wiring harness routed near the fender panel. ● **SEE FIGURE 44–23**.

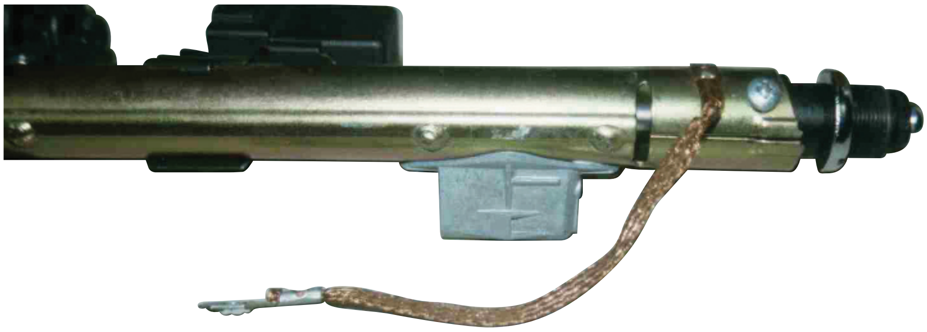


FIGURE 44–23 To help prevent underhood electromagnetic devices from interfering with the antenna input, it is important that all ground wires, including the one from this power antenna, be properly grounded.

REVIEW QUESTIONS

1. What is the relationship between electricity and magnetism?
2. What is the difference between mutual induction and self-induction?
3. What is the result if a magnet cracks?
4. How can EMI be reduced or controlled?
5. What is the difference between a "married" ignition coil and a "divorced" ignition coil?

CHAPTER QUIZ

1. Technician A says that magnetic lines of force can be seen by placing iron filings on a piece of paper and then holding them over a magnet. Technician B says that the effects of magnetic lines of force can be seen using a compass. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. Unlike magnetic poles ___________, and like magnetic poles ___________.
   - **a.** repel; attract
   - **b.** attract; repel
   - **c.** repel; repel
   - **d.** attract; attract
3. The conventional theory for current flow is being used to determine the direction of magnetic lines of force. Technician A says that the left-hand rule should be used. Technician B says that the right-hand rule should be used. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Technician A says that a relay is an electromagnetic switch. Technician B says that a solenoid uses a movable core. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Two technicians are discussing electromagnetic induction. Technician A says that the induced voltage can be increased if the speed is increased between the conductor and the magnetic lines of force. Technician B says that the induced voltage can be increased by increasing the strength of the magnetic field. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. An ignition coil operates using the principle(s) of ___________.
   - **a.** electromagnetic induction
   - **b.** self-induction
   - **c.** mutual induction
   - **d.** All of the above
7. Electromagnetic interference can be reduced by using a ___________.
   - **a.** resistance
   - **b.** capacitor
   - **c.** coil
   - **d.** Any of the above
8. An ignition coil is an example of a ___________.
   - **a.** solenoid
   - **b.** step-down transformer
   - **c.** step-up transformer
   - **d.** relay
9. Magnetic field strength is measured in ___________.
   - **a.** ampere-turns
   - **b.** flux
   - **c.** density
   - **d.** coil strength
10. Two technicians are discussing ignition coils. Technician A says that some ignition coils have the primary and secondary windings electrically connected. Technician B says that some coils have totally separate primary and secondary windings that are not electrically connected. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter 45

ELECTRONIC FUNDAMENTALS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss semiconductors including doping, P-type material, and N-type material.
- Describe diodes, including zener diodes.
- Discuss high-voltage spike protection.
- Discuss diode ratings.
- Discuss light-emitting diodes.
- Describe photo diodes.
- Describe photoresistors.
- Describe silicon-controlled rectifiers.
- Describe thermistors.
- Describe rectifier bridges.
- Describe transistors, including field-effect transistors and phototransistors.
- Describe integrated circuits.
- Describe transistor gates.
- Describe operational amplifiers.
- Discuss electronic component failure causes.
- Describe how to test diodes and transistors.
- Discuss converters and inverters and how they are used.
- Explain electrostatic discharge damage and how to avoid it.

KEY TERMS:

Anode 511 • Base 516 • Bipolar transistor 516 • Cathode 511 • CHMSL 515 • Clamping diode 512 • Collector 516 • Darlington pair 517 • Despiking diode 512 • Diode 510 • Doping 509 • Dual inline pins (DIP) 518 • Emitter 516 • ESD 522 • FET 517 • Forward bias 511 • Germanium 509 • Heat sink 518 • Hole theory 510 • Impurities 509 • Integrated circuit (IC) 518 • Inverter 522 • Junction 511 • Light-emitting diode (LED) 513 • MOSFET 517 • NPN transistor 516 • NTC 515 • N-type material 510 • Op-amps 519 • Photodiodes 514 • Photons 514 • Photoresistor 514 • Phototransistor 518 • Peak inverse voltage (PIV) 513 • Peak reverse voltage (PRV) 513 • PNP transistor 516 • P-type material 510 • PWM 520 • Rectifier bridge 515 • Reverse bias 511 • SCR 515 • Semiconductors 509 • Silicon 509 • Spike protection resistor 512 • Suppression diode 512 • Thermistor 515 • Threshold voltage 516 • Transistor 516 • Zener diode 511

SEMICONDUCTORS

DEFINITION Semiconductors are neither conductors nor insulators. The flow of electrical current is caused by the movement of electrons in materials known as conductors, having *fewer* than four electrons in their atom's outer orbit. Insulators contain *more* than four electrons in their outer orbit and cannot conduct electricity because their atomic structure is stable (no free electrons).

Semiconductors are materials that contain exactly four electrons in the outer orbit of their atom structure and are, therefore, neither good conductors nor good insulators.

EXAMPLES OF SEMICONDUCTORS Two examples of semiconductor materials are **germanium** and **silicon**, which have exactly four electrons in their valance ring and no free electrons to provide current flow. However, both of these semiconductor materials can be made to conduct current if another material is added to provide the necessary conditions for electron movement.

CONSTRUCTION When another material is added to a semiconductor material in very small amounts, it is called **doping**. The doping elements are called **impurities**; therefore, after their addition, the germanium and silicon are no longer considered *pure* elements. The material added to pure silicon or germanium to make it electrically conductive represents only one atom of impurity for every 100 *million* atoms of the pure semiconductor material. The resulting atoms are still electrically *neutral* because the number of electrons still equals the number of protons of the combined materials. These combined materials are classified into two groups depending on the number of electrons in the bonding between the two materials:

- N-type materials
- P-type materials

N-TYPE MATERIAL **N-type material** is silicon or germanium that is doped with an element such as *phosphorus*, *arsenic*, or *antimony*, each having five electrons in its outer orbit. These five electrons are combined with the four electrons of the silicon or germanium to total nine electrons. There is room for only eight electrons in the bonding between the semiconductor material and the doping material. This leaves extra electrons, and even though the material is still electrically neutral, these extra electrons tend to repel other electrons outside the material. ● **SEE FIGURE 45–1**.

P-TYPE MATERIAL **P-type material** is produced by doping silicon or germanium with the element *boron* or the element *indium*. These impurities have only three electrons in their outer shell and, when combined with the semiconductor material, result in a material with seven electrons, one electron *less* than is required for atom bonding. This lack of one electron makes the material able to attract electrons, even though the material still has a neutral charge. This material tends to attract electrons to fill the holes for the missing eighth electron in the bonding of the materials. ● **SEE FIGURE 45–2**.

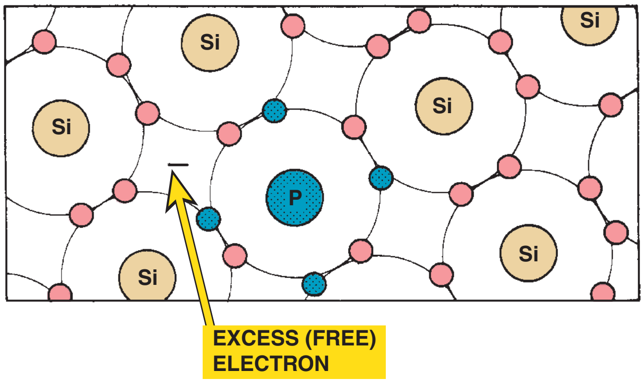


FIGURE 45–1 N-type material. Silicon (Si) doped with a material (such as phosphorus) with five electrons in the outer orbit results in an extra free electron.

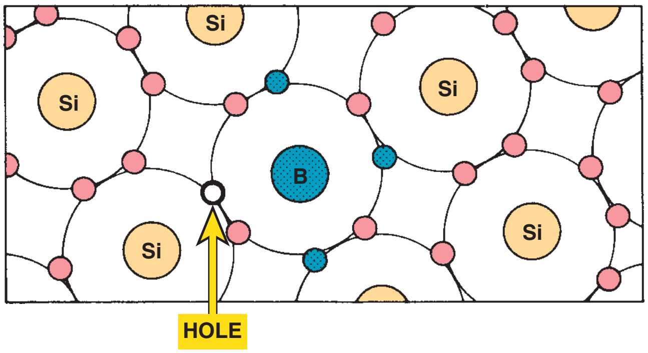


FIGURE 45–2 P-type material. Silicon (Si) doped with a material, such as boron (B), with three electrons in the outer orbit results in a hole capable of attracting an electron.

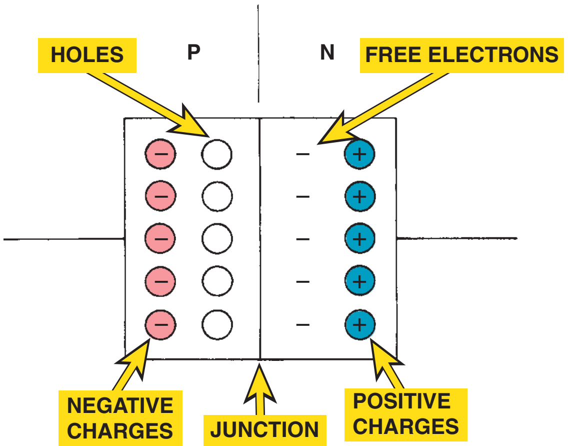


FIGURE 45–3 Unlike charges attract and the current carriers (electrons and holes) move toward the junction.

FREQUENTLY ASKED QUESTION

What Is the Hole Theory?

Current flow is expressed as the movement of electrons from one atom to another. In semiconductor and electronic terms, the movement of electrons fills the holes of the P-type material. Therefore, as the holes are filled with electrons, the unfilled holes move opposite to the flow of the electrons. This concept of hole movement is called the **hole theory** of current flow. The holes move in the direction opposite to that of electron flow. For example, think of an egg carton, where if an egg is moved in one direction, the holes created move in the opposite direction. ● **SEE FIGURE 45–3**.

SUMMARY OF SEMICONDUCTORS The following is a summary of semiconductor fundamentals:

1. The two types of semiconductor materials are P type and N type. N-type material contains extra electrons; P-type material contains holes due to missing electrons. The number of excess electrons in an N-type material must remain constant, and the number of holes in the P-type material must also remain constant. Because electrons are interchangeable, movement of electrons in or out of the material is possible to maintain a balanced material.
2. In P-type semiconductors, electrical conduction occurs mainly as a result of holes (absence of electrons). In N-type semiconductors, electrical conduction occurs mainly as a result of electrons (excess of electrons).
3. Hole movement results from the jumping of electrons into new positions.
4. Under the effect of a voltage applied to the semiconductor, electrons travel toward the positive terminal and holes move toward the negative terminal. The direction of hole current agrees with the conventional direction of current flow.

DIODES

CONSTRUCTION A **diode** is an electrical one-way check valve made by combining a P-type material and an N-type material. The word *diode* means “having two electrodes.” Electrodes are electrical

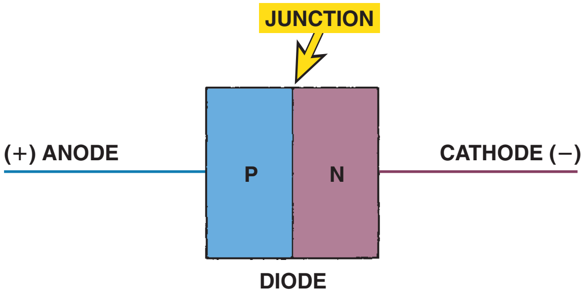


FIGURE 45–4 A diode is a component with P-type and N-type materials together. The negative electrode is called the cathode and the positive electrode is called the anode.

connections: The positive electrode is called the **anode**; the negative electrode is called the **cathode**. The point where the two types of materials join is called the **junction**. ● **SEE FIGURE 45–4**.

OPERATION The N-type material has one extra electron, which can flow into the P-type material. The P type requires electrons to fill its holes. If a battery's positive terminal (+) is connected to the diode's P-type material and negative (−) to the N-type material, the electrons that left the N-type material and flowed into the P-type material to fill the holes are quickly replaced by the electron flow from the battery. Current flows through a forward-bias diode for the following reasons:

- Electrons move toward the holes (P-type material).
- Holes move toward the electrons (N-type material).

As a result, current flows through the diode with low resistance. This condition is called **forward bias**.

If the battery connections are reversed and the positive side of the battery is connected to the N-type material, the electrons are pulled toward the battery, and away from the junction of the N-type and P-type materials. (Remember, unlike charges attract, whereas like charges repel.) Because electrical conduction requires the flow of electrons across the junction of the N-type and P-type materials, and because the battery connections are actually reversed, the diode offers very high resistance to current flow. This condition is called **reverse bias**. ● **SEE FIGURE 45–5**.

Therefore, diodes allow current flow only when current of the correct polarity is connected to the circuit.

- Diodes are used in alternators to control current flow in one direction, which changes the AC voltage generated into DC voltage.
- Diodes are also used in computer controls, relays, air-conditioning circuits, and many other circuits to prevent possible damage due to reverse current flows that may be generated within the circuit. ● **SEE FIGURE 45–6**.

FREQUENTLY ASKED QUESTION

What Is the Difference between Electricity and Electronics?

Electronics usually means that solid-state devices are used in the electrical circuits. Electricity as used in automotive applications usually means electrical current flow through resistance and loads without the use of diodes, transistors, or other electronic devices.

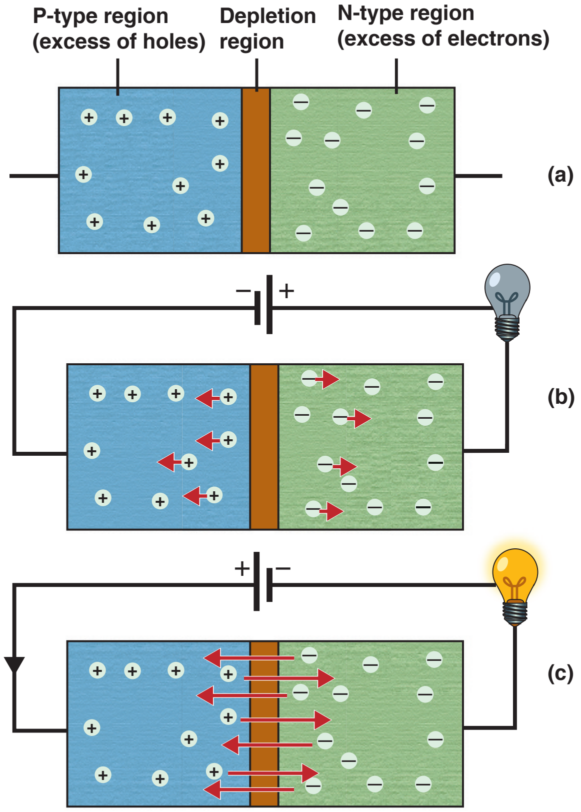

P-type region (excess of holes)
Depletion region
N-type region (excess of electrons)
(a)
−
+
(b)
+
−
(c)

FIGURE 45–5 (a) A diode consist of P-type and N-type materials separated by a depletion region. (b) When connected to a voltage source in the reverse bias situation, the charge carriers are forced apart and no current flows across the depletion region. (c) When the diode is connected in the forward bias direction, the charge carriers are allowed to cross the depletion region and current can flow from the anode (+) to the cathode (−).

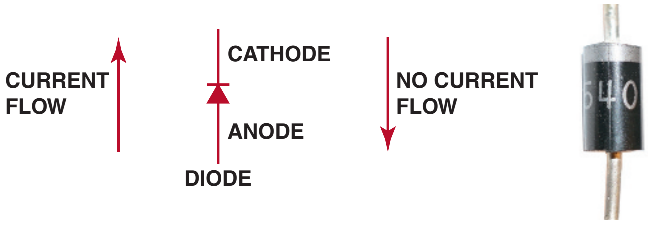


FIGURE 45–6 Diode symbol and electrode names. The stripe on one end of a diode represents the cathode end of the diode.

ZENER DIODES A **zener diode** is a specially constructed diode designed to operate with a reverse-bias current. Zener diodes were named in 1934 for their inventor, Clarence Melvin Zener, an American professor of physics.

A zener diode acts as any diode in that it blocks reverse-bias current, but only up to a certain voltage. Above this certain voltage (called the *breakdown voltage* or the zener region), a zener diode conducts current in the opposite direction without damage to the diode. A zener diode is heavily doped, and the reverse-bias voltage does not harm the material. The voltage drop across a zener diode remains practically the same before and after the breakdown voltage, and this factor makes a zener diode perfect for voltage regulation. Zener diodes can be constructed for various breakdown voltages and can be used in a variety of automotive and electronic applications, especially for electronic voltage regulators used in the charging system. ● **SEE FIGURE 45–7**.

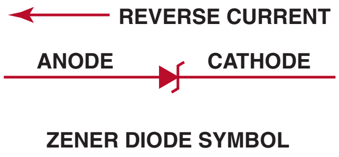


FIGURE 45–7 A zener diode blocks current flow until a certain voltage is reached, then it permits current to flow.

HIGH-VOLTAGE SPIKE PROTECTION

CLAMPING DIODES Diodes can be used as a high-voltage clamping device when the power (+) is connected to the cathode (–) of the diode. If a coil is pulsed on and off, a high-voltage spike is produced whenever the coil is turned off. To control and direct this possibly damaging high-voltage spike, a diode can be installed across the leads to the coil to redirect the high-voltage spike back through the coil windings to prevent possible damage to the rest of the vehicle's electrical or electronic circuits. A diode connected across the terminals of a coil to control voltage spikes is called a **clamping diode**. Clamping diodes can also be called **despiking** or **suppression diodes**. ● **SEE FIGURE 45–8**.

CLAMPING DIODE APPLICATION The diode is used to help prevent the high-voltage spike generated inside the A/C clutch coil from damaging delicate electronic circuits anywhere in the vehicle's electrical system. ● **SEE FIGURE 45–9**.

Because most automotive circuits eventually are electrically connected to each other in parallel, a high-voltage surge anywhere in the vehicle could damage electronic components in other circuits.

The circuits most likely to be affected by the high-voltage surge, if the diode fails, are the circuits controlling the operation of the A/C compressor clutch and any component that uses a coil, such as those of the blower motor and climate control units.

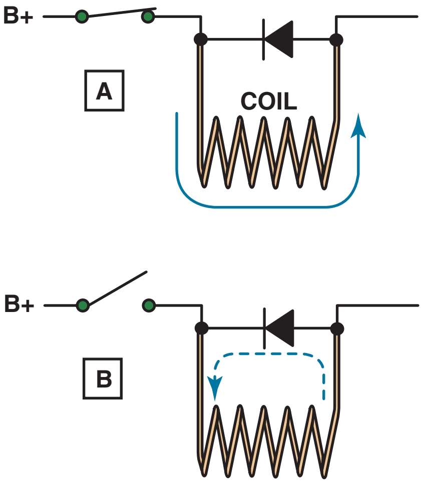


FIGURE 45–8 (a) Notice that when the coil is being energized, the diode is reverse biased and the current is blocked from passing through the diode. The current flows through the coil in the normal direction. (b) When the switch is opened, the magnetic field surrounding the coil collapses, producing a high-voltage surge in the reverse polarity of the applied voltage. This voltage surge forward biases the diode, and the surge is dissipated harmlessly back through the windings of the coil.

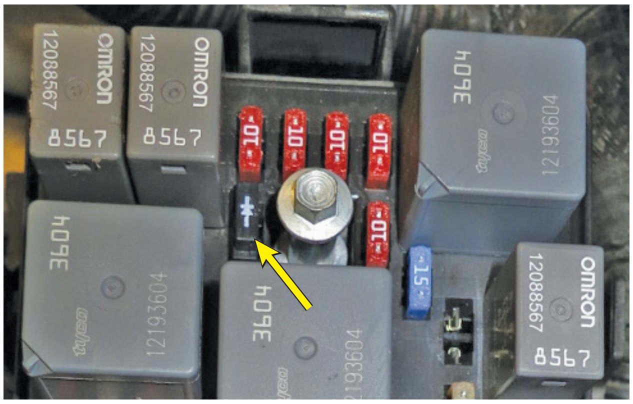


FIGURE 45–9 A diode connected to both terminals of the air-conditioning compressor clutch used to reduce the high-voltage spike that results when a coil (compressor clutch coil) is de-energized.

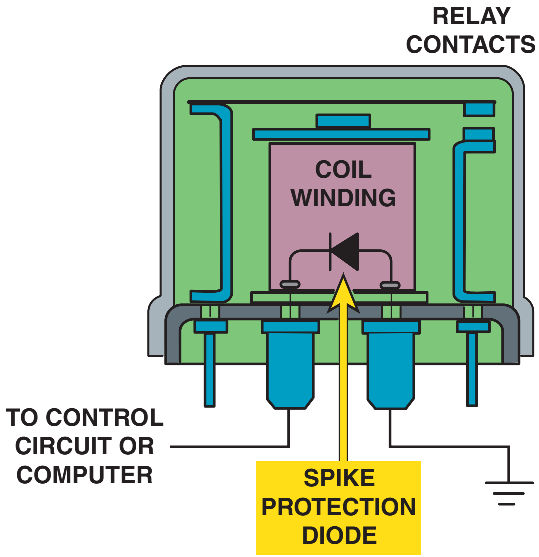


FIGURE 45–10 Spike protection diodes are commonly used in computer-controlled circuits to prevent damaging high-voltage surges that occur any time current flowing through a coil is stopped.

Many relays are equipped with a diode to prevent a voltage spike when the contact points open and the magnetic field in the coil winding collapses. ● **SEE FIGURE 45–10**.

DESPIKING ZENER DIODES Zener diodes can also be used to control high-voltage spikes and keep them from damaging delicate electronic circuits. Zener diodes are most commonly used in electronic fuel-injection circuits that control the firing of the injectors. If clamping diodes were used in parallel with the injection coil, the resulting clamping action tends to delay the closing of the fuel-injector nozzle. A zener diode is commonly used to clamp only the higher voltage portion of the resulting voltage spike without affecting the operation of the injector. ● **SEE FIGURE 45–11**.

DESPIKING RESISTORS All coils must use some protection against high-voltage spikes that occur when the voltage is removed from any coil. Instead of a diode installed in parallel with the coil windings, a resistor can be used, called a **spike protection resistor**. ● **SEE FIGURE 45–12**.

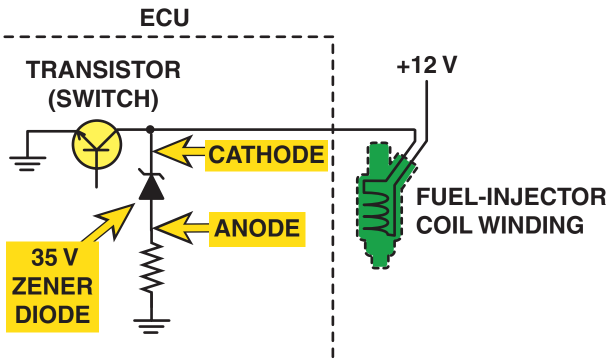


FIGURE 45–11 A zener diode is commonly used inside automotive computers to protect delicate electronic circuits from high-voltage spikes. A 35 volt zener diode conducts any voltage spike higher than 35 volts resulting from the discharge of the fuel-injector coil safely to ground through a current-limiting resistor in series with the zener diode.

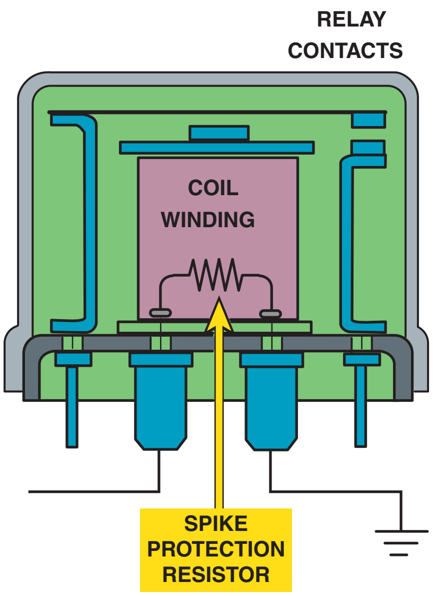


FIGURE 45–12 A despiking resistor is used in many automotive applications to help prevent harmful high-voltage surges from being created when the magnetic field surrounding a coil collapses when the coil circuit is opened.

Resistors are preferred instead of diodes for voltage spike protection for two reasons:

Reason 1	Coils usually fail when shorted, rather than open, as this shorted condition results in greater current flow in the circuit. A diode installed in the reverse-bias direction cannot control this extra current, whereas a resistor in parallel can help reduce potentially damaging current flow if the coil becomes shorted.
Reason 2	The protective diode can also fail, and diodes usually fail by shorting before they blow open. If a diode becomes shorted, excessive current can flow through the coil circuit, perhaps causing damage. A resistor usually fails open and, therefore, even in failures could not in itself cause a problem.

Resistors on coils are often used in relays and in climate-control circuit solenoids that control vacuum to the various air-management system doors, as well as other electronically controlled appliances.

DIODE RATINGS

SPECIFICATIONS Most diodes are rated according to the following:

- Maximum current flow in the forward-bias direction. Diodes are sized and rated according to the amount of current they are designed to handle in the forward-bias direction. This rating is normally from 1 to 5 amperes for most automotive applications.
- This rating of resistance to reverse-bias voltage is called the **peak inverse voltage (PIV)** rating, or the **peak reverse voltage (PRV)** rating. It is important that the service technician specifies and uses only a replacement diode that has the same or a higher rating than specified by the vehicle manufacturer for both amperage and PIV rating. Typical 1 ampere diodes use an industry numbering code that indicates the PIV rating. For example:

  1N 4001-50 V PIV
  1N 4002-100 V PIV
  1N 4003-200 V PIV (most commonly used)
  1N 4004-400 V PIV
  1N 4005-600 V PIV
- "1N" means that the diode has one P-N junction. A higher-rating diode can be used with no problems (except for slightly higher cost, even though the highest rated diode generally costs less than $1). Never substitute a *lower*-rated diode than is specified.

DIODE VOLTAGE DROP The voltage drop across a diode is about the same voltage as that required to forward bias the diode. If the diode is made from germanium, the forward voltage is 0.3 to 0.5 volt. If the diode is made from silicon, the forward voltage is 0.5 to 0.7 volt.

NOTE: When diodes are tested using a digital multimeter, the meter displays the voltage drop across the P-N junction (about 0.5 to 0.7 volt) when the meter is set to the *diode-check* position.

LIGHT-EMITTING DIODES

OPERATION All diodes radiate some energy during normal operation. Most diodes radiate heat because of the junction barrier voltage drop (typically 0.6 volt for silicon diodes). **Light-emitting diodes (LED)** radiate light when current flows through the diode in the forward-bias direction. ● **SEE FIGURE 45–13**.

The forward-bias voltage required for an LED ranges between 1.5 and 2.2 volts.

An LED only lights if the voltage at the anode (positive electrode) is at least 1.5 to 2.2 volts higher than the voltage at the cathode (negative electrode).

NEED FOR CURRENT LIMITING If an LED is connected across a 12 volt automotive battery, the LED lights brightly, but only for

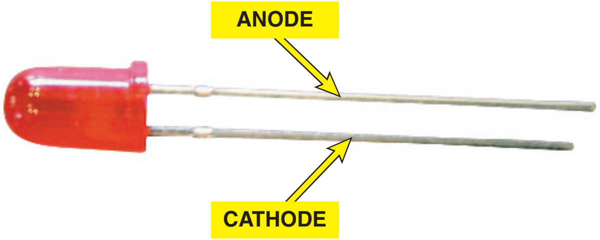


FIGURE 45–13 A typical light-emitting diode (LED). This particular LED is designed with a built-in resistor so that 12 volt DC may be applied directly to the leads without an external resistor. Normally a 300 to 500 ohm, 0.5 watt resistor is required to be attached in series with the LED, to control current flow to about 0.020 ampere (20 milliamperes), or damage to the P-N junction may occur.

a second or two. Excessive current (amperes) that flows across the P-N junction of any electronic device can destroy the junction. A resistor *must* be connected in series with every diode (including LEDs) to control current flow across the P-N junction. This protection should include the following:

1. The value of the resistor should be from 300 to 500 ohms for each P-N junction. Commonly available resistors in this range include 470, 390, and 330 ohm resistors.
2. The resistors can be connected to either the anode or the cathode end. (Polarity of the resistor does not matter.) Current flows through the LED in series with the resistor, and the resistor controls the current flow through the LED, regardless of its position in the circuit.
3. Resistors protecting diodes can be actual resistors or other current-limiting loads, such as lamps or coils. With the current-limiting devices to control the current, the average LED requires about 20 to 30 milliamperes (mA), or 0.020 to 0.030 ampere.

FREQUENTLY ASKED QUESTION

How Does an LED Emit Light?

An LED contains a chip that houses P-type and N-type materials. The junction between these regions acts as a barrier to the flow of electrons between the two materials. When a voltage of 1.5 to 2.2 volts is applied to the correct polarity, current flows across the junction. As the electrons enter the P-type material, it combines with the holes in the material and releases energy in the form of light (called **photons**). The intensity and color the light produces depends on materials used in the manufacture of the semiconductor.

LEDs are very efficient compared to conventional incandescent bulbs, which depend on heat to create light. LEDs generate very little heat, with most of the energy consumed converted directly into light. LEDs are reliable and are being used for taillights, brake lights, daytime running lights, and headlights in some vehicles.

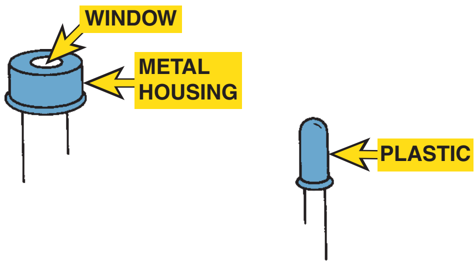


FIGURE 45–14 Typical photodiodes. They are usually built into a plastic housing so that the photodiode itself may not be visible.

PHOTODIODES

PURPOSE AND FUNCTION All semiconductor P-N junctions emit energy, mostly in the form of heat or light, such as with an LED. In fact, if an LED is exposed to bright light, a voltage potential is established between the anode and the cathode. **Photodiodes** are specially constructed to respond to various wavelengths of light with a "window" built into the housing. ● **SEE FIGURE 45–14**.

Photodiodes are frequently used in steering wheel controls for transmitting tuning, volume, and other information from the steering wheel to the data link and the unit being controlled. If several photodiodes are placed on the steering column end and LEDs or phototransistors are placed on the steering wheel side, data can be transmitted between the two moving points without the interference that could be caused by physical contact-types of units.

CONSTRUCTION A photodiode is sensitive to light. When light energy strikes the diode, electrons are released and the diode conducts in the forward-bias direction. (The light energy is used to overcome the barrier voltage.)

The resistance across the photodiode decreases as the intensity of the light increases. This characteristic makes the photodiode a useful electronic device for controlling some automotive lighting systems, such as automatic headlights. The symbol for a photodiode is shown in ● **FIGURE 45–15**.

PHOTORESISTORS

A **photoresistor** is a semiconductor material (usually cadmium sulfide) that changes resistance with the presence or absence of light.

Dark = High resistance
Light = Low resistance

Because resistance is reduced when the photoresistor is exposed to light, the photoresistor can be used to control headlight dimmer relays and automotive headlights. ● **SEE FIGURE 45–16**.

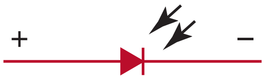


FIGURE 45–15 Symbol for a photodiode. The arrows represent light striking the P-N junction of the photodiode.

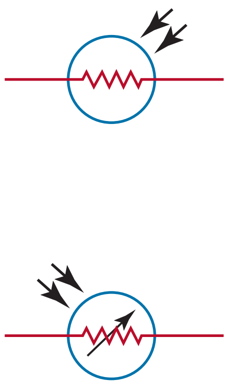


FIGURE 45–16 Either symbol may be used to represent a photoresistor.

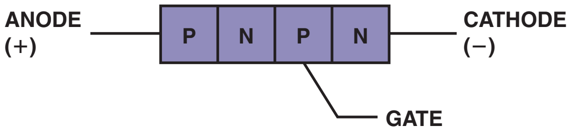


FIGURE 45–17 Symbol and terminal identification of an SCR.

SILICON-CONTROLLED RECTIFIERS

CONSTRUCTION A **silicon-controlled rectifier (SCR)** is commonly used in the electronic circuits of various automotive applications. An SCR is a semiconductor device that looks like two diodes connected end to end. ● **SEE FIGURE 45–17**.

If the anode is connected to a higher voltage source rather than the cathode in a circuit, no current flows, as occurs with a diode. If, however, a positive voltage source is connected to the gate of the SCR, current can flow from anode to cathode with a typical voltage drop of 1.2 volts (double the voltage drop of a typical diode, at 0.6 volt).

Voltage applied to the gate is used to turn the SCR on. However, if the voltage source at the gate is shut off, the current still continues to flow through the SCR until the source current is stopped.

USES OF AN SCR SCRs can be used to construct a circuit for a **center high-mounted stoplight (CHMSL)**. If this third stoplight is wired into either the left- or the right-side brake light circuit, the CHMSL also flashes whenever the turn signals are used for the side that was connected to the CHMSL. When two SCRs are used, both brake lights must be activated to supply current to the CHMSL. The current to the CHMSL is shut off when both SCRs lose their power source (when the brake pedal is released, which stops the current flow to the brake lights). ● **SEE FIGURE 45–18**.

THERMISTORS

CONSTRUCTION A **thermistor** is a semiconductor material, such as silicon, that has been doped to provide a given resistance. When the thermistor is heated, the electrons within the crystal gain energy and electrons are released. This means that a thermistor actually produces a small voltage when heated.

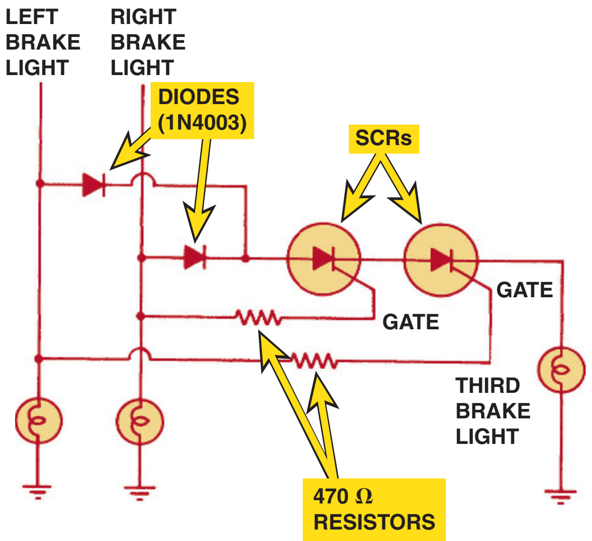


FIGURE 45–18 Wiring diagram for a center high-mounted stoplight (CHMSL) using SCRs.

	COPPER WIRE	NTC THERMISTOR
Cold	Lower resistance	Higher resistance
Hot	Higher resistance	Lower resistance

CHART 45–1

The resistance changes opposite to that of a copper wire with changes in temperature.

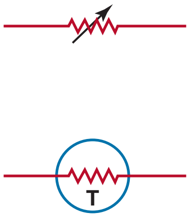


FIGURE 45–19 Symbols used to represent a thermistor.

If voltage is applied to a thermistor, its resistance decreases because the thermistor itself is acting as a current carrier rather than as a resistor at higher temperatures.

USES OF THERMISTORS A thermistor is commonly used as a temperature-sensing device for coolant temperature and intake manifold air temperature. Because thermistors operate in a manner opposite to that of a typical conductor, they are called **negative temperature coefficient (NTC)** thermistors; their resistance decreases as the temperature increases. ● **SEE CHART 45–1**.

Thermistor symbols are shown in ● **FIGURE 45–19**.

RECTIFIER BRIDGES

DEFINITION The word *rectify* means "to set straight"; therefore, a rectifier is an electronic device (such as a diode) used to convert a changing voltage into a straight or constant voltage. A **rectifier bridge** is a group of diodes that is used to change an AC current into a DC current. A rectifier bridge is used in alternators to rectify the AC voltage produced in the stator (stationary

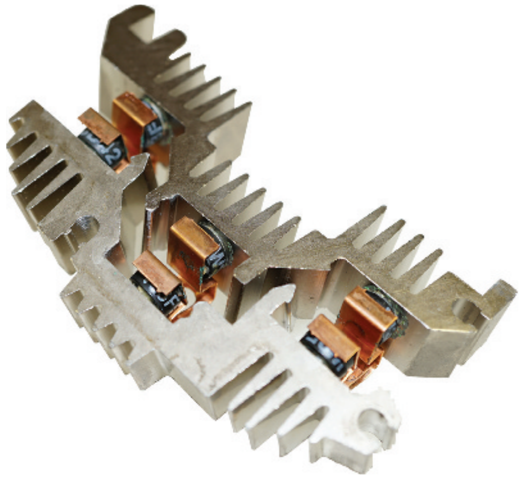


FIGURE 45–20 This rectifier bridge contains six diodes; the three on each side are mounted in an aluminum-finned unit to help keep the diodes cool during alternator operation.

windings) of the alternator into DC voltage. These rectifier bridges contain six diodes: one pair of diodes (one positive and one negative) for each of the three stator windings. ● **SEE FIGURE 45–20**.

TRANSISTORS

PURPOSE AND FUNCTION A **transistor** is a semiconductor device that can perform the following electrical functions:

1. Act as an electrical switch in a circuit
2. Act as an amplifier of current in a circuit
3. Regulate the current in a circuit

The word *transistor*, derived from the words *transfer* and *resistor*, is used to describe the transfer of current across a resistor. A transistor is made of three alternating sections or layers of P-type and N-type materials. This type of transistor is usually called a **bipolar transistor**.

CONSTRUCTION A transistor that has P-type material on each end with N-type material in the center is called a **PNP transistor**. Another type, with the exact opposite arrangement, is called an **NPN transistor**.

The material at one end of a transistor is called the **emitter** and the material at the other end is called the **collector**. The **base** is in the center and the voltage applied to the base is used to control current through a transistor.

TRANSISTOR SYMBOLS All transistor symbols contain an arrow indicating the emitter part of the transistor. The arrow points in the direction of current flow (conventional theory).

When an arrowhead appears in any semiconductor symbol, it stands for a P-N junction and it points from the P-type material toward the N-type material. The arrow on a transistor is always attached to the *emitter* side of the transistor. ● **SEE FIGURE 45–21**.

HOW A TRANSISTOR WORKS A transistor is similar to two back-to-back diodes that can conduct current in only one direction. As in a diode, N-type material can conduct electricity by means of its supply of free electrons, and P-type material conducts by means of its supply of positive holes.

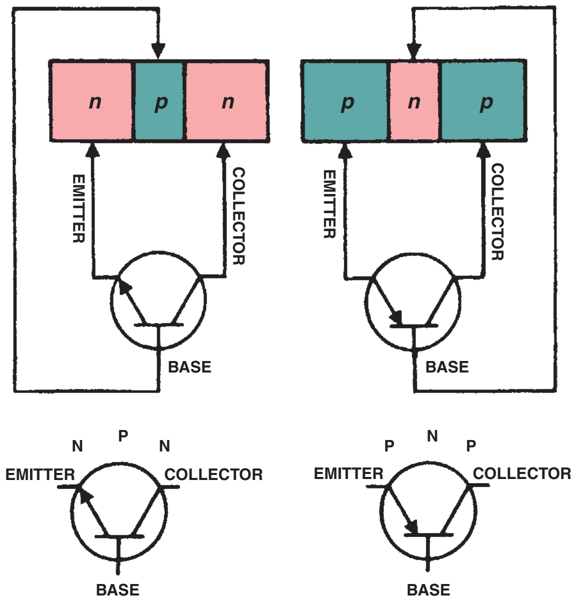


FIGURE 45–21 The symbols used to identify NPN and PNP transistors. (bottom) How the P and N material is used in each type. (top).

	RELAY	TRANSISTOR
Low-current circuit	Coil (terminals 85 and 86)	Base and emitter
High-current circuit	Contacts terminals 30 and 87	Collector and emitter

CHART 45–2

Comparison between the control (low-current) and high-current circuits of a transistor compared to a mechanical relay.

FREQUENTLY ASKED QUESTION

Is a Transistor Similar to a Relay?

Yes, in many cases a transistor is similar to a relay.

Both use a low current to control a higher current circuit. ● **SEE CHART 45–2**.

A relay can only be on or off. A transistor can provide a variable output if the base is supplied a variable current input.

A transistor allows current flow if the electrical conditions allow it to switch on, in a manner similar to the working of an electromagnetic relay. The electrical conditions are determined, or switched, by means of the base, or *B*. The base carries current only when the proper voltage and polarity are applied. The main circuit current flow travels through the other two parts of the transistor: the emitter *E* and the collector *C*. ● **SEE FIGURE 45–22**.

If the base current is turned off or on, the current flow from collector to emitter is turned off or on. The current controlling the base is called the control current. The control current must be high enough to switch the transistor on or off. (This control voltage, called the **threshold voltage**, must be above approximately 0.3 volt for germanium and 0.6 volt for silicon transistors.) This

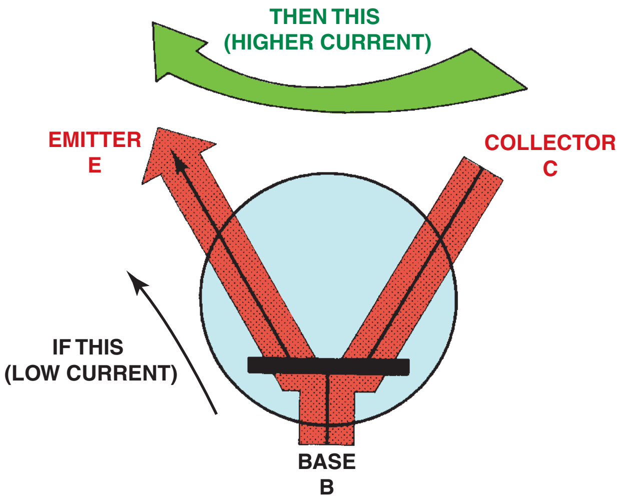


FIGURE 45–22 Basic transistor operation. A small current flowing through the base and emitter of the transistor turns on the transistor and permits a higher amperage current to flow from the collector and the emitter.

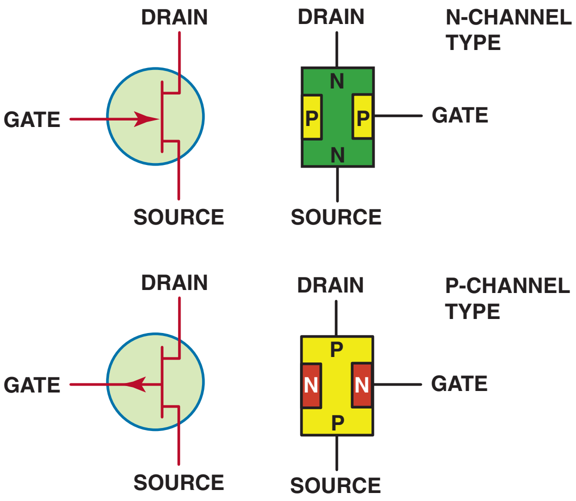


FIGURE 45–23 The three terminals of a field-effect transistor (FET) are called the source, gate, and drain.

control current can also “throttle” or regulate the main circuit, in a manner similar to the operation of a water faucet.

HOW A TRANSISTOR AMPLIFIES A transistor can amplify a signal if the signal is strong enough to trigger the base of a transistor on and off. The resulting on–off current flow through the transistor can be connected to a higher-powered electrical circuit. This results in a higher-powered circuit being controlled by a lower-powered circuit. This low-powered circuit’s cycling is exactly duplicated in the higher-powered circuit and, therefore, any transistor can be used to amplify a signal. However, because some transistors are better than others for amplification, specialized types of transistors are used for each specialized circuit function.

FIELD-EFFECT TRANSISTORS **Field-effect transistors (FETs)** have been used in most automotive applications since the mid-1980s. They use less electrical current and rely mostly on the strength of a small voltage signal to control the output. The parts of a typical FET include the *source, gate,* and *drain.* ● **SEE FIGURE 45–23**.

Many FETs are constructed of metal oxide semiconductor (MOS) materials, called **MOSFETs**. MOSFETs are highly sensitive to static electricity and can be easily damaged if exposed to excessive current or high-voltage surges (spikes). Most automotive electronic circuits use MOSFETs, which explains why it is vital for the service technician to use caution to avoid doing anything that could result in a high-voltage spike, and perhaps destroy an expensive computer module. Some vehicle manufacturers recommend that technicians wear an antistatic wristband when working with modules that contain MOSFETs. Always follow the vehicle manufacturer’s instructions found in service information to avoid damaging electronic modules or circuits.

FREQUENTLY ASKED QUESTION

What Does the Arrow Mean on a Transistor Symbol?

The arrow on a transistor symbol is always on the emitter and points toward the N-type material. The arrow on a diode also points toward the N-type material. To know which type of transistor is being shown, note which direction the arrow points.

- PNP: pointing in
- NPN: not pointing in

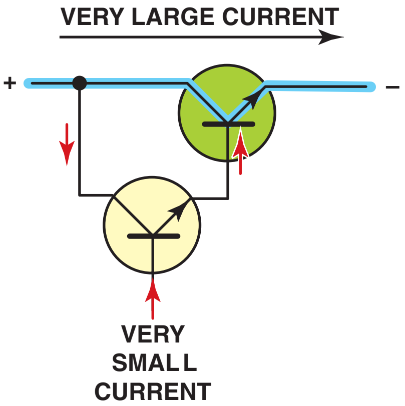


FIGURE 45–24 A Darlington pair consists of two transistors wired together, allowing for a very small current to control a larger current flow circuit.

FREQUENTLY ASKED QUESTION

What Is a Darlington Pair?

A **Darlington pair** consists of two transistors wired together. This arrangement permits a very small current flow to control a large current flow. The Darlington pair is named for Sidney Darlington, an American physicist for Bell Laboratories from 1929 to 1971. Darlington amplifier circuits are commonly used in electronic ignition systems, computer engine control circuits, and many other electronic applications. ● **SEE FIGURE 45–24**.

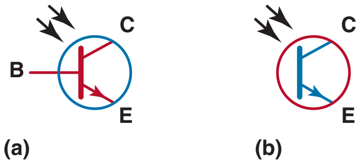


FIGURE 45–25 Symbols for a phototransistor. (a) This symbol uses the line for the base; (b) this symbol does not.

PHOTOTRANSISTORS Similar in operation to a photodiode, a **phototransistor** uses light energy to turn on the base of a transistor. A phototransistor is an NPN transistor that has a large exposed base area to permit light to act as the control for the transistor. Therefore, a phototransistor may or may not have a base lead. If not, then it has only a collector and emitter lead. When the phototransistor is connected to a powered circuit, the light intensity is amplified by the gain of the transistor. Phototransistors, along with photo diodes, are used in some steering wheel position sensors. ● **SEE FIGURE 45–25**.

INTEGRATED CIRCUITS

PURPOSE AND FUNCTION Solid-state components are used in many electronic semiconductors and/or circuits. They are called "solid-state" because they have no moving parts, just higher or lower voltage levels within the circuit. Discrete (individual) diodes, transistors, and other semiconductor devices were often used to construct early electronic ignition and electronic voltage regulators. Newer-style electronic devices use the same components, but they are now combined (integrated) into one group of circuits, and are thus called an **integrated circuit (IC)**.

CONSTRUCTION Integrated circuits are usually encased in a plastic housing called a CHIP with two rows of inline pins. This arrangement is called the **dual inline pins (DIP)** chips. ● **SEE FIGURE 45–26**.

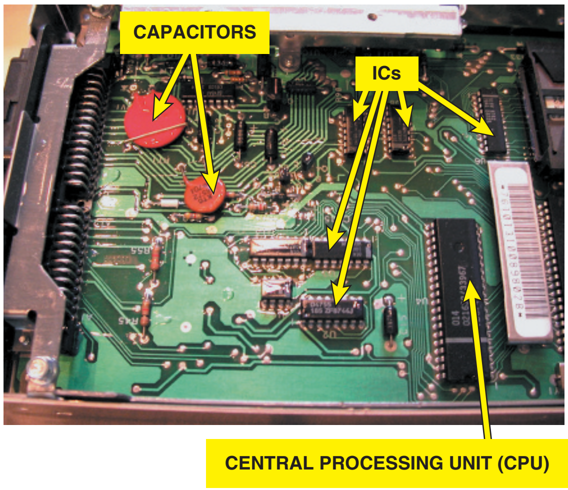


FIGURE 45–26 A typical automotive computer with the case removed to show all of the various electronic devices and integrated circuits (ICs). The CPU is an example of a DIP chip and the large red and orange devices are ceramic capacitors.

FREQUENTLY ASKED QUESTION

What Causes a Transistor or Diode to Blow?

Every automotive diode and transistor is designed to operate within certain voltage and amperage ranges for individual applications. For example, transistors used for switching are designed and constructed differently from transistors used for amplifying signals.

Because each electronic component is designed to operate satisfactorily for its particular application, any severe change in operating current (amperes), voltage, or heat can destroy the *junction.* This failure can cause either an open circuit (no current flows) or a short (current flows through the component all the time when the component should be blocking the current flow).

Therefore, most computer circuits are housed as an integrated circuit in a DIP chip.

HEAT SINK **Heat sink** is a term used to describe any area around an electronic component that, because of its shape or design, can conduct damaging heat away from electronic parts. Examples of heat sinks include the following:

1. Ribbed electronic ignition control units
2. Cooling slits and cooling fan attached to an alternator
3. Fuel injector drivers inside the PCM that conduct heat to the aluminum case of the unit

Heat sinks are necessary to prevent damage to diodes, transistors, and other electronic components due to heat buildup. Excessive heat can damage the junction between the N-type and P-type materials used in diodes and transistors.

TRANSISTOR GATES

PURPOSE AND FUNCTION Knowledge of the basic operation of electronic gates is important in understanding how computers work. A gate is an electronic circuit whose output depends on the location and voltage of two inputs.

CONSTRUCTION Whether a transistor is on or off depends on the voltage at the base of the transistor. For the transistor to turn on, a voltage difference between the base of the transmitter and the emitter should be at least a 0.6 volt. Most electronic and computer circuits use 5 volts as a power source. If two transistors are wired together, several different outputs can be received, depending on how the two transistors are wired. ● **SEE FIGURE 45–27**.

OPERATION If the voltage at *A* is higher than that of the emitter, the top transistor is turned on; however, the bottom transistor is off unless the voltage at *B* is also higher. If both transistors are turned on, the output signal voltage is high. If only one of the two transistors is on, the output is zero (off or no voltage). Because it requires both *A* and *B* to be on to result in a voltage output, this circuit is called an *AND gate*. In other words, both

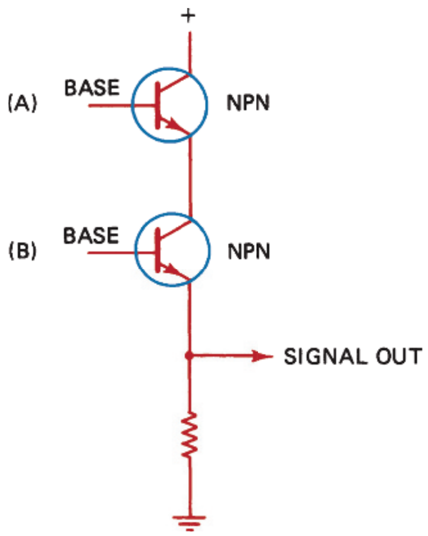


FIGURE 45–27 Typical AND gate circuit using two transistors. The emitter is always the line with the arrow. Notice that both transistors must be turned on before there is voltage present at the point labeled "signal out."

transistors have to be on before the gate opens and allows a voltage output. Other types of gates can be constructed using various connections to the two transistors. For example:

AND gate. Requires both transistors to be on to get an output.

OR gate. Requires either transistor to be on to get an output.

NAND (NOT-AND) gate. Output is on unless both transistors are on.

NOR (NOT-OR) gate. Output is on only when both transistors are off.

Gates represent logic circuits that can be constructed so that the output depends on the voltage (on or off; high or low) of the inputs to the bases of transistors. Their inputs can come from sensors or other circuits that monitor sensors, and their outputs can be used to operate an output device, if amplified and controlled by other circuits. For example, the blower motor is commanded on when the following events occur, to cause the control module to turn it on.

1. The ignition must be on (input).
2. The air-conditioning is commanded on.
3. The engine coolant temperature is within a predetermined limit.

If all of these conditions are met, the control module commands the blower motor on. If any of the input signals are incorrect, the control module cannot perform the correct command.

OPERATIONAL AMPLIFIERS

Operational amplifiers (op-amps) are used in circuits to control and amplify digital signals. Op-amps are frequently used for motor control for airflow door operation as part of the climate control system. Op-amps can provide the proper voltage polarity and current (amperes) to control the direction of permanent magnetic (PM) motors. The symbol for an op-amp is shown in ● **FIGURE 45–28**.

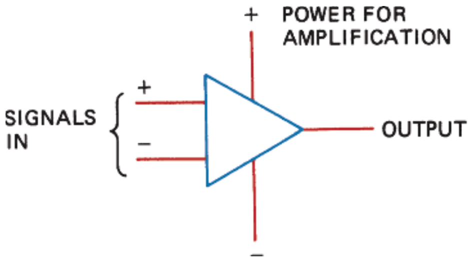


FIGURE 45–28 Symbol for an operational amplifier (op-amp).

FREQUENTLY ASKED QUESTION

What Are Logic Highs and Lows?

All computer circuits and most electronic circuits (such as gates) use various combinations of high and low voltages. High voltages are typically those above 5 volts, and low is generally considered zero (ground). However, high voltages do not *have* to begin at 5 volts. *High, or the number 1, to a computer is the presence of voltage above a certain level.* For example, a circuit could be constructed where any voltage higher than 3.8 volts is considered high. *Low, or the number 0, to a computer is the absence of voltage or a voltage lower than a certain value.* For example, a voltage of 0.62 volt may be considered low. Various associated names and terms can be summarized.

- Logic low = Low voltage = Number 0 = Reference low
- Logic high = Higher voltage = Number 1 = Reference high

ELECTRONIC COMPONENT FAILURE CAUSES

Electronic components, such as electronic ignition modules, electronic voltage regulators, onboard computers, and any other electronic circuit are generally quite reliable; however, failure can occur. Frequent causes of premature failure include the following:

- **Poor connections.** It has been estimated that most engine computers returned as defective have simply had poor connections at the wiring harness terminal ends. These faults are often intermittent and hard to find.

NOTE: When cleaning electronic contacts, use a pencil eraser. This cleans the contacts without harming the thin, protective coating used on most electronic terminals.

- **Heat.** The operation and resistance of electronic components and circuits are affected by heat. Electronic components should be kept as cool as possible and never hotter than 260°F (127°C).
- **Voltage spikes.** A high-voltage spike can literally burn a hole through semiconductor material. The source of these high-voltage spikes is often the discharge of a coil without

proper (or with defective) despiking protection. A poor electrical connection at the battery or other major electrical connection can cause high-voltage spikes to occur, because the *entire wiring harness creates its own magnetic field*, similar to that formed around a coil. If the connection is loose and momentary loss of contact occurs, a high-voltage surge can occur through the entire electrical system. To help prevent this type of damage, ensure that all electrical connections, including grounds, are properly clean and tight.

CAUTION: One of the major causes of electronic failure occurs during jump starting a vehicle. Always check that the ignition switch is off on both vehicles when making the connection. Always double-check that the correct battery polarity (+ to + and − to −) is being performed.

- **Excessive current.** All electronic circuits are designed to operate within a designated range of current (amperes). If a solenoid or relay is controlled by a computer circuit, the resistance of that solenoid or relay becomes part of that control circuit. If a coil winding inside the solenoid or relay becomes shorted, the resulting lower resistance increases the current through the circuit. Even though individual components are used with current-limiting resistors in series, the coil winding resistance is also used as a current-control component in the circuit. If a computer fails, always measure the resistance across all computer-controlled relays and solenoids. The resistance should be within specifications (generally *over* 20 ohms) for each component that is computer controlled.

NOTE: Some computer-controlled solenoids are pulsed on and off rapidly. This type of solenoid is used in many electronically shifted transmissions. Their resistance is usually about half of the resistance of a simple on–off solenoid—usually between 10 and 15 ohms. Because the computer controls the on-time of the solenoid, the solenoid and its circuit control are called pulse-width modulated (PWM).

HOW TO TEST DIODES AND TRANSISTORS

TESTERS Diodes and transistors can be tested with an ohmmeter. The diode or transistor being tested must be disconnected from the circuit for the results to be meaningful.

- Use the *diode-check* position on a digital multimeter.
- In the diode-check position on a digital multimeter, the meter applies a higher voltage than when the ohms test function is selected.
- This slightly higher voltage (about 2 to 3 volts) is enough to forward bias a diode or the P-N junction of transistors.

DIODES Using the diode test position, the meter applies a voltage. The display shows the voltage drop across the diode P-N junction. A good diode should give an over limit (OL) reading with the test leads attached to each lead of the diode in one way, and a voltage reading of 0.400 to 0.600 volt when the leads are reversed. This reading is the voltage drop or the barrier voltage across the P-N junction of the diode.

1. A low-voltage reading with the meter leads attached both ways across a diode means that the diode is *shorted* and must be replaced.
2. An OL reading with the meter leads attached both ways across a diode means that the diode is *open* and must be replaced.

● **SEE FIGURE 45–29**.

TRANSISTORS Using a digital meter set to the diode-check position, a good transistor should show a voltage drop of 0.400 to 0.600 volt between the following:

- The emitter (*E*) and the base (*B*) and between the base (*B*) and the collector (*C*) with a meter connected one way, and OL when the meter test leads are reversed.
- An OL reading (no continuity) in both directions when a transistor is tested between the emitter (*E*) and the collector (*C*). (A transistor tester can also be used if available.)

● **SEE FIGURE 45–30**.

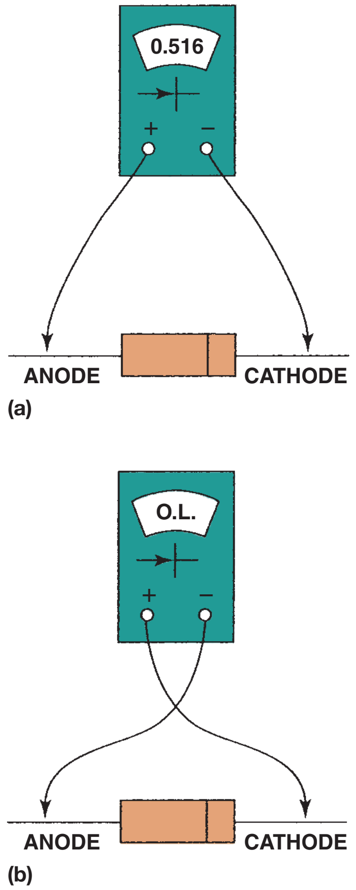


FIGURE 45–29 To check a diode, select "diode check" on a digital multimeter. The display indicates the voltage drop (difference) between the meter leads. The meter itself applies a low-voltage signal (usually about 3 volts) and displays the difference on the display. (a) When the diode is forward biased, the meter should display a voltage between 0.500 and 0.700 volt (500 to 700 millivolts). (b) When the meter leads are reversed, the meter should read OL (over limit) because the diode is reverse biased and blocking current flow.

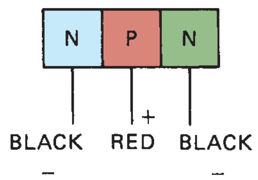


FIGURE 45–30 If the red (positive) lead of the ohmmeter (or a multimeter set to diode check) is touched to the base (center) and the black (negative lead) touched to the emitter or collector, the meter should forward bias the P-N junction and indicate on the meter as low resistance. If the meter reads high resistance, reverse the meter leads, putting the black on the base (center) lead and the red on the collector and emitter. If the meter indicates low resistance, the transistor is a good PNP type. Check all P-N junctions in the same way.

CONVERTERS AND INVERTERS

CONVERTERS DC to DC converters (usually written as DC–DC converter) are electronic devices used to transform DC voltage from one level to another higher or lower level. They are used to distribute various levels of DC voltage throughout a vehicle from a single power bus (or voltage source).

EXAMPLES OF USE One example of a DC–DC converter circuit is the circuit the PCM uses to convert 14 to 5 volts. The 5 volts are called the reference voltage, abbreviated V-ref, and used to power many sensors in a computer-controlled engine management system. The schematic of a typical 5 volt V-ref interfacing with the TP sensor circuit is shown in ● **FIGURE 45–31**.

The PCM operates on 14 volts, using the principle of DC conversion, to provide a constant 5 volts of sensor reference voltage to the TP sensor and others. The TP sensor demands little current, so the V-ref circuit is a low-power DC voltage converter in the range of 1 watt. . The PCM uses a DC–DC converter, which is a small semiconductor device called a voltage regulator, and is designed to convert battery voltage to a constant 5 volts, , regardless of changes in the charging voltage.

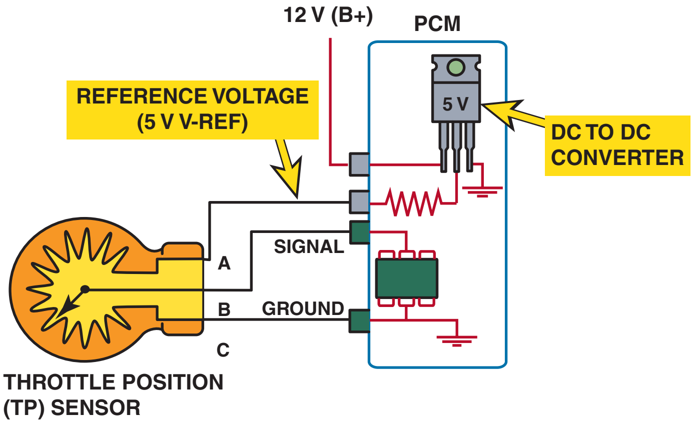


FIGURE 45–31 A DC to DC converter is built into most powertrain control modules (PCMs) and is used to supply the 5 volt reference, called V-ref, to many sensors used to control the internal combustion engine.

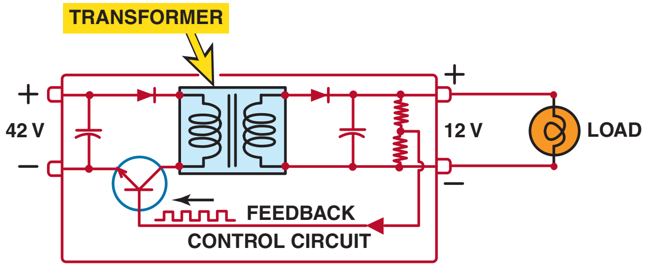


FIGURE 45–32 This DC–DC converter is designed to convert 42 volts to 14 volts, to provide 12 volt power to accessories on a hybrid-electric vehicle operating with a 42 volt electrical system.

WARNING

Always follow the manufacturer's safety precautions for discharging capacitors in DC–DC converter circuits.

Hybrid-electric vehicles use DC–DC converters to provide higher or lower DC voltage levels and current requirements.

A high-power DC–DC converter schematic is shown in ● **FIGURE 45–32** and represents how a nonelectronic DC–DC converter works.

The central component of a converter is a transformer that physically isolates the input (42 volts) from the output (14 volts). The power transistor pulses the high-voltage coil of the transformer, and the resulting changing magnetic field induces a voltage in the coil windings of the lower voltage side of the transformer. The diodes and capacitors help control and limit the voltage and frequency of the circuit.

DC–DC CONVERTER CIRCUIT TESTING Usually a DC control voltage is used, which is supplied by a digital logic circuit to shift the voltage level to control the converter. A voltage test can indicate if the correct voltages are present when the converter is on and off.

Voltage measurements are usually specified to diagnose a DC–DC converter system. A digital multimeter (DMM) that is CAT III rated should be used.

HIGH-VOLTAGE CIRCUIT PRECAUTIONS Whenever working on or near potential high-voltage circuits, adhere to the following:

1. Always follow the manufacturer's safety precautions when working with high-voltage circuits. These circuits are usually indicated by orange wiring.

WARNING

Do not touch the terminals of a battery that are being used to power an inverter. There is always a risk that those battery terminals could deliver a much greater shock than from batteries alone, if a motor or inverter should develop a fault.

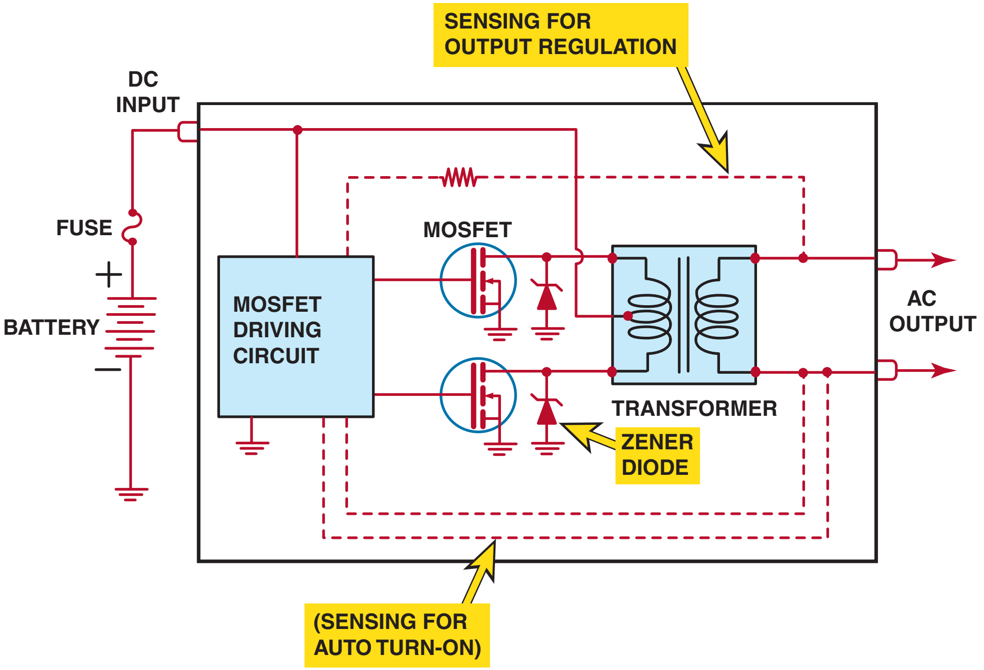


FIGURE 45–33 A typical circuit for an inverter designed to change direct current from a battery to alternating current for use by the electric motors used in a hybrid-electric vehicle.

2. Never tap into wires in a DC–DC converter circuit to access power for another circuit.
3. Never tap into wires in a DC–DC converter circuit to access a ground for another circuit.
4. Never block airflow to a DC–DC converter heat sink.
5. Never use a heat sink for a ground connection for a meter, scope, or accessory connection.
6. Never connect or disconnect a DC–DC converter while the converter is powered up.
7. Never connect a DC–DC converter to a larger voltage source than specified.

INVERTERS An **inverter** is an electronic circuit that changes DC into AC. In most DC–AC inverters, the switching transistors, which are usually MOSFETs, are turned on alternately for short pulses. As a result, the transformer produces a modified sine wave output, rather than a true sine wave. ● **SEE FIGURE 45–33**.

The waveform produced by an inverter is not the perfect sine wave of household AC, but is rather more like a pulsing DC that reacts similar to sine wave AC in transformers and in induction motors. ● **SEE FIGURE 45–34**.

Inverters power AC motors. An inverter converts DC power to AC power at the required frequency and amplitude. The inverter consists of three half-bridge units, and the output voltage is mostly created by a pulse-width modulation (PWM) technique. The three-phase voltage waves are shifted 120 degrees to each other to power each of the three phases.

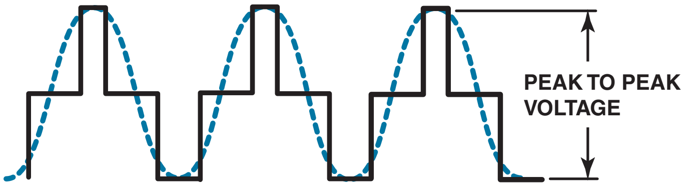


FIGURE 45–34 The switching (pulsing) MOSFETs create a waveform called a modified sine wave (solid lines), compared to a true sine wave (dotted lines).

ELECTROSTATIC DISCHARGE

DEFINITION **Electrostatic discharge (ESD)** is created when static charges build up on the human body when movement occurs. The friction of the clothing and the movement of shoes against carpet or vinyl floors cause a high voltage to build. Then when we touch a conductive material, such as a doorknob, the static charge is rapidly discharged. These charges, although just slightly painful to us, can cause severe damage to delicate electronic components. The following are typical static voltages:

- If you can feel it, it is at least 3,000 volts.
- If you can hear it, it is at least 5,000 volts.
- If you can see it, it is at least 10,000 volts.

Although these voltages seem high, the current, in amperes, is extremely low. However, sensitive electronic components, such as vehicle computers, radios, and instrument panel clusters, can be ruined if exposed to as little as 30 volts. This is a problem because components can be harmed at voltages lower than we can feel.

AVOIDING ESD To help prevent damage to components, follow these easy steps:

1. Keep the replacement electronic component in the protective wrapping until just before installation.
2. Before handling any electronic component, ground yourself by touching a metal surface to drain away any static charge.
3. Do not touch the terminals of electronic components.
4. If working in an area where you could come in contact with terminals, wear a static electrically grounding wrist strap available at most electronic parts stores.

If these precautions are observed, ESD damage can be eliminated or reduced. Remember, just because the component works even after being touched does not mean that damage has not occurred. Often, a section of the electronic component may be damaged, yet does not fail until several days or weeks later.

REVIEW QUESTIONS

1. What is the difference between P-type material and N-type material?
2. How can a diode be used to suppress high-voltage surges in automotive components or circuits containing a coil?
3. How does a transistor work?
4. What precautions should be observed to eliminate or reduce ESD damage?
5. What is the difference between forward bias and reverse bias when discussing a diode?

CHAPTER QUIZ

1. A semiconductor is a material _____________.
   - **a.** with fewer than four electrons in the outer orbit of its atoms
   - **b.** with more than four electrons in the outer orbit of its atoms
   - **c.** with exactly four electrons in the outer orbit of its atoms
   - **d.** determined by other factors besides the number of electrons
2. What device changes resistance with temperature?
   - **a.** Rectifier bridge
   - **b.** Photo diode
   - **c.** Thermistor
   - **d.** Photo resistor
3. A diode installed across a coil with the cathode toward the battery positive is called a(n) _____________.
   - **a.** clamping diode
   - **b.** forward-bias diode
   - **c.** SCR
   - **d.** transistor
4. Solid state devices that are commonly used in automotive electronics include _____________.
   - **a.** operational amplifiers
   - **b.** transistor gates
   - **c.** integrated circuits
   - **d.** All of the above
5. A transistor can _____________.
   - **a.** switch on and off
   - **b.** amplify
   - **c.** throttle
   - **d.** All of the above
6. A zener diode is normally used for voltage regulation. A zener diode, however, can also be used for high-voltage spike protection, if connected _____________.
   - **a.** positive to anode, negative to cathode
   - **b.** positive to cathode, ground to anode
   - **c.** negative to anode, cathode to a resistor, then to a lower voltage terminal
   - **d.** Both a and c
7. The forward-bias voltage required for an LED is _____________.
   - **a.** 0.3 to 0.5 volt
   - **b.** 0.5 to 0.7 volt
   - **c.** 1.5 to 2.2 volts
   - **d.** 4.5 to 5.1 volts
8. Faults or failures in electronic components could be caused by all of the following EXCEPT _____________.
   - **a.** loose connector terminals
   - **b.** a loose alternator belt
   - **c.** jumper cables reversed when jump-starting
   - **d.** a voltage spike
9. What is the purpose and function of an inverter?
   - **a.** To change the polarity of DC voltages
   - **b.** To change low DC voltage to high DC voltage
   - **c.** To change DC voltage to AC voltage
   - **d.** To change AC voltage to DC voltage
10. To avoid damage from an electrostatic discharge, the technician should _____________ before handling sensitive electronic components.
    - **a.** wear dark clothing
    - **b.** be sure to wear insulated shoes
    - **c.** touch the housing of the component before removing it from the protective cover
    - **d.** touch a metal surface on the vehicle

Chapter 46

CAN AND NETWORK COMMUNICATIONS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss how networks connect to the data link connector and to other modules.
- Describe the types of networks and serial communications used on vehicles.
- Describe General Motors communications protocols.
- Describe Ford communications protocols.
- Describe Chrysler communications protocols.
- Describe the features of a controller area network.
- Describe the network communications of common Asian vehicle brands.
- Describe European BUS communications.
- Explain how to diagnose module communication faults.
- Discuss the OBD-II data link connector.

KEY TERMS:

Breakout box (BOB) 533 • BUS 525 • CAN 527 • Class 2 527 • GMLAN 527 • Multiplexing 524 • Network 525 • Node 524 • Programmable controller interface (PCI) 530 • Serial communications interface (SCI) 531 • Serial data 524 • Splice pack 525 • State of health (SOH) 534 • SWCAN 527 • Terminating resistors 534 • Twisted pair 524 • UART-based protocol (UBP) 529

NETWORK FUNDAMENTALS

NEED FOR NETWORK Since the 1990s, vehicles have used modules to control the operation of most electrical components. A typical vehicle has 10 or more modules, and they communicate with each other over data lines or hard wiring, depending on the application.

ADVANTAGES Most modules are connected together in a network because of the following advantages:

- A decreased number of wires are needed, thereby saving weight and cost, as well as helping with installation at the factory and decreased complexity, making servicing easier.
- Common sensor data can be shared with those modules that may need the information, such as vehicle speed, outside air temperature, and engine coolant temperature. ● **SEE FIGURE 46–1**.

MODULES AND NODES Each module, also called a **node**, must communicate to other modules. For example, if the driver depresses the window-down switch, the power window switch sends a window-down message to the body control module. The body control module then sends the request to the driver's side window module. This module is responsible for actually performing the task by supplying power and ground to the window lift motor in the current polarity to cause the window to go down. The module also contains a circuit that monitors the current flow through the motor and stops and/or reverses the window motor if an obstruction causes the window motor to draw more than the normal amount of current.

TYPES OF COMMUNICATION The types of communications include the following:

- **Differential.** In the differential form of BUS communication, a difference in voltage is applied to two wires, which are twisted to help reduce electromagnetic interference (EMI). These transfer wires are called a **twisted pair**.
- **Parallel.** In the parallel type of BUS communication, the send and receive signals are on different wires.
- **Serial data.** The **serial data** is data transmitted by a series of rapidly changing voltage signals pulsed from low to high or from high to low.
- **Multiplexing.** The process of **multiplexing** involves the sending of multiple signals of information at the same time over a signal wire and separating the signals at the receiving end.

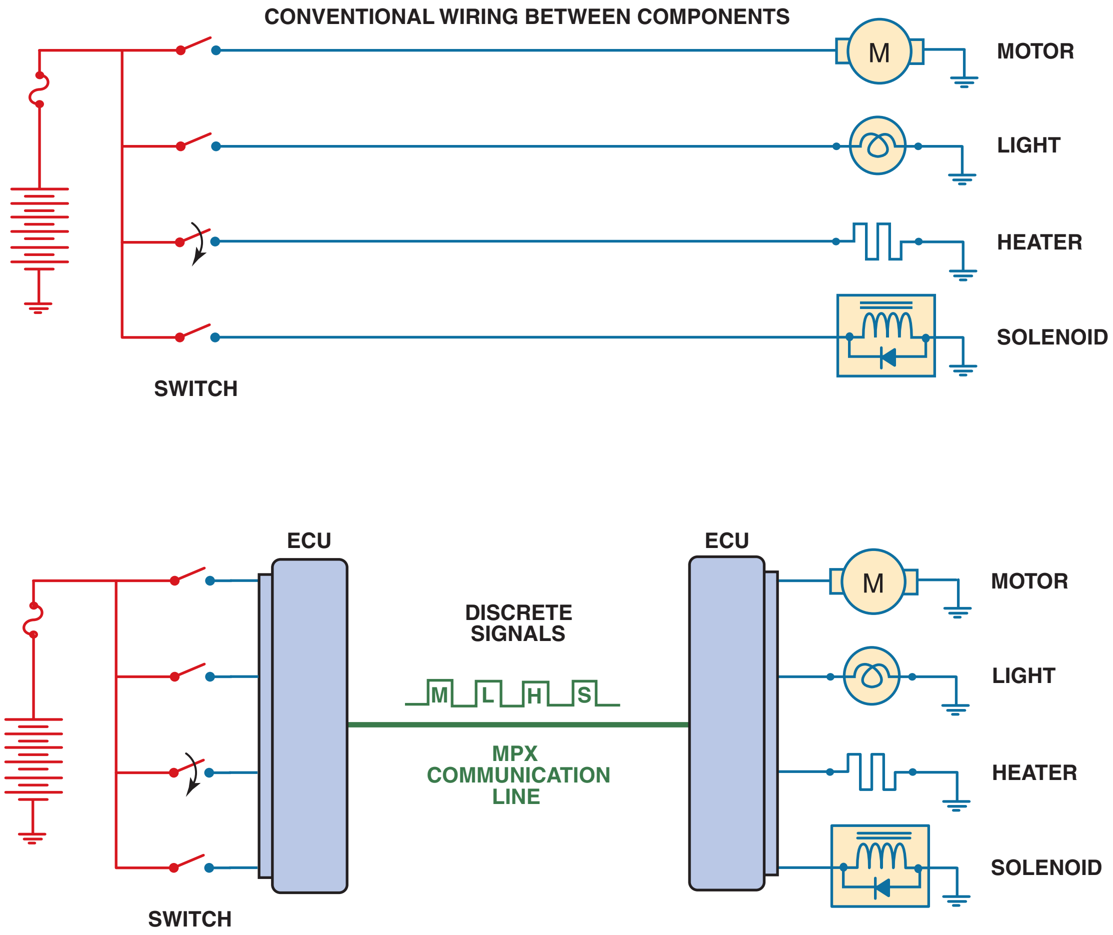


FIGURE 46–1 Module communications makes controlling multiple electrical devices and accessories easier by utilizing simple low-current switches to signal another module, which does the actual switching of the current to the device.

This system of intercommunication of computers or processors is referred to as a **network**. ● **SEE FIGURE 46–2**.

By connecting the computers together on a communications network, they can easily share information back and forth. This multiplexing has the following advantages:

- Elimination of redundant sensors and dedicated wiring for these multiple sensors
- Reduction of the number of wires, connectors, and circuits
- Addition of more features and option content to new vehicles
- Weight reduction due to fewer components, wires, and connectors, thereby increasing fuel economy
- Changeable features with software upgrades versus component replacement

FREQUENTLY ASKED QUESTION

What Is a Twisted Pair?

A twisted pair is used to transmit low-voltage signals, using two wires that are twisted together. Electromagnetic interference can create a voltage in a wire and twisting the two signal wires cancels out the induced voltage. A twisted pair means that the two wires have at least nine turns per foot (turns per meter). A rule of thumb is a twisted pair should have one twist per inch of length.

MODULE COMMUNICATIONS CONFIGURATION

The three most common types of networks used on vehicles include the following:

1. **Ring link networks.** In a ring-type network, all modules are connected to each other by a serial data line (in a line) until all are connected in a ring. ● **SEE FIGURE 46–3**.
2. **Star link networks.** In a star link network, a serial data line attaches to each module and then each is connected to a central point. This central point is called a **splice pack**, abbreviated SP, such as in “SP 306.” The splice pack uses a bar to splice all of the serial lines together. Some GM vehicles use two or more splice packs to tie the modules together. When more than one splice pack is used, a serial data line connects one splice pack to the others. In most applications, the BUS

FREQUENTLY ASKED QUESTION

What Is a BUS?

A **BUS** is a term used to describe a communications network. Therefore, there are *connections to the BUS* and *BUS communications*, both of which refer to digital messages being transmitted among electronic modules or computers.

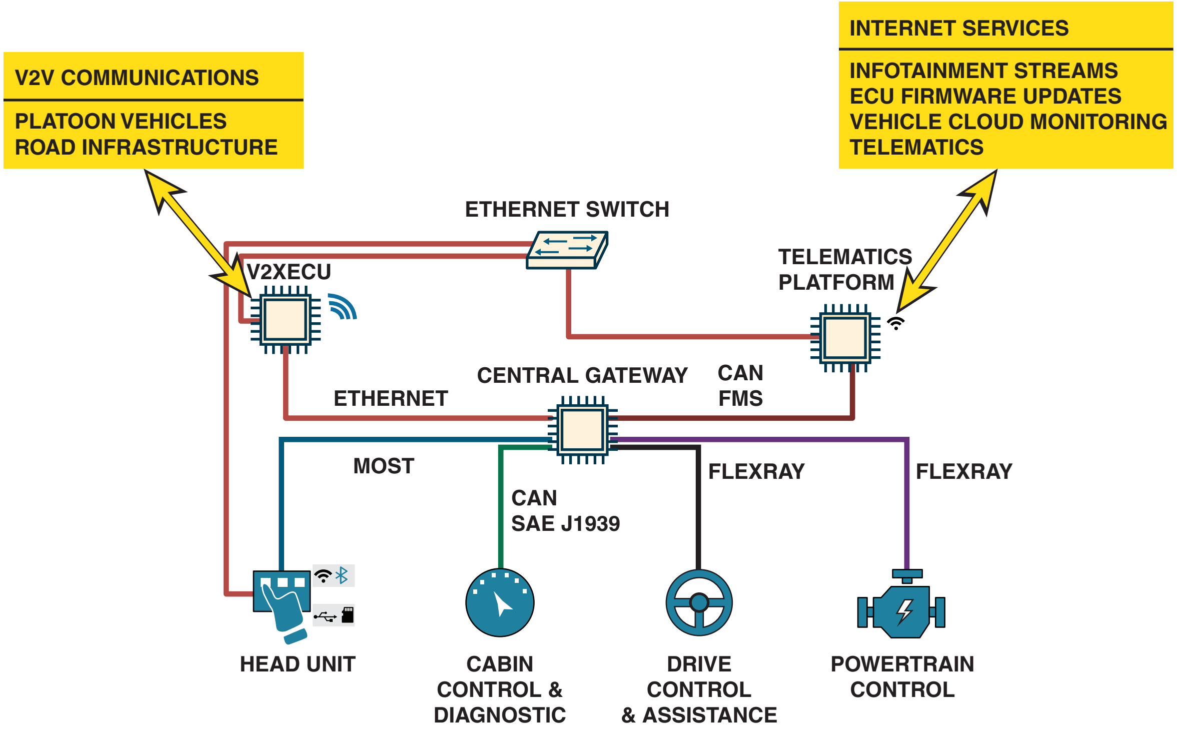

V2V COMMUNICATIONS
PLATOON VEHICLES
ROAD INFRASTRUCTURE
INTERNET SERVICES
INFOTAINMENT STREAMS
ECU FIRMWARE UPDATES
VEHICLE CLOUD MONITORING
TELEMATICS
ETHERNET SWITCH
V2XECU
TELEMATICS PLATFORM
ETHERNET
CENTRAL GATEWAY
CAN FMS
MOST
CAN SAE J1939
FLEXRAY
FLEXRAY
HEAD UNIT
CABIN CONTROL & DIAGNOSTIC
DRIVE CONTROL & ASSISTANCE
POWERTRAIN CONTROL

FIGURE 46–2 A network allows all modules to communicate with other modules.

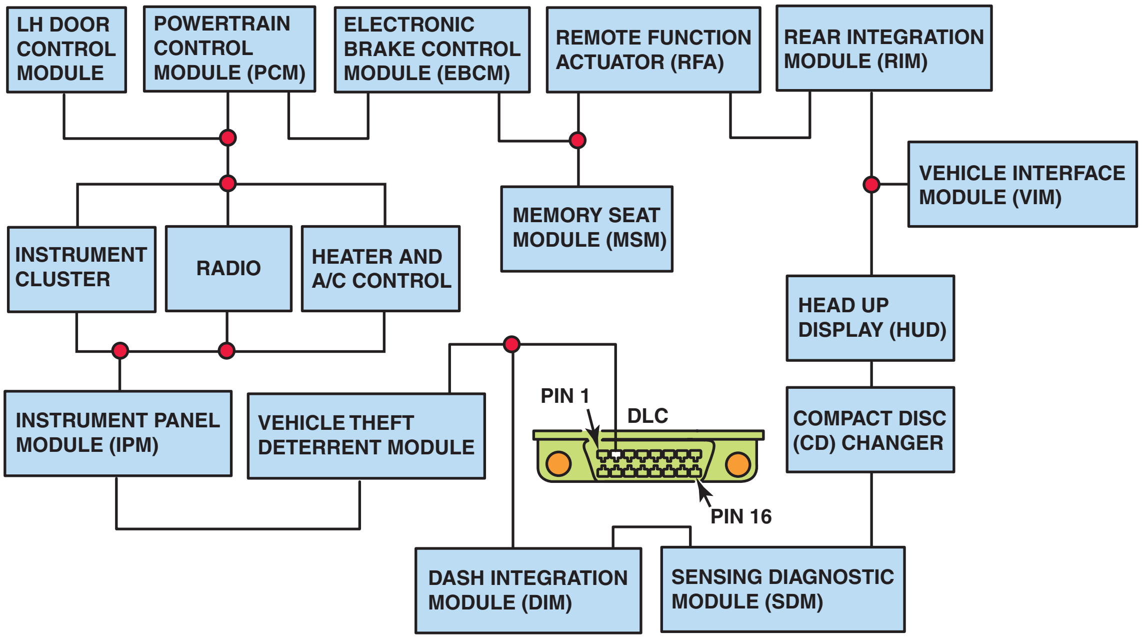

LH DOOR CONTROL MODULE
POWERTRAIN CONTROL MODULE (PCM)
ELECTRONIC BRAKE CONTROL MODULE (EBCM)
REMOTE FUNCTION ACTUATOR (RFA)
REAR INTEGRATION MODULE (RIM)
VEHICLE INTERFACE MODULE (VIM)
MEMORY SEAT MODULE (MSM)
INSTRUMENT CLUSTER
RADIO
HEATER AND A/C CONTROL
HEAD UP DISPLAY (HUD)
PIN 1
DLC
COMPACT DISC (CD) CHANGER
INSTRUMENT PANEL MODULE (IPM)
VEHICLE THEFT DETERRENT MODULE
PIN 16
DASH INTEGRATION MODULE (DIM)
SENSING DIAGNOSTIC MODULE (SDM)

FIGURE 46–3 A ring link network reduces the number of wires it takes to interconnect all of the modules.

FREQUENTLY ASKED QUESTION

What Is a Protocol?

A protocol is a set of rules or a standard used between computers or electronic control modules. Protocols include the type of electrical connectors, voltage levels, and frequency of the transmitted messages. Protocols, therefore, include both the hardware and software needed to communicate between modules.

bar used in each splice pack can be removed. When the BUS bar is removed, a special tool (J 42236) can be installed in place of the removed BUS bar. Using this tool, the serial data line for each module can be isolated and tested for a possible problem. Using the special tool at the splice pack makes diagnosing this type of network easier than many others. ● **SEE FIGURE 46–4**.

3. **Ring/star hybrid.** In a ring/star network, the modules are connected using both types of network configurations. Check service information (SI) for details on how this network is connected on the vehicle being diagnosed and always follow the recommended diagnostic steps.

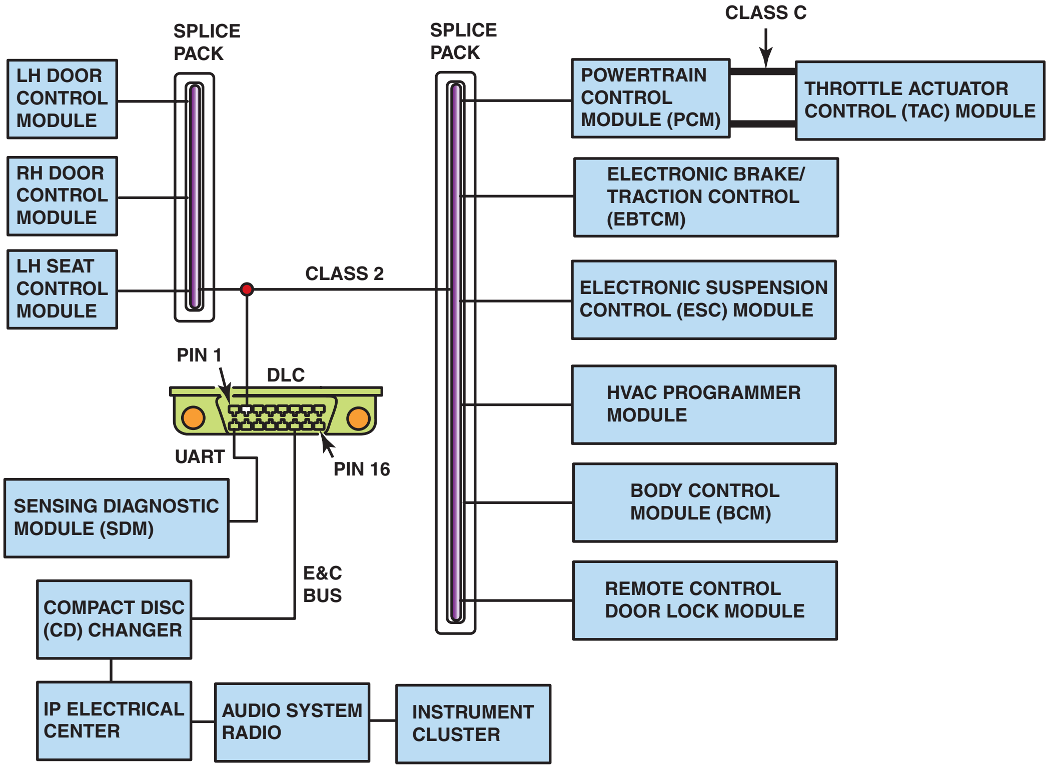

CLASS C
SPLICE PACK
SPLICE PACK
LH DOOR CONTROL MODULE
RH DOOR CONTROL MODULE
LH SEAT CONTROL MODULE
POWERTRAIN CONTROL MODULE (PCM)
THROTTLE ACTUATOR CONTROL (TAC) MODULE
ELECTRONIC BRAKE/ TRACTION CONTROL (EBTCM)
CLASS 2
ELECTRONIC SUSPENSION CONTROL (ESC) MODULE
PIN 1
DLC
HVAC PROGRAMMER MODULE
UART
PIN 16
SENSING DIAGNOSTIC MODULE (SDM)
BODY CONTROL MODULE (BCM)
E&C BUS
COMPACT DISC (CD) CHANGER
REMOTE CONTROL DOOR LOCK MODULE
IP ELECTRICAL CENTER
AUDIO SYSTEM RADIO
INSTRUMENT CLUSTER

FIGURE 46–4 In a star link network, all of the modules are connected using splice packs.

NETWORK COMMUNICATIONS CLASSIFICATIONS The Society of Automotive Engineers (SAE) standards include the following three categories of in-vehicle network communications:

- **Class A.** Low-speed networks, meaning less than 10,000 bits per second (bps, or 10 kbs), are generally used for trip computers, entertainment, and other convenience features.
- **Class B.** Medium-speed networks, meaning 10,000 to 125,000 bps (10 to 125 kbs), are generally used for information transfer among modules, such as instrument clusters, temperature sensor data, and other general uses.
- **Class C.** High-speed networks, meaning 125,000 to 1,000,000 bps, are generally used for real-time powertrain and vehicle dynamic control. High-speed BUS communication systems now use a **controller area network (CAN).** ● **SEE FIGURE 46–5.**

GENERAL MOTORS COMMUNICATIONS PROTOCOLS

CLASS 2 COMMUNICATIONS **Class 2** is a serial communications system that operates by toggling between 0 and 7 volts at a transfer rate of 10.4 kbs. Class 2 is used for most high-speed communications between the powertrain control module and other control modules, plus to the scan tool. Class 2 is the primary high-speed serial communications system used by GMCAN (CAN) and is connected to terminal 2 of the DLC. ● **SEE FIGURE 46–6.**

GMLAN General Motors, like all vehicle manufacturers, must use high-speed serial data to communicate with scan tools on all vehicles effective with the 2008 model year. As mentioned, the standard is called controller area network (CAN), which General Motors calls **GMLAN**, which stands for **GM local area network.**

General Motors uses two versions of GMLAN.

- **Low-speed GMLAN.** The low-speed version is used for driver-controlled functions, such as power windows and door locks. The baud rate for low-speed GMLAN is 33,300 bps. The GMLAN low-speed serial data is not connected directly to the data link connector and uses one wire. The voltage toggles between 0 and 5 volts after an initial 12 volt spike, which indicates to the modules to turn on or wake up and listen for data on the line. Low-speed GMLAN is also known as **single-wire CAN**, or **SWCAN**, and is located at pin 1 of the DLC.
- **High-speed GMLAN.** The baud rate is almost real time at 500 bps. This serial data method uses a two-twisted-wire circuit, which is connected to the data link connector on pins 6 and 14. ● **SEE FIGURE 46–7.**

FREQUENTLY ASKED QUESTION

Why Is a Twisted Pair Used?

A twisted pair is where two wires are twisted to prevent electromagnetic radiation from affecting the signals passing through the wires. By twisting the two wires about once every inch (9 to 16 times per foot), the interference is canceled by the adjacent wire.

● **SEE FIGURE 46–8.**

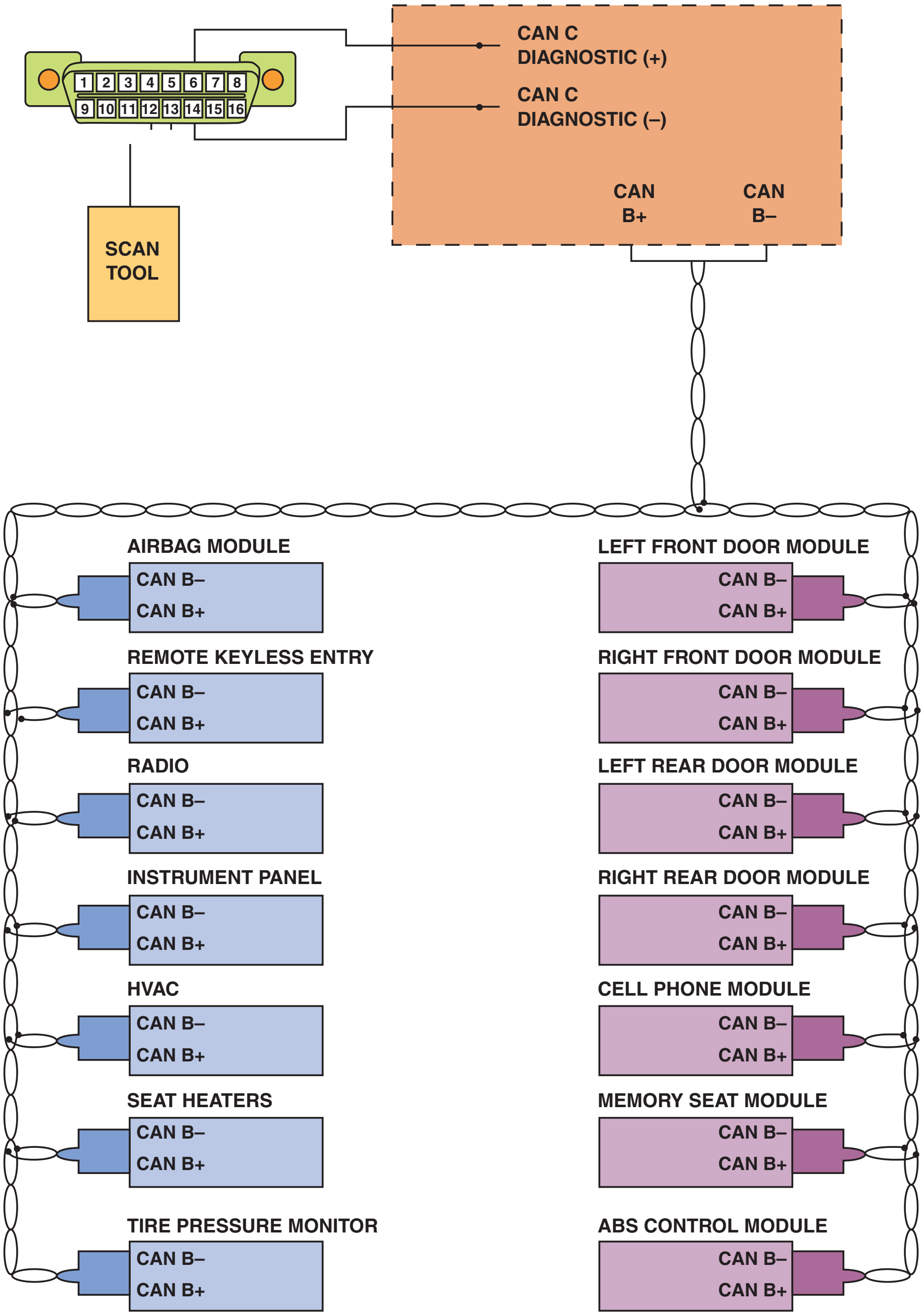

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
SCAN TOOL
CAN C DIAGNOSTIC (+)
CAN C DIAGNOSTIC (–)
CAN B+
CAN B–
AIRBAG MODULE
CAN B–
CAN B+
REMOTE KEYLESS ENTRY
CAN B–
CAN B+
RADIO
CAN B–
CAN B+
INSTRUMENT PANEL
CAN B–
CAN B+
HVAC
CAN B–
CAN B+
SEAT HEATERS
CAN B–
CAN B+
TIRE PRESSURE MONITOR
CAN B–
CAN B+
LEFT FRONT DOOR MODULE
CAN B–
CAN B+
RIGHT FRONT DOOR MODULE
CAN B–
CAN B+
LEFT REAR DOOR MODULE
CAN B–
CAN B+
RIGHT REAR DOOR MODULE
CAN B–
CAN B+
CELL PHONE MODULE
CAN B–
CAN B+
MEMORY SEAT MODULE
CAN B–
CAN B+
ABS CONTROL MODULE
CAN B–
CAN B+

FIGURE 46–5 A typical BUS system showing module CAN communications and twisted pairs of wire.

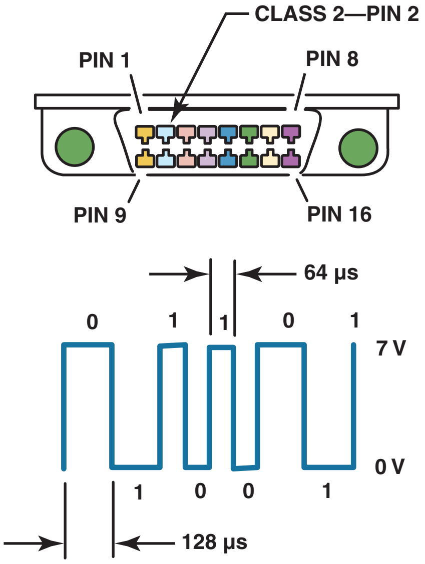

CLASS 2—PIN 2
PIN 1
PIN 8
PIN 9
PIN 16
64 μs
0
1
1
0
1
7 V
0 V
1
0
0
1
128 μs

FIGURE 46–6 Class 2 serial data communication is accessible at the data link connector at pin 2.

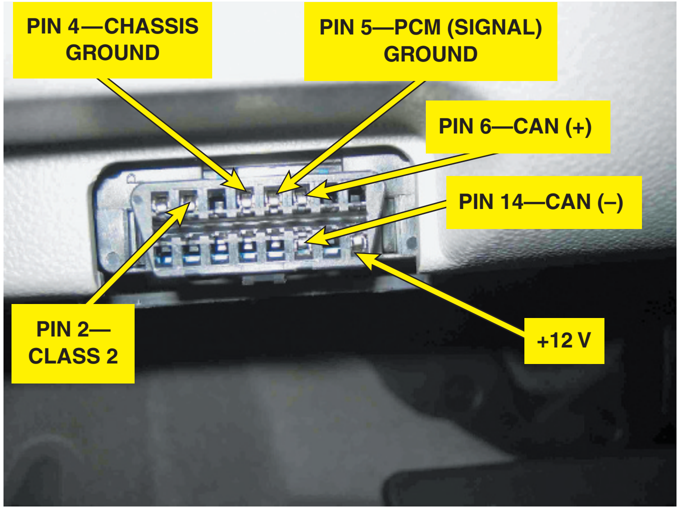

PIN 4—CHASSIS GROUND
PIN 5—PCM (SIGNAL) GROUND
PIN 6—CAN (+)
PIN 14—CAN (–)
PIN 2—CLASS 2
+12 V

FIGURE 46–7 GMLAN uses pins at terminals 6 and 14. Pin 1 is used for low-speed GMLAN on 2006 and newer GM vehicles.

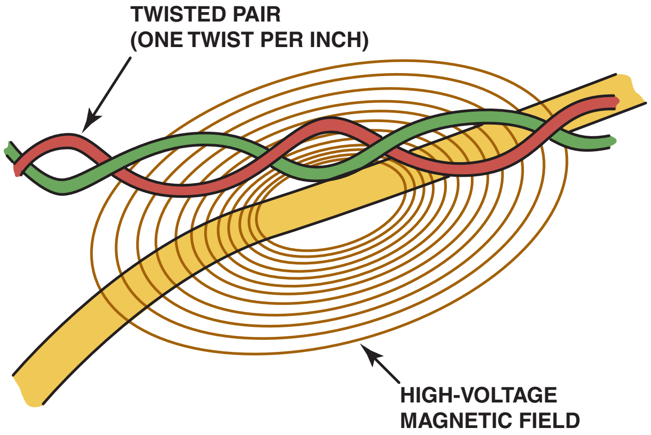

TWISTED PAIR
(ONE TWIST PER INCH)
HIGH-VOLTAGE
MAGNETIC FIELD

FIGURE 46–8 A twisted pair is used by several different network communications protocols to reduce interference that can be induced in the wiring from nearby electromagnetic sources.

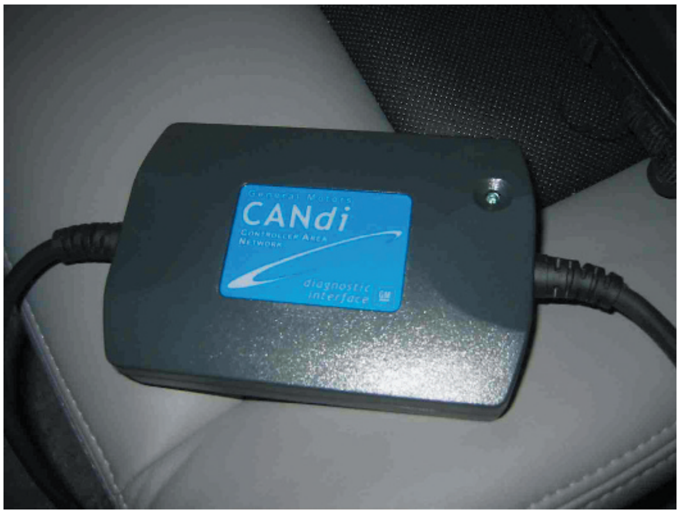

CANdi
diagnostic interface

FIGURE 46–9 A CANdi module flashes the green LED rapidly if communication is detected.

A CANdi (CAN diagnostic interface) module is required to be used with the Tech 2 to be able to connect a GM vehicle equipped with GMLAN. ● **SEE FIGURE 46–9**.

FORD NETWORK COMMUNICATIONS PROTOCOLS

UART-BASED PROTOCOL Newer Fords use the CAN for scan tool diagnosis, and **UART-based protocol (UBP)** for some modules. ● **SEE FIGURES 46–10 AND 46–11**.

FREQUENTLY ASKED QUESTION

What Are U Codes?

The U diagnostic trouble codes were at first "undefined" but are now network-related codes. Use the network codes to help pinpoint the circuit or module that is not working correctly.

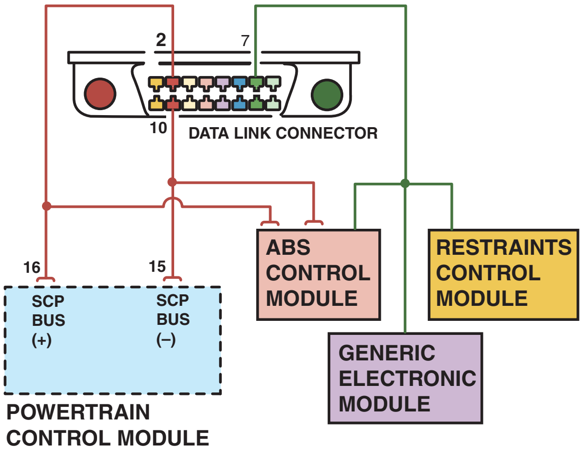

2
7
10
DATA LINK CONNECTOR
16
15
SCP BUS (+)
SCP BUS (–)
POWERTRAIN CONTROL MODULE
ABS CONTROL MODULE
RESTRAINTS CONTROL MODULE
GENERIC ELECTRONIC MODULE

FIGURE 46–10 A scan tool can be used to check communications with the SCP BUS through terminals 2 and 10 and to the other modules connected to terminal 7 of the data link connector.

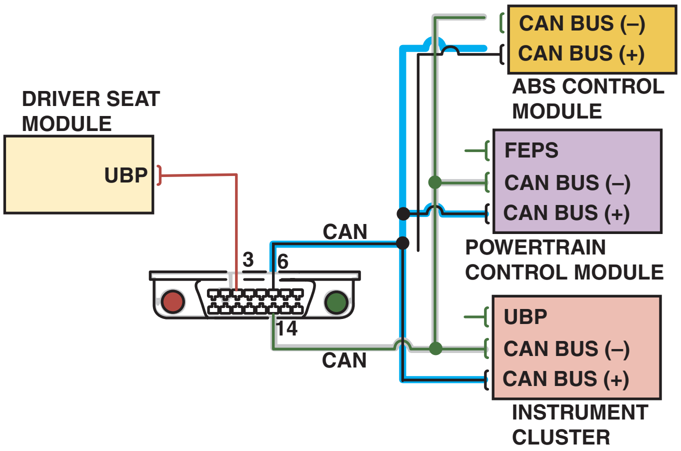

DRIVER SEAT MODULE
UBP
CAN
3
6
14
CAN
CAN BUS (–)
CAN BUS (+)
ABS CONTROL MODULE
FEPS
CAN BUS (–)
CAN BUS (+)
POWERTRAIN CONTROL MODULE
UBP
CAN BUS (–)
CAN BUS (+)
INSTRUMENT CLUSTER

FIGURE 46–11 Many Fords use UBP module communications along with CAN.

CHRYSLER COMMUNICATIONS PROTOCOLS

CCD Since the late 1980s, the Chrysler Collision Detection (CCD) multiplex network is used for scan tool and module communications. It is a differential-type communication and uses a twisted pair of wires. The modules connected to the network apply a bias voltage on each wire. CCD signals are divided into plus and minus (CCD+ and CCD−) and the voltage difference does not exceed 0.02 volt. The baud rate is 7,812.5 bps.

NOTE: The "collision" in the Chrysler Collision Detection BUS communications refers to the program that avoids conflicts of information exchange within the BUS, and does not refer to airbags or other accident-related circuits of the vehicle.

The circuit is active without a scan tool command. ● **SEE FIGURE 46–12**.

The modules on the CCD BUS apply a bias voltage on each wire by using termination resistors. ● **SEE FIGURE 46–13**.

The difference in voltage between CCD+ and CCD− is less than 20 millivolts. For example, using a digital meter with the black

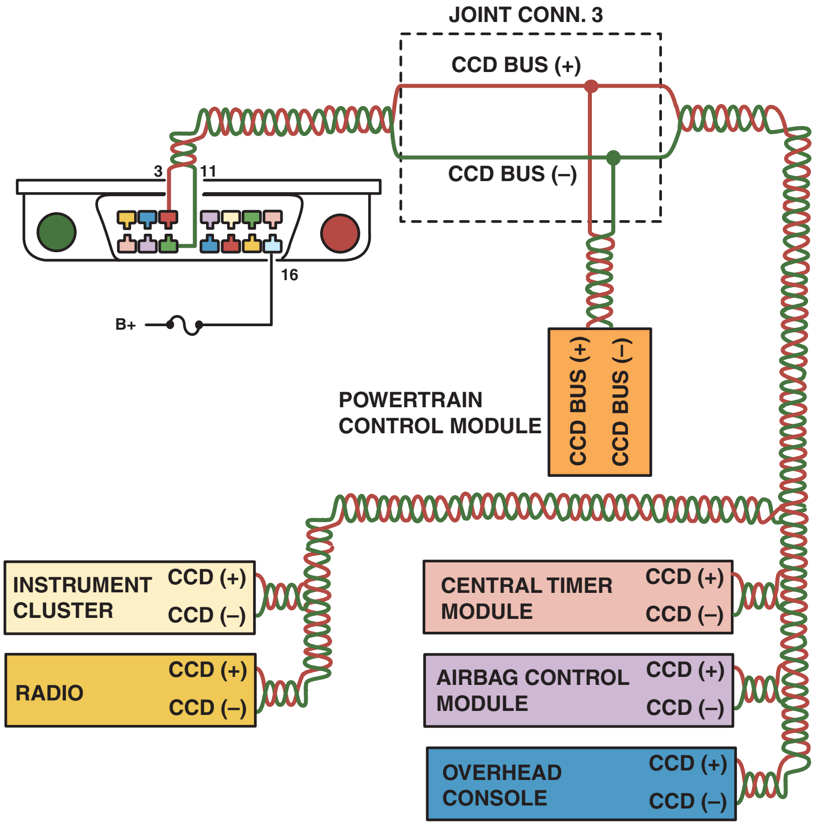

JOINT CONN. 3
CCD BUS (+)
CCD BUS (–)
3
11
16
B+
POWERTRAIN CONTROL MODULE
CCD BUS (+)
CCD BUS (–)
INSTRUMENT CLUSTER
CCD (+)
CCD (–)
RADIO
CCD (+)
CCD (–)
CENTRAL TIMER MODULE
CCD (+)
CCD (–)
AIRBAG CONTROL MODULE
CCD (+)
CCD (–)
OVERHEAD CONSOLE
CCD (+)
CCD (–)

FIGURE 46–12 CCD signals are labeled plus (+) and minus (–) and use a twisted pair of wires. Notice that terminals 3 and 11 of the data link connector are used to access the CCD BUS from a scan tool. Pin 16 is used to supply 12 volts to the scan tool.

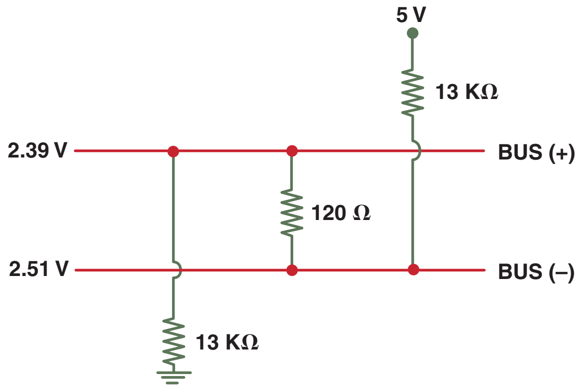

5 V
13 KΩ
2.39 V
BUS (+)
120 Ω
2.51 V
BUS (–)
13 KΩ

FIGURE 46–13 The differential voltage for the CCD BUS is created by using resistors in a module.

meter lead attached to ground and the red meter lead attached at the data link connector, a normal reading could include

- Terminal 3 = 2.45 volts
- Terminal 11 = 2.47 volts

This is an acceptable reading because the readings are 20 millivolts (0.020 volt) of each other. If both had been exactly 2.5 volts, then this could indicate that the two data lines are shorted together. The module providing the bias voltage is usually the body control module on passenger cars and the front control module on Jeeps and trucks.

PROGRAMMABLE CONTROLLER INTERFACE The Chrysler **programmable controller interface (PCI)** is a one-wire communication protocol that connects at the OBD-II DLC at terminal 2. The PCI BUS is connected to all modules on the BUS in a star configuration and operates at a baud rate of 10,200 bps. The voltage signal toggles between 7.5 and 0 volt. If this voltage is checked at terminal 2 of the OBD-II DLC, a voltage of about 1 volt indicates the average voltage, and means that the BUS is functioning and is not shorted-to-ground. PCI and CCD are often used in the same vehicle. ● **SEE FIGURE 46–14**.

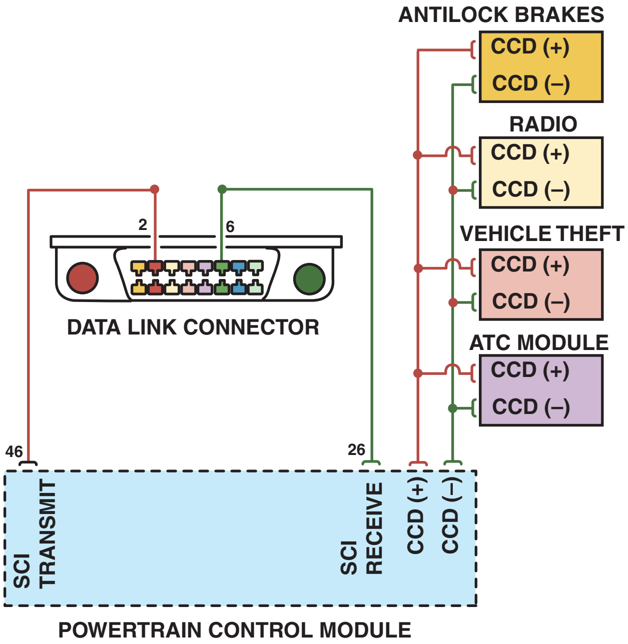

ANTILOCK BRAKES
CCD (+)
CCD (–)
RADIO
CCD (+)
CCD (–)
VEHICLE THEFT
CCD (+)
CCD (–)
ATC MODULE
CCD (+)
CCD (–)
2
6
DATA LINK CONNECTOR
46
26
SCI TRANSMIT
SCI RECEIVE
CCD (+)
CCD (–)
POWERTRAIN CONTROL MODULE

FIGURE 46–14 Many Chrysler vehicles use both SCI and CCD for module communication.

SERIAL COMMUNICATIONS INTERFACE Chrysler used **serial communications interface (SCI)** for most scan tool and flash reprogramming functions until it was replaced with CAN. SCI is connected at the OBD-II data link connector (DLC) at terminals 6 (SCI receive) and 2 (SCI transmit). A scan tool must be connected to test the circuit.

CONTROLLER AREA NETWORK

BACKGROUND Robert Bosch Corporation developed the CAN protocol, which was called CAN 1.2, in 1993. The CAN protocol was approved by the Environmental Protection Agency (EPA) for 2003 and newer vehicle diagnostics, and became a legal requirement for all vehicles by 2008. The CAN diagnostic systems use pins 6 and 14 in the standard 16-pin OBD-II (J-1962) connector. Before CAN, the scan tool protocol had been manufacturer-specific.

CAN FEATURES The CAN protocol offers the following features:

- Faster than other BUS communication protocols
- Cost-effective because it is an easier system than others to use
- Less affected by electromagnetic interference (Data is transferred on two wires that are twisted together, called twisted pair, to help reduce EMI interference.)
- Message-based rather than address-based, which makes it easier to expand
- No wake-up needed because it is a two-wire system
- Supports up to 15 modules plus a scan tool
- Uses a 120 ohm resistor at the ends of each pair to reduce electrical noise
- Applies 2.5 volts on both wires:

  H (high) goes to 3.5 volts when active

  L (low) goes to 1.5 volts when active

  ● **SEE FIGURE 46–15**.

CAN CLASS A, B, AND C There are three classes of CAN and they operate at different speeds. The CAN A, B, and C networks can all be linked using a gateway within the same vehicle. The gateway is usually one of the many modules in the vehicle.

- **CAN A.** This class operates on only one wire at slow speeds and is, therefore, less expensive to build. CAN A operates a data transfer rate of 33.33 kbs in normal mode and up to 83.33 kbs during reprogramming mode. CAN A uses the vehicle ground as the signal return circuit.
- **CAN B.** This class operates on a two-wire network and does not use the vehicle ground as the signal return circuit. CAN B uses a data transfer rate of 95.2 kbs. Instead, CAN B (and CAN C) uses two network wires for differential signaling. This means that the two data signal voltages are opposite to each other and used for error detection by constantly being compared. In this case, when the signal voltage at one of the CAN data wires goes high (CAN H), the other one goes low (CAN L), hence the name *differential signaling*. Differential signaling is also used for redundancy, in case one of the signal wires shorts out.
- **CAN C.** This class is the highest speed CAN protocol, with speeds up to 500 kbs. Beginning with 2008 models, all vehicles sold in the United States must use CAN BUS for scan tool communications. Most vehicle manufacturers started using CAN in older models; it is easy to determine if a vehicle is equipped with CAN. The CAN BUS communicates to the scan tool through terminals 6 and 14 of the DLC, indicating that the vehicle is equipped with CAN. ● **SEE FIGURE 46–16**.

The total voltage remains constant at all times and the electromagnetic field effects of the two data BUS lines cancel each other out. The data BUS line is protected against received radiation and is virtually neutral in sending radiation.

HONDA/TOYOTA COMMUNICATIONS

The primary BUS communication on pre-CAN-equipped vehicles is ISO 9141-2 using terminals 7 and 15 at the OBD-II DLC. ● **SEE FIGURE 46–17**.

A factory scan tool or an aftermarket scan tool equipped with enhanced original equipment (OE) software is needed to access many of the BUS messages. ● **SEE FIGURE 46–18**.

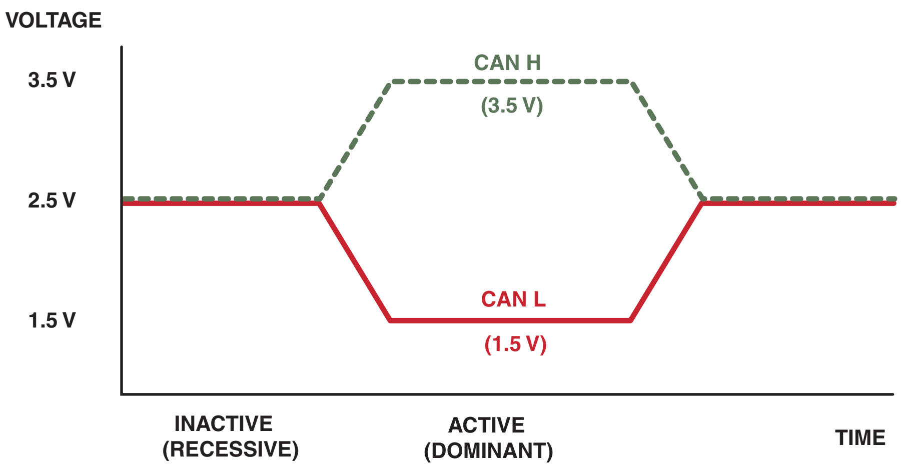


FIGURE 46–15 CAN uses a differential type of module communication where the voltage on one wire is the equal, but opposite, voltage on the other wire. When no communication is occurring, both wires have 2.5 volts applied. When communication is occurring, CAN H goes up 1 to 3.5 volts and CAN L goes down 1 to 1.5 volts.

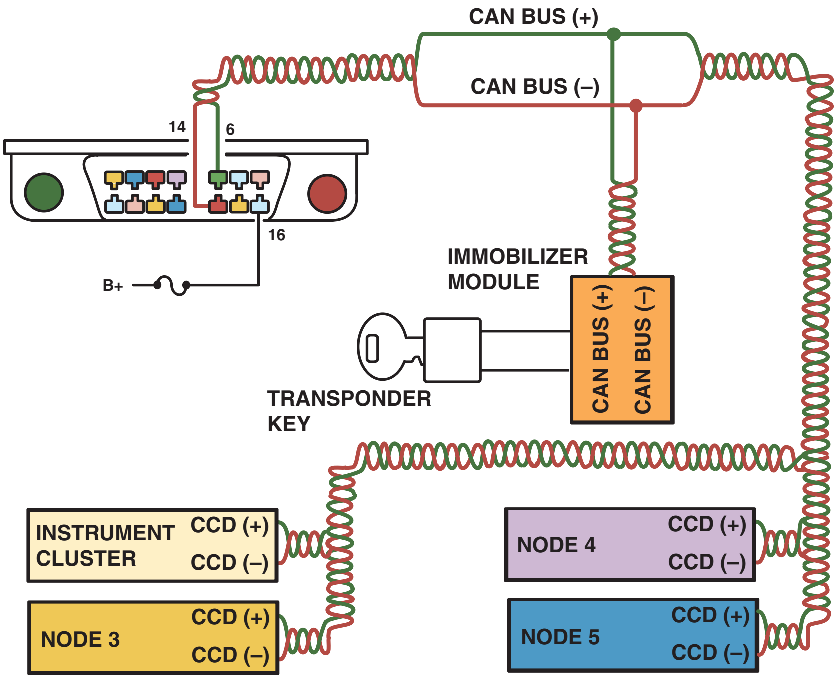

CAN BUS (+)
CAN BUS (–)
14
6
16
B+
IMMOBILIZER MODULE
CAN BUS (+)
CAN BUS (–)
TRANSPONDER KEY
INSTRUMENT CLUSTER
CCD (+)
CCD (–)
NODE 3
CCD (+)
CCD (–)
NODE 4
CCD (+)
CCD (–)
NODE 5
CCD (+)
CCD (–)

FIGURE 46–16 A typical (generic) system showing how the CAN BUS is connected to various electrical accessories and systems in the vehicle.

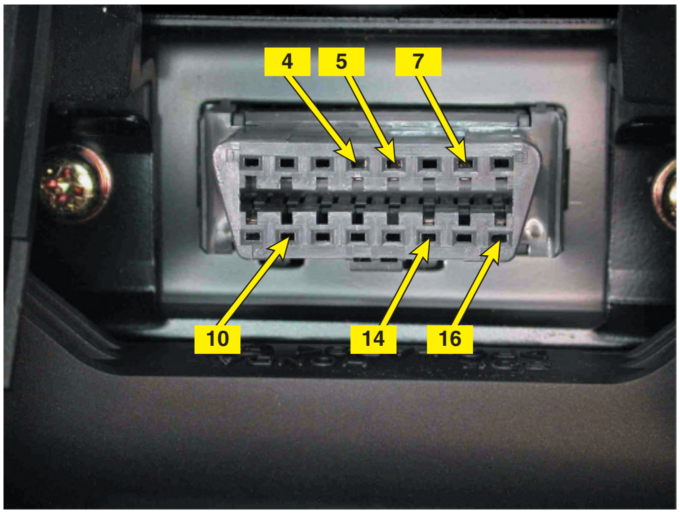
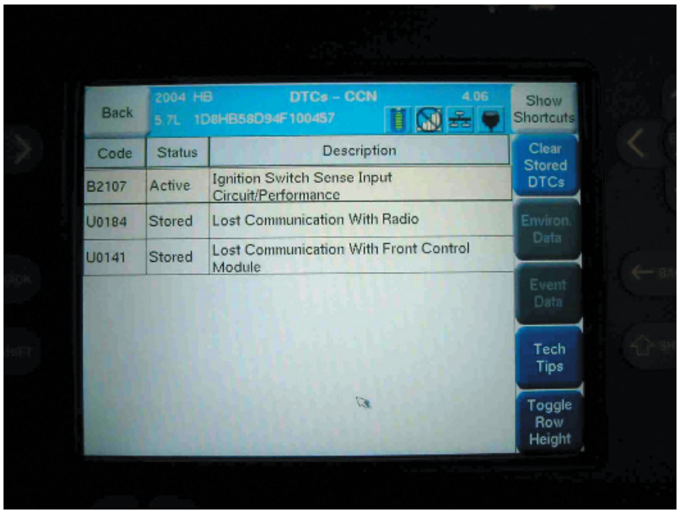


FIGURE 46–17 A DLC from a pre-CAN Acura. It shows terminals in cavities 4, 5 (grounds), 7, 10, 14, and 16 (B+).


Back
Show Shortcuts
Clear Stored DTCs
Environ. Data
Event Data
Tech Tips
Toggle Row Height

2004 HB DTCs – CCN 4.06
5.7L 1D8HB58D94F100457

Code	Status	Description
B2107	Active	Ignition Switch Sense Input Circuit/Performance
U0184	Stored	Lost Communication With Radio
U0141	Stored	Lost Communication With Front Control Module

FIGURE 46–18 A Honda scan display showing a B and two U codes, all indicating a BUS-related problem(s).

EUROPEAN BUS COMMUNICATIONS

MEDIA-ORIENTED SYSTEM TRANSPORT BUS The media-oriented system transport (MOST) BUS uses fiber optics for module-to-module communications in a ring or star configuration. This BUS system is currently being used for entertainment equipment data communications for videos, CDs, and other media systems in the vehicle.

MOTOROLA INTERCONNECT BUS Motorola interconnect (MI) is a single-wire serial communications protocol, using one master control module and many sub-modules. Typical application of

FREQUENTLY ASKED QUESTION

How Do You Know What System Is Used?

Use service information to determine which network communication protocol is used. However, due to the various systems on some vehicles, it may be easier to look at the data link connection to determine the system. All OBD-II vehicles have terminals in the following cavities:

Terminal 4: chassis ground

Terminal 5: computer (signal) ground

Terminal 16: 12 volt positive

The terminals in cavities 6 and 14 mean that this vehicle is equipped with CAN as the only module communication protocol available at the DLC. To perform a test of the BUS, use a breakout box (BOB) to gain access to the terminals while connecting to the vehicle, using a scan tool. ● **SEE FIGURE 46–19** for a typical OBD-II connector breakout box.

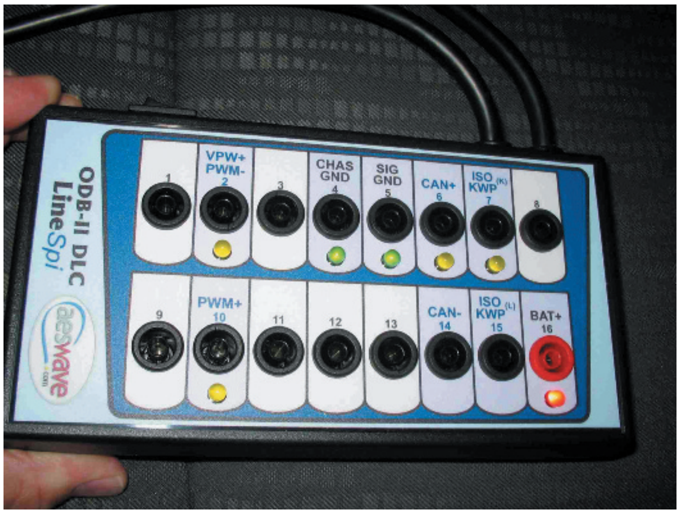

ODB-II DLC
LineSpi
aeswave
1
VPW+ PWM- 2
3
CHAS GND 4
SIG GND 5
CAN+ 6
ISO KWP (K) 7
8
9
PWM+ 10
11
12
13
CAN- 14
ISO KWP (L) 15
BAT+ 16

FIGURE 46–19 A **breakout box (BOB)** used to access the BUS terminals while using a scan tool to activate the modules. This breakout box is equipped with LEDs that light when data circuits are active.

the MI BUS protocol is with power and memory mirrors, seats, windows, and headlight levelers.

DISTRIBUTED SYSTEM INTERFACE BUS

Distributed system interface (DSI) BUS protocol was developed by Motorola and uses a two-wire serial BUS. This BUS protocol is currently being used for safety-related sensors and components.

BOSCH-SIEMENS-TEMIC BUS

The Bosch-Siemens-Temic (BST) BUS is another system that is used for safety-related components and sensors in a vehicle, such as airbags. The BST BUS is a two-wire system and operates up to 250,000 bps.

BYTEFLIGHT BUS

The byteflight BUS is used in safety critical systems, such as airbags, and uses the time division multiple access (TDMA) protocol, which operates at 10 million bps using a plastic optical fiber (POF).

FLEXRAY BUS

FlexRay BUS is a version of byteflight and is a high-speed serial communication system for in-vehicle networks. FlexRay is commonly used for steer-by-wire and brake-by-wire systems.

DOMESTIC DIGITAL BUS

The domestic digital BUS, commonly designated D2B, is an optical BUS system connecting audio, video, computer, and telephone components in a single-ring structure with a speed of up to 5,600,000 bps.

LOCAL INTERCONNECT NETWORK BUS

Local interconnect network (LIN) is a BUS protocol used between intelligent sensors and actuators and has a BUS speed of 19,200 bps.

NETWORK COMMUNICATIONS DIAGNOSIS

STEPS TO FINDING A FAULT

When a network communications fault is suspected, perform the following steps:

STEP 1 **Check everything that does and does not work.** Often accessories that do not seem to be connected can help identify which module or BUS circuit is at fault.

STEP 2 **Perform module status test.** Use a factory-level scan tool or an aftermarket scan tool equipped with enhanced software that allows OE-like functions. Check if the components or systems can be operated through the scan tool. ● **SEE FIGURE 46–20**.

- **Ping modules.** Start the Class 2 diagnosis by using a scan tool and select *diagnostic circuit check*. If no diagnostic trouble codes (DTCs) are shown, there could be a communication problem. Select *message monitor,* which displays the status of all of the modules on the Class 2 BUS circuit. The modules that are awake are shown as active and the scan tool can be used to ping individual modules or command all modules. The ping command should change the status from "active" to "inactive." ● **SEE FIGURE 46–21**.

NOTE: If an excessive parasitic draw is being diagnosed, use a scan tool to ping the modules in one way to determine if one of the modules is not going to sleep and cause excessive battery drain.

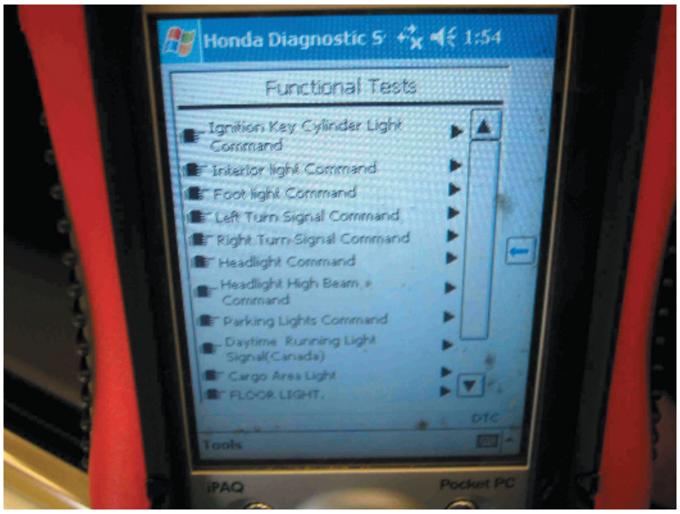
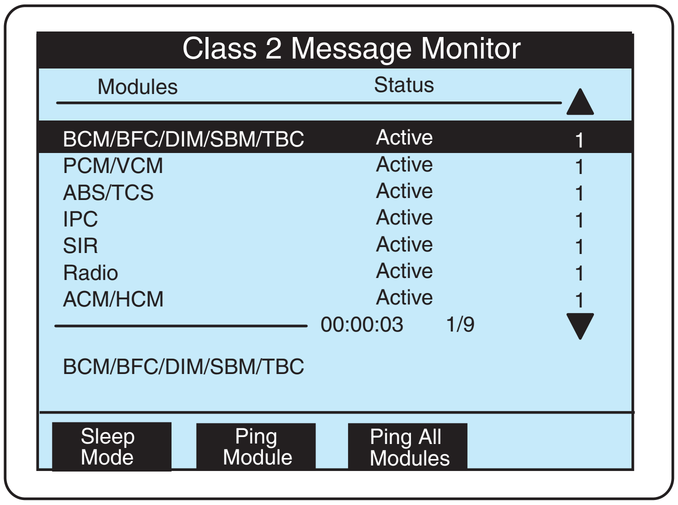

Honda Diagnostic S
1:54
Functional Tests
Ignition Key Cylinder Light Command
Interior light Command
Foot light Command
Left Turn Signal Command
Right Turn Signal Command
Headlight Command
Headlight High Beam Command
Parking Lights Command
Daytime Running Light Signal(Canada)
Cargo Area Light
FLOOR LIGHT.
DTC
Tools
iPAQ
Pocket PC

FIGURE 46–20 This Honda scan tool allows the technician to turn on individual lights and operate individual power windows and other accessories that are connected to the BUS system.



Class 2 Message Monitor

Modules	Status	
BCM/BFC/DIM/SBM/TBC	Active	1
PCM/VCM	Active	1
ABS/TCS	Active	1
IPC	Active	1
SIR	Active	1
Radio	Active	1
ACM/HCM	Active	1

00:00:03 1/9

BCM/BFC/DIM/SBM/TBC

Sleep Mode
Ping Module
Ping All Modules

FIGURE 46–21 Modules used in a General Motors vehicle can be "pinged" using a Tech 2 scan tool.

- **Check state of health.** All modules on the Class 2 BUS circuit have at least one other module responsible for reporting **state of health (SOH)**. If a module fails to send a state of health message within five seconds, the companion module sets a diagnostic trouble code for the module that did not respond. The defective module is not capable of sending this message.

STEP 3 **Check the resistance of the terminating resistors.** Most high-speed BUS systems use resistors at each end, called **terminating resistors**. These resistors are used to help reduce interference into other systems in the vehicle. Usually two 120 ohm resistors are installed at each end and are, therefore, connected electrically in parallel. Two 120 ohm resistors connected in parallel measure 60 ohms if tested using an ohmmeter. ● **SEE FIGURE 46–22**.

TECH TIP

No Communication? Try Bypass Mode

If a Tech 2 scan tool shows "no communication," try using the bypass mode to see what should be on the data display. To enter bypass mode, perform the following steps:

STEP 1 Select tool option (F3).

STEP 2 Set communications to bypass (F5).

STEP 3 Select enable.

STEP 4 Input make/model and year of vehicle.

STEP 5 Note all parameters that should be included, as shown. The values are not shown.

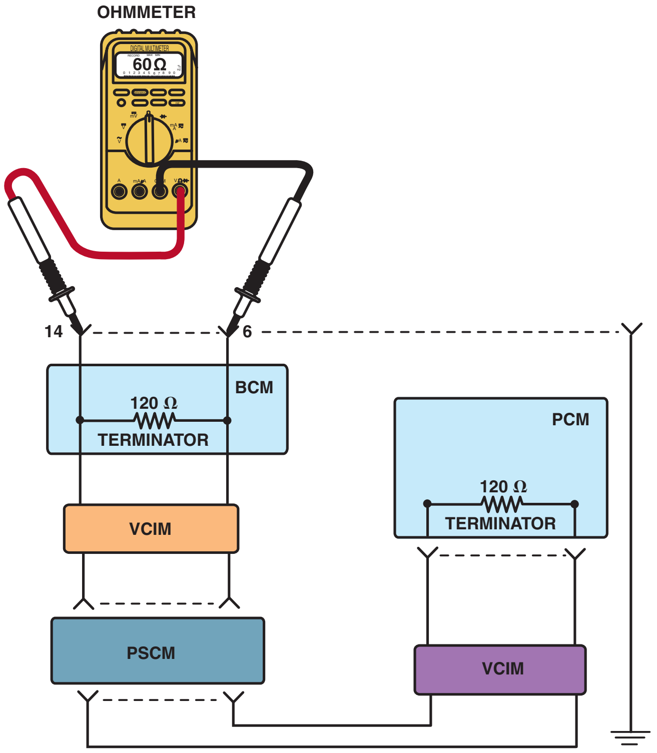


FIGURE 46–22 Checking the terminating resistors using an ohmmeter at the DLC.

CASE STUDY

The Radio Caused No-Start Story

A GMC pickup truck did not start. A technician checked with a subscription-based helpline service and discovered that a fault with the Class 2 data circuit could prevent the engine from starting. The advisor suggested that a module should be disconnected one at a time to see if one of them was taking the data line to ground. The first one the technician disconnected was the radio. The engine started and ran. Apparently the Class 2 serial data line was shorted-to-ground inside the radio, which took the entire BUS down. When BUS communication is lost, the PCM is not able to energize the fuel pump, ignition, or fuel injectors, so the engine does not start. The radio was replaced to solve the no-start condition.

Summary:

Complaint—The engine did not start.
Cause—A hotline service helped the technician narrow the cause to a fault in the radio that took the Class 2 data line to ground.
Correction—The radio was replaced, which restored proper operation of the Class 2 data BUS.

STEP 4 **Check data BUS for voltages.** Use a digital multi-meter set to DC volts to monitor communications and check the BUS for proper operation. Some BUS conditions and possible causes include the following:

- **Signal is zero volt all of the time.** Check for short- to-ground by unplugging modules one at a time to check if one module is causing the problem.
- **Signal is high or 12 volts all of the time.** The BUS circuit could be shorted to 12 volts. Check with the customer to see if any service or body repair work was done recently. Try unplugging each module one at a time to pin down which module is causing the communications problem.
- **A variable voltage usually indicates that messages are being sent and received.** CAN and Class 2 can be identified by looking at the data link connector for a terminal in cavity number 2. Class 2 is active all of the time the ignition is "on," and, therefore, voltage variation between zero and seven volts can be measured using a DMM set to read DC volts. ● **SEE FIGURE 46–23**.

STEP 5 **Use a digital storage oscilloscope to monitor the waveforms of the BUS circuit.** Using a scope on the data line terminals can show if communication is being transmitted. Typical faults and their causes include the following:

- **Normal operation.** Normal operation shows variable voltage signals on the data lines. It is impossible to know what information is being transmitted, but, if there is activity with short sections of inactivity, this indicates normal data line transmission activity. ● **SEE FIGURE 46–24**.

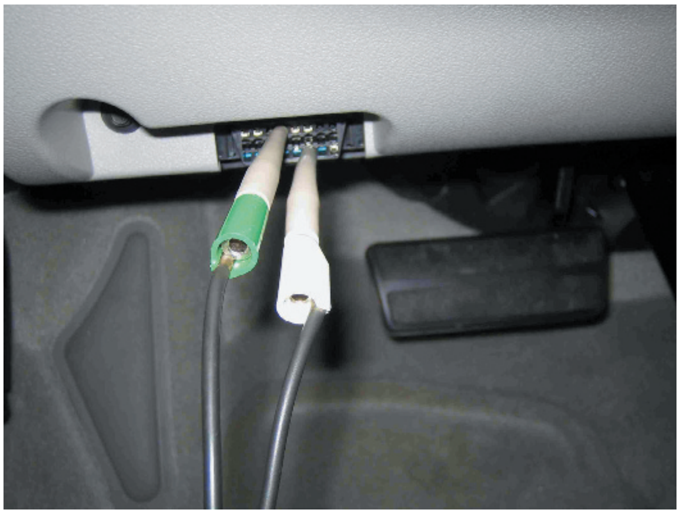


FIGURE 46–23 Use front-probe terminals to access the data link connector. Always follow the specified back-probe and front-probe procedures as found in service information.

- **High voltage.** If there is a constant high-voltage signal without any change, this indicates that the data line is shorted-to-voltage.
- **Zero or low voltage.** If the data line voltage is zero or almost zero and not showing any higher voltage signals, the data line is short-to-ground.

STEP 6 **Follow factory service information instructions to isolate the cause of the fault.** This step often involves disconnecting one module at a time to see if it is the cause of a short-to-ground or an open in the BUS circuit.

OBD-II DATA LINK CONNECTOR

All OBD-II vehicles use a 16-pin connector that includes the following:

Pin 4 = chassis ground
Pin 5 = signal ground
Pin 16 = battery power (4 A max)

● **SEE FIGURE 46–25**.

FREQUENTLY ASKED QUESTION

Which Module Is the Gateway Module?

The gateway module is responsible for communicating with other modules and acts as the main communications module for scan tool data. Most General Motors vehicles use the body control module (BCM) or the instrument panel control (IPC) module as the gateway. To verify which module is the gateway, check the schematic and look for one that has voltage applied during all of the following conditions:

- Key on, engine off
- Engine cranking
- Engine running

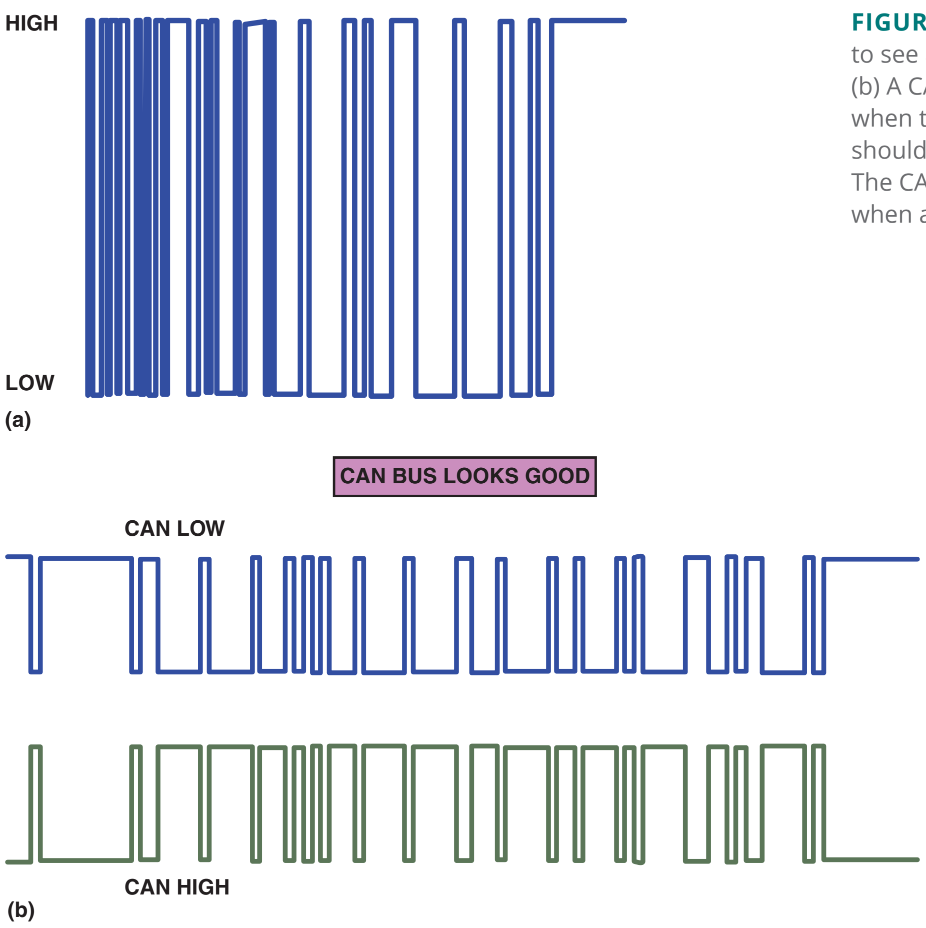
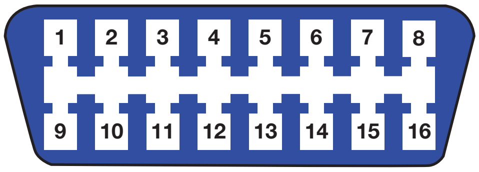


FIGURE 46–24 (a) Data is sent in packets, so it is normal to see activity and then a flat line between messages. (b) A CAN BUS should show voltages that are opposite when there is normal communications. CAN H circuit should go from 2.5 volts at rest to 3.5 volts when active. The CAN L circuit goes from 2.5 volts at rest to 1.5 volts when active.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

PIN	DESCRIPTION	PIN	DESCRIPTION
1	Vendor Option	9	Vendor Option
2	J1850 Bus+	10	J1850 Bus–
3	Vendor Option	11	Vendor Option
4	Chassis Ground	12	Vendor Option
5	Signal Ground	13	Vendor Option
6	CAN (J-2234) High	14	CAN (J-2234) Low
7	ISO 9141-2 K-Line	15	ISO 9141-2 L-Line
8	Vendor Option	16	Battery Power

FIGURE 46–25 A 16-pin OBD-II DLC with terminals identified. Scan tools use the power pin (16) and ground pin (4) for power so that a separate cigarette lighter plug is not necessary on OBD-II vehicles.

TECH TIP

Check Computer Data Line Circuit Schematic

Many General Motors vehicles use more than one type of BUS communications protocol. Check service information (SI) and look at the schematic for computer data line circuits, which should show all of the data BUSes and their connectors to the diagnostic link connector (DLC). ● **SEE FIGURE 46–26**.

GENERAL MOTORS VEHICLES

- SAE J-1850 (VPW, Class 2, 10.4 kbs) standard, which uses pins 2, 4, 5, and 16, but not 10
- GM Domestic OBD-II

Pins 1 and 9: CCM (comprehensive component monitor) slow baud rate, 8,192 UART (prior to 2006)

Pin 1 (2006+): low-speed GMLAN

Pins 2 and 10: OEM enhanced, fast rate, 40,500 baud rate

Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

Pins 6 and 14: GMLAN

ASIAN, CHRYSLER, AND EUROPEAN VEHICLES

- ISO 9141-2 standard, which uses pins 4, 5, 7, 15, and 16
- Chrysler Domestic Group OBD-II

Pins 2 and 10: CCM

Pins 3 and 14: OEM enhanced, 60,500 baud rate

Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

FORD VEHICLES

- SAE J-1850 (PWM, 41.6 kbs) standard, which uses pins 2, 4, 5, 10, and 16
- Ford Domestic OBD-II

Pins 2 and 10: CCM

Pins 6 and 14: OEM enhanced, Class C, 40,500 baud rate

Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

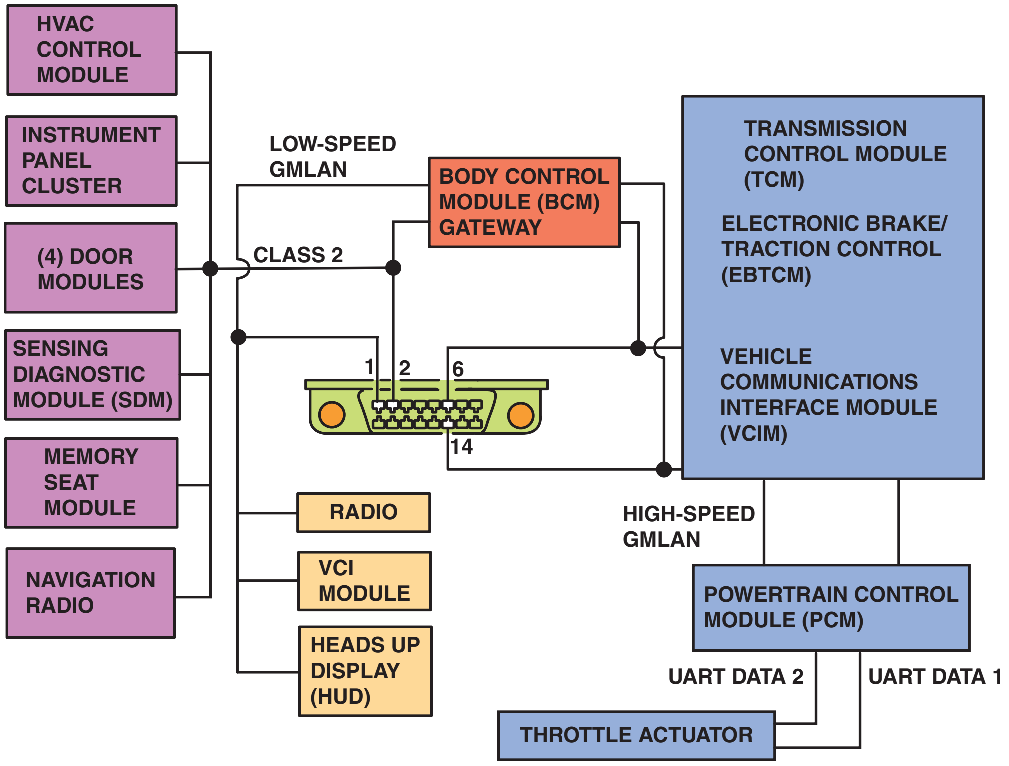

HVAC CONTROL MODULE
INSTRUMENT PANEL CLUSTER
(4) DOOR MODULES
SENSING DIAGNOSTIC MODULE (SDM)
MEMORY SEAT MODULE
NAVIGATION RADIO
LOW-SPEED GMLAN
CLASS 2
BODY CONTROL MODULE (BCM) GATEWAY
1
2
6
14
RADIO
VCI MODULE
HEADS UP DISPLAY (HUD)
TRANSMISSION CONTROL MODULE (TCM)
ELECTRONIC BRAKE/ TRACTION CONTROL (EBTCM)
VEHICLE COMMUNICATIONS INTERFACE MODULE (VCIM)
HIGH-SPEED GMLAN
POWERTRAIN CONTROL MODULE (PCM)
UART DATA 2
UART DATA 1
THROTTLE ACTUATOR

FIGURE 46–26 This schematic of a Chevrolet Equinox shows that the vehicle uses a GMLAN BUS (DLC pins 6 and 14), plus a Class 2 (pin 2) and UART. Pin 1 connects to the low-speed GMLAN network.

REVIEW QUESTIONS

1. Why is a communication network used?
2. Why are the two wires twisted if used for network communications?
3. Why is a gateway module used?
4. What are U codes?
5. What is the purpose of the terminating resistors?

CHAPTER QUIZ

1. Technician A says that module communications networks are used to reduce the number of wires in a vehicle. Technician B says that a communications network is used to share data from sensors, which can be used by many different modules. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. A module is also known as a __________.
   - **a.** bus
   - **b.** node
   - **c.** terminator
   - **d.** resistor pack
3. A high-speed CAN BUS communicates with a scan tool through which terminal(s)?
   - **a.** 6 and 14
   - **b.** 2
   - **c.** 7 and 15
   - **d.** 4 and 16
4. In a star link network, a serial data line connects all of the modules to __________.
   - **a.** a central point
   - **b.** each other
   - **c.** the vehicle fuse box
   - **d.** chassis ground
5. Network diagnosis is being discussed. Technician A says that a test light can be used at the DLC to determine if the CAN BUS has activity. Technician B says that a break-out box can be used to determine if there is activity on the CAN BUS. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. What does the word collision mean in the CCD protocol?
   - **a.** Prevents a crash
   - **b.** Prevents conflicts
   - **c.** Used by the airbag system only
   - **d.** None of the above
7. GMLAN is the General Motors term for which type of module communication?
   - **a.** CCD
   - **b.** Class 2
   - **c.** High-speed CAN
   - **d.** MOST
8. What protocol do Ford and Asian vehicles use?
   - **a.** MOST
   - **b.** CAN
   - **c.** UART
   - **d.** None of the above
9. Which terminal of the OBD-II data link connector is the signal ground for CAN vehicles including Asian vehicles?
   - **a.** 1
   - **b.** 3
   - **c.** 4
   - **d.** 5
10. Terminal 16 of the OBD-II data link connector is used for what?
    - **a.** Chassis ground
    - **b.** 12 volt positive
    - **c.** Module (signal ground)
    - **d.** Manufacturer’s discretion

Chapter

47

AUTOMOTIVE 12-VOLT BATTERIES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the purpose and function of a battery.
- Describe the construction of a battery.
- Describe how a battery works.
- Discuss specific gravity and how charge indicators work.
- Discuss battery construction types, including valve-regulated batteries.
- Describe the causes and types of battery failure.
- List battery ratings.
- List battery sizes.

KEY TERMS:

AGM 542 • Ampere hour 544 • Battery Council International (BCI) 544 • CA 544 • CCA 544 • Cells 540 • Deep cycling 544 • Electrolyte 540 • Enhanced Flooded Battery (EFB) 542 • Flooded lead acid (FLA) 541 • Gassing 539 • Gel battery 543 • Grid 539 • MCA 544 • Partitions 540 • Porous lead 539 • Recombinant battery 543 • Reserve capacity 544 • Sediment chamber 538 • SLA 543 • SLI 538 • Specific gravity 541 • Sponge lead 539 • SVR 543 • VRLA 543

INTRODUCTION

PURPOSE AND FUNCTION Every electrical component in a vehicle is supplied current from the battery. The battery is one of the most important parts of a vehicle because it is the heart or foundation of the electrical system. The primary purpose of an automotive battery is to provide a source of electrical power for starting, and for electrical demands that exceed alternator output.

WHY BATTERIES ARE IMPORTANT The battery also acts as a voltage stabilizer for the entire electrical system. The battery is a voltage stabilizer because it acts as a reservoir from where large amounts of current (amperes) can be used quickly during starting, and replaced back gradually by the alternator during charging.

- The battery *must* be in good (serviceable) condition before the charging and cranking systems can be tested. For example, if a battery is discharged, the cranking circuit (starter motor) could test as being defective because the battery voltage might drop below specifications.
- The charging circuit could also test as being defective because of a weak or discharged battery. It is important to test the vehicle battery before further testing of the cranking or charging system.

FREQUENTLY ASKED QUESTION

What Is a SLI Battery?

Sometimes the term *SLI* is used to describe a type of battery. **SLI** means **starting, lighting, and ignition,** and describes the use of a typical automotive battery. Other types of batteries used in industry are usually batteries designed to be deep cycled and are usually not as suitable for automotive needs.

BATTERY CONSTRUCTION

CASE Most automotive battery cases (container or covers) are constructed of polypropylene, a thin (approximately 0.08 inch or 0.02 millimeter thick), strong, and lightweight plastic. In contrast, containers for industrial batteries and some truck batteries are constructed of a hard, thick rubber material.

Inside the case are six cells (for a 12-volt battery). Each cell has positive and negative plates. Built into the bottom of many batteries are ribs that support the lead-alloy plates and provide a space for sediment to settle, called the **sediment chamber**.

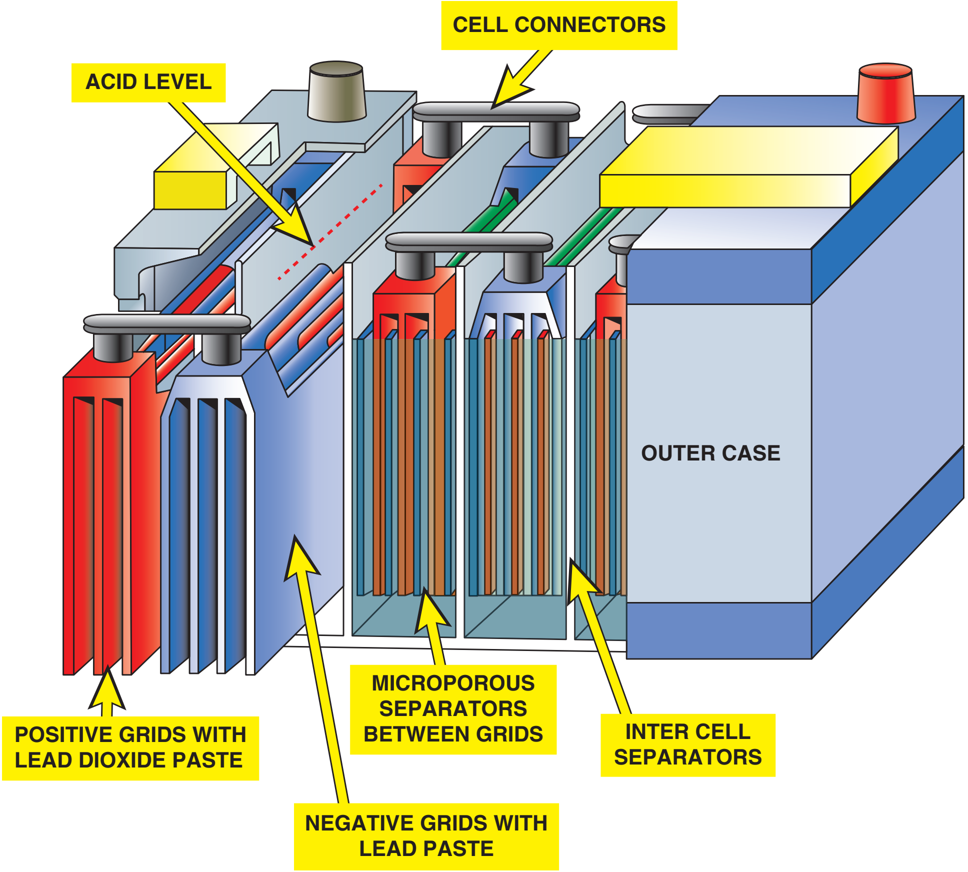

CELL CONNECTORS
ACID LEVEL
OUTER CASE
POSITIVE GRIDS WITH LEAD DIOXIDE PASTE
MICROPOROUS SEPARATORS BETWEEN GRIDS
INTER CELL SEPARATORS
NEGATIVE GRIDS WITH LEAD PASTE

FIGURE 47–1 Batteries are constructed of plates grouped into cells and installed in a plastic case.

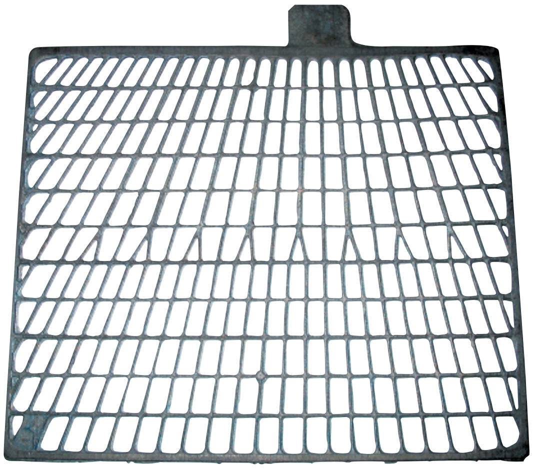


FIGURE 47–2 A grid from a battery used in both positive and negative plates.

This space prevents spent active material from causing a short circuit between the plates at the bottom of the battery. ● **SEE FIGURE 47–1**.

GRIDS Battery grids hold the active material and provide the electrical pathways for the current created in the plate. Each positive and negative plate in a battery is constructed on a framework, or **grid**, made primarily of lead. Lead is a soft material and must be strengthened for use in an automotive battery grid. Adding antimony or calcium to the pure lead adds strength to the lead grids. ● **SEE FIGURE 47–2**.

A maintenance-free battery uses little water during normal service because of the alloy material used to construct the battery plate grids. Maintenance-free battery grids use calcium instead of antimony. A typical lead–calcium grid uses only 0.09% to 0.12% calcium. Using low amounts of calcium instead of higher amounts of antimony reduces **gassing**. Gassing is the release of hydrogen and oxygen from the battery that occurs during charging and results in water usage. Low-maintenance batteries use a low percentage of antimony or use antimony only in the positive grids and calcium in the negative grids.

The percentages that make up the alloy of the plate grids constitute the major difference between standard and maintenance-free batteries. The chemical reactions that occur inside each battery are identical, regardless of the type of material used to construct the grid plates.

POSITIVE PLATES The positive plates have *lead dioxide (peroxide)* placed onto the grid framework. This process is called *pasting*. This active material can react with the sulfuric acid of the battery and is dark brown in color.

NEGATIVE PLATES The negative plates are pasted to the grid with a pure **porous lead**, called **sponge lead**, and are gray in color.

SEPARATORS The positive and the negative plates must be installed alternately next to each other without touching. Nonconducting *separators* are used, which allow room for the reaction of the acid with both plate materials, yet insulate the plates to prevent shorts. These separators are porous (with many small holes) and have ribs facing the positive plate. Separators can be made from resin-coated paper, porous rubber, fiberglass, or expanded plastic. Many batteries use envelope-type separators that encase the entire plate. This helps prevent any material that may shed from the plates from causing a short circuit between plates at the bottom of the battery.

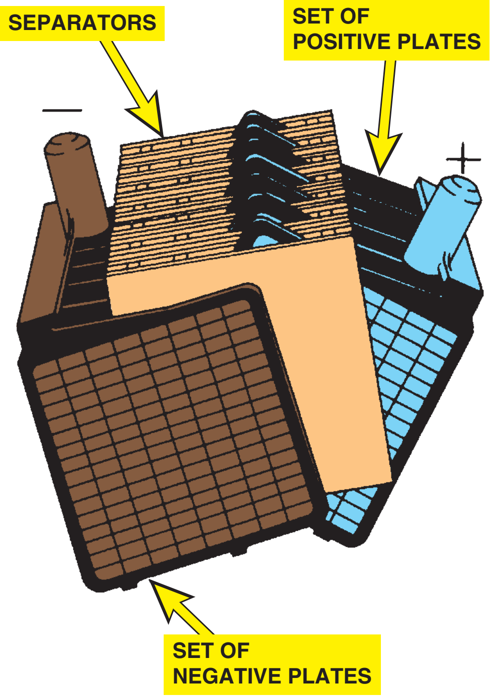


FIGURE 47–3 Two groups of plates are combined to form a battery element.

CELLS **Cells** are constructed of positive and negative plates with insulating separators between each plate. Most batteries use one more negative plate than positive plate in each cell. However, many newer batteries use the same number of positive and negative plates. A cell is also called an element. Each cell is actually a 2.1-volt battery, regardless of the number of positive or negative plates used. The greater the number of plates used in each cell, the greater the amount of *current* that can be produced. Typical batteries contain four positive plates and five negative plates per cell. A 12-volt battery contains six cells connected in series, which produce 12.6 volts ($6 \times 2.1 = 12.6$) and contain 54 plates (9 plates per cell × 6 cells). If the same 12-volt battery had five positive plates and six negative plates, for a total of 11 plates per cell ($5 + 6$), or 66 plates (11 plates × 6 cells), it has the same voltage, but the amount of current that the battery could produce is increased. ● **SEE FIGURE 47–3**.

The amperage capacity of a battery is determined by the amount of active plate material in the battery and the area of the plate material exposed to the electrolyte in the battery.

PARTITIONS Each cell is separated from the other cells by **partitions**, which are made of the same material as that used for the outside case of the battery. Electrical connections between cells are provided by lead connectors that loop over the top of the partition and connect the plates of the cells together. Many batteries connect the cells directly through the partition connectors, which provide the shortest path for the current and the lowest resistance. ● **SEE FIGURE 47–4**.

ELECTROLYTE **Electrolyte** is the term used to describe the acid solution in a battery. The electrolyte used in automotive batteries is a solution (liquid combination) of 36% sulfuric acid and 64% water. This electrolyte is used for both lead–antimony and lead–calcium (maintenance-free) batteries. The chemical symbol for this sulfuric acid solution is H_2SO_4.

H_2 = Symbol for hydrogen (the subscript 2 means that there are two atoms of hydrogen)

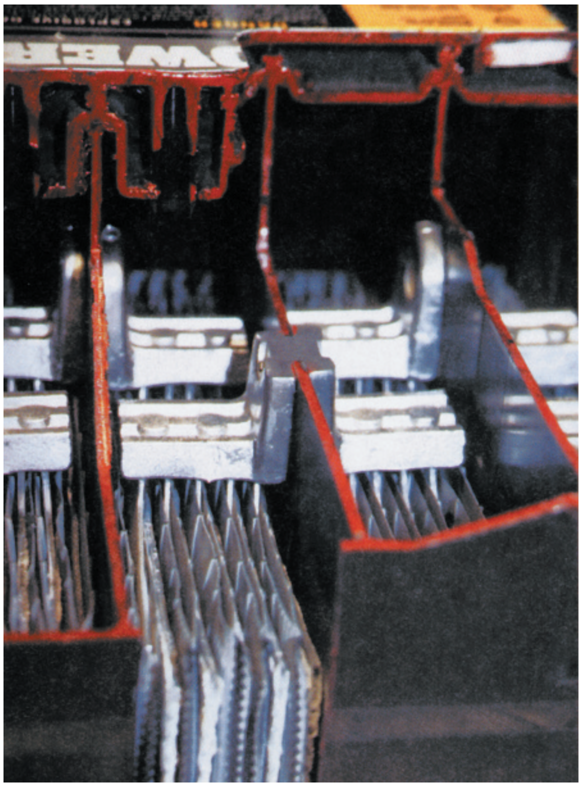


FIGURE 47–4 A cutaway battery showing the connection of the cells to each other through the partition.

S = Symbol for sulfur

O_4 = Symbol for oxygen (the subscript 4 indicates that there are four atoms of oxygen)

Electrolyte is sold premixed in a proper proportion and is factory installed or added to the battery when the battery is sold. Additional electrolyte must *never* be added to any battery after the original electrolyte fill. It is normal for some water (H_2O) to escape during charging as a result of the chemical reactions. The escape of gases from a battery during charging or discharging is called gassing. Only pure distilled water should be added to a battery. If distilled water is not available, clean drinking water can be used.

HOW A BATTERY WORKS

PRINCIPLE INVOLVED The principle on which a battery works is based on a scientific principle discovered years ago, which states that

- When two dissimilar metals are placed in an acid, electrons flow between the metals if a circuit is connected between them.
- This can be demonstrated by pushing a steel nail and a piece of solid copper wire into a lemon. Connect a voltmeter to the ends of the copper wire and the nail, and voltage is displayed.

A fully charged lead–acid battery has a positive plate of lead dioxide (peroxide) and a negative plate of lead surrounded by a sulfuric acid solution (electrolyte). The difference in potential (voltage) between lead peroxide and lead in acid is approximately 2.1 volts.

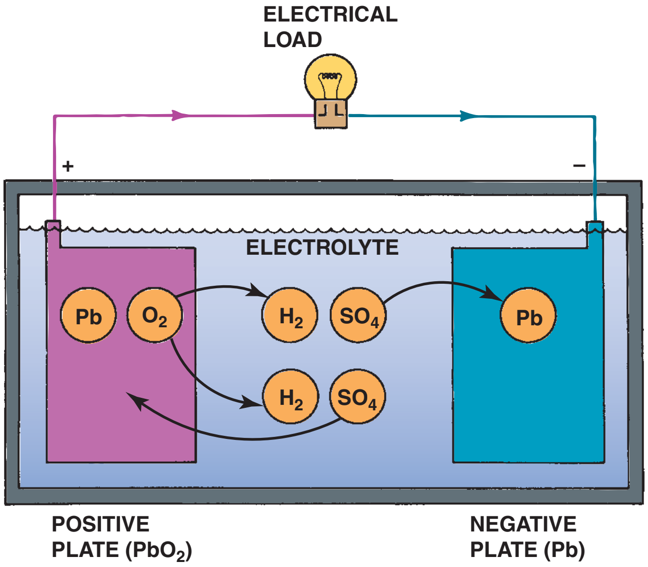


FIGURE 47–5 Chemical reaction for a lead–acid battery that is fully charged being discharged by the attached electrical load.

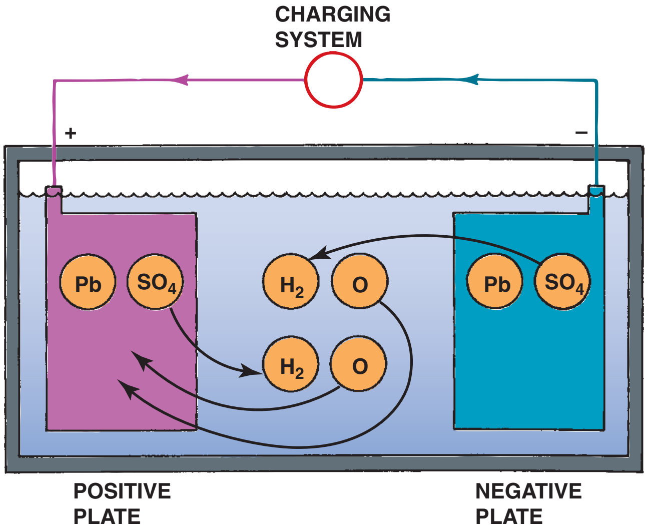


FIGURE 47–6 Chemical reaction for a lead–acid battery that is fully discharged being charged by the attached generator.

DURING DISCHARGING The positive plate lead dioxide (PbO_2) combines with the SO_4, forming $PbSO_4$ from the electrolyte and releases its O_2 into the electrolyte, forming H_2O. The negative plate also combines with the SO_4 from the electrolyte and becomes lead sulfate ($PbSO_4$). ● **SEE FIGURE 47–5.**

FULLY DISCHARGED STATE When the battery is fully discharged, both the positive and the negative plates are $PBSO_4$ (lead sulfate) and the electrolyte has become water (H_2O). As the battery is being discharged, the plates and the electrolyte approach the completely discharged state. There is also the danger of freezing when a battery is discharged because the electrolyte is mostly water.

CAUTION: Never charge or jump start a frozen battery because the hydrogen gas can get trapped in the ice and ignite if a spark is caused during the charging process. The result can be an explosion.

DURING CHARGING During charging, the sulfate from the acid leaves both the positive and the negative plates and returns to the electrolyte, where it becomes a normal-strength sulfuric acid solution. The positive plate returns to lead dioxide (PbO_2), the negative plate is again pure lead (Pb), and the electrolyte becomes H_2SO_4. ● **SEE FIGURE 47–6.**

FREQUENTLY ASKED QUESTION

Is There an Easy Way to Remember How a Battery Works?

Yes. Think of the sulfuric acid solution in the electrolyte being deposited, then removed from the plates.

- **During discharge.** The acid (SO_4) is leaving the electrolyte and getting onto both plates.
- **During charging.** The acid (SO_4) is being forced from both plates and enters the electrolyte.

SPECIFIC GRAVITY

DEFINITION The amount of sulfate in the electrolyte is determined by the electrolyte's **specific gravity**, which is the ratio of the weight of a given volume of a liquid to the weight of an equal volume of water. In other words, the denser the liquid is, the higher its specific gravity. Pure water is the basis for this measurement and is given a specific gravity of 1.000 at 80°F (27°C). Pure sulfuric acid has a specific gravity of 1.835; the *correct* concentration of water and sulfuric acid (called electrolyte—64% water, 36% acid) is 1.260 to 1.280 at 80°F (27°C). The higher the battery's specific gravity, the more fully it is charged. ● **SEE FIGURE 47–7.**

CHARGE INDICATORS Some batteries are equipped with a built-in state-of-charge indicator, commonly called *green eyes*. This indicator is simply a small, ball-type hydrometer that is installed in one cell. This hydrometer uses a plastic ball that floats if the electrolyte density is sufficient (which it is when the battery is about 65% charged). When the ball floats, it appears in the hydrometer's sight glass, changing its color. ● **SEE FIGURE 47–8.**

Because the hydrometer is testing only one cell (out of six on a 12-volt battery), and because the hydrometer ball can easily stick in one position, do not trust that this is accurate information about a state of charge (SOC) of the battery.

Values of specific gravity, state of charge, and battery voltage at 80°F (27°C) are given in ● **CHART 47–1.**

BATTERY CONSTRUCTION TYPES

FLOODED BATTERIES

Conventional batteries use a liquid electrolyte and are called **flooded lead acid (FLA)** batteries. In this design, vents are used to allow the gases (hydrogen and oxygen) to escape. It is this loss of the hydrogen and oxygen that results in a battery using water during normal use.

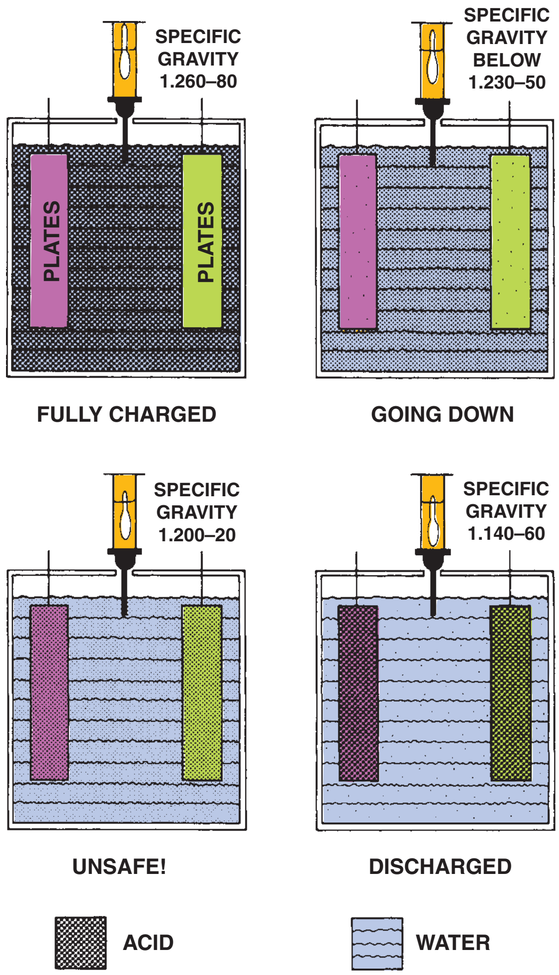

SPECIFIC GRAVITY 1.260–80
PLATES
PLATES
FULLY CHARGED
SPECIFIC GRAVITY BELOW 1.230–50
GOING DOWN
SPECIFIC GRAVITY 1.200–20
UNSAFE!
SPECIFIC GRAVITY 1.140–60
DISCHARGED
ACID
WATER

FIGURE 47–7 As the battery becomes discharged, the specific gravity of the battery acid decreases. Because the electrolyte is close to water when discharged, a dead battery can freeze in cold weather.

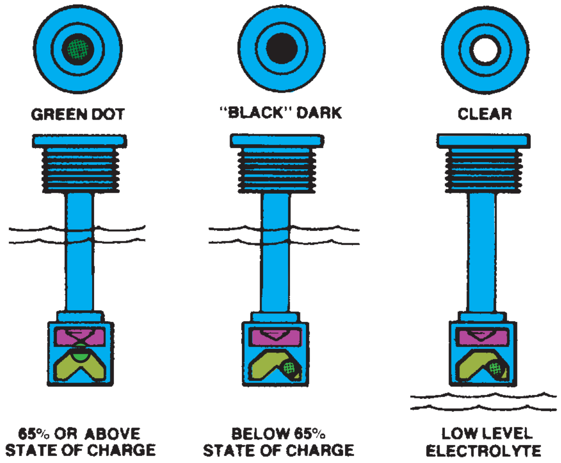


FIGURE 47–8 Typical battery charge indicator. If the specific gravity is low (battery discharged), the ball drops away from the reflective prism. When the battery is charged enough, the ball floats and reflects the color of the ball (usually green) back up through the sight glass and the sight glass is dark.

ENHANCED FLOODED BATTERIES **Enhanced Flooded Battery (EFB)** is a flooded battery (NOT an absorbed glass mat battery) that is optimized to work with stop/start vehicle systems. Using wet cells, the design allows for improved charge acceptance and greater durability when being operated in a vehicle that uses a stop/start system. In stop/start vehicle, the engine stops running when at idle speed, then restarts when the driver releases the brake pedal. This operation requires a robust battery and starter motor to function correctly over an estimated life of over 500,000 stops and starts.

SPECIFIC GRAVITY	STATE OF CHARGE	BATTERY VOLTAGE (V)
1.265	Fully charged	12.6 or higher
1.225	75% charged	12.4
1.190	50% charged	12.2
1.155	25% charged	12.0
Lower than 1.120	Discharged	11.9 or lower

CHART 47–1

A comparison showing the relationship among specific gravity, battery voltage, and state of charge.

ABSORBED GLASS MAT The acid used in an **absorbed glass mat (AGM)** battery is totally absorbed into the separator, making the battery leak proof and spill proof. The battery is assembled by compressing the cell about 20%, then inserting it into the container. The compressed cell helps reduce damage caused by vibration and helps keep the acid tightly against the plates. The sealed maintenance-free design uses a pressure release valve in each cell. Unlike conventional batteries that use a liquid electrolyte, called flooded cell batteries, most of the hydrogen and oxygen given off during charging remains inside the battery. The separator or mat is only 90% to 95% saturated with electrolyte, thereby allowing a portion of the mat to be filled with gas. The gas spaces provide channels to allow the hydrogen and oxygen gases to recombine rapidly and safely. Because the acid is totally absorbed into the glass mat separator, an AGM battery can be mounted in any direction. AGM batteries also have a longer service life, often lasting 7 to 10 years. Absorbed glass mat batteries are used as standard equipment in some vehicles, such as the Chevrolet Corvette, and in most Toyota/Lexus hybrid-electric vehicles. ● **SEE FIGURES 47–9 AND 47–10**.

GELLED ELECTROLYTE BATTERY In a gelled electrolyte battery, silica is added to the electrolyte, which turns the electrolyte

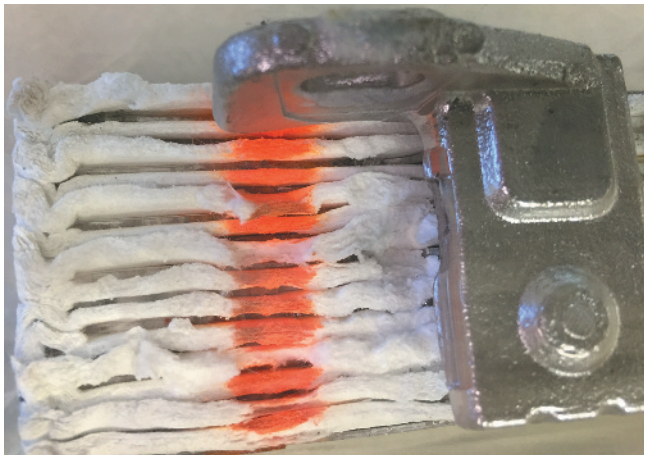


FIGURE 47–9 A close up of an AGM cell showing the mat totally encasing the plates.

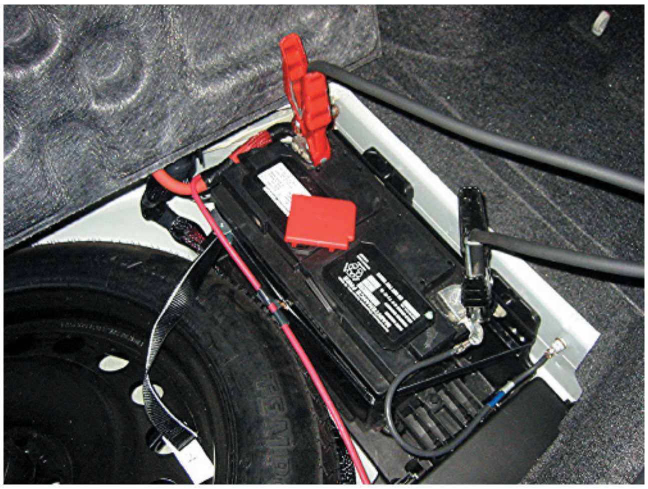


FIGURE 47–10 An AGM battery under the floor next to the spare tire on a Lexus NX300h hybrid-electric vehicle.

into a substance similar to gelatin. This type of battery is also called a **gel battery**. Gel batteries are usually not used in automotive applications but instead are used in electric wheelchairs and scooters.

VALVE-REGULATED LEAD–ACID BATTERIES Both AGM and gel batteries are called **valve-regulated lead–acid (VRLA)**, also called **sealed valve-regulated (SVR)** or **sealed lead–acid (SLA)**, batteries. These batteries use a low-pressure venting system that releases excess gas and automatically reseals if a buildup of gas is created due to overcharging.

Both types of valve-regulated lead–acid batteries are also called **recombinant battery** design. A recombinant-type battery means that the oxygen gas generated at the positive plate travels through the dense electrolyte to the negative plate. When the oxygen reaches the negative plate, it reacts with the lead, which consumes the oxygen gas and prevents the formation of hydrogen gas. It is because of this oxygen recombination that VRLA batteries do not use water.

CAUSES AND TYPES OF BATTERY FAILURE

NORMAL LIFE Most automotive batteries have a useful service life of three to seven years; however, proper care can help increase the life of a battery, but abuse can shorten it. The major cause of premature battery failure is overcharging.

BATTERY SULFATION During charging of a battery, the lead sulfate is converted back to lead. When a battery is left in a discharged condition, the lead sulfate re-crystallizes into hard lead sulfate. This process is called sulfation or a *sulfated battery*.

CHARGING VOLTAGE The automotive charging circuit, consisting of an alternator and connecting wires, must operate correctly to prevent damage to the battery.

- Charging voltages higher than 15.5 volts can damage a battery by warping the plates as a result of the heat of overcharging.
- AGM batteries can be damaged if charged at a voltage higher than 14.5 volts.

Overcharging also causes the active plate material to disintegrate and fall out of the supporting grid framework. Vibration or bumping can also cause internal damage similar to that caused by overcharging. It is important, therefore, to ensure that all automotive batteries are securely clamped with the battery hold-down bracket in the vehicle. The shorting of cell plates can occur without notice. If one of the six cells of a 12-volt battery is shorted, the resulting voltage of the battery is only 10 volts ($12 - 2 = 10$). With only 10 volts available, the starter *usually* is not able to start the engine.

BATTERY HOLD-DOWNS All batteries must be attached securely to the vehicle to prevent battery damage. Normal vehicle vibrations can cause the active materials inside the battery to shed. Battery hold-down clamps or brackets help reduce vibration, which can greatly reduce the capacity and life of any battery. ● **SEE FIGURE 47–11**.

BATTERY VENT TUBES If a battery is installed inside a vehicle, vent tubes are used to route battery fumes to the outside so they don't get into the passenger compartment. ● **SEE FIGURE 47–12.**

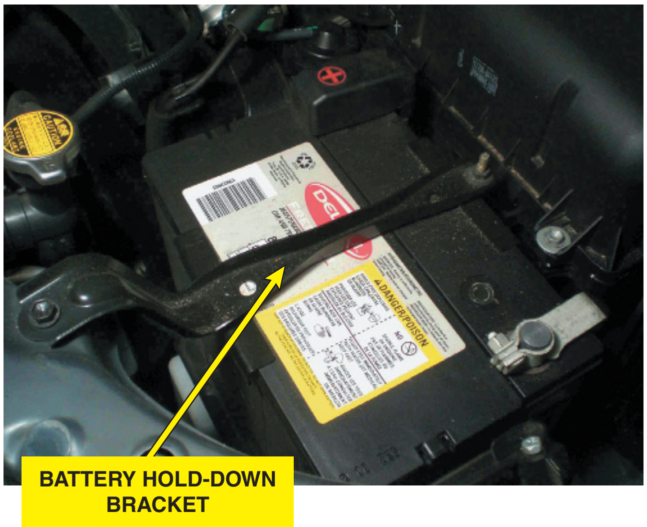


FIGURE 47–11 A typical battery hold-down bracket. All batteries should use a bracket to prevent battery damage due to vibration and shock.

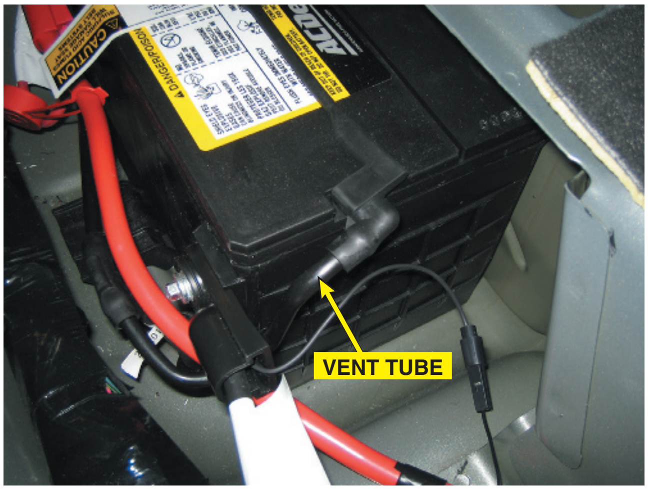


FIGURE 47–12 A battery installed under the rear seat of a Cadillac showing the vent tubes.

FREQUENTLY ASKED QUESTION

What Determines Battery Capacity?

The capacity of any battery is determined by the amount of active plate material in the battery. A battery with a large number of thin plates can produce high current for a short period. If a few thick plates are used, the battery can produce low current for a long period. A trolling motor battery used for fishing must supply a low current for a long period of time. An automotive battery is required to produce a high current for a short period for cranking. Therefore, every battery is designed for a specific application.

FREQUENTLY ASKED QUESTION

What Is Deep Cycling?

Deep cycling is almost fully discharging a battery and then completely recharging it. Golf cart batteries are an example of lead–acid batteries that must be designed to be deep cycled. A golf cart must be able to cover two 18-hole rounds of golf and then be fully recharged overnight. Charging is hard on batteries because the internal heat generated can cause plate warpage, so these specially designed batteries use thicker plate grids that resist warpage. Normal automotive batteries are not designed for repeated deep cycling.

BATTERY RATINGS

COLD-CRANKING AMPERES Every automotive battery must be able to supply electrical power to crank the engine in cold weather and still provide battery voltage high enough to operate the ignition system for starting. The cold-cranking ampere rating of a battery is the number of amperes that can be supplied by a battery at 0°F (−18°C) for 30 seconds while the battery still maintains a voltage of 1.2 volts per cell or higher. This means that the battery voltage is 7.2 volts for a 12-volt battery and 3.6 volts for a 6-volt battery. The cold-cranking performance rating is called **cold-cranking amperes (CCA)**. Try to purchase a battery with the highest CCA for the money. See the vehicle manufacturer's specifications for recommended battery capacity.

CRANKING AMPERES The designation **CA** refers to the number of amperes that can be supplied by a battery at 32°F (0°C). This rating results in a higher number than the more stringent CCA rating. ● **SEE FIGURE 47–13**.

MARINE CRANKING AMPERES **Marine cranking amperes (MCA)** is similar to cranking amperes and is tested at 32°F (0°C).

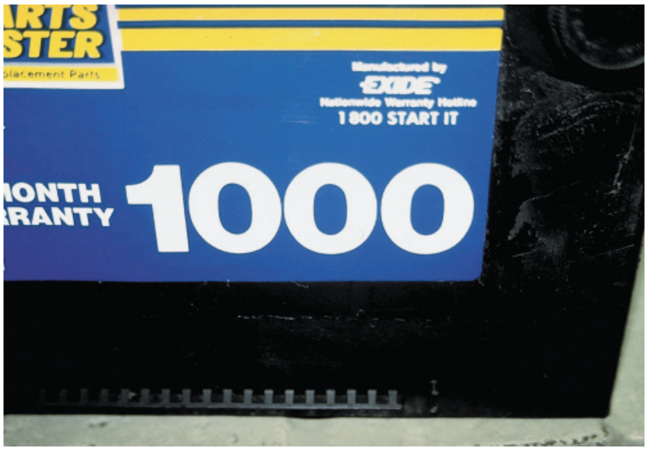


FIGURE 47–13 This battery has a cranking amperes (CA) rating of 1,000. This means that this battery is capable of cranking an engine for 30 seconds at a temperature of 32°F (0°C) at a minimum of 1.2 volts per cell (7.2 volts for a 12-volt battery).

RESERVE CAPACITY The **reserve capacity** rating for batteries is *the number of minutes* that the battery can produce 25 amperes and still have a battery voltage of 1.75 volts per cell (10.5 volts for a 12-volt battery). This rating is actually a measurement of the time a vehicle can be driven in the event of a charging system failure.

AMPERE HOUR **Ampere hour** is an older battery rating system that measures how many amperes of current the battery can produce over a period of time. For example, a battery that has a 50 amp-hour (A-H) rating can deliver 50 amperes for 1 hour or 1 ampere for 50 hours or any combination that equals 50 amp-hours.

BATTERY SIZES

BCI GROUP SIZES Battery sizes are standardized by the **Battery Council International (BCI)**. When selecting a replacement battery, check the specified group number in service information, battery application charts at parts stores, or the owner's manual.

TYPICAL GROUP SIZE APPLICATIONS

- **24/24F (top terminals).** Fits many Honda, Acura, Infiniti, Lexus, Nissan, and Toyota vehicles.
- **34/78 (dual terminals, both side and top posts).** Fits many General Motors pickups and SUVs, as well as midsize and larger GM sedans and large Chrysler/Dodge vehicles.
- **35 (top terminals).** Fits many Japanese-brand vehicles.
- **65 (top terminals).**Fits most large Ford/Mercury passenger cars, trucks, and SUVs.
- **75 (side terminals).** Fits some General Motors small- and midsize cars, and some Chrysler/Dodge vehicles.
- **78 (side terminals).** Fits many General Motors pickups and SUVs, as well as midsize and larger GM sedans.

Exact dimensions can be found on the Internet by searching for BCI battery sizes.

REVIEW QUESTIONS

1. Why can discharged batteries freeze?
2. What are the battery-rating methods?
3. Why can a battery explode if it is exposed to an open flame or spark?
4. What is meant by a sulfated battery?
5. What does the BCI group number mean?

CHAPTER QUIZ

1. When a battery becomes completely discharged, both positive and negative plates become _________ and the electrolyte becomes _________.
   - **a.** H_2SO_4; Pb
   - **b.** $PbSO_4$; H_2O
   - **c.** PbO_2; H_2SO_4
   - **d.** $PbSO_4$; H_2SO_4
2. A fully charged 12-volt battery should indicate _________.
   - **a.** 12.6 volts or higher
   - **b.** a specific gravity of 1.265 or higher
   - **c.** 12 volts
   - **d.** Both a and b
3. Some vehicles use an AGM-type battery. This means the electrolyte is _________ inside the battery.
   - **a.** a dry powder
   - **b.** liquid
   - **c.** absorbed into the separator
   - **d.** a gel-like form
4. What makes a battery “low maintenance” or “maintenance free”?
   - **a.** The material that is used to construct the grids.
   - **b.** The plates are constructed of different metals.
   - **c.** The electrolyte is hydrochloric acid solution.
   - **d.** The battery plates are smaller, making more room for additional electrolytes.
5. Batteries can fail in what way?
   - **a.** Overcharging
   - **b.** Vibration
   - **c.** Sulfation
   - **d.** Any of the above
6. Which battery rating is tested at 0°F (−18°C)?
   - **a.** Cold-cranking amperes (CCA)
   - **b.** Cranking amperes (CA)
   - **c.** Reserve capacity
   - **d.** Battery voltage test
7. Which battery rating is expressed in minutes?
   - **a.** Cold-cranking amperes (CCA)
   - **b.** Cranking amperes (CA)
   - **c.** Reserve capacity
   - **d.** Battery voltage test
8. What battery rating is tested at 32°F (0°C)?
   - **a.** Cold-cranking amperes (CCA)
   - **b.** Cranking amperes (CA)
   - **c.** Reserve capacity
   - **d.** Battery voltage test
9. What group publishes battery sizes?
   - **a.** SAE
   - **b.** BCI
   - **c.** API
   - **d.** CCA
10. A charge indicator (eye) operates by showing green or red when the battery is charged and dark if the battery is discharged. This charge indicator detects _________.
    - **a.** battery voltage
    - **b.** specific gravity
    - **c.** electrolyte water pH
    - **d.** internal resistance of the cells

Chapter 48

12-VOLT BATTERY TESTING AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- List the precautions for working with batteries.
- List the symptoms of a weak or defective battery.
- Describe how to inspect and clean terminals and hold-downs.
- Discuss how to test batteries for open circuit voltage.
- Discuss how to test batteries for specific gravity.
- Describe how to perform a battery load test.
- Describe how to perform a conductance test.
- Explain how to safely charge a battery.
- Describe float-type battery chargers.
- Explain how to safely jump start a battery.
- Discuss how to perform a battery drain test.
- Describe how to prevent loss of memory functions and reinitialize memory functions.
- Describe how to troubleshoot batteries.

KEY TERMS:

Battery electrical drain test 554 • Dynamic voltage 547 • Hydrometer 548 • IOD 554 • Load test 548 • Open circuit voltage 547 • Parasitic load test 554 • Three-minute charge test 549

BATTERY SERVICE SAFETY CONSIDERATIONS

HAZARDS Batteries contain acid and release explosive gases (hydrogen and oxygen) during normal charging and discharging cycles.

SAFETY PROCEDURES To help prevent physical injury or damage to the vehicle, always adhere to the following safety procedures:

1. When working on any electrical component on a vehicle, disconnect the negative battery cable from the battery. When the negative cable is disconnected, all electrical circuits in the vehicle are open, which prevents accidental electrical contact between an electrical component and ground. Any electrical spark has the potential to cause explosion and personal injury.
2. Wear eye protection (goggles preferred) when working around any battery.
3. Wear protective clothing to avoid skin contact with battery acid.
4. Always adhere to all safety precautions as stated in the service procedures for the equipment used for battery service and testing.
5. Never smoke or use an open flame around any battery.
6. Never attempt to jump start or charge a frozen battery.

SYMPTOMS OF A WEAK OR DEFECTIVE BATTERY

The following warning signs indicate that a battery is near the end of its useful life:

- **Uses water in one or more cells.** This indicates that the plates are sulfated and that, during the charging process, the water in the electrolyte is being turned into separate hydrogen and oxygen gases. ● **SEE FIGURE 48–1.**
- **Excessive corrosion on battery cables or connections.** Corrosion is more likely to occur if the battery is sulfated, creating hot spots on the plates. When the battery is being charged, the acid fumes are forced out of the vent holes and onto the battery cables, connections, and even on the battery tray underneath the battery. ● **SEE FIGURE 48–2.**

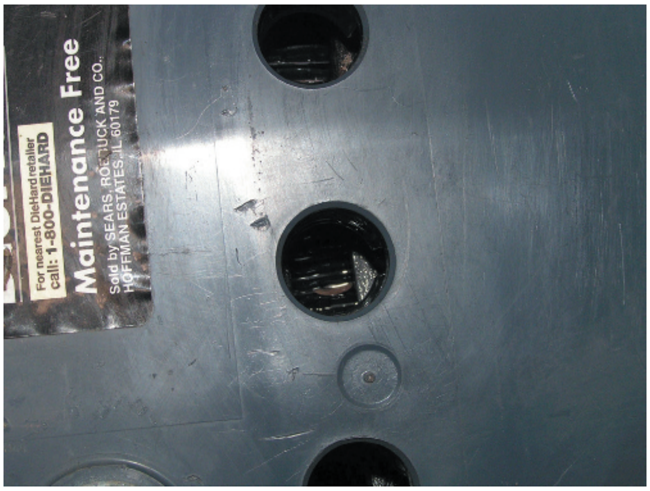


FIGURE 48–1 A visual inspection on this battery shows the electrolyte level is below the plates in all cells. Not many batteries can be checked for the electrolyte level and, if low, the battery is likely at the end of its normal service life.

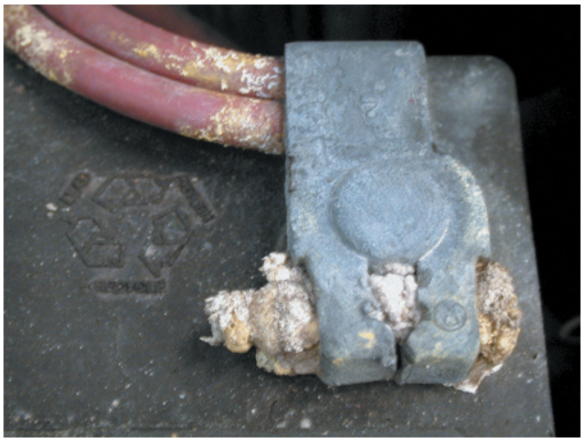


FIGURE 48–2 Corrosion on a battery cable could be an indication that the battery itself is either being overcharged or is sulfated, creating a lot of gassing of the electrolyte.

TECH TIP

Dynamic versus Open Circuit Voltage

Open circuit voltage is the voltage (usually of a battery) that exists without a load being applied. **Dynamic voltage** is the voltage of the power source (battery) with the circuit in operation. A vehicle battery, for example, may indicate that it has 12.6 volts or more, but that voltage drops when the battery is put under a load, such as cranking the engine. If the battery voltage drops too much, the starter motor rotates more slowly and the engine may not start.

If the dynamic voltage is lower than specified, the battery may be weak or defective or the circuit may be defective.

- **Slower than normal engine cranking.** When the capacity of the battery is reduced due to damage or age, it is less likely to be able to supply the necessary current for starting the engine, especially during cold weather.

BATTERY MAINTENANCE

NEED FOR MAINTENANCE Most new-style batteries are of a maintenance-free design that uses lead–calcium, instead of lead–antimony, plate grid construction. Because lead–calcium batteries do not release as much gas as the older-style, lead–antimony, batteries, there is less consumption of water during normal service. Also, with less gassing, less corrosion is observed on the battery terminals, wiring, and support trays. If the electrolyte level can be checked, and if it is low, add only distilled water. Distilled water is recommended by all battery manufacturers, but if distilled water is not available, clean ordinary drinking water, low in mineral content, can be used.

Battery maintenance includes making certain that the battery case is clean, and checking that the battery cables and hold-down fasteners are clean and tight.

BATTERY TERMINAL CLEANING Many battery-related faults are caused by poor electrical connections at the battery. Battery cable connections should be checked and cleaned to prevent voltage drop at the connections. One common reason for an engine to not start is loose or corroded battery cable connections. Perform an inspection and check for the following conditions:

- Loose or corroded connections at the battery terminals (should not be able to be moved by hand)
- Loose or corroded connections at the ground connector on the engine block
- Wiring that has been modified to add auxiliary power for a sound system or other electrical accessory

If the connections are loose or corroded, use 1 tablespoon of baking soda in 1 quart (liter) of water and brush this mixture onto the battery and housing to neutralize the acid. Mechanically clean the connections and wash the area with water. ● **SEE FIGURE 48–3**.

BATTERY HOLD-DOWN The battery should also be secured with a hold-down bracket to prevent vibration from damaging the plates inside the battery. The hold-down bracket should be snug enough to prevent battery movement, yet not so tight as to cause the case to crack. Factory-original hold-down brackets are often available through local automobile dealers, and universal hold-down units are available through local automotive parts stores.

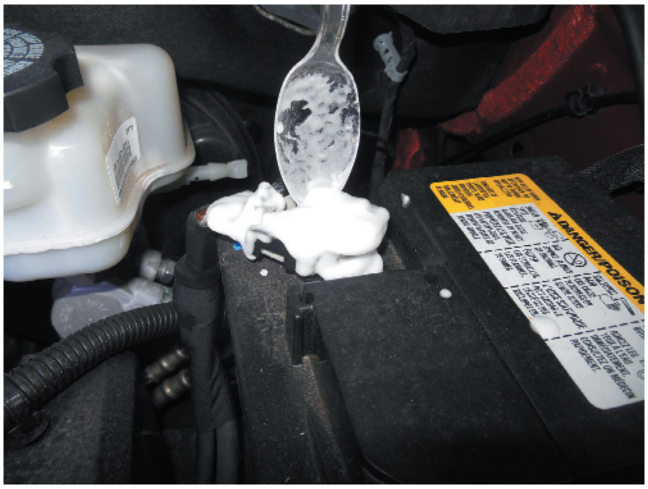


FIGURE 48–3 Using a baking soda and water paste to remove the corrosion on a battery terminal.

BATTERY VOLTAGE TEST

STATE OF CHARGE Testing the battery voltage with a voltmeter is a simple method for determining the state of charge of any battery. ● **SEE FIGURE 48–4**. The voltage of a battery does not necessarily indicate whether the battery can perform satisfactorily, but it does indicate to the technician more about the battery's condition than a simple visual inspection. A battery that "looks good" may not be good. This test is commonly called an *open circuit battery voltage test* because it is conducted with an open circuit, no current flowing, and no load applied to the battery.

1. If the battery has just been charged or the vehicle has recently been driven, it is necessary to remove the surface charge from the battery before testing. A surface charge is a charge of higher-than-normal voltage that is just on the surface of the battery plates. The surface charge is quickly removed when the battery is loaded and, therefore, does not accurately represent the true state of charge of the battery.
2. To remove the surface charge, turn the headlights on high beam (brights) for one minute, then turn the headlights off and wait two minutes.
3. With the engine and all electrical accessories off, and the doors shut (to turn off the interior lights), connect a voltmeter to the battery posts. Connect the red positive lead to the positive post and the black negative lead to the negative post.

NOTE: If the meter reads negative (−), the battery has been reverse charged (has reversed polarity) and should be replaced, or the meter has been connected incorrectly.

4. Read the voltmeter and compare the results with the state of charge (SOC). The voltages shown are for a battery at or near room temperature (70°F to 80°F, or 21°C to 27°C). ● **SEE CHART 48–1**.

BATTERY VOLTAGE (V)	STATE OF CHARGE
12.6 or higher	100% charged
12.4	75% charged
12.2	50% charged
12.0	25% charged
11.9 or lower	Discharged

CHART 48–1

The estimated state of charge of a 12-volt battery after the surface charge has been removed.

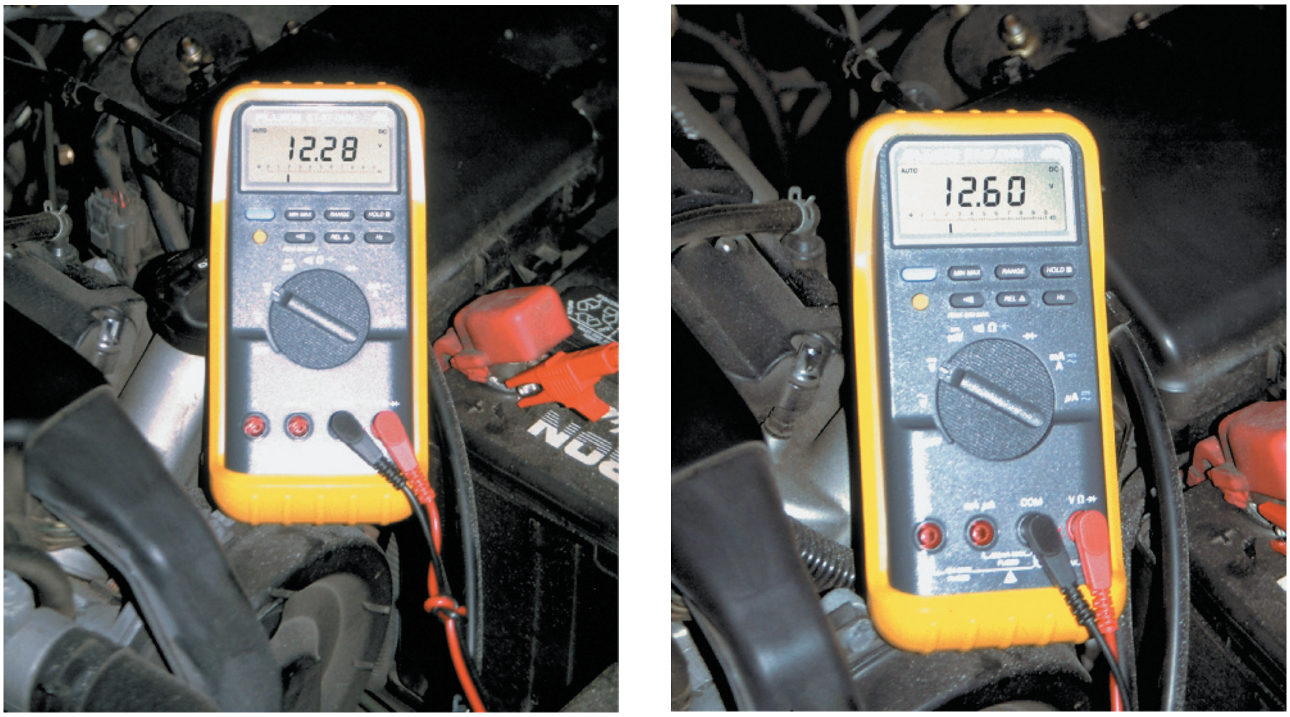
HYDROMETER TESTING

If the battery has removable filler caps, the specific gravity of the electrolyte can also be checked. A **hydrometer** is a tester that measures the specific gravity. ● **SEE FIGURE 48–5**.

The specific gravity test indicates the state of battery charge and can indicate a defective battery if the specific gravity of one or more cells varies by more than 0.050 from the value of the highest-reading cell. ● **SEE CHART 48–2**.

BATTERY LOAD TESTING

TERMINOLOGY One test to determine the condition of any battery is the **load test.** Most automotive starting and charging testers use a carbon pile to create an electrical load on the battery. The amount of the load is determined by the original CCA rating of the battery, which should be at least 75% charged before performing a load test. The capacity is measured in cold-cranking



(a)

(b)

FIGURE 48–4 (a) A voltage reading of 12.28 volts indicates that the battery is not fully charged and should be charged before testing. (b) A battery that measures 12.6 volts or higher after the surface charge has been removed is 100% charged.

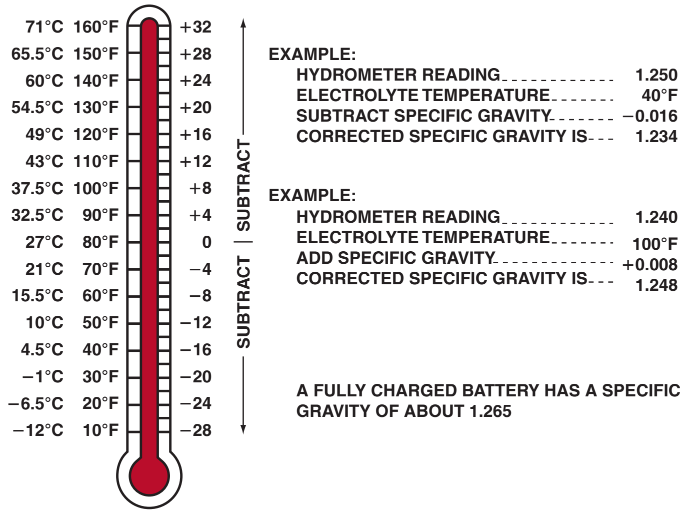

71°C 160°F +32
65.5°C 150°F +28
60°C 140°F +24
54.5°C 130°F +20
49°C 120°F +16
43°C 110°F +12
37.5°C 100°F +8
32.5°C 90°F +4
27°C 80°F 0
21°C 70°F −4
15.5°C 60°F −8
10°C 50°F −12
4.5°C 40°F −16
−1°C 30°F −20
−6.5°C 20°F −24
−12°C 10°F −28
SUBTRACT
SUBTRACT
EXAMPLE:
HYDROMETER READING 1.250
ELECTROLYTE TEMPERATURE 40°F
SUBTRACT SPECIFIC GRAVITY −0.016
CORRECTED SPECIFIC GRAVITY IS 1.234
EXAMPLE:
HYDROMETER READING 1.240
ELECTROLYTE TEMPERATURE 100°F
ADD SPECIFIC GRAVITY +0.008
CORRECTED SPECIFIC GRAVITY IS 1.248
A FULLY CHARGED BATTERY HAS A SPECIFIC GRAVITY OF ABOUT 1.265

FIGURE 48–5 When testing a battery using a hydrometer, the reading must be corrected if the temperature is above or below 80°F (27°C).

SPECIFIC GRAVITY	BATTERY VOLTAGE (V)	STATE OF CHARGE
1.265	12.6 or higher	100% charged
1.225	12.4	75% charged
1.190	12.2	50% charged
1.155	12.0	25% charged
lower than 1.120	11.9 or lower	Discharged

CHART 48–2

Measuring the specific gravity can detect a defective battery. A battery should be at least 75% charged before being load tested.

FREQUENTLY ASKED QUESTION

What Is the Three-Minute Charge Test?

A **three-minute charge test** is used to check if a battery is sulfated and is performed as follows:

- Connect a battery charger and a voltmeter to the battery terminals.
- Charge the battery at a rate of 40 amperes for three minutes.
- At the end of three minutes, read the voltmeter.

Results: If the voltage is above 15.5 volts, replace the battery. If the voltage is below 15.5 volts, the battery is not sulfated and should be charged and retested.

This is not a valid test for many maintenance-free batteries. Due to the high internal resistance, a discharged battery may not start to accept a charge for several hours. Always use another alternative battery test before discarding a battery based on the results of the three-minute charge test.

amperes, which is the number of amperes that a battery can supply at 0°F (−18°C) for 30 seconds.

TEST PROCEDURE To perform a battery load test, take the following steps:

STEP 1 **Determine the CCA rating of the battery.** The proper electrical load used to test a battery is half of the CCA rating, or three times the ampere-hour rating, with a minimum 150 ampere load. ● **SEE FIGURE 48–6.**

STEP 2 **Connect the load tester to the battery.** Follow the instructions for the tester being used.

STEP 3 **Apply the load for a full 15 seconds.** Observe the voltmeter during the load testing and check the voltage at the end of the 15-second period, while the battery is still under load. A good battery should indicate above 9.6 volts.

STEP 4 **Repeat the test.** Many battery manufacturers recommend performing the load test twice, using the first load period to remove the surface charge on the battery and the second test to provide a truer indication of the condition of the battery. Wait 30 seconds between tests to allow time for the battery to recover. ● **SEE FIGURE 48–7.**

Results: If the battery fails the load test, recharge the battery and retest. If the load test is failed again, replacement of the battery is required.

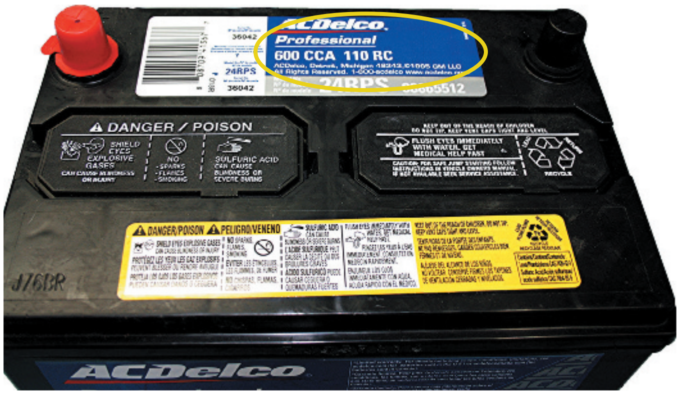

ACDelco Professional
600 CCA 110 RC
24RPS
DANGER / POISON
ACDelco

FIGURE 48–6 This battery has a CCA rating of 600 amperes and a reserve capacity (RC) of 110 minutes.

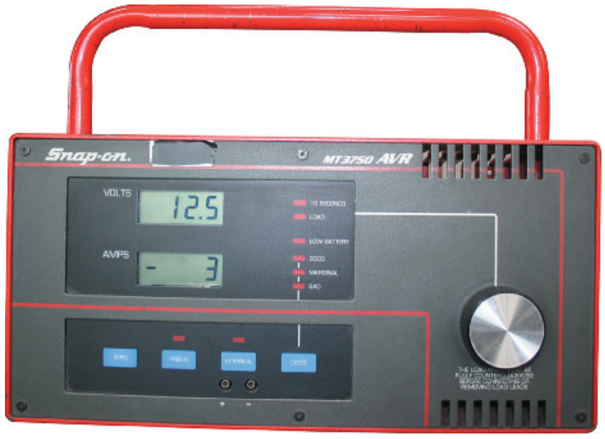

Snap-on
MT3750 AVR
VOLTS
12.5
AMPS
3

FIGURE 48–7 A Snap-on battery tester that is capable of performing a battery load test, as well as starter and alternator amperage tests.

FREQUENTLY ASKED QUESTION

How Should You Test a Vehicle Equipped with Two Batteries?

Many vehicles equipped with a diesel engine use two batteries. These batteries are usually electrically connected in parallel to provide additional current (amperes) at the same voltage. ● **SEE FIGURE 48–8**.

Some heavy-duty trucks and buses connect two batteries in series to provide about the same current as one battery, but with twice the voltage, as shown in ● **FIGURE 48–9**.

To successfully test the batteries, they should be disconnected and tested separately. If just one battery is found to be defective, most experts recommend that both be replaced to help prevent future problems. Because the two batteries are electrically connected, a fault in one battery can cause the good battery to discharge into the defective battery, thereby affecting both, even if just one battery is defective.

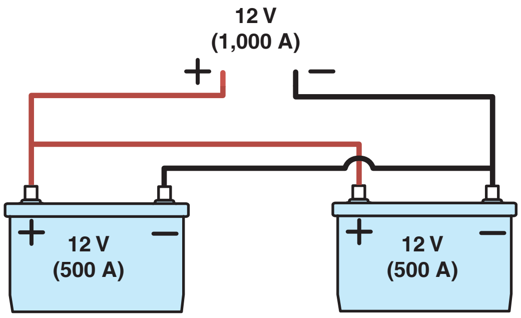


FIGURE 48–8 Most light-duty vehicles equipped with two batteries are connected in parallel as shown. Two 500 ampere, 12-volt batteries are capable of supplying 1,000 amperes at 12 volts, which is needed to start many diesel engines.

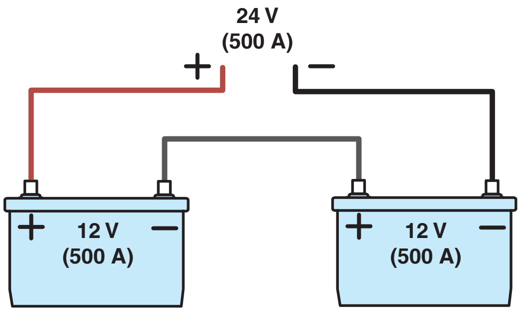


FIGURE 48–9 Many heavy-duty trucks and buses use two 12-volt batteries connected in series to provide 24 volts.

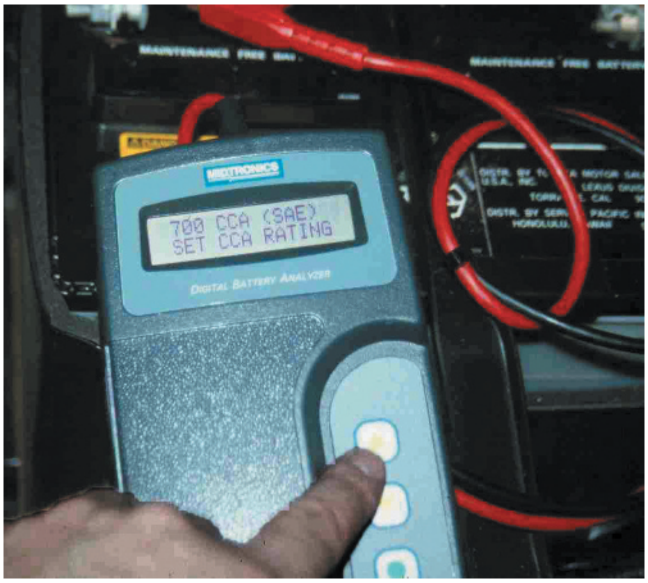


FIGURE 48–10 A conductance tester is very easy to use and has proved to accurately determine battery condition if the connections are properly made. Follow the instructions on the display exactly for best results.

ELECTRONIC CONDUCTANCE TESTING

TERMINOLOGY General Motors Corporation, Chrysler Corporation, and Ford specify that an electronic conductance tester be used to test batteries in vehicles still under factory warranty. Conductance is a measure of how well a battery can create current. This tester sends a small signal through the battery and then measures a part of the AC response. Conductance testers can be used to test flooded or absorbed glass mat-type (AGM) batteries. The unit can determine the following information about a battery:

- CCA
- State of charge
- Voltage of the battery
- Defects such as shorts and opens

However, a conductance tester is not designed to accurately determine the state of charge or CCA rating of a new battery. Unlike a battery load test, a conductance tester can be used on a battery that is discharged. This type of tester should only be used to test batteries that have been in service. ● **SEE FIGURE 48–10**.

WARNING

Never Charge or Jump Start a Frozen Battery

A discharged battery can freeze because the electrolyte becomes mostly water. Never attempt to charge or jump start a vehicle that has a frozen battery. When the battery freezes, it often bulges at the sides because water expands about 9% when it freezes, forming ice crystals that occupy more space than water. The crystals can trap bubbles of hydrogen and oxygen that are created during the chemical processes in a battery. When attempting to charge or jump start the frozen battery, these pockets of gases can explode. Because the electrolyte expands, the freezing action usually destroys the plates and can loosen the active material from the grids. It is rare for a frozen battery to be restored to useful service.

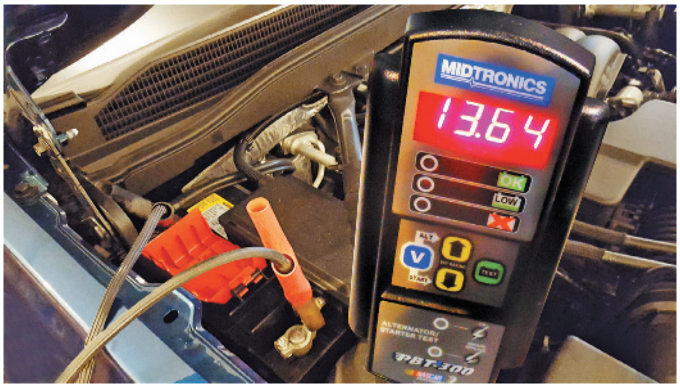


FIGURE 48–11 A Midtronics tester that can not only test the battery but can also detect faults with the starter and alternator.

TEST PROCEDURE

STEP 1 Connect the unit to the positive and negative terminals of the battery. If testing a side-post battery, always use the lead adapters, and *never* use steel bolts, as these can cause an incorrect reading.

NOTE: Test results can be incorrectly reported on the display if proper, clean connections to the battery are not made. Also, be sure that all accessories and the ignition switch are in the off position.

STEP 2 Enter the CCA rating (if known) and push the arrow keys.

STEP 3 The tester determines and displays one of the following:

- **Good battery.** The battery can return to service.
- **Charge and retest.** Fully recharge the battery and return it to service.
- **Replace the battery.** The battery is not serviceable and should be replaced.
- **Bad cell–replace.** The battery is not serviceable and should be replaced.

Some conductance testers can check the charging and cranking circuits, too. ● **SEE FIGURE 48–11.**

BATTERY CHARGING

CHARGING PROCEDURE

If the state of charge of a battery is low, it must be recharged. It is best to slow charge any battery to prevent possible overheating damage to the battery. Perform the following steps:

STEP 1 **Determine the charge rate.** The charge rate is based on the current state of charge and charging rate. ● **SEE CHART 48–3** for the recommended charging rate.

STEP 2 **Connect a battery charger to the battery.** Be sure the charger is not plugged in when connecting a charger to a battery. Always follow the battery charger's instructions for proper use.

STEP 3 **Set the charging rate.** The initial charge rate should be about 35 amperes for 30 minutes to help start the charging process. Fast charging a battery increases the temperature of the battery and can cause warping of the plates inside the battery. Fast charging also increases the amount of gassing (release of hydrogen and oxygen), which can create a health and fire hazard. The battery

TECH TIP

Charge Batteries at 1% of Their CCA Rating

Many batteries are damaged due to overcharging. To help prevent damages, such as warped plates and excessive release of sulfur smell gases, charge batteries at a rate equal to 1% of the battery's CCA rating. For example, a battery with a 700 CCA rating should be charged at 7 amperes (700 × 0.01 = 7 amperes). No harm occurs to the battery at this charge rate, even though it may take longer to achieve a full charge. This means that a battery may require eight or more hours to become fully charged, depending on the battery capacity and state of charge (SOC).

OPEN CIRCUIT VOLTAGE	BATTERY SPECIFIC GRAVITY*	STATE OF CHARGE	CHARGING TIME TO FULL CHARGE AT 80°F**					
			at 60 amps	at 50 amps	at 40 amps	at 30 amps	at 20 amps	at 10 amps
12.6	1.265	100%	FULL CHARGE					
12.4	1.225	75%	15 min.	20 min.	27 min.	35 min.	48 min.	90 min.
12.2	1.190	50%	35 min.	45 min.	55 min.	75 min.	95 min.	180 min.
12.0	1.155	25%	50 min.	65 min.	85 min.	115 min.	145 min.	260 min.
11.8	1.120	0%	65 min.	85 min.	110 min.	150 min.	195 min.	370 min.

CHART 48–3

Battery charging guideline showing the charging times that vary according to state of charge, temperature, and charging rate. It may take eight hours or more to charge a fully discharged battery.

* Correct for temperature.

** If colder, it'll take longer.

FIGURE 48–12 A typical industrial battery charger. Be sure that the ignition switch is in the off position before connecting any battery charger. Connect the cables of the charger to the battery before plugging the charger into the outlet. This helps prevent a voltage spike and spark that could occur if the charger happened to be accidentally left on. Always follow the battery charger manufacturer's instructions.

temperature should not exceed 125°F (52°C) (hot to the touch).

- Fast charge: 15 amperes maximum
- Slow charge: 5 amperes maximum

● **SEE FIGURE 48–12**.

CHARGING AGM BATTERIES Charging an AGM battery requires a different charger than is used to recharge a flooded-type battery. The differences include the following:

- The AGM can be charged with high current, up to 75% of the ampere-hour rating due to lower internal resistance.
- The charging voltage has to be kept at or below 14.4 volts to prevent damage.

Because most conventional battery chargers use a charging voltage of 16 volts or higher, a charger specifically designed to charge AGM batteries must be used.

Absorbed glass mat batteries are often used as auxiliary batteries in hybrid electric vehicles when the battery is located inside the vehicle.

TECH TIP

Always Use Adapters on Side-Post Batteries

Side-post batteries require that an adapter be used when charging the battery, if it is removed from the vehicle. Do not use steel bolts. If a bolt is threaded into the terminal, only the parts of the threads that contact the battery terminal are conducting all of the charging current. An adapter or a bolt with a nut attached is needed to achieve full contact with the battery terminals. ● **SEE FIGURE 48–13**.

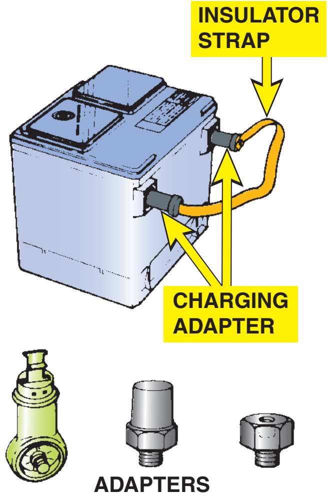


FIGURE 48–13 Adapters should be used on side-terminal batteries whenever charging.

FREQUENTLY ASKED QUESTION

Should Batteries Be Kept Off of Concrete Floors?

All batteries should be stored in a cool, dry place when not in use. Many technicians have been warned not to store or place a battery on concrete. According to battery experts, it is the temperature difference between the top and the bottom of the battery that causes a difference in the voltage potential between the top (warmer section) and the bottom (colder section). It is this difference in temperature that causes self-discharge to occur.

In fact, submarines cycle seawater around their batteries to keep all sections of the battery at the same temperature to help prevent self-discharge.

Therefore, always store or place batteries up off the floor and in a location where the entire battery can be kept at the same temperature, avoiding extreme heat and freezing temperatures. Concrete cannot drain the battery directly because the case of the battery is a very good electrical insulator.

BATTERY CHARGE TIME The time needed to charge a completely discharged battery can be estimated by using the reserve capacity rating of the battery in minutes divided by the charging rate.

Hours needed to charge the battery =
Reserve capacity ÷ Charge current

For example, if a 10 ampere charge rate is applied to a discharged battery that has a 90 minute reserve capacity, the time needed to charge the battery is nine hours.

90 minutes ÷ 10 amperes = 9 hours

12V
CTEK
MODE
MULTI US 3300

FIGURE 48–14 A typical float-type battery charger connected to a vehicle placed in storage for the winter. This type of charger can be left connected to the battery all winter long without it causing any harm to the battery.

FLOAT-TYPE BATTERY CHARGERS

PURPOSE AND FUNCTION A float-type charger, sometimes referred to by the brand name "Battery Tender," will only turn on and charge a battery when it has self-discharged below a certain level. This is not the same as a trickle charger, which will continuously apply a small current to the battery regardless of the charge level. A float-type battery charger is often referred to as a "smart battery charger." While a float-type charger can be used to charge a battery during normal service operations, it is usually used when a vehicle is being stored for an extended period of time. ● **SEE FIGURE 48–14**.

OPERATION The operational modes or stages of a typical float-type battery charger include the following:

1. **Constant current or bulk charging** (battery 0–80% state-of-charge): In this mode of operation, the charger supplying a constant current to the battery. In this mode, the battery voltage is allowed to rise as it is being recharged.
2. **Absorption stage** (battery 80–95% state-of-charge): This mode switches mode switches to where the charger voltage is held to where the charger voltage is held constant and the battery current is allowed to reduce. This stage is reached when the battery voltage reaches about 2.4 volts per cell (14.6 volts for a 12-volt battery). It is this region where the last 20% of battery capacity is returned.
3. **Float mode** (battery 95–100% state-of-charge): In this mode, the voltage applied to the battery is maintained at about 2.25 volts per cell (13.5 volts for a 12-volt battery). During this mode of operation, the charger will maintain the full charge without boiling the electrolyte or overcharging the battery.

JUMP STARTING

PROCEDURE To jump start another vehicle with a dead battery, connect good-quality copper jumper cables or a jump box to the good battery and the dead battery, as shown in ● **FIGURE 48–15**.

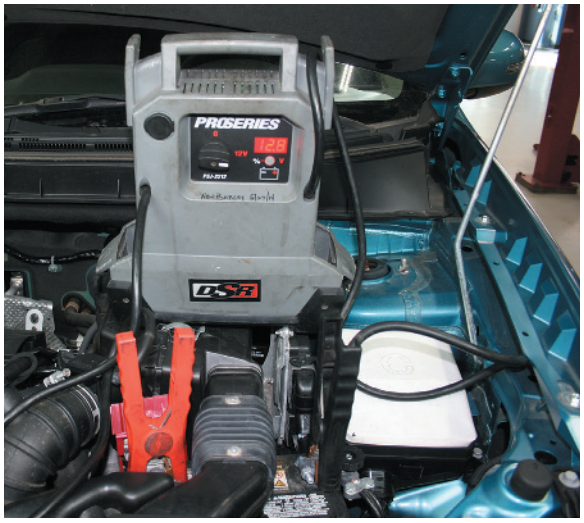


FIGURE 48–15 A typical battery jump box used to jump start vehicles. These hand-portable units have almost made jumper cables obsolete.

When using jumper cables or a battery jump box, the last connection made should always be on the engine block or an engine bracket on the dead vehicle as far from the battery as possible.

It is normal for a spark to occur when the jumper cables finally complete the jumping circuit, and this spark could cause an explosion of the gases around the battery. Many newer vehicles have special ground and/or positive power connections built away from the battery just for the purpose of jump starting. Check the owner's manual or service information for the exact location.

TECH TIP

Look at the Battery Date Code

All major battery manufacturers' stamp codes on the battery case give the date of manufacture and other information about the battery. Most battery manufacturers use a number to indicate the year of manufacture and a letter to indicate the month of manufacture, except the letter I, because it can be confused with the number 1. For example:

A = January
B = February
C = March
D = April
E = May
F = June
G = July
H = August
J = September
K = October
L = November
M = December

The shipping date from the manufacturing plant is usually indicated by a *sticker* on the body of the battery. Almost every battery manufacturer uses just one letter and one number to indicate the month and year. ● **SEE FIGURE 48–16**.

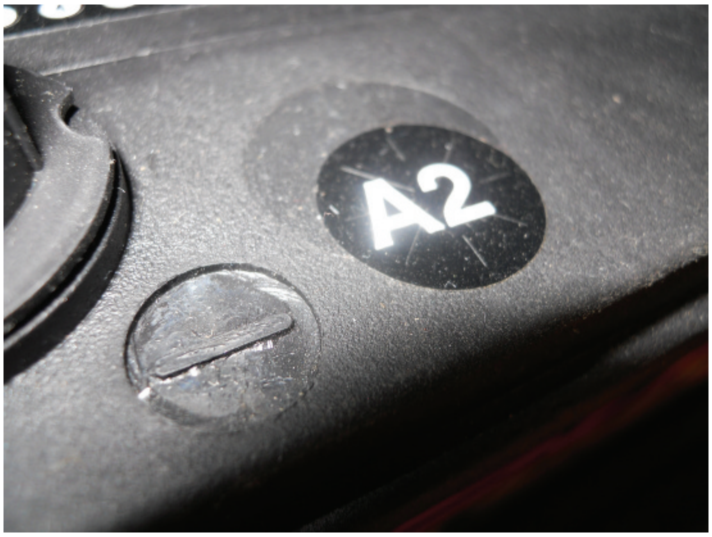


FIGURE 48–16 The sticker on this battery indicates that it was shipped from the factory January, 2022.

BATTERY ELECTRICAL DRAIN TEST

TERMINOLOGY The **battery electrical drain test** determines if any component or circuit in a vehicle is causing a drain on the battery when everything is off. This test is also called the **ignition off draw (IOD)** or **parasitic load test.**

Many electronic components draw a continuous, slight amount of current from the battery when the ignition is off.

This test should be performed when one of the following conditions exists:

1. When a battery is being charged or replaced (a battery drain could have been the cause for charging or replacing the battery)
2. When the battery is suspected of being drained

PROCEDURE FOR BATTERY ELECTRICAL DRAIN TEST

- **Inductive DC ammeter.** The fastest and easiest method to measure battery electrical drain is to connect an inductive DC ammeter that is capable of measuring low current (10 milliamperes). ● **SEE FIGURE 48–17** for an example of a clamp-on digital multimeter (DMM) being used to measure battery drain.
- **DMM set to read milliamperes.** The following is the procedure for performing the battery electrical drain test using a DMM set to read DC amperes:

STEP 1 Make certain that all lights, accessories, and ignition are off.

STEP 2 Check all vehicle doors to be certain that the interior courtesy (dome) lights are off.

STEP 3 Disconnect the *negative* (–) battery cable and install a parasitic load tool, as shown in ● **FIGURE 48–18**.

STEP 4 Start the engine and drive the vehicle about 10 minutes, being sure to turn on all the lights and accessories, including the radio.

STEP 5 Turn the engine and all accessories off, including the underhood light.

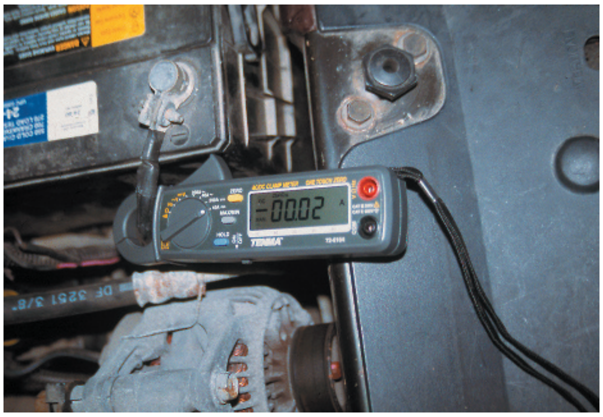


FIGURE 48–17 This mini clamp-on digital multimeter is being used to measure the amount of battery electrical drain that is present. In this case, a reading of 20 milliamperes (displayed on the meter as 00.02 ampere) is within the normal range of 20 to 30 milliamperes. Be sure to clamp around all of the positive battery cables or all of the negative battery cables, whichever is easiest to get the clamp around.

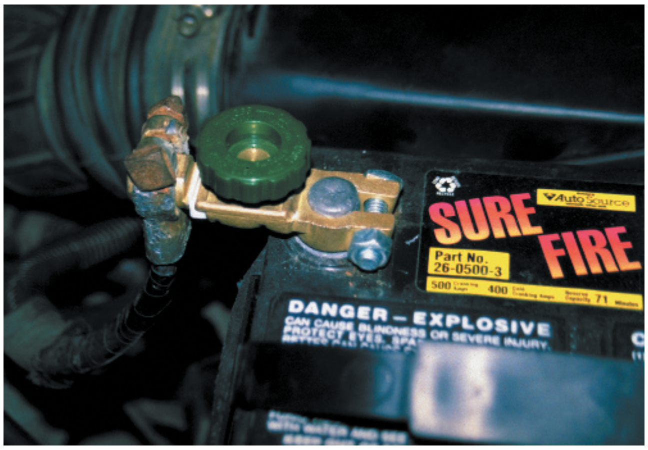


FIGURE 48–18 After connecting the shut-off tool, start the engine and operate all accessories. Stop the engine and turn off everything. Connect the ammeter across the shut-off switch in parallel. Wait 20 minutes. This time allows all electronic circuits to “time out” or shut down. Open the switch—all; current now flows through the ammeter. A reading greater than specified (usually greater than 50 milliamperes, or 0.05 ampere) indicates a problem that should be corrected.

STEP 6 Connect an ammeter across the parasitic load tool switch and wait 20 minutes for all computers and circuits to shut down.

STEP 7 Open the switch on the load tool and read the battery electrical drain on the meter display.

SPECIFICATIONS Results:

- Normal = 20 to 30 milliamperes (0.02 to 0.03 ampere)
- Maximum allowable = 50 milliamperes (0.05 ampere)

BATTERY DRAIN AND RESERVE CAPACITY It is normal for a battery to self-discharge, even if there is not an electrical load, such as computer memory, to drain the battery. According to General Motors, this self-discharge is about 13 milliamperes (0.013 ampere) .

CASE STUDY

The Chevrolet Battery Story

A Chevrolet Impala was being diagnosed for a dead battery. Testing for a battery drain (parasitic draw) showed 2.25 amperes, which was clearly over the acceptable value of 0.050 or less. At the suggestion of the shop supervisor, the technician used a Tech 2 scan tool to check if all of the computers and modules went to sleep after the ignition was turned off. The scan tool display indicated that the instrument panel (IP) showed that it remained awake after all of the others had gone into sleep mode. The IP cluster was unplugged and the vehicle was tested for an electrical drain again. This time, it was only 32 milliamperes (0.032 ampere), well within the normal range. Replacing the IP cluster solved the excessive battery drain.

Summary:

Complaint—The battery was dead.

Cause—Excessive battery drain (parasitic draw) was found. Using a scan tool to test the modules, it was discovered that the instrument panel cluster (IPC) remained awake and never powered down when the ignition was turned off.

Correction—The IPC was replaced, which corrected the excessive battery drain problem.

Some vehicle manufacturers specify a maximum allowable parasitic draw or battery drain be based on the reserve capacity of the battery. The calculation used is the reserve capacity of the battery divided by 4; this equals the maximum allowable battery drain. For example, a battery rated at 120 minutes reserve capacity should have a maximum battery drain of 30 milliamperes .

120 minutes reserve capacity ÷ 4 = 30 mA

FINDING THE SOURCE OF THE DRAIN If there is a drain, check and temporarily disconnect the following components:

1. Underhood light
2. Glove compartment light
3. Trunk light

If after disconnecting these three components the battery drain draws more than 50 milliamperes (0.05 ampere), disconnect one fuse at a time from the fuse box until the excessive drain drops to normal.

NOTE: Do not reinsert fuses after they have been removed as this action can cause modules to "wake up," leading to an inconclusive test.

If the excessive battery drain stops after one fuse is disconnected, the source of the drain is located in that particular circuit, as labeled on the fuse box. Continue to disconnect the *power-side* wire connectors from each component included in that particular circuit until the test light goes off. The source of the battery drain can then be traced to an individual component or part of one circuit.

WHAT TO DO IF A BATTERY DRAIN STILL EXISTS If all the fuses have been disconnected and the drain still exists, the source of the drain has to be between the battery and the fuse box. The most common sources of drain under the hood include the following:

1. **The alternator.** Disconnect the alternator wires and retest. If the ammeter now reads a normal drain, the problem is a defective diode(s) in the alternator.
2. **PCM or control module** staying on and not going to sleep. The procedure usually involves disconnecting one module at a time, then checking to see if the battery drain has been reduced or eliminated. Check service information for the exact procedures to follow to determine if the modules are staying awake.

MAINTAINING ELECTRONIC MEMORY FUNCTIONS

BATTERY DISCONNECT ISSUES Whenever a battery is disconnected or replaced, many electrical/electronic modules may lose their memory including

1. Radio presets and clock functions plus antitheft (if equipped) ● **SEE FIGURE 48–19.**
2. Security system
3. PCM engine idle learn
4. Auto power windows/sunroof

To prevent having to reinitialize these modules, a "memory saver" can be used keep power applied to the electrical system when the battery is disconnected.

MAINTAINING MEMORY METHODS There are two ways to connect power to prevent the loss of memory function:

1. Connect a battery (9-volt dry cell or 12-volt auxiliary battery) to the auxiliary power socket (cigarette lighter).
2. Connect a 12-volt auxiliary battery to terminals 4 and 16 of the data link connector (DLC). Use a commercially available memory saver for this procedure to help prevent possible damage that could occur if 12-volt power is accidentally applied to data lines at the DLC. ● **SEE FIGURE 48–20.**

Make the connections to the vehicle, using either method, before disconnecting the vehicle battery. The applied voltage, which is connected the electrical system through the power plug

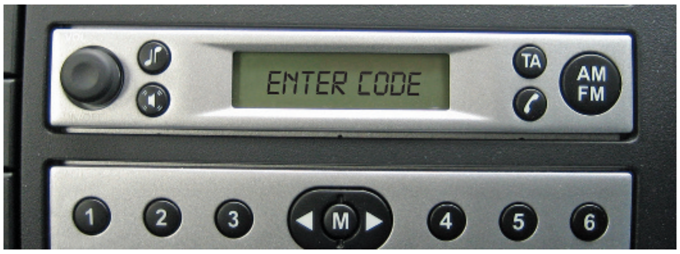


FIGURE 48–19 The battery was replaced in this Ford Focus and the radio displayed "enter code" when the replacement battery was installed. Thankfully, the owner had the code required to unlock the radio.

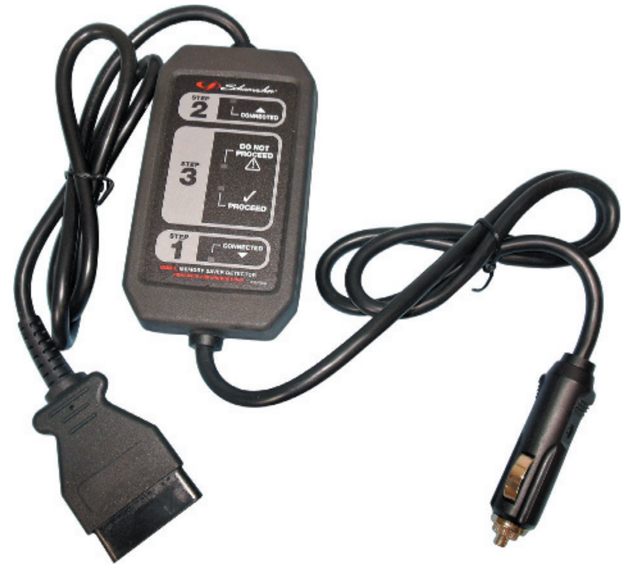


FIGURE 48–20 A special tool that includes a lighter plug that can be plugged into a jump-start battery unit and the other end connected to the data link connector (DLC) of the vehicle to maintain the memory functions.

FREQUENTLY ASKED QUESTION

How Is a New Battery Registered?

Some vehicles require that a new battery be *registered* so that the powertrain control module (PCM) "knows" that the battery has been replaced. Over time, every battery loses capacity and as a result, the charging voltage usually needs to be increased to keep the battery performing correctly. If a new battery is installed without being registered, the PCM may overcharge the new battery leading to a possible premature battery failure. The steps needed to be performed to resister a battery include the following:

Step 1 When installing a new battery, ensure that the replacement battery is the same type (AGM or flooded) as the original plus the same size and capacity as the original.

Step 2 Use a factory or factory level aftermarket scan tool to the DLC and turn the ignition on (KOEO).

Step 3 Check the instructions for the scan tool to where to precede to register the battery and follow the on-screen directions.

The scan tool will perform the following:

- Sets the battery capacity to 80% (charging to a higher state-of-charge than 80% shortens the life of any battery)
- The current battery statistics such as the charge level and calculated battery temperature are deleted.

If a different size or type of battery is being installed, then the PCM needs to be coded to match the specifications of the new and different battery.

A scan tool is needed to register the new battery to the vehicle. Always follow the vehicle manufacturer's recommended procedures when replacing a battery.

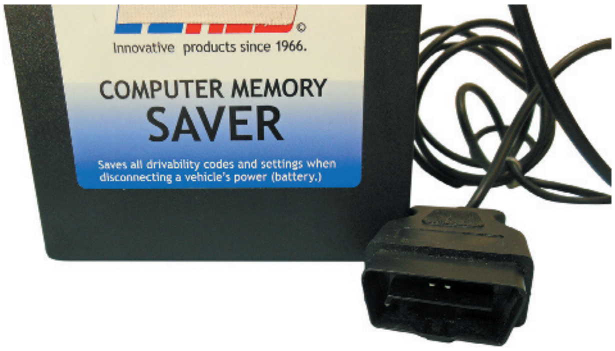

Innovative products since 1966.
COMPUTER MEMORY
SAVER
Saves all drivability codes and settings when disconnecting a vehicle's power (battery.)

FIGURE 48–21 A memory saver tool that uses a 12-volt battery to connect to the power (terminal 16) and ground (terminals 4 and 5) of the DLC.

or DLC, will keep all memory functions, so they do not need to be reset. ● **SEE FIGURE 48–21.**

REINITIALIZATION If a memory saver was not used and the battery was disconnected, then the memory functions need to be reinitialized, which can include the following:

1. **Auto power windows** To reset proper operation, use the window control for each window and hold the down button for a few seconds after the window reaches the bottom. Repeat for the up button, if the vehicle is equipped with auto up function.
2. **Radio antitheft** To unlock an antitheft radio that has lost power, a code number is needed to get the radio to function

FREQUENTLY ASKED QUESTION

Where Is the Battery?

Many vehicle manufacturers today place the battery under the backseat, under the front fender, or in the trunk. ● **SEE FIGURE 48–22.**

Often, the battery is not visible, even if it is located under the hood. When testing or jump starting a vehicle, look for a battery access point.

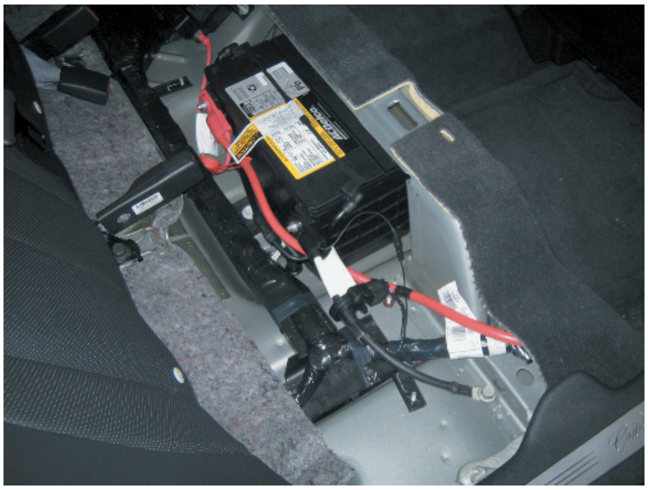


FIGURE 48–22 Many newer vehicles have batteries that are sometimes difficult to find. Some are located under plastic panels under the hood, under the front fender, or even under the rear seat, as shown here.

again. Check service information for the exact procedure to follow if the owner does not have the radio code number, which is usually with the owner's manual.

3. **Intelligent battery systems** Some vehicles, usually European brands, use an intelligent battery system that monitors the battery operation including state of charge, voltage, and temperature. As the battery ages, the system can compensate by changing the charging voltage. When a new battery is installed, the vehicle must have the new battery registered so that the system does not overcharge the new battery. The replacement battery must be the same type (flooded or AGM) as the original to avoid potential issues.

BATTERY SYMPTOM GUIDE

The following list assists technicians in troubleshooting batteries.

Problem	Possible Causes and/or Solutions
1. Headlights are dimmer than normal	1. Discharged battery or poor connections on the battery, engine, or body
2. Solenoid clicks	2. Discharged battery or poor connections on the battery, or an engine fault, such as coolant on top of the pistons, causing a hydrostatic lock
3. Engine is slow in cranking	3. Discharged battery, high-resistance battery cables, or defective starter or solenoid
4. Battery does not accept a charge	4. Possible loose battery cable connections. (If the battery is a maintenance-free type, attempt to fast charge the battery for several hours. If the battery still does not accept a charge, replace the battery.)
5. Battery is using water	5. Check charging system for too high a voltage. (If the voltage is normal, the battery is showing signs of gradual failure. Load test and replace the battery, if necessary.)

REVIEW QUESTIONS

1. What are the results of a voltmeter test of a battery and its state of charge?
2. What are the steps for performing a battery load test?
3. How is a battery drain test performed?
4. Why should a battery not be fast charged?
5. Why do some vehicles need to have a new battery registered?

CHAPTER QUIZ

1. Technician A says that a memory saver should be used when replacing a battery. Technician B says that modules reset their memories automatically. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. A battery should be checked for __________.
   - **a.** being securely held down
   - **b.** having clean and tight battery terminals
   - **c.** the battery case being clean
   - **d.** All of the above
3. What precautions are needed when charging an AGM-type battery?
   - **a.** Keep the charger away from the battery as far as possible.
   - **b.** Charging amperage should be set to less than 10 amperes.
   - **c.** Charging voltage should be at or below 14.4 volts.
   - **d.** Keep the charging time to less than one hour.
4. A battery has just been changed on a popular European vehicle. What service should the technician perform before returning the vehicle to the owner?
   - **a.** Charge the battery overnight.
   - **b.** Register the new battery to the vehicle.
   - **c.** Allow the vehicle to sit overnight with the headlights on, then recharge the battery.
   - **d.** No additional steps are required, other than just installing the battery.
5. A defective battery causes which of the following symptoms?
   - **a.** Slow cranking
   - **b.** Excessive voltage (over 16 volts)
   - **c.** Smooth, clean connectors, indicating overheating of the cables
   - **d.** None of these
6. When measuring the specific gravity of the electrolyte, the maximum allowable difference between the highest and lowest hydrometer reading is __________.
   - **a.** 0.010
   - **b.** 0.020
   - **c.** 0.050
   - **d.** 0.50

7. A battery high-rate discharge (load capacity) test is being performed on a 12-volt battery. Technician A says that a good battery should have a voltage reading of higher than 9.6 volts, while under load, at the end of the 15-second test. Technician B says that a battery conductance tester is often used to load the battery to two times the CCA rating of the battery. Which technician is correct?
  - **a.** Technician A only
  - **b.** Technician B only
  - **c.** Both Technicians A and B
  - **d.** Neither Technician A nor B

8. Why should the technician wear protective clothing and eye protection when working around batteries?
  - **a.** The battery may be hot.
  - **b.** There may be explosive gases present around the battery.
  - **c.** Battery cables present a puncture hazard.
  - **d.** None of these

9. Normal battery drain (parasitic drain) in a vehicle with many computer and electronic circuits is __________.
  - **a.** 20 to 30 milliamperes
  - **b.** 2 to 3 amperes
  - **c.** 150 to 300 milliamperes
  - **d.** None of the above

10. When jump starting, __________.
  - **a.** the last connection should be the positive post of the dead battery
  - **b.** the last connection should be the engine block of the dead vehicle
  - **c.** the alternator must be disconnected on both vehicles
  - **d.** Both a and c

Chapter 49

STARTING SYSTEM PARTS AND OPERATION

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the parts and operation of a cranking circuit.
- Explain push button starting.
- Discuss starter motor operation.
- Explain the components of a starter motor.
- Describe gear reduction starters.
- Describe the function of starter drives.
- Describe the function of solenoids.
- Discuss stop-start system operation.

KEY TERMS:

Advanced engagement (AE) starter 568 • Armature 564 • Brush-end housing 563 • Brushes 564 • CEMF 562 • Commutator-end housing 563 • Commutator segments 564 • Compression spring 567 • Drive-end housing 563 • Field coils 564 • Field housing 563 • Field poles 564 • Ground brushes 564 • Hold-in winding 567 • Insulated brushes 564 • Mesh spring 566 • Neutral safety switch 560 • Overrunning clutch 566 • Permanently engaged (PE) starter 569 • Pole shoes 563 • Pull-in winding 567 • RVS 561 • Starter drive 566 • Starter solenoid 567 • Stop-start 568 • Tandem solenoid (TS) starter 568 • Through bolts 563

CRANKING CIRCUIT

PARTS INVOLVED For any engine to start, it must first be rotated using an external power source. It is the purpose and function of the cranking circuit to create the necessary power and transfer it from the battery to the starter motor, which rotates the engine.

The cranking circuit includes those mechanical and electrical components that are required to crank the engine for starting. The control circuit includes those wires and components that carry a relatively small current such as the ignition switch, safety switch, and solenoid. The power circuit carries the heavy current needed to crank the engine and includes the battery itself, plus the battery cables, solenoid, and starter motor. Modern cranking circuits include the following:

1. **Starter motor.** The starter is normally a 0.5 to 2.6 horsepower (0.4 to 2 kilowatts) electric motor that can develop nearly 8 horsepower (6 kilowatts) for a very short time when first cranking a cold engine. ● **SEE FIGURE 49–1**.
2. **Battery.** The battery must be of the correct capacity and be at least 75% charged to provide the necessary current and voltage for correct starter operation.
3. **Starter solenoid or relay.** The high current required by the starter must be able to be turned on and off. A large switch would be required if the current were controlled by the driver directly. Instead, a small current switch (ignition switch) operates a solenoid or relay that controls the high current to the starter.
4. **Starter drive.** The starter drive uses a small pinion gear that contacts the engine flywheel gear teeth and transmits starter motor power to rotate the engine.

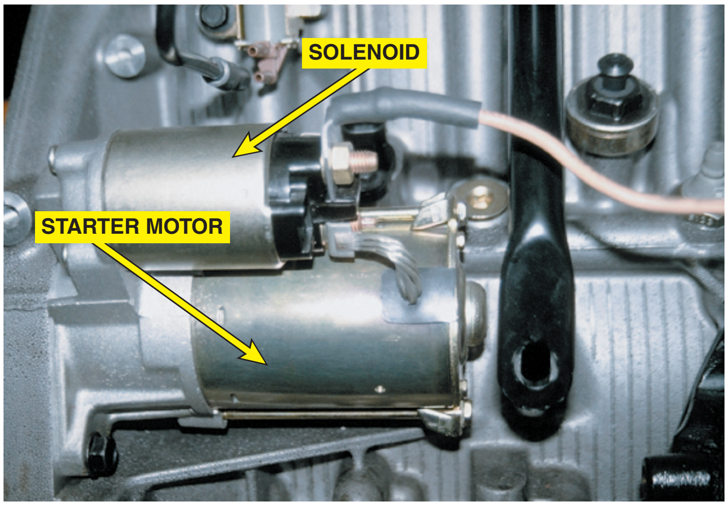


FIGURE 49–1 A typical solenoid-operated starter.

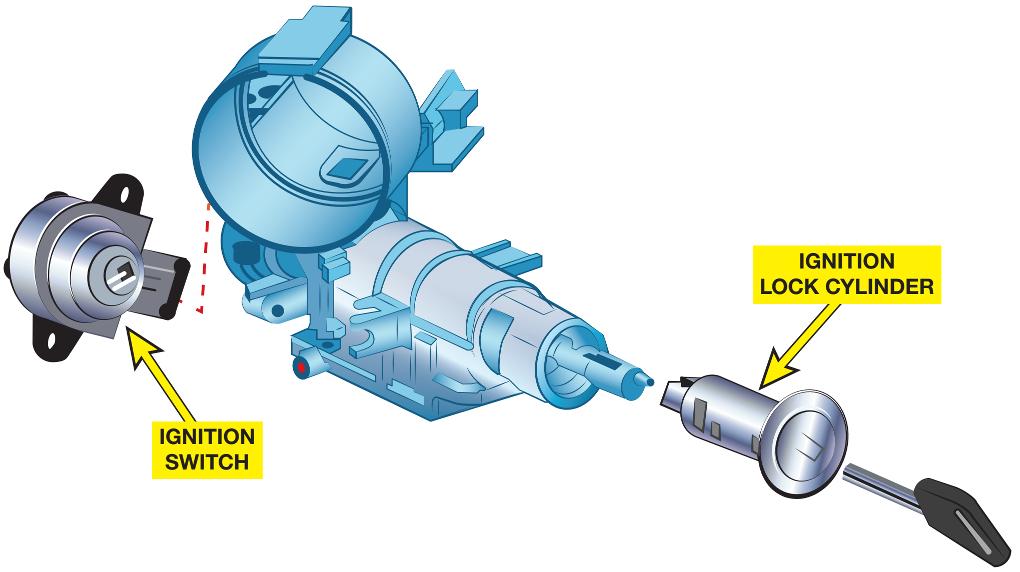


FIGURE 49–2 The lock cylinder is often a separate part from the electrical ignition switch and operates it directly or uses a link between two components.

5. **Ignition switch.** The ignition switch and safety control switches control the starter motor operation. ● **SEE FIGURE 49–2**.

CONTROL CIRCUIT PARTS AND OPERATION The engine is cranked by an electric motor that is controlled by a key-operated ignition switch. The ignition switch does not operate the starter unless the automatic transmission is in neutral or park, or the clutch pedal is depressed on manual transmission/transaxle vehicles. This is to prevent any accident that might result from the vehicle moving forward or rearward when the engine is started. The types of controls that are used to be sure that the vehicle does not move when being cranked include the following:

- Many automobile manufacturers use an electric switch called a **neutral safety switch**, which opens the circuit between the ignition switch and the starter to prevent starter motor operation, unless the gear selector is in neutral or park. The safety switch can be attached either to the steering column inside the vehicle near the floor or on the side of the transmission.
- Many manufacturers use a mechanical blocking device in the steering column to prevent the driver from turning the key switch to the start position unless the gear selector is in neutral or park.
- Many manual transmission vehicles also use a safety switch to permit cranking only if the clutch is depressed. This switch is commonly called the *clutch safety switch*. ● **SEE FIGURE 49–3**.

PUSH BUTTON START

OPERATION Push button start systems and many key operated systems use the computer to crank the engine. The ignition switch start position on the push-to-start button is used as an input signal to the powertrain control module (PCM). Before the PCM cranks the engine, the following conditions must be met:

- The brake pedal is depressed.

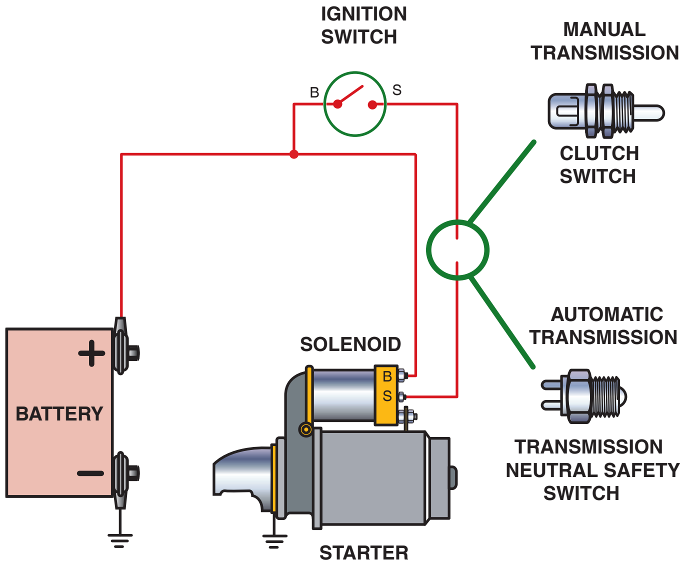


FIGURE 49–3 To prevent the engine from cranking, an electrical switch is usually installed to open the circuit between the ignition switch and the starter solenoid. The control circuit includes the small wiring and components needed to control the solenoid. The starter solenoid controls the electrical current flow through the large battery cables of the power circuit that operates the starter motor.

- The gear selector is in park or neutral.
- The correct key fob (code) is present in the vehicle.

A typical push-button-to-start system includes the following sequence:

- When the start button is depressed, or the key is turned to the start position, the PCM cranks the engine until it senses that the engine has started.
- The PCM can detect that the engine has started by looking at the engine speed signal.
- Normal cranking speed can vary between 100 and 250 RPM. If the engine speed exceeds 400 RPM, the PCM

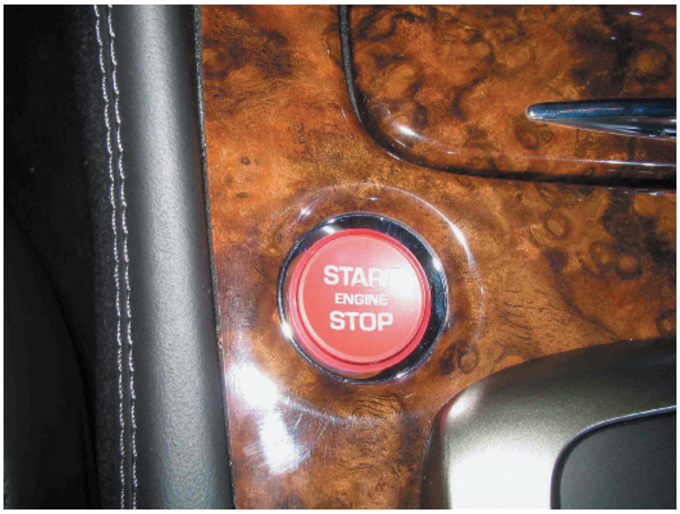


FIGURE 49–4 Instead of using an ignition key to start the engine, some vehicles are using a start button, which is also used to stop the engine, as shown on this Jaguar.

FIGURE 49–5 The top button on this key fob is the remote start button.

determines that the engine has started and opens the circuit to the "S" (start) terminal of the starter solenoid that stops the starter motor.

Computer-controlled starting is almost always part of the system if a push-button start is used. ● **SEE FIGURE 49–4**.

REMOTE STARTING Remote starting, sometimes called **remote vehicle start (RVS)**, is a system that allows the driver to start the engine of the vehicle from inside the house or a building at a distance of about 200 feet (65 m). The doors remain locked to reduce the possibility of theft. This feature allows the heating or air-conditioning system to start before the driver arrives. ● **SEE FIGURE 49–5**.

NOTE: Most remote start systems turn off the engine after 10 minutes of run time unless reset by using the remote.

STARTER MOTOR OPERATION

PRINCIPLES A starter motor uses electromagnetic principles to convert electrical energy from the battery (up to 300 amperes) to mechanical power (up to 8 horse power [6 kilowatts]) to crank the engine. Current for the starter motor or power circuit is controlled by a solenoid or relay, which is itself controlled by the driver-operated ignition switch.

The current travels through the brushes and into the armature windings, where other magnetic fields are created around each copper wire loop in the armature. The two strong magnetic fields created inside the starter housing create the force that rotates the armature.

Inside the starter housing is a strong magnetic field created by the field coil magnets. The armature, a conductor, is installed inside this strong magnetic field, with little clearance between the armature and the field coils.

The two magnetic fields act together, and their lines of force "bunch up" or are strong on one side of the armature loop wire and become weak on the other side of the conductor. This causes the conductor (armature) to move from the area of strong magnetic field strength toward the area of weak magnetic field strength. ● **SEE FIGURES 49–6 AND 49–7**.

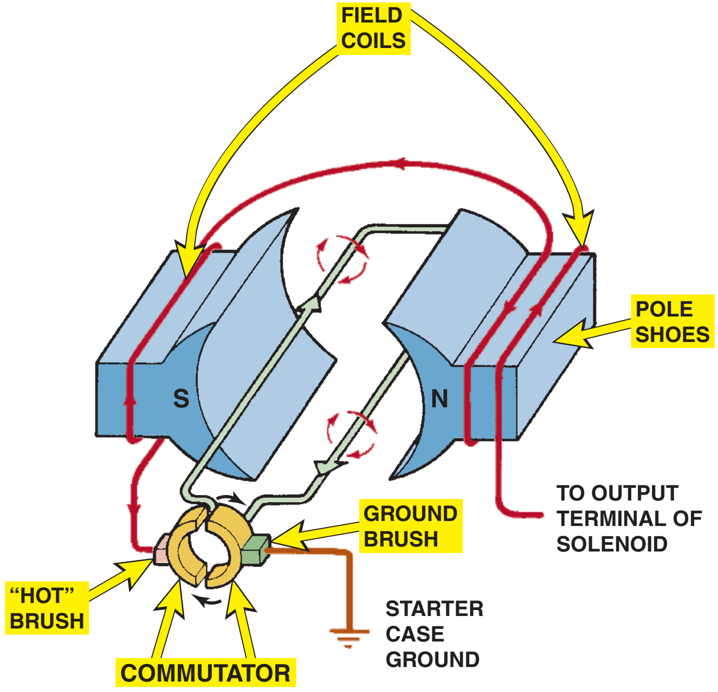


FIGURE 49–6 This series-wound electric motor shows the basic operation with only two brushes: one hot brush and one ground brush. The current flows through both field coils, then through the hot brush and the loop winding of the armature, before reaching ground through the ground brush.

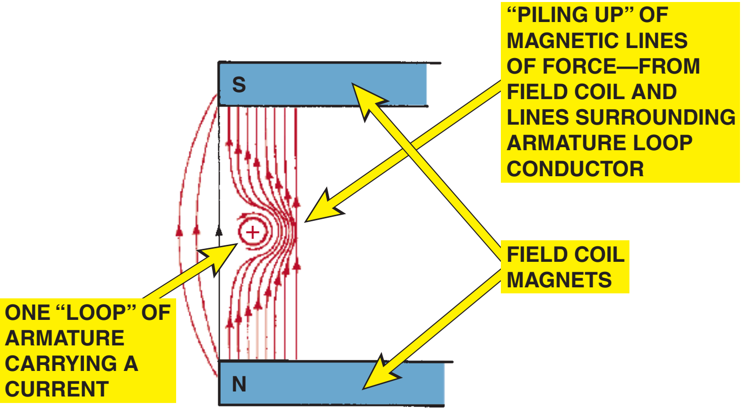

"PILING UP" OF MAGNETIC LINES OF FORCE—FROM FIELD COIL AND LINES SURROUNDING ARMATURE LOOP CONDUCTOR
S
FIELD COIL MAGNETS
ONE "LOOP" OF ARMATURE CARRYING A CURRENT
N

FIGURE 49–7 The interaction of the magnetic fields of the armature loops and field coils creates a stronger magnetic field on the right side of the conductor, causing the armature loop to move toward the left.

The difference in magnetic field strength causes the armature to rotate. This rotation force (torque) is increased as the current flowing through the starter motor increases. The torque of a starter is determined by the strength of the magnetic fields inside the starter. Magnetic field strength is measured in ampere-turns. If the current or the number of turns of wire is increased, the magnetic field strength is increased.

The magnetic field of the starter motor is provided by two or more pole shoes and field windings. The pole shoes are made of iron and are attached to the frame with large screws. ● **SEE FIGURE 49–8**.

● **FIGURE 49–9** shows the paths of magnetic flux lines within a four-pole motor.

The field windings are usually made of a heavy copper ribbon to increase their current-carrying capacity and electromagnetic field strength. ● **SEE FIGURE 49–10**.

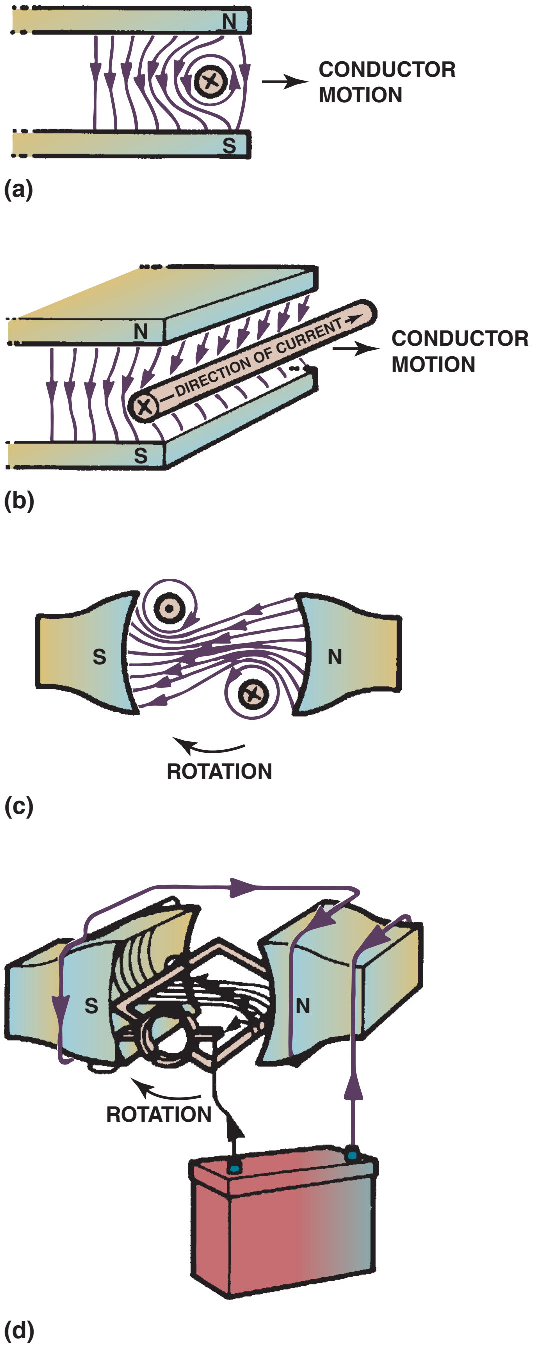


FIGURE 49–8 The armature loops rotate due to the difference in the strength of the magnetic field. The loops move from a strong magnetic field strength toward a weaker magnetic field strength.

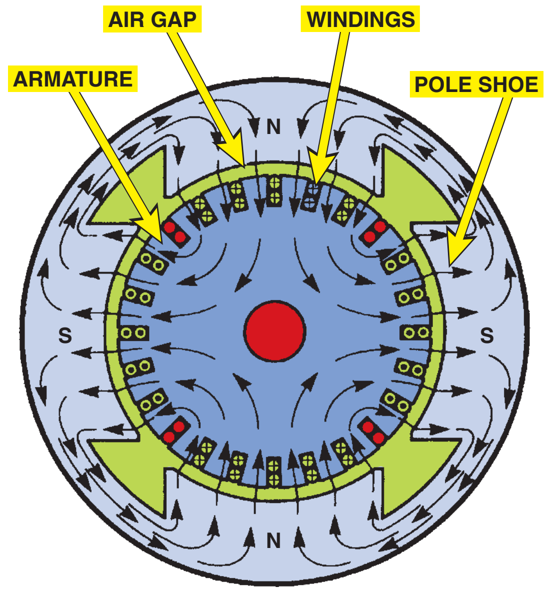


FIGURE 49–9 Magnetic lines of force in a four-pole motor.

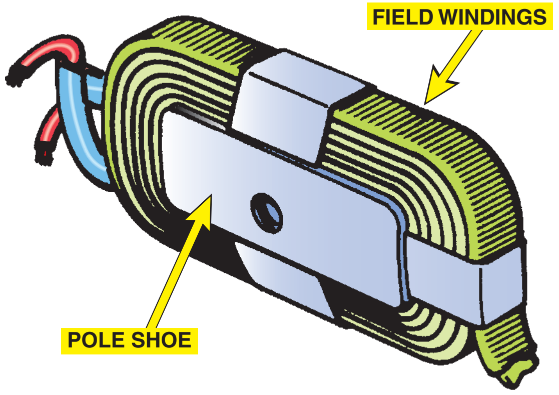


FIGURE 49–10 A pole shoe and field winding.

Automotive starter motors usually have four pole shoes and two to four field windings to provide a strong magnetic field within the motor. Pole shoes that do not have field windings are magnetized by flux lines from the wound poles.

SERIES MOTORS A series motor develops its maximum torque at the initial start (0 RPM) and develops less torque as the speed increases.

- A series motor is commonly used for an automotive starter motor because of its high starting power characteristics.
- A series starter motor develops less torque at high RPM because a current is produced in the starter itself that acts against the current from the battery. Because this current works against battery voltage, it is called **counterelectromotive force**, or **CEMF**. This CEMF is produced by electromagnetic induction in the armature conductors, which are cutting across the magnetic lines of force formed by the field coils. This induced voltage operates against the applied voltage supplied by the battery, which reduces the strength of the magnetic field in the starter.
- Because the power (torque) of the starter depends on the strength of the magnetic fields, the torque of the starter decreases as the starter speed increases. A series-wound

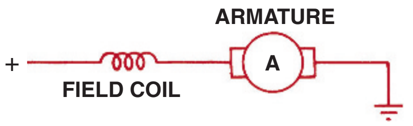


FIGURE 49–11 This wiring diagram illustrates the construction of a series-wound electric motor. Notice that all current flows through the field coils, then through the armature (in series) before reaching ground.

starter also draws less current at higher speeds and keeps increasing in speed under light loads. This could lead to the destruction of the starter motor unless controlled or prevented. ● **SEE FIGURE 49–11**.

SHUNT MOTORS Shunt-type electric motors have the field coils in parallel (or shunt) across the armature.

A shunt-type motor has the following features:

- A shunt motor does not decrease in torque at higher motor RPM because the CEMF produced in the armature does not decrease the field coil strength.
- A shunt motor, however, does not produce as high a starting torque as that produced by a series-wound motor and is not used for starters. Some small electric motors, such as those used for windshield wipers, use a shunt motor, but most use permanent magnets rather than electromagnets.

● **SEE FIGURE 49–12**.

PERMANENT MAGNET MOTORS A permanent magnet (PM) starter uses permanent magnets that maintain constant field strength, the same as a shunt-type motor, so they have similar operating characteristics. To compensate for the lack of torque, all PM starters use gear reduction to multiply starter motor torque. The permanent magnets used are an alloy of neodymium, iron, and boron and are almost 10 times more powerful than previously used permanent magnets. The magnets replace the electromagnetic field coils and pole shoes. This eliminates the motor field circuit, which in turn eliminates the potential for field coil faults and other electrical problems. The motor has only an armature circuit.

COMPOUND MOTORS A compound-wound, or compound, motor has the operating characteristics of a series motor *and* a shunt-type motor because some of the field coils are connected to the armature in series and some (usually only one) are connected directly to the battery in parallel (shunt) with the armature.

Compound-wound starter motors are commonly used in Ford, Chrysler, and some GM starters. The shunt-wound field coil is called a shunt coil and is used to limit the maximum speed of the starter. Because the shunt coil is energized as soon as the battery current is sent to the starter, it is used to engage the starter drive on older Ford positive engagement-type starters. ● **SEE FIGURE 49–13**.

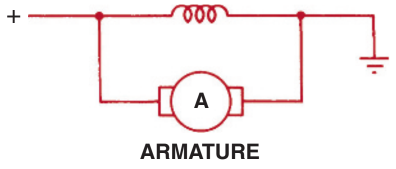


FIGURE 49–12 This wiring diagram illustrates the construction of a shunt-type electric motor and shows the field coils in parallel (or shunt) across the armature.

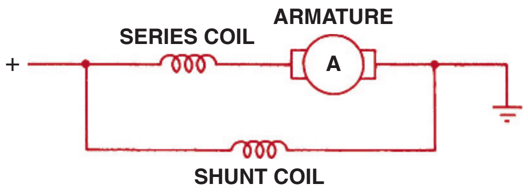


FIGURE 49–13 A compound motor is a combination of series and shunt types, using part of the field coils connected electrically in series with the armature and part in parallel (shunt).

STARTER MOTOR COMPONENTS

PARTS INVOLVED A starter consists of the main structural support called the **field housing**, one end of which is called a **commutator-end** (or **brush-end) housing** and the other end a **drive-end housing**. The drive-end housing contains the drive pinion gear, which meshes with the engine flywheel gear teeth to start the engine. The commutator-end plate supports the end containing the starter brushes. **Through bolts** hold the three components together. ● **SEE FIGURE 49–14**.

- **Field coils.** The steel housing of the starter motor contains permanent magnets or four electromagnets that are connected directly to the positive post of the battery to provide a strong magnetic field inside the starter. The four electromagnets use heavy copper or aluminum wire wrapped around a soft-iron core, which is contoured to fit against the rounded internal surface of the starter frame. The soft-iron cores are called **pole shoes**. Two of the four pole shoes are wrapped with copper wire in one direction to create a north pole magnet, and the other two pole shoes are wrapped in the opposite direction to create a south pole magnet. These magnets, when energized, create strong magnetic fields inside the starter housing and,

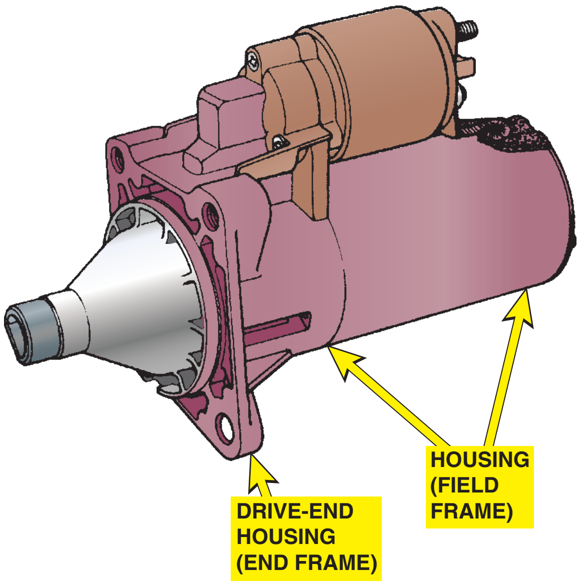


FIGURE 49–14 A typical starter motor showing the drive-end housing.

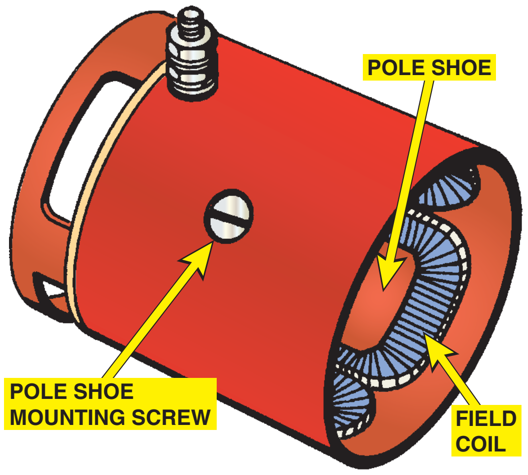


FIGURE 49–15 Pole shoes and field windings installed in the housing.

therefore, are called **field coils**. The soft-iron cores (pole shoes) are often called **field poles**. ● **SEE FIGURE 49–15**.

- **Armature.** Inside the field coils is an **armature** that is supported with either bushings or ball bearings at both ends, which permit it to rotate. The armature is constructed of thin, circular discs of steel laminated together and wound lengthwise with heavy-gauge insulated copper wire. The laminated iron core supports the copper loops of wire and helps concentrate the magnetic field produced by the coils. ● **SEE FIGURE 49–16**.

Insulation between the laminations helps increase the magnetic efficiency in the core. For reduced resistance, the armature conductors are made of a thick copper wire. The two ends of each conductor are attached to two adjacent commutator bars.

The commutator is made of copper bars insulated from each other by mica or some other insulating material. ● **SEE FIGURE 49–17**.

The armature core, windings, and commutator are assembled on a long armature shaft. This shaft also carries the pinion gear that meshes with the engine flywheel ring gear.

STARTER BRUSHES To supply the proper current to the armature, a four-pole motor must have four brushes riding on the commutator. Most automotive starters have two grounded and two insulated brushes, which are held against the commutator by spring force.

The ends of the copper armature windings are soldered to **commutator segments**. The electrical current that passes through the field coils is then passed to the commutator of the armature by brushes that can move over the segments of the rotating armature. These **brushes** are made of a combination of copper and carbon.

- The copper used here is a good conductor material.
- The carbon added to the starter brushes helps provide the graphite-type lubrication needed to reduce wear of the brushes and the commutator segments.

The starter uses four brushes—two brushes to transfer the current from the field coils to the armature and two brushes to provide the ground return path for the current that flows through the armature.

The two sets of brushes include the following:

1. Two **insulated brushes**, which are in holders and are insulated from the housing.
2. Two **ground brushes**, which use bare, stranded copper wire connections to the brushes. The ground brush holders are not insulated and attach directly to the field housing or brush-end housing. ● **SEE FIGURE 49–18**.

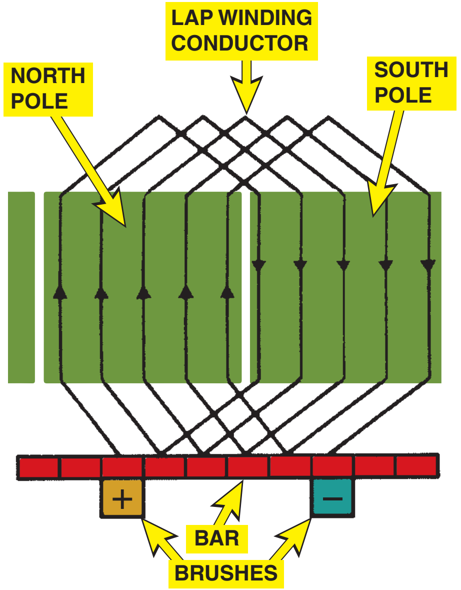


FIGURE 49–17 An armature showing how its copper wire loops are connected to the commutator.

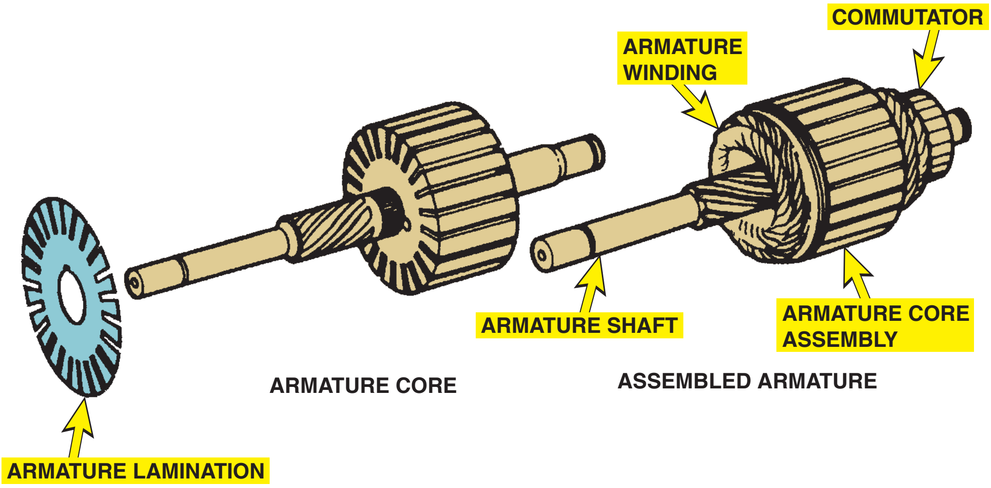


FIGURE 49–16 A typical starter motor armature. The armature core is made from thin sheet metal sections assembled on the armature shaft, which is used to increase the magnetic field strength.

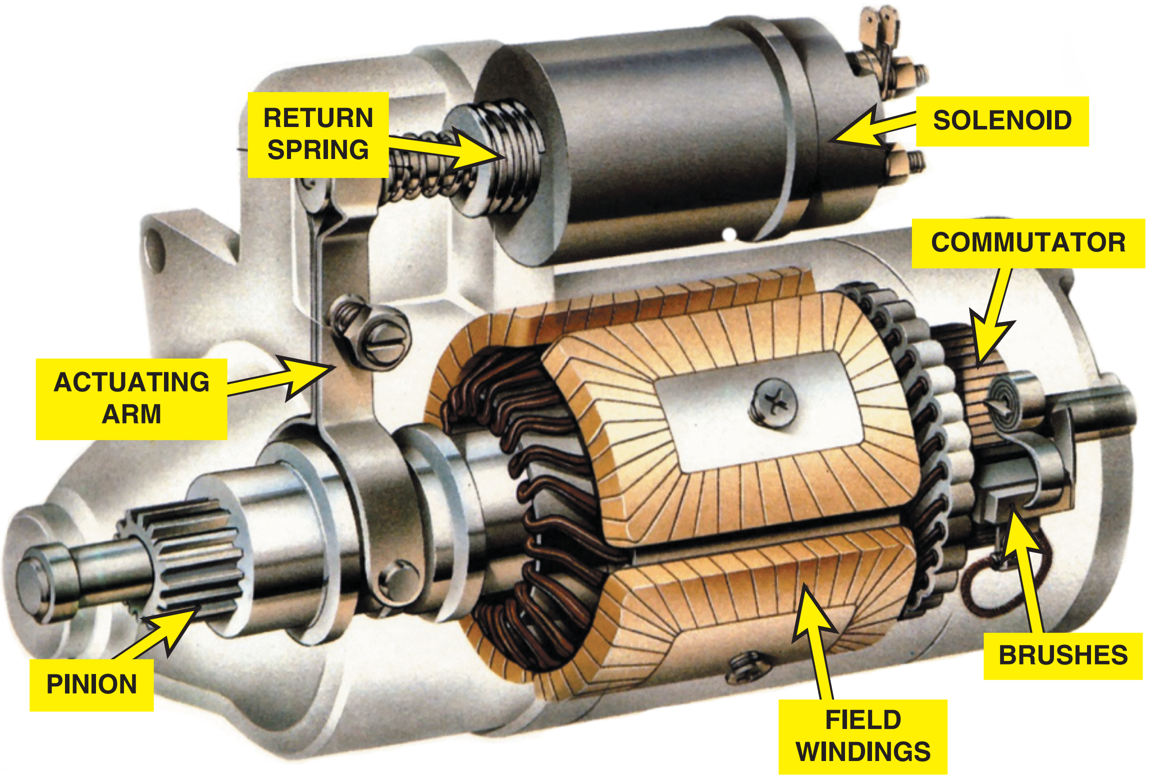


FIGURE 49–18 A cutaway of a typical starter motor showing the commutator, brushes, and brush spring.

TECH TIP

Don't Hit That Starter!

In the past, it was common to see service technicians hitting a starter in their effort to diagnose a no-crank condition. Often the shock of the blow to the starter aligned or moved the brushes, armature, and bushings. Many times, the starter functioned after being hit, even if only for a short time.

However, most starters today use permanent magnet fields, and the magnets can be easily broken if hit. A magnet that is broken becomes two weaker magnets. Some early permanent magnet starters used magnets that were glued or bonded to the field housing. If struck with a heavy tool, the magnets could be broken with parts of the magnet falling onto the armature and into the bearing pockets, making the starter impossible to repair or rebuild. ● **SEE FIGURE 49–19**.

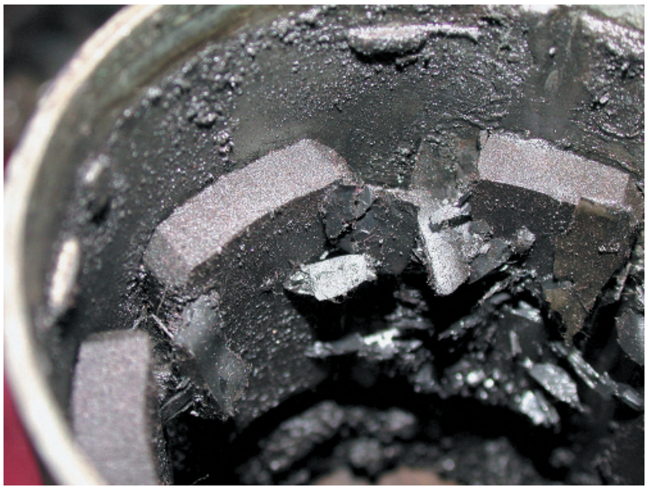


FIGURE 49–19 This starter permanent magnet field housing was ruined when someone used a hammer on the field housing in an attempt to "fix" a starter that did not work. A total replacement is the only solution in this case.

GEAR-REDUCTION STARTERS

PURPOSE AND FUNCTION Gear-reduction starters are used by many automotive manufacturers. The purpose of the gear reduction (typically 2:1 to 4:1) is to increase starter motor speed and provide the torque multiplication necessary to crank an engine.

As a series-wound motor increases in rotational speed, the starter produces less power, and less current is drawn from the battery because the armature generates greater CEMF as the starter speed increases. However, a starter motor's maximum torque occurs at 0 RPM and torque decreases with increasing RPM. A smaller starter using a gear-reduction design can produce the necessary cranking power with reduced starter amperage requirements. Lower current requirements mean that smaller battery cables can be used. Many permanent magnet starters use a planetary gear set (a type of gear reduction) to provide the necessary torque for starting. ● **SEE FIGURE 49–20**.

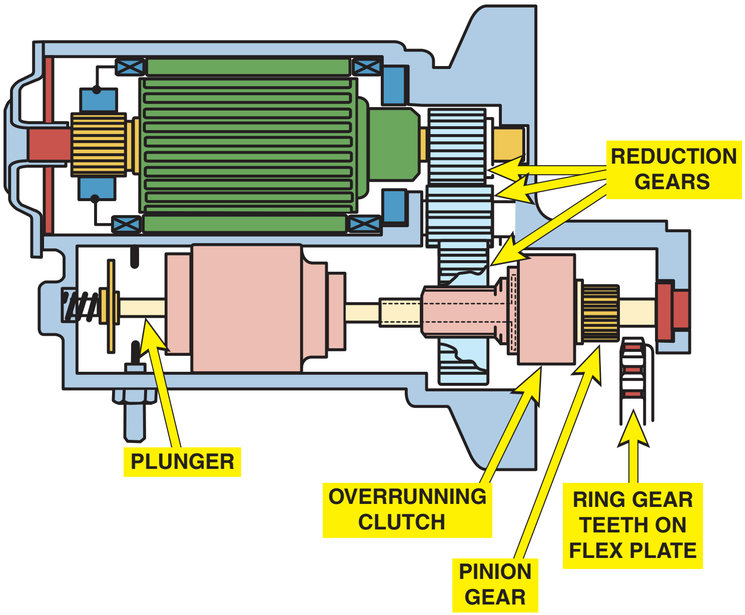


FIGURE 49–20 A typical gear-reduction starter.

STARTER DRIVES

PURPOSE AND FUNCTION A **starter drive** includes small pinion gears that mesh with and rotate the larger gear on the engine flywheel or flex plate for starting. The pinion gear must engage with the engine gear slightly *before* the starter motor rotates to prevent serious damage to either the starter gear or the engine, but must be disengaged after the engine starts. The ends of the starter pinion gear are tapered to help the teeth mesh more easily without damaging the flywheel ring gear teeth. ● **SEE FIGURE 49–21**.

STARTER DRIVE GEAR RATIO The ratio of the number of teeth on the engine ring gear to the number on the starter pinion is between 15:1 and 20:1. A typical small starter pinion gear has 9 teeth that turn an engine ring gear with 166 teeth. This provides an 18:1 gear reduction; thus, the starter motor is rotating approximately 18 times faster than the engine. Normal cranking speed for the engine is 200 RPM (varies from 70 to 250 RPM). This means that the starter motor speed is 18 times faster, or 3,600 starter RPM (200 × 18 = 3,600). If the engine starts and is accelerated to 2,000 RPM (normal cold engine speed), the starter is destroyed by the high speed (36,000 RPM), if the starter was not disengaged from the engine. ● **SEE FIGURE 49–22**.

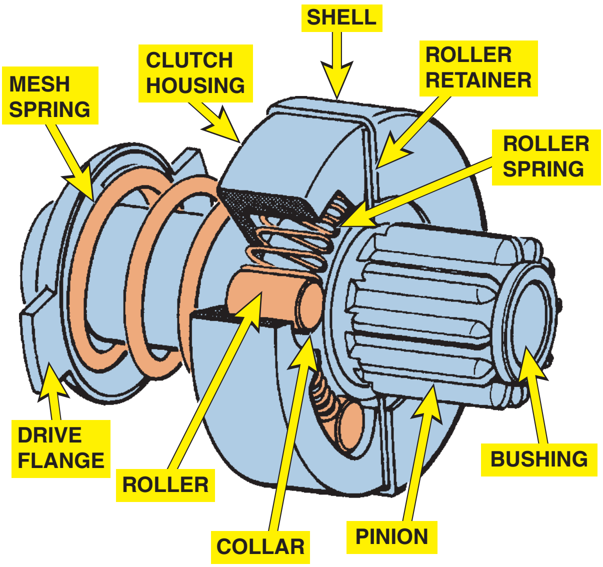


FIGURE 49–21 A cutaway of a typical starter drive showing all of the internal parts.

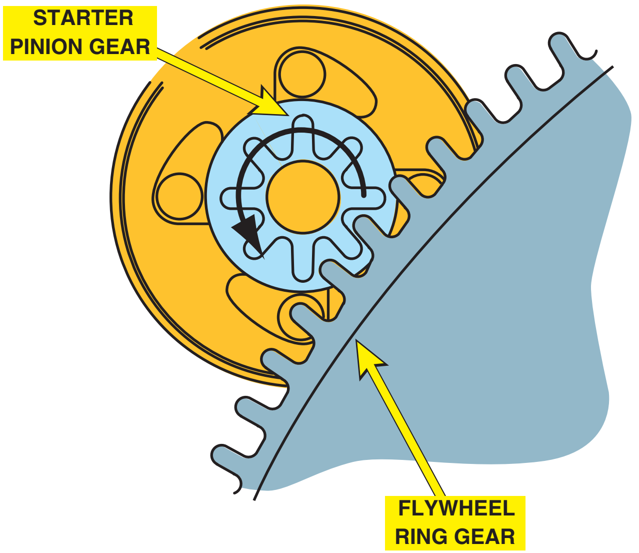


FIGURE 49–22 The ring gear to pinion gear ratio is usually 15:1 to 20:1.

STARTER DRIVE OPERATION All starter drive mechanisms use a type of one-way clutch that allows the starter to rotate the engine, but then turns freely if the engine speed is greater than the starter motor speed. This clutch, called an **overrunning clutch**, protects the starter motor from damage if the ignition switch is held in the start position after the engine starts. The overrunning clutch, which is built in as a part of the starter drive unit, uses steel balls or rollers installed in tapered notches. ● **SEE FIGURE 49–23**.

This taper forces the balls or rollers tightly into the notch when rotating in the direction necessary to start the engine. When the engine rotates faster than the starter pinion, the balls or rollers are forced out of the narrow tapered notch, allowing the pinion gear to turn freely (overrun).

The spring between the drive tang or pulley and the overrunning clutch and pinion is called a **mesh spring**. It helps cushion

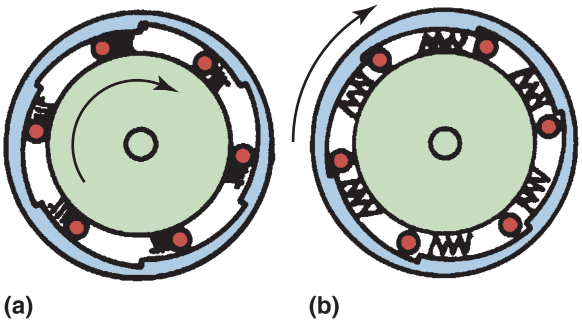

(a) (b)

FIGURE 49–23 Operation of the overrunning clutch. (a) Starter motor is driving the starter pinion and cranking the engine. The rollers are wedged against spring force into their slots. (b) The engine has started and is rotating faster than the starter armature. Spring force pushes the rollers so they can rotate freely.

FREQUENTLY ASKED QUESTION

What Is a Bendix?

Older-model starters often used a Bendix drive mechanism, which used inertia to engage the starter pinion with the engine flywheel gear. Inertia is the tendency of a stationary object to remain stationary, because of its weight, unless forced to move. On these older-model starters, the small starter pinion gear was attached to a shaft with threads, and the weight of this gear caused it to be spun along the threaded shaft and mesh with the flywheel whenever the starter motor spun. If the engine speed was greater than the starter speed, the pinion gear was forced back along the threaded shaft and out of mesh with the flywheel gear. The Bendix drive mechanism has generally not been used since the early 1960s, but some technicians use this term when describing a starter drive.

and control the engagement of the starter drive pinion with the engine flywheel gear. This spring is also called a **compression spring** because the starter solenoid or starter yoke compresses the spring and the spring tension causes the starter pinion to engage the engine flywheel.

FAILURE MODE A starter drive is generally a dependable unit and does not require replacement unless defective or worn. The major wear occurs in the overrunning clutch section of the starter drive unit. The steel balls or rollers wear and often do not wedge tightly into the tapered notches as is necessary for engine cranking.

A worn starter drive can cause the starter motor to operate and then stop cranking the engine further, creating a "whining" noise. The whine indicates that the starter motor is operating and that the starter drive is not rotating the engine flywheel. The entire starter drive is replaced as a unit. The overrunning clutch section of the starter drive cannot be serviced or repaired separately because the drive is a sealed unit. Starter drives are most likely to fail intermittently at first and then more frequently, until replacement becomes necessary to start the engine. Intermittent starter drive failure (starter whine) is often most noticeable during cold weather.

STARTER SOLENOIDS

SOLENOID OPERATION A **starter solenoid** is an electromagnetic switch containing two separate, but connected, electromagnetic windings. This switch is used to engage the starter drive and control the current from the battery to the starter motor.

SOLENOID WINDINGS The two internal windings contain approximately the same number of turns but are made from different-gauge wire. Both windings together produce a strong magnetic field that pulls a metal plunger into the solenoid. The plunger is attached to the starter drive through a shift fork lever. When the ignition switch is turned to the start position, the motion of the plunger into the solenoid causes the starter drive to move into mesh with the flywheel ring gear.

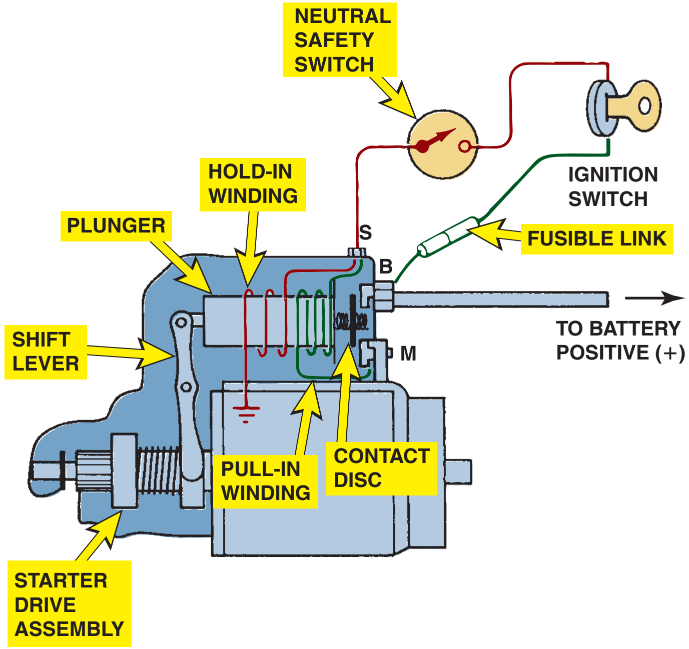


FIGURE 49–24 Wiring diagram of a typical starter solenoid. Notice that both the pull-in winding and the hold-in winding are energized when the ignition switch is first turned to the "start" position. As soon as the solenoid contact disc makes electrical contact with both the B and M terminals, the battery current is conducted to the starter motor and electrically neutralizes the pull-in winding.

1. The heavier-gauge winding (called the **pull-in winding**) is needed to draw the plunger into the solenoid and is grounded through the starter motor.
2. The lighter-gauge winding (called the **hold-in winding**), which is grounded through the starter frame, produces enough magnetic force to keep the plunger in position. The main purpose of using two separate windings is to permit as much current as possible to operate the starter and yet provide the strong magnetic field required to move the starter drive into engagement. ● **SEE FIGURE 49–24**.

OPERATION

1. The solenoid operates as soon as the ignition or computer-controlled relay energizes the "S" (start) terminals. At that instant, the plunger is drawn into the solenoid enough to engage the starter drive.
2. The plunger makes contact with a metal disc that connects the battery terminal post of the solenoid to the motor

FREQUENTLY ASKED QUESTION

How Are Starters Made So Small?

Starters and most components in a vehicle are being made as small and as light in weight as possible to help increase vehicle performance and fuel economy. A starter can be constructed smaller due to the use of gear reduction and permanent magnets to achieve the same cranking torque as a straight drive starter, but using much smaller components. ● **SEE FIGURE 49–25** for an example of an automotive starter armature that is palm size.

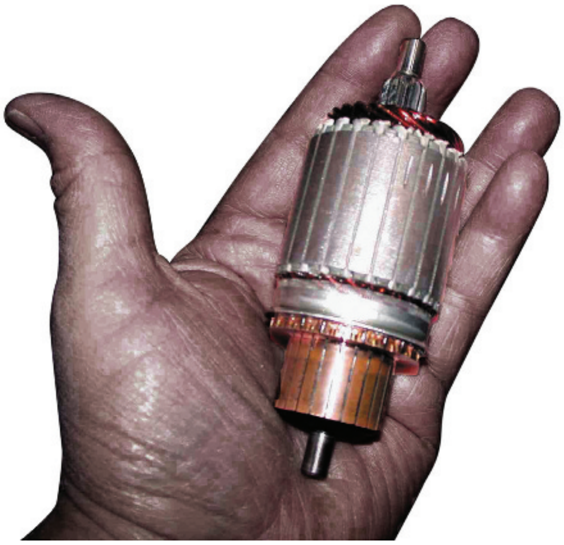


FIGURE 49–25 A palm-size starter armature.

terminal. This permits full battery current to flow through the solenoid to operate the starter motor.

3. The contact disc also electrically disconnects the pull-in winding. The solenoid *has* to work to supply current to the starter. Therefore, if the starter motor operates at all, the solenoid is working, even though it may have high external resistance that could cause slow starter motor operation.

STOP-START SYSTEMS

PURPOSE AND FUNCTION **Stop-start** systems are designed to increase fuel economy and reduce exhaust emissions. Fuel economy and the reduction of CO_2 emissions are estimated to be 5% to 10%, depending on the vehicle and how it is being operated. With stop-start mechanism, the engine is stopped to reduce the fuel consumption when the vehicle is stopped at traffic signals or in stop and go traffic conditions. Various vehicle manufacturers refer to stop-start systems using different terms including

- Auto Stop (● **SEE FIGURE 49–26.**)
- Stop-Start
- Idle-Stop (Honda)
- Smart Stop (Toyota)
- Intelligent Stop and Go (Kia)
- Auto Start/Stop (BMW)
- Engine Stop-Start (ESS)-Chrysler

CONDITIONS FOR STOP-START TO OCCUR Before the PCM engages the stop-start function, the following parameters must be achieved:

- Engine speed is within idling range.
- Accelerator pedal is not depressed.
- Vehicle speed is low or zero, depending on the type of starter used.
- Battery state-of-charge (SOC) is above threshold.
- Hood is closed.

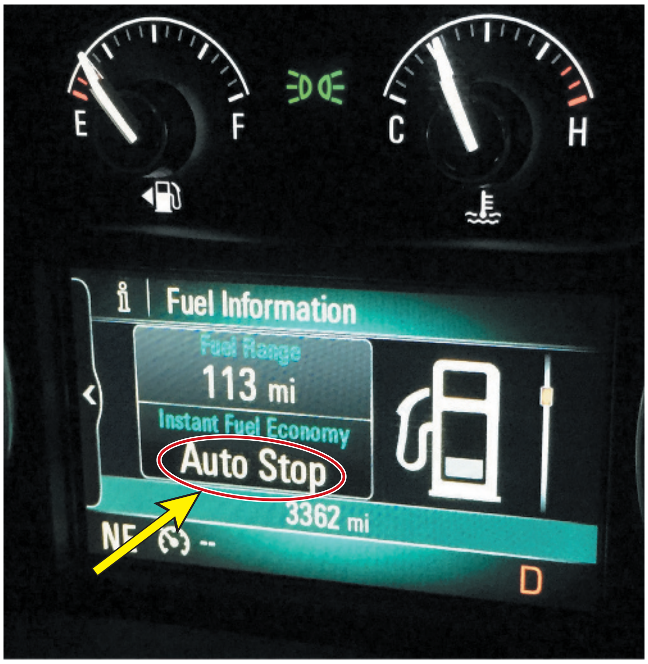


FIGURE 49–26 A Buick Auto Stop system lets the driver know when the engine is stopped.

STOP-START SYSTEM COMPONENTS It is estimated that a stop-start system starts the engine about 500,000 times in the life of the vehicle compared to about 5,000 times for a conventional starting system. A typical stop-start system includes the following components:

1. An absorbed glass-mat (AGM) or enhanced lead–acid (ELA) battery.
2. Battery sensor—Used by the PCM to determine the current entering and leaving the battery in order to estimate the battery SOC.
3. Hood switch—Used by the PCM to disengage stop-start if the hood is open.
4. HVAC control unit—Used to start the engine if cooling or heat is required in the passenger compartment.

STARTER MOTOR DESIGNS Because the engine needs to be restarted many times a day, if driving in heavy congested traffic, the starter used must be robust and capable of starting the engine over 500,000 times during the life of the system. There are three designs of starters used in stop-start system including

1. **Advanced Engagement (AE) Starter.** An advanced engagement starter works like a typical starter. When energized, the pinion shifts forward by the starter solenoid and engages with the engine's ring gear/flywheel, and immediately spins. This starter design requires that the engine speed is zero before re-engagement and engine restart can occur. To survive, the increased usage requires long-life electrical brushes, plus an enhanced pinion spring mechanism that reduces ring gear/flywheel wear.
2. **Tandem Solenoid (TS) Starter.** Using a starter that has two solenoids allows the starter to engage the flywheel of the engine when it is still moving, such as when the vehicle is coasting to a stop. A tandem solenoid starter design is also able to start the engine within 0.5 and 1.5 seconds, compared to about 3 seconds for a conventional starter. A conventional

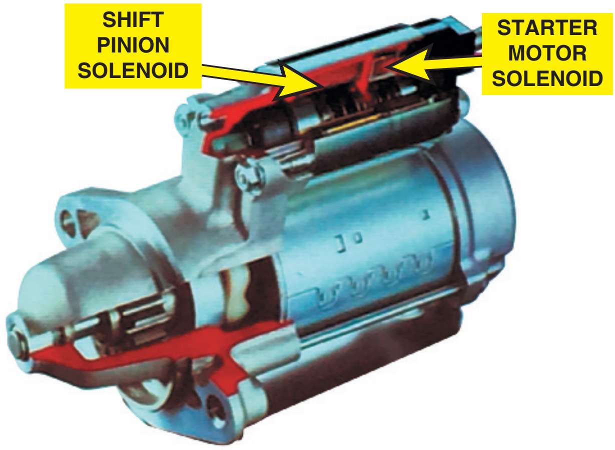


FIGURE 49–27 Using two solenoids allows independent control of the pinion gear and motor energization.

starter uses the solenoid to engage the starter pinion, then, when it is being held by the hold-in winding, the solenoid energizes the starter motor cranking the engine. The use of a dual solenoid allows the two functions of the starter solenoid to work independently: One solenoid is used to engage the starter drive into the engine ring gear. The other solenoid is used to engage the operation of the starter motor. ● **SEE FIGURE 49–27**. This allows the engine to be re-engaged (and restarted) by the starter motor when the engine RPM is falling from idle (about 600 RPM) to zero RPM. A tandem solenoid starter is almost identical in size and shape, so it can be used on almost any engine.

3. **Permanently Engaged (PE) Starter.** A permanently engaged starter delivers the quickest and quietest restart times of all starter motor-based systems. In this system, the starter and flywheel gears are permanently connected, so there are no concerns with gear engagement and disengagement. The PE starter eliminates the starter pinion gear shifting mechanism with its slight delay in activating by mounting the starter to the engine permanently engaged with the flywheel. When a restart is needed, the motor is simply energized, which immediately re-cranks the engine. There is no waiting or delay since the starter gear is already mated to the flywheel. The flywheel does require a special clutching mechanism to disconnect it from engine RPM after engine start.

FREQUENTLY ASKED QUESTION

Can a Stop-Start System Be Turned Off?

Sometimes. Some vehicles equipped with a stop-start system can be turned off using a button on the dash or center stack. ● **SEE FIGURE 49–28**.

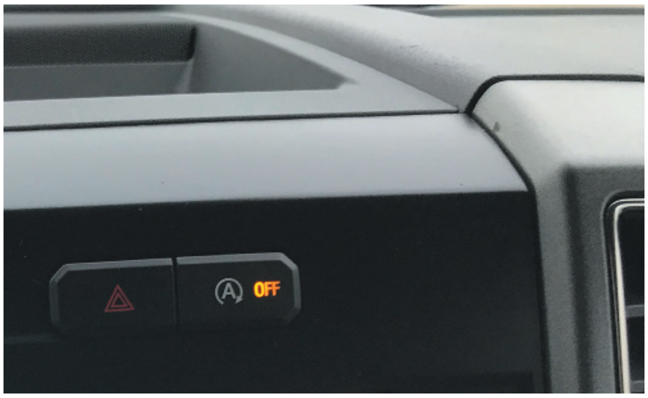


FIGURE 49–28 The stop-start system on this Ford F-150 pickup truck can be turned off using a switch on the dash.

REVIEW QUESTIONS

1. What is the difference between the control circuit and the power (motor) circuit sections of a typical cranking circuit?
2. What are the parts of a typical starter?
3. Why does a gear-reduction unit reduce the amount of current required by the starter motor?
4. What are the symptoms of a defective starter drive?
5. Why are there two windings in the starter solenoid?

CHAPTER QUIZ

1. Starter motors operate on the principle that __________.
   a. the field coils rotate in the opposite direction from the armature
   b. opposite magnetic poles repel
   c. like magnetic poles repel
   d. the armature rotates from a strong magnetic field toward a weaker magnetic field
2. Series-wound electric motors __________.
   a. produce electrical power
   b. produce maximum power at 0 RPM
   c. produce maximum power at high RPM
   d. use a shunt coil
3. Technician A says that a defective solenoid can cause a starter whine. Technician B says that a defective starter drive can cause a starter whining noise. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. The neutral safety switch is located __________.
   a. between the starter solenoid and the starter motor
   b. inside the ignition switch itself
   c. between the ignition switch and the starter solenoid
   d. in the battery cable between the battery and the starter solenoid

5. The brushes are used to transfer electrical power between __________.
- **a.** field coils and the armature
- **b.** the commutator segments
- **c.** the solenoid and the field coils
- **d.** the armature and the solenoid

6. The faster a starter motor rotates, __________.
- **a.** the more current it draws from the battery
- **b.** the less CEMF is generated
- **c.** the less current it draws from the battery
- **d.** the greater the amount of torque produced

7. Normal cranking speed of the engine is about __________.
- **a.** 2,000 RPM
- **b.** 1,500 RPM
- **c.** 1,000 RPM
- **d.** 200 RPM

8. The push button used on a push button starting system is used to signal the__________
- **a.** PCM
- **b.** starter solenoid
- **c.** field coils
- **d.** armature

9. Permanent magnets are commonly used for what part of the starter?
- **a.** Armature
- **b.** Solenoid
- **c.** Field coils
- **d.** Commutator

10. A stop-start system includes what components?
- **a.** A special starter
- **b.** An AGM or ELA battery
- **c.** A switch to turn the system off in some vehicles
- **d.** All of the above

Chapter 50

STARTING SYSTEM DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the procedure to troubleshoot a starting system problem.
- Discuss how to perform a voltage drop test on the cranking circuit.
- Perform control circuit testing.
- Perform a starter amperage test and determine necessary action.
- Describe the procedure to remove a starter motor.
- Explain starter motor bench testing.
- Describe the procedure to install a starter motor.
- Describe how to troubleshoot starting systems based on their symptoms.

KEY TERMS:

Bench testing 575 • Voltage drop 572

STARTING SYSTEM TROUBLESHOOTING PROCEDURE

OVERVIEW The proper operation of the starting system depends on a good battery, good cables and connections, and a good starter motor. Because a starting problem can be caused by a defective component anywhere in the starting circuit, it is important to check for the proper operation of each part of the circuit to diagnose and repair the problem quickly.

STEPS INVOLVED The following are the steps involved in the diagnosis of a fault in the cranking circuit:

STEP 1 **Verify the customer concern.** Sometimes the customer is not aware of how the cranking system is supposed to work, especially if it is computer controlled.

STEP 2 **Visually inspect the battery and battery connections.** The starter is the highest amperage draw device used in a vehicle and any faults, such as corrosion on battery terminals, can cause cranking system problems.

STEP 3 **Test battery condition.** Perform a battery load or conductance test on the battery to be sure that the battery is capable of supplying the necessary current for the starter.

STEP 4 **Check the control circuit.** An open or high resistance anywhere in the control circuit can cause the starter motor to not engage. Items to check include

- "S" terminal of the starter solenoid
- Neutral safety or clutch switch
- Starter enable relay (if equipped)
- Antitheft system fault (If the engine does not crank or start and the theft indicator light is on or flashing, there is likely a fault in the theft deterrent system. Check service information for the exact procedures to follow before attempting to service the cranking circuit. ● **SEE FIGURE 50–1**.)

STEP 5 **Check voltage drop of the starter circuit.** Any high resistance in either the power side or ground side of the starter circuit causes the starter to rotate slowly or not at all.

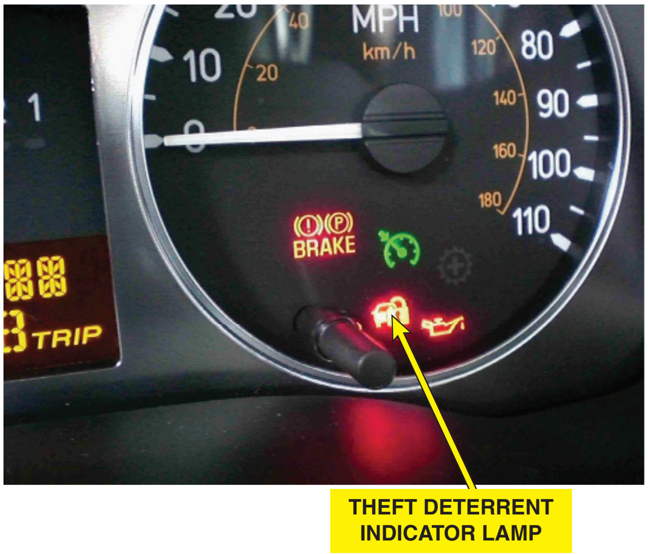


FIGURE 50–1 A theft deterrent indicator lamp of the dash. A flashing lamp usually indicates a fault in the system, and the engine may not start.

TECH TIP

Voltage Drop Is Resistance

Many technicians have asked, "Why measure voltage drop when the resistance can be easily measured using an ohmmeter?" Think of a battery cable with all the strands of the cable broken, except for one strand. If an ohmmeter were used to measure the resistance of the cable, the reading would be very low, probably less than 1 ohm. However, the cable is not capable of conducting the amount of current necessary to crank the engine. In less severe cases, several strands can be broken, thereby affecting the operation of the starter motor. Although the resistance of the battery cable does not indicate an increase, the restriction to current flow causes heat and a drop of voltage available at the starter. Because resistance is not effective until current flows, measuring the voltage drop (differences in voltage between two points) is the most accurate method of determining the true resistance in a circuit.

How much is too much? According to Bosch Corporation, all electrical circuits should have a maximum of 3% loss of the circuit voltage to resistance. Therefore, in a 12 volt circuit, the maximum loss of voltage in cables and connections should be 0.36 volt ($12 \times 0.03 = 0.36$ volt). The remaining 97% of the circuit voltage (11.64 volts) is available to operate the electrical device (load). Just remember:

- Low-voltage drop = Low resistance
- High-voltage drop = High resistance

VOLTAGE DROP TESTING

PURPOSE **Voltage drop** is the drop in voltage that occurs when current is flowing through a resistance. That is, a voltage drop is the difference between voltage at the source and voltage at the electrical device to which it is flowing. The higher the voltage drop is, the greater is the resistance in the circuit. Even though voltage drop testing can be performed on any electrical circuit, the most common areas of testing include the cranking circuit and the charging circuit wiring and connections. Voltage drop testing should be performed on both the power side and ground side of the circuit.

A high-voltage drop (high resistance) in the cranking circuit wiring can cause slow engine cranking with less than normal starter amperage drain as a result of the excessive circuit resistance. If the voltage drop is high enough, such as that caused by dirty battery terminals, the starter may not operate. A typical symptom of high resistance in the cranking circuit is a "clicking" of the starter solenoid.

TEST PROCEDURE Voltage drop testing of the wire involves connecting a voltmeter set to read DC volts to the suspected high-resistance cable ends and cranking the engine. ● **SEE FIGURES 50–2 THROUGH 50–4**.

NOTE: Before a difference in voltage (voltage drop) can be measured between the ends of a battery cable, current must be flowing through the cable. Resistance is not effective unless current is flowing. If the engine is not being cranked, current is not flowing through the battery cables and the voltage drop cannot be measured.

STEP 1 Disable the ignition or fuel injection as follows:

- Disconnect the primary (low-voltage) electrical connection(s) from the ignition module or ignition coils.
- Remove the fuel-injection fuse or relay, or the electrical connection leading to all of the fuel injectors.

CAUTION: Never disconnect the high-voltage ignition wires unless they are connected to ground. The high voltage that could occur when cranking can cause the ignition coil to fail (arc internally).

STEP 2 Connect one lead of the voltmeter to the starter motor battery terminal and the other end to the positive battery terminal.

STEP 3 Crank the engine and observe the reading while cranking. (Disregard the first higher reading.) The reading should be less than 0.20 volt (200 millivolts).

STEP 4 If accessible, test the voltage drop across the "B" and "M" terminals of the starter solenoid with the engine cranking. The voltage drop should be less than 0.20 volt (200 millivolts).

STEP 5 Repeat the voltage drop on the ground side of the cranking circuit by connecting one voltmeter lead to the negative battery terminal and the other at the starter housing. Crank the engine and observe the voltmeter display. The voltage drop should be less than 0.2 volt (200 millivolts).

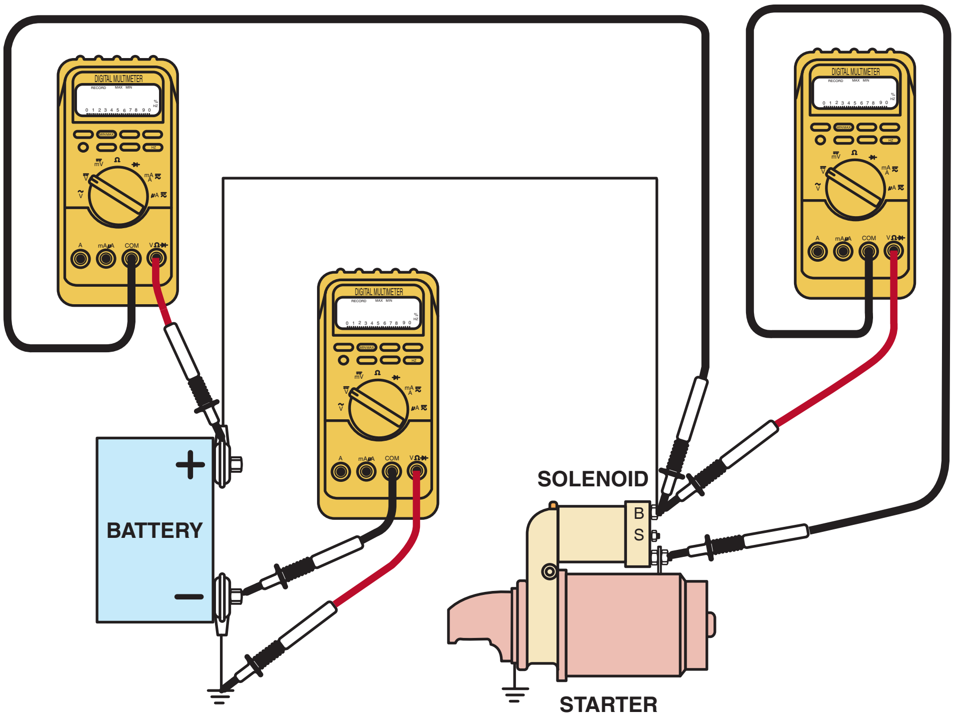

SOLENOID
B
S
BATTERY
+
−
STARTER

FIGURE 50–2 Voltmeter hookups for voltage drop testing of a solenoid-type cranking circuit.

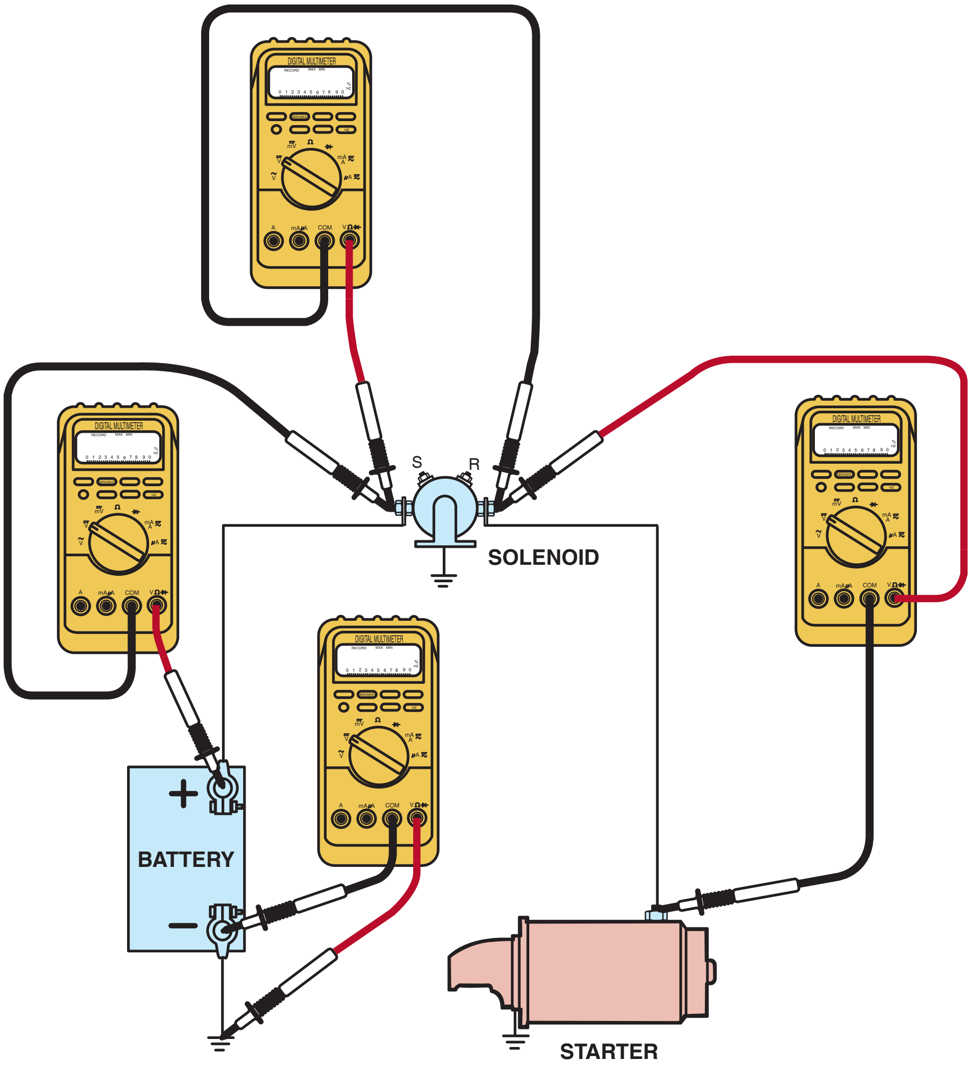

S
R
SOLENOID
BATTERY
+
−
STARTER

FIGURE 50–3 Voltmeter hookups for voltage drop testing of a Ford cranking circuit.

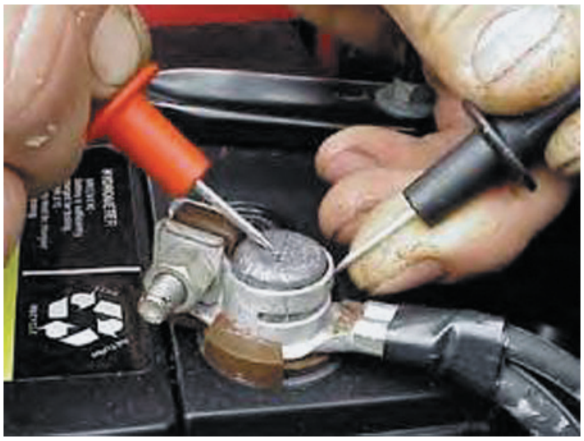


FIGURE 50–4 To test the voltage drop of the battery cable connection, place one voltmeter lead on the battery terminal and the other voltmeter lead on the cable end and crank the engine. The voltmeter reads the difference in voltage between the two leads, which should not exceed 0.20 volt (200 millivolts).

TECH TIP

A Warm Cable Equals High Resistance

If a cable or connection is warm to the touch, there is electrical resistance in the cable or connection. The resistance changes electrical energy into heat energy. Therefore, if a voltmeter is not available, touch the battery cables and connections while cranking the engine. If any cable or connection is hot to the touch, it should be cleaned or replaced.

CONTROL CIRCUIT TESTING

PARTS INVOLVED The control circuit for the starting circuit includes the battery, ignition switch, neutral or clutch safety switch, theft deterrent system, and starter solenoid. When the ignition switch is rotated to the start position, current flows through the ignition switch and neutral safety switch to activate the solenoid. High current then flows directly from the battery through the solenoid and to the starter motor. Therefore, an open or break anywhere in the control circuit prevents the operation of the starter motor.

If a starter is inoperative, first check for voltage at the "S" (start) terminal of the starter solenoid. Check for faults with the following:

- Neutral safety or clutch switch
- Blown crank fuse
- Open at the ignition switch in the crank position
- Starter relay or module, if equipped

Some models with antitheft controls use a relay to open this control circuit to prevent starter operation.

STARTER AMPERAGE TEST

REASON FOR A STARTER AMPERAGE TEST A starter should be tested to see if the reason for slow or no cranking is due to a fault with the starter motor or another problem. A voltage drop test is used to find out if the battery cables and connections are okay. A starter amperage draw test determines if the starter motor is the cause of a no or slow cranking concern.

TEST PREPARATION Before performing a starter amperage test, be certain that the battery is sufficiently charged (75% or more) and capable of supplying adequate starting current. Connect a starter amperage tester following the tester's instructions. ● **SEE FIGURE 50–5**.

A starter amperage test should be performed when the starter fails to operate normally (is slow in cranking) or as part of a routine electrical system inspection.

SPECIFICATIONS Some service manuals specify normal starter amperage for starter motors being tested on the vehicle; however, most service manuals only give the specifications for bench testing a starter without a load applied. These specifications are helpful in making certain that a repaired starter meets exact specifications, but they do not apply to starter testing on the vehicle. If exact specifications are not available, the following can be used as general *maximum* amperage draw specifications for testing a starter on the vehicle. (Ignore the initial current surge when the starter is first engaged and just record the cranking amperage.)

- **4-cylinder engines** = 150 to 185 amperes (normally less than 100 amperes) at room temperature
- **6-cylinder engines** = 160 to 200 amperes (normally less than 125 amperes) at room temperature
- **8-cylinder engines** = 185 to 250 amperes (normally less than 150 amperes) at room temperature
- High *mechanical* resistance = High starter amperage draw
- High *electrical* resistance = Low starter amperage draw

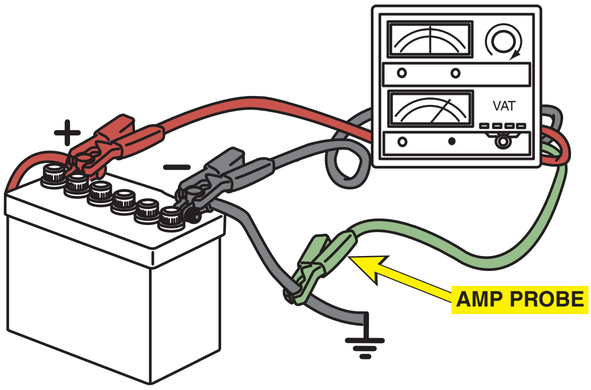


FIGURE 50–5 A starter amperage tester uses an amp probe around the positive or negative battery cables.

TECH TIP

Watch the Dome Light

When diagnosing any starter-related problem, open the door of the vehicle and observe the brightness of the dome or interior light(s).

The brightness of any electrical lamp is proportional to the voltage of the battery.

Normal operation of the starter results in a slight dimming of the dome light.

If the light remains bright, the problem is usually an open in the control circuit.

If the light goes out or almost goes out, there could be a problem with the following:

- A shorted or grounded armature of field coils inside the starter
- Loose or corroded battery connections or cables
- Weak or discharged battery

Excessive current draw may indicate one or more of the following:

1. Binding of starter armature as a result of worn bushings
2. Oil too thick (viscosity too high) for weather conditions
3. Shorted or grounded starter windings or cables
4. Tight or seized engine
5. Shorted starter motor (usually caused by fault with the field coils or armature)

CASE STUDY

The Case of the No-Crank Camaro

The owner of a Camaro SS equipped with a 6.2 liter V-8 and a six-speed manual transmission had the car towed to a shop for a no crank, no start condition. The technician used a scan tool and was able to retrieve a stored diagnostic trouble code (DTC) P0807. This code indicated a fault with the clutch pedal position (CPP) sensor. The clutch pedal position sensor was removed and it was found to be internally shorted. A new sensor was installed and the technician performed a relearn procedure as specified in service information. The car was then able to crank and start and verified that no codes were present.

Summary:

Complaint—The customer stated that the engine would not crank or start.
Cause—A shorted clutch pedal position (CPP) sensor.
Correction—The clutch pedal position sensor was replaced and a relearn procedure was performed.

Lower amperage draw and slow or no cranking may indicate one or more of the following:

- Dirty or corroded battery connections
- High internal resistance in the battery cable(s)
- High internal starter motor resistance
- Poor ground connection between the starter motor and the engine block

STARTER REMOVAL

PROCEDURE After testing has confirmed that a starter motor may need to be replaced, most vehicle manufacturers recommend the following general steps and procedures:

STEP 1 Disconnect the negative battery cable.

STEP 2 Hoist the vehicle safely.

NOTE: This step may not be necessary. Check service information for the specified procedure for the vehicle being serviced. Some starters are located under the intake manifold. ● **SEE FIGURE 50–6.**

STEP 3 Remove the starter retaining bolts and lower the starter to gain access to the wire(s) connection(s) on the starter.

STEP 4 Disconnect and label the wire(s) from the starter and remove the starter.

STEP 5 Inspect the flywheel (flexplate) for ring gear damage. Also check that the mounting holes are clean and the mounting flange is clean and smooth. Service as needed.

BENCH TESTING

Every starter should be tested before installation in a vehicle. **Bench testing** is the usual method and involves clamping the starter in a vise to prevent rotation during operation and connecting heavy-gauge jumper wires (minimum 4 gauge) to both a

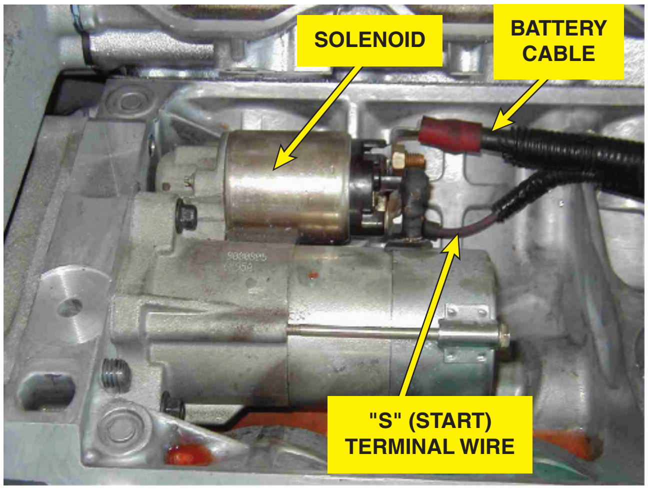


FIGURE 50–6 The starter is located under the intake manifold on this Cadillac Northstar engine.

good battery and the starter. The starter motor should rotate as fast as specifications indicate and not draw more than the free-spinning amperage permitted. A typical amperage specification for a starter being tested on a bench (not installed in a vehicle) usually ranges from 60 to 100 amperes.

STARTER INSTALLATION

After verifying that the starter assembly is functioning correctly, verify that the negative battery cable has been disconnected. Then safely hoist the vehicle, if necessary. The following are the usual steps to install a starter. Be sure to check service information for the exact procedures to follow for the vehicle being serviced.

STEP 1 Check service information for the exact wiring connections to the starter and/or the solenoid.

STEP 2 Verify that all electrical connections on the starter motor and/or the solenoid are correct for the vehicle and that they are in good condition.

NOTE: Be sure that the locking nuts for the studs are tight. Often, the retaining nut that holds the wire to the stud is properly tightened, but if the stud itself is loose, cranking problems can occur.

STEP 3 Attach the power and control wires.

STEP 4 Install the starter, and torque all the fasteners to factory specifications and tighten evenly.

STEP 5 Perform a starter amperage draw test and check for proper engine cranking.

CAUTION: Be sure to install all factory heat shields to help ensure problem-free starter operation under all weather and driving conditions.

STARTING SYSTEM SYMPTOM GUIDE

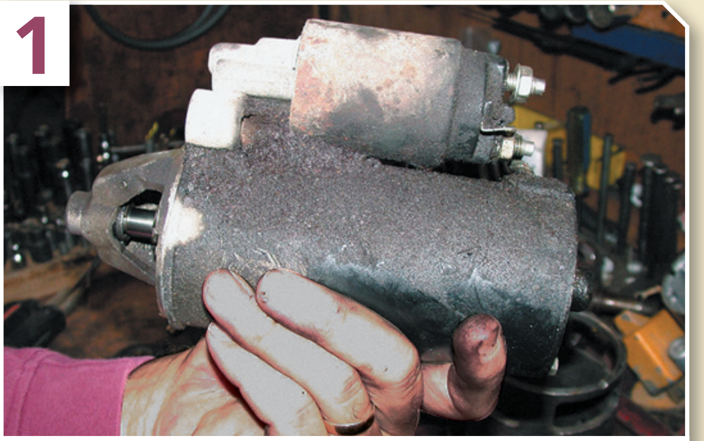
The following list assists technicians in troubleshooting starting systems:

Problem	**Possible Causes**
1. Starter motor whines	1. Possible defective starter drive; worn starter drive engagement yoke; defective flywheel; improper starter drive to flywheel clearance
2. Starter rotates slowly	2. Possible high resistance in the battery cables or connections; possible defective or discharged battery; possible worn starter bushings, causing the starter armature to drag on the field coils; possible worn starter brushes or weak brush springs; possible defective (open or shorted) field coil
3. Starter fails to rotate	3. Possible defective ignition switch or neutral safety switch, or open in the starter motor control circuit; theft deterrent system fault; possible defective starter solenoid
4. Starter produces grinding noise	4. Possible defective starter drive unit; possible defective flywheel; possible incorrect distance between the starter pinion and the flywheel; possible cracked or broken starter drive-end housing; worn or damaged flywheel or ring gear teeth
5. Starter clicks when engaged	5. Low battery voltage; loose or corroded battery connections

STARTER OVERHAUL

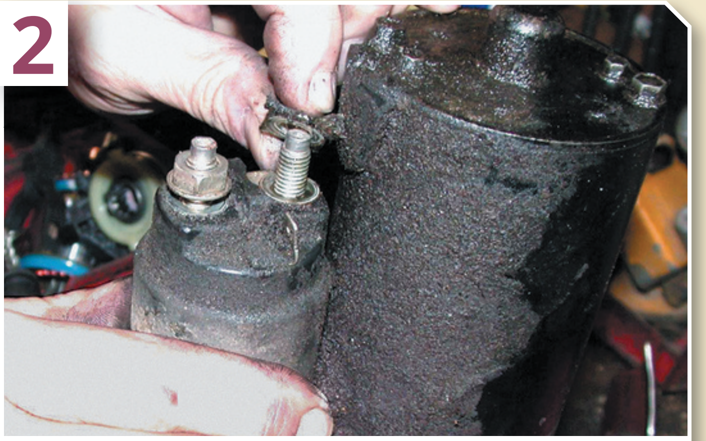
STEP BY STEP

1



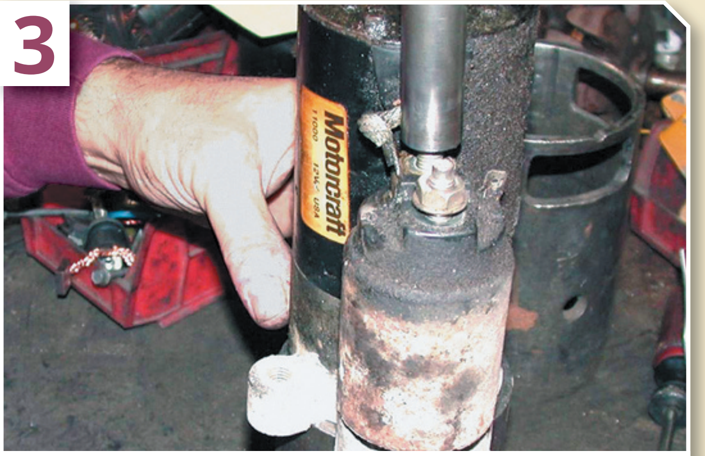
This dirty and greasy starter can be restored to useful service.

2



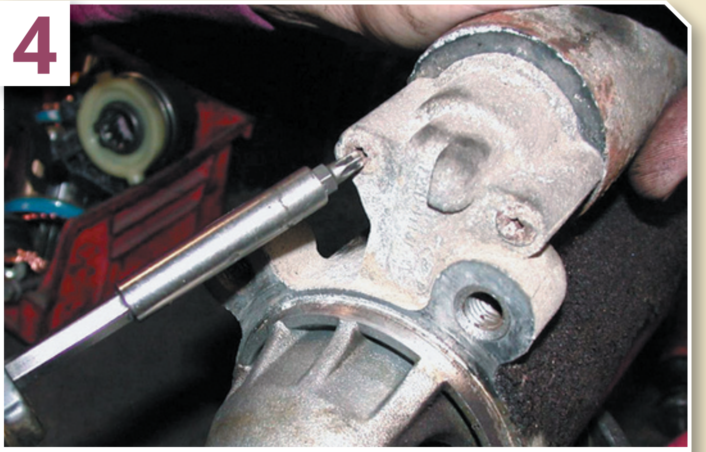
The connecting wire between the solenoid and the starter is removed.

3



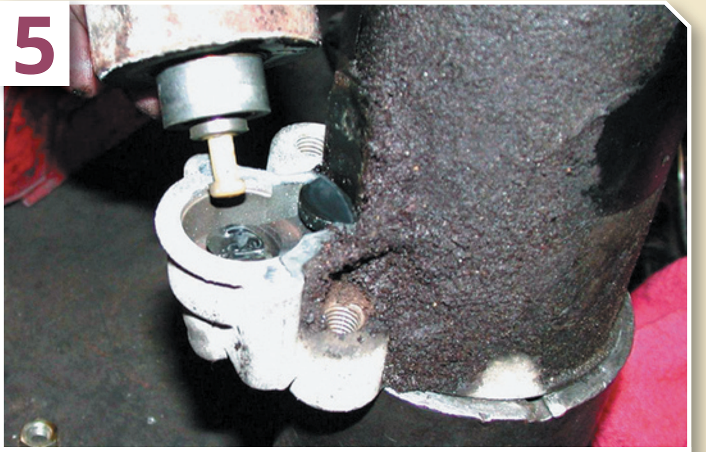
An old starter field housing is being used to support the drive-end housing of the starter as it is being disassembled. This rebuilder is using an electric impact wrench to remove the solenoid fasteners.

4



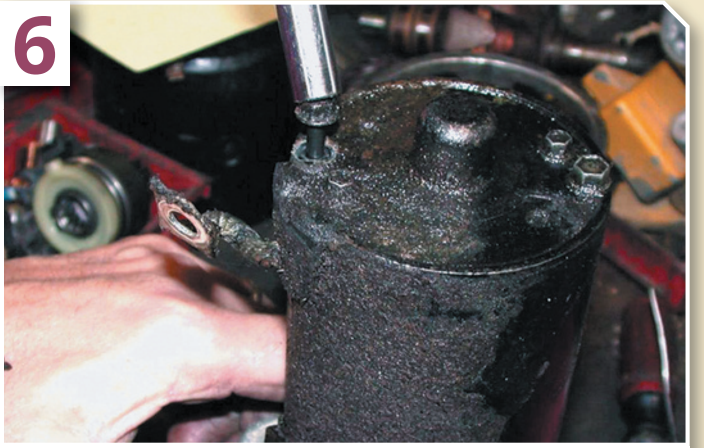
A Torx driver is used to remove the solenoid attaching screws.

5



After the retaining screws have been removed, the solenoid can be separated from the starter motor. This rebuilder always replaces the solenoid.

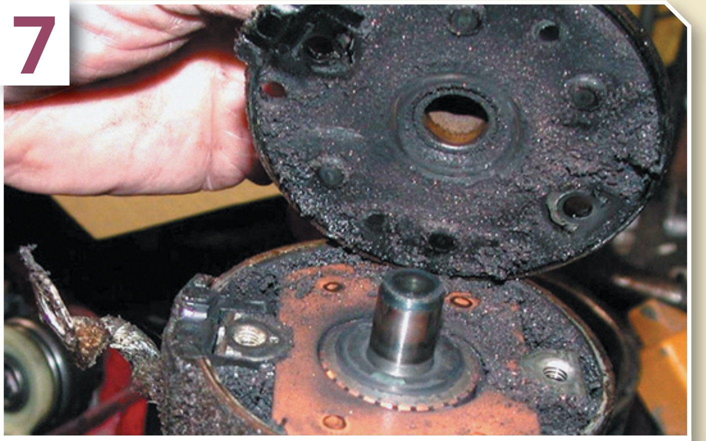
6



The through bolts are being removed.

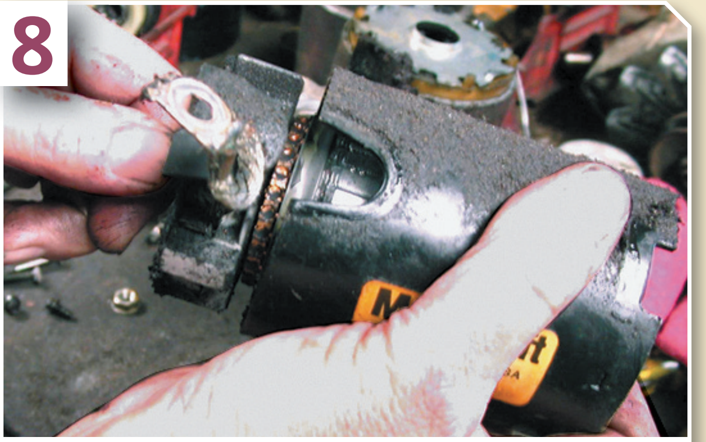
STARTER OVERHAUL

7



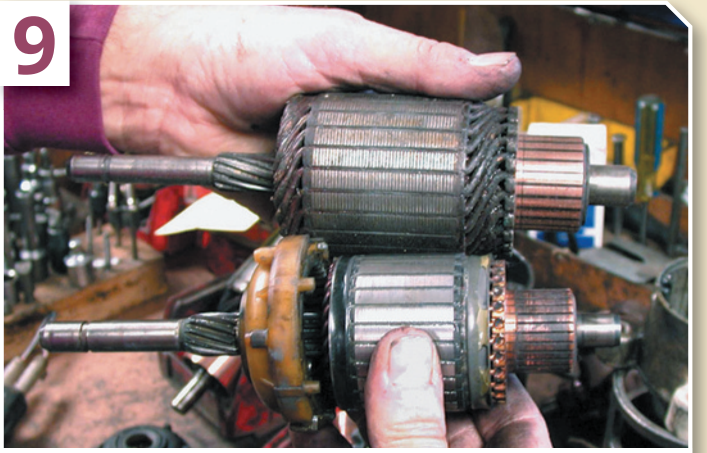
The brush end plate is removed.

8



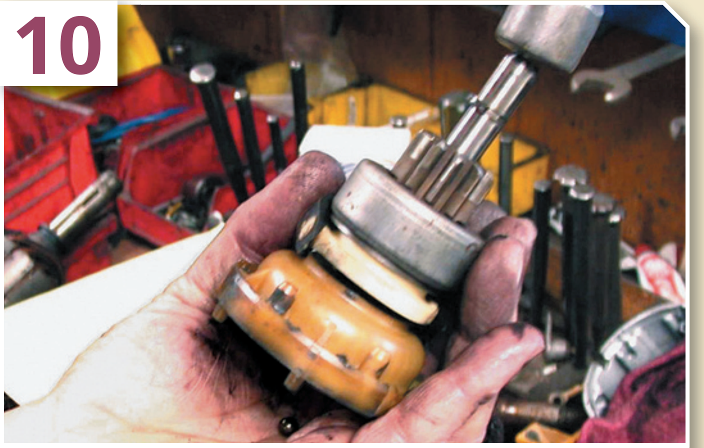
The armature assembly is removed from the field frame.

9



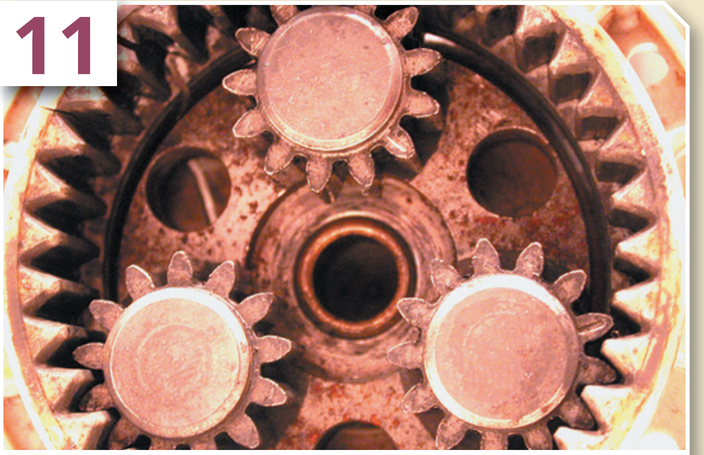
Notice that the length of a direct-drive starter armature (top) is the same length as the overall length of a gear-reduction armature, except smaller in diameter.

10



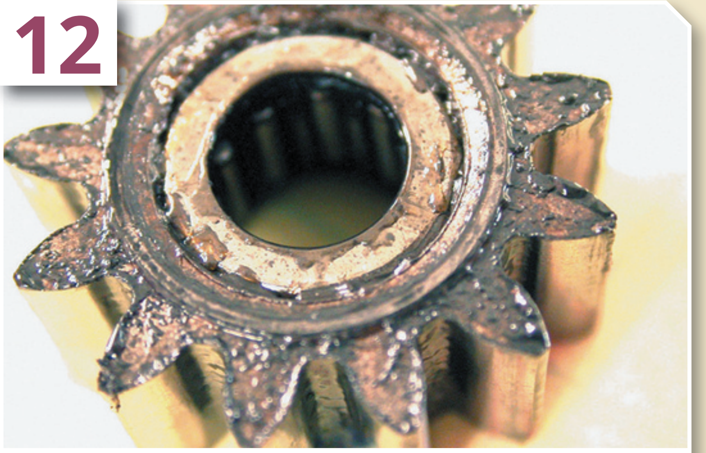
A light tap with a hammer dislodges the armature thrust ball (in the palm of the hand) from the center of the gear-reduction assembly.

11



This figure shows the planetary ring gear and pinion gears.

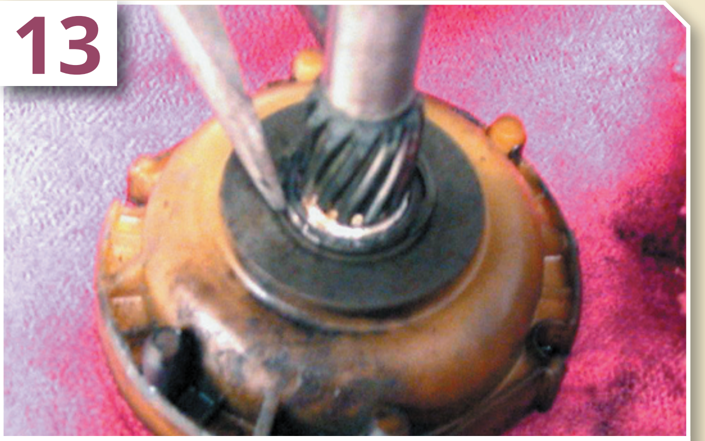
12



A close-up of one of the planetary gears, which shows the small needle bearings on the inside.

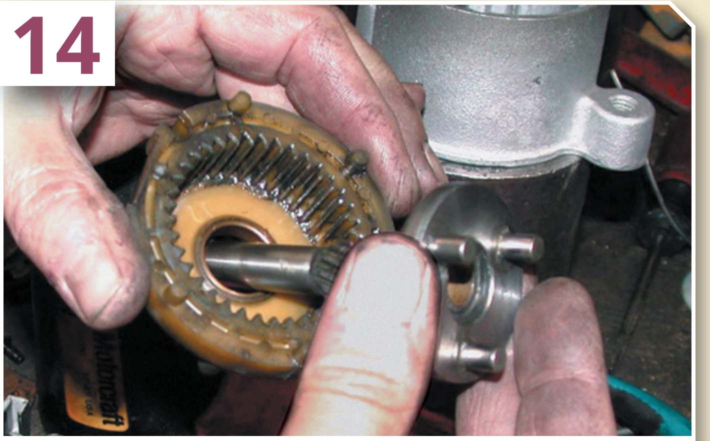
STEP BY STEP

13



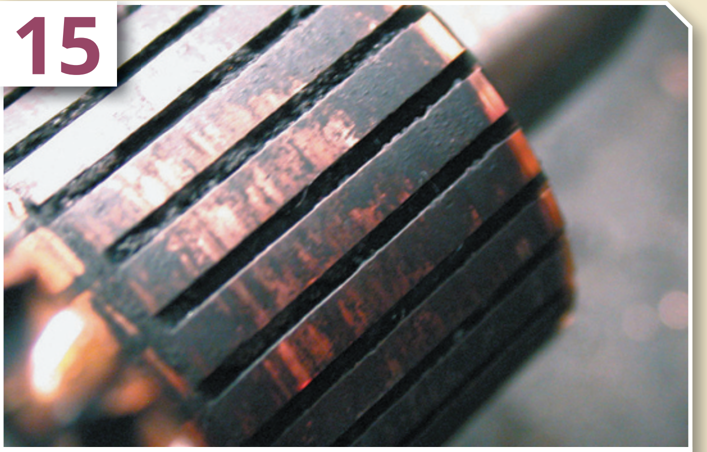
The clip is removed from the shaft so the planetary gear assembly can be separated and inspected.

14



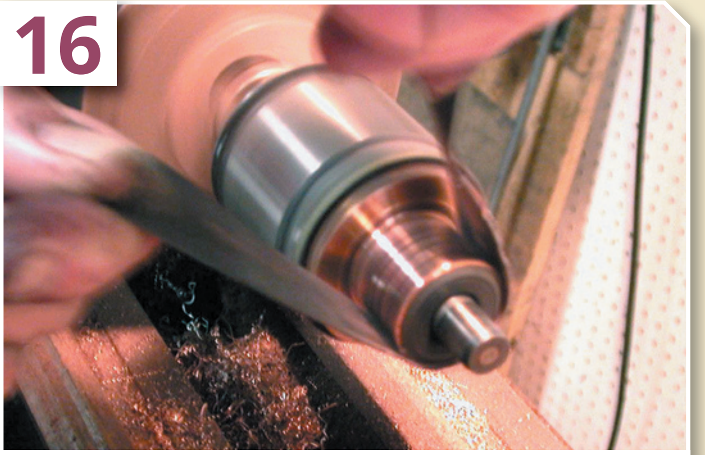
The shaft assembly is being separated from the stationary gear assembly.

15



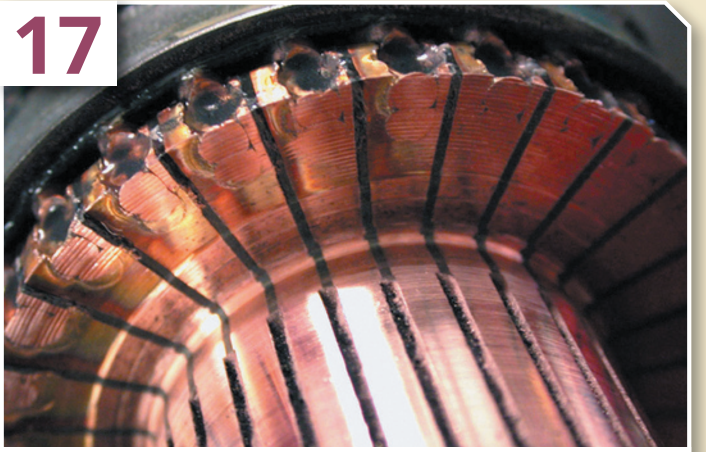
The commutator on the armature is discolored and the brushes may not have been making good contact with the segments.

16



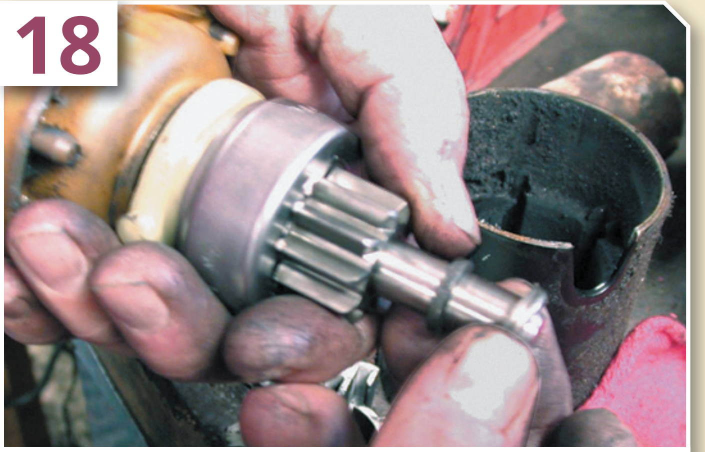
All of the starter components are placed in a tumbler with water-based cleaner. The armature is installed in a lathe and the commutator is resurfaced using emery cloth.

17



The finished commutator looks like new.

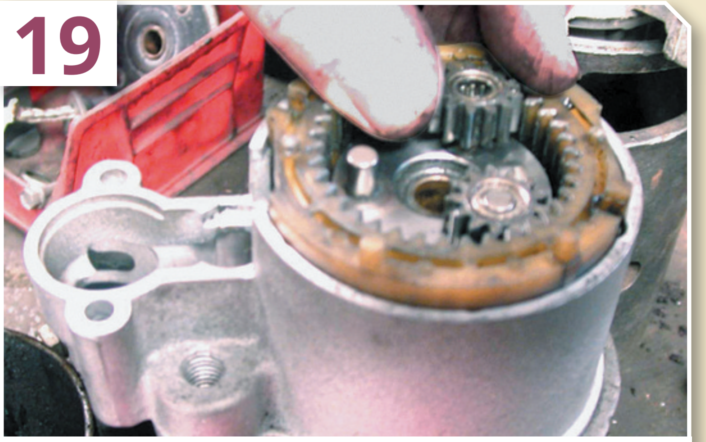
18



Starter reassembly begins by installing a new starter drive on the shaft assembly. The stop ring and stop ring retainer are then installed.

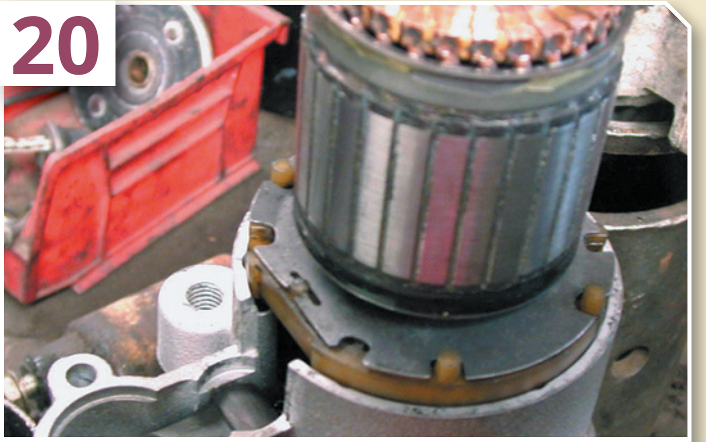
STARTER OVERHAUL

19



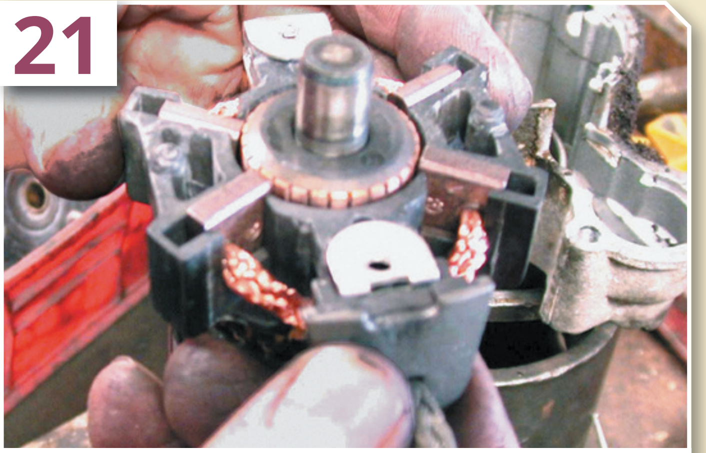
The gear-reduction assembly is positioned along with the shift fork (drive lever) into the cleaned drive-end housing.

20



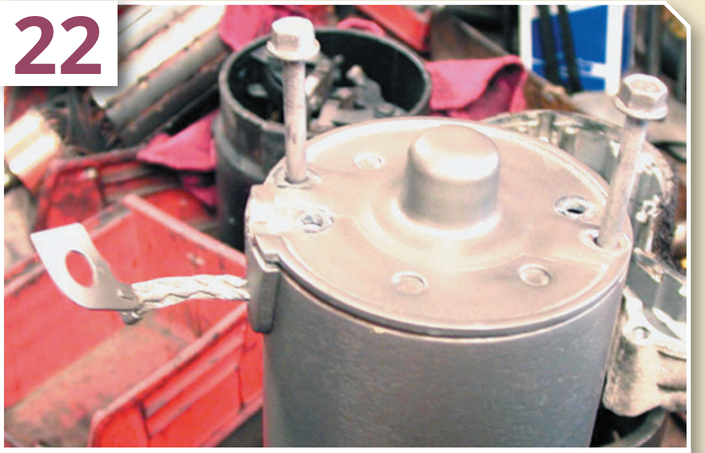
After gear retainer has been installed over the gear-reduction assembly, the armature is installed.

21



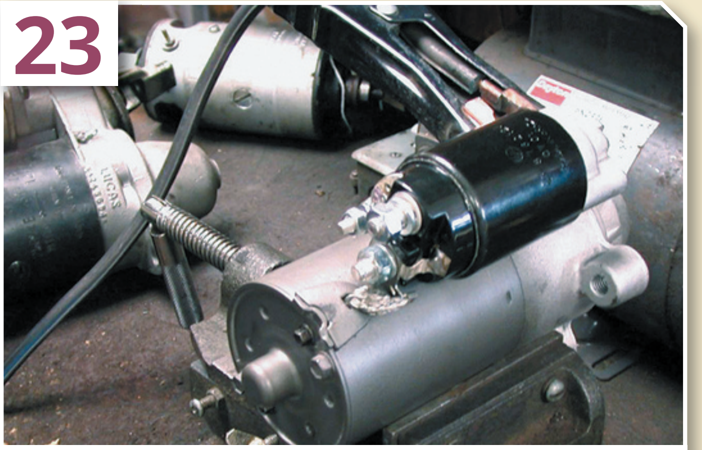
New brushes are being installed into the brush holder assembly.

22



The brush end plate and the through bolts are installed, being sure that the ground connection for the brushes is clean and tight.

23



This starter was restored to useful service by replacing the solenoid, the brushes, and the starter drive assembly, plus a thorough cleaning and attention to detail in the reassembly.

REVIEW QUESTIONS

1. What are the steps involved in the diagnosis of a fault in the cranking circuit?
2. What are the steps taken to perform a voltage drop test of the cranking circuit?
3. What are the steps necessary to replace a starter?
4. What are typical starter amperage draw for four-, six-, and eight-cylinder engines?
5. What could be the cause of excessive starter current draw?

CHAPTER QUIZ

1. Which one of these would NOT be a diagnostic step when diagnosing a "no crank" customer concern?
   - **a.** Check the condition of the engine oil
   - **b.** Check operation of the theft deterrent systems
   - **c.** Check the battery with a load test
   - **d.** Test for proper operation of the starter enable relay
2. Two technicians are discussing what could be the cause of slow cranking and excessive current draw. Technician A says that an engine mechanical fault could be the cause. Technician B says that the starter motor could be binding or defective. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. A V-6 is being checked for starter amperage draw. The initial surge current was about 210 amperes and about 160 amperes during cranking. Technician A says the starter is defective and should be replaced because the current flow exceeds 200 amperes. Technician B says this is normal current draw for a starter motor on a V-6 engine. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. What is the first step for removing a starter?
   - **a.** Hoist the vehicle
   - **b.** Disconnect the battery positive cable
   - **c.** Disconnect the battery negative cable
   - **d.** Remove the battery cable from the starter
5. Technician A says that a discharged battery (lower than normal battery voltage) can cause solenoid clicking. Technician B says that a discharged battery or dirty (corroded) battery cables can cause solenoid clicking. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Slow cranking by the starter can be caused by all of these EXCEPT ____________.
   - **a.** a low or discharged battery
   - **b.** corroded or dirty battery cables
   - **c.** engine mechanical problems
   - **d.** an open neutral safety switch
7. Bench testing of a starter should be done ____________.
   - **a.** after reassembling an old starter
   - **b.** before installing a new starter
   - **c.** after removing the old starter
   - **d.** Both a and b
8. What is the symptom of an engine mechanical fault that can cause a slow-crank or a no-crank condition?
   - **a.** Excessive current draw
   - **b.** Low current draw and rapidly spinning starter motor
   - **c.** Starter solenoid clicking
   - **d.** Any of the above
9. A technician connects one lead of a digital voltmeter to the positive (+) terminal of the battery and the other meter lead to the battery terminal (B) of the starter solenoid and then cranks the engine. During cranking, the voltmeter displays a reading of 878 millivolts. Technician A says that this reading indicates that the positive battery cable resistance is too high. Technician B says that this reading indicates that the starter is defective. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. After installing the starter, the technician should perform which of the following?
    - **a.** Attach the negative battery cable
    - **b.** Check the starter for proper operation
    - **c.** Perform a starter voltage drop test before starting the engine
    - **d.** Both a and b

Chapter

51

CHARGING SYSTEM PARTS AND OPERATION

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain why an alternator generates an AC and changes it to DC.
- Describe an alternator's construction, including overrunning pulleys.
- Describe the components and operation of an alternator.
- Discuss how an alternator works.
- List the factors determining an alternator's output voltage and current.
- Explain how the voltage of an alternator is regulated.
- Explain how the heat produced by an alternator is regulated.
- Discuss computer-controlled alternators.

KEY TERMS:

Alternator 582 • Claw poles 584 • Delta winding 587 • Diodes 586 • Drive-end (DE) housing 582 • Duty cycle 590 • EPM 590 • OAD 584 • OAP 583 • Rotor 584 • Slip-ring-end (SRE) housing 582 • Stator 585 • Thermistor 589

PRINCIPLE OF ALTERNATOR OPERATION

PURPOSE AND FUNCTION It is the purpose and function of the charging system to keep the battery fully charged. The Society of Automotive Engineers (SAE) term for the unit that generates electricity is *generator.* The term **alternator** is most commonly used in the trade and is used here as well.

PRINCIPLES All electrical alternators use the principle of electromagnetic induction to generate electrical power from mechanical power. Electromagnetic induction involves the generation of electric current in a conductor when the conductor is moved through a magnetic field. The amount of current generated can be increased by the following factors:

1. Increasing the *speed* of the conductors through the magnetic field
2. Increasing the *number* of conductors passing through the magnetic field
3. Increasing the *strength* of the magnetic field

CHANGING AC TO DC An alternator generates an alternating current (AC) because the current changes polarity during the alternator's rotation. However, a battery cannot "store" AC; therefore, this AC is changed to direct current (DC) by diodes inside the alternator. Diodes are one-way electrical check valves that permit current to flow in only one direction.

ALTERNATOR CONSTRUCTION

HOUSING An alternator is constructed using a two-piece cast aluminum housing. Aluminum is used because of its lightweight, nonmagnetic properties, and heat transfer properties needed to help keep the alternator cool. A front ball bearing is pressed into the front housing, called the **drive-end (DE) housing**, to provide the support and friction reduction necessary for the belt-driven rotor assembly. The rear housing, or the **slip-ring-end (SRE) housing**, usually contains either a roller bearing or ball bearing support for the rotor and mounting for the brushes, diodes, and internal voltage regulator (if so equipped). ● **SEE FIGURES 51–1 AND 51–2**.

FIGURE 51–1 A typical alternator on a Chevrolet V-8 engine that is driven by the accessory drive belt at the front of the engine.

ALTERNATOR OVERRUNNING PULLEYS Many alternators are equipped with an **overrunning alternator pulley (OAP)**, also called an *overrunning clutch pulley* or an *alternator clutch pulley*. The purpose of this pulley is to help eliminate noise and vibration in the accessory drive belt system, especially when the engine is at idle speed. At idle, engine impulses are transmitted to the alternator through the accessory drive belt. The mass of the rotor of the alternator tends to want to keep spinning, but the engine crankshaft speeds up and slows down slightly due to the power impulses. Using a one-way clutch in the alternator pulley allows the belt to apply power to the alternator in only one direction, thereby reducing fluctuations in the belt. ● **SEE FIGURES 51–3 AND 51–4**.

A conventional drive pulley attaches to the alternator (rotor) shaft with a nut and lock washer. In the overrunning clutch pulley, the inner race of the clutch acts as the nut as it screws on to the shaft. Special tools are required to remove and install this type of pulley.

TECH TIP

Alternator Horsepower and Engine Operation

Many technicians are asked how much power certain accessories require. A 100 ampere alternator requires about 2 horsepower from the engine. One horsepower is equal to 746 watts. Watts are calculated by multiplying amperes times volts.

$$\textbf{Power in watts} = \textbf{100 A} \times \textbf{14.5 V} = \textbf{1,450 W}$$
$$\textbf{1 hp} = \textbf{746 W}$$

Therefore, 1,450 watts is about 2 horsepower.

Allowing about 20% for mechanical and electrical losses adds another 0.4 horsepower. Therefore, when someone asks how much power it takes to produce 100 amperes from an alternator, the answer is 2.4 horsepower.

Many alternators delay the electrical load to prevent the engine from stumbling when a heavy electrical load is applied. The voltage regulator or vehicle computer is capable of gradually increasing the output of the alternator over a period of several minutes. Even though 2 horsepower does not sound like much, a sudden demand for 2 horsepower from an idling engine can cause the engine to run rough or stall. The difference in part numbers of various alternators is often an indication of the time interval over which the load is applied. Therefore, using the wrong replacement alternator could cause the engine to stall!

Another type of alternator pulley uses a dampener spring inside, plus a one-way clutch. These units have the following names. ● **SEE FIGURES 51–5**.

- Isolating Decoupler Pulley (IDP)
- Active Alternator Pulley (AAP)

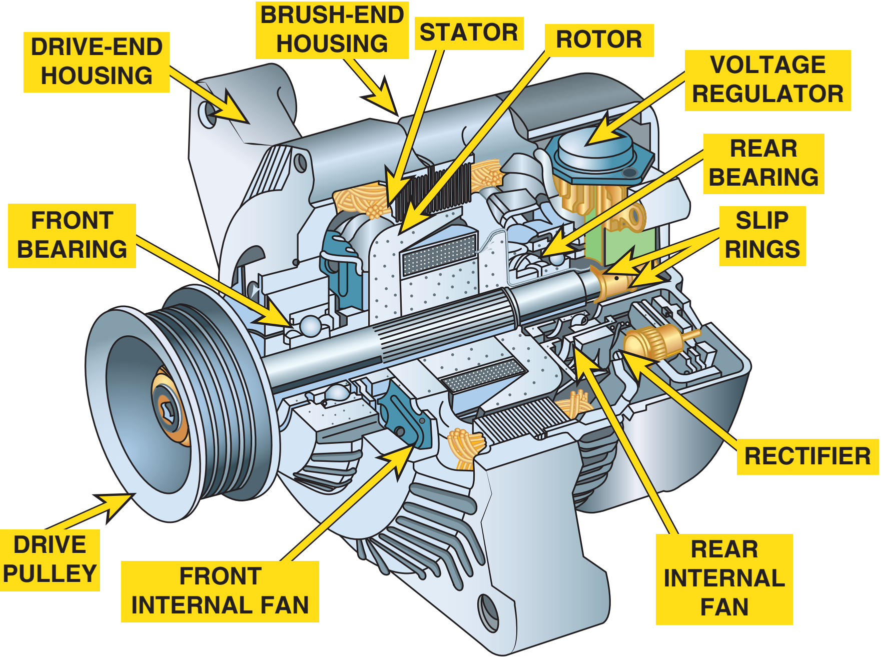


FIGURE 51–2 The end frame toward the drive belt is called the drive-end housing and the rear section is called the slip-ring-end housing.

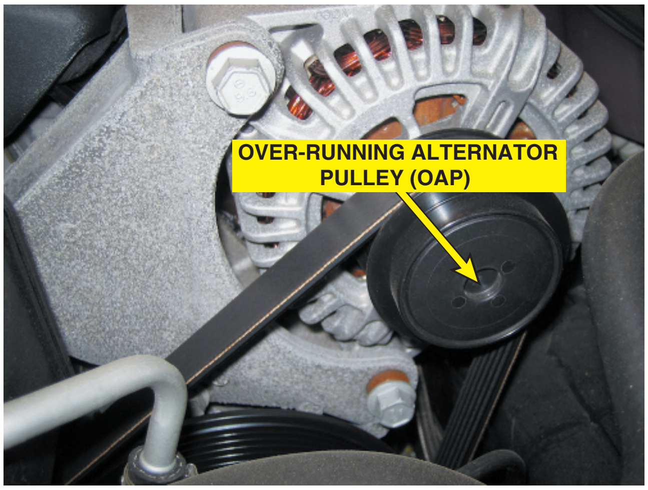

OVER-RUNNING ALTERNATOR PULLEY (OAP)

FIGURE 51–3 An OAP on a Chevrolet Corvette alternator.

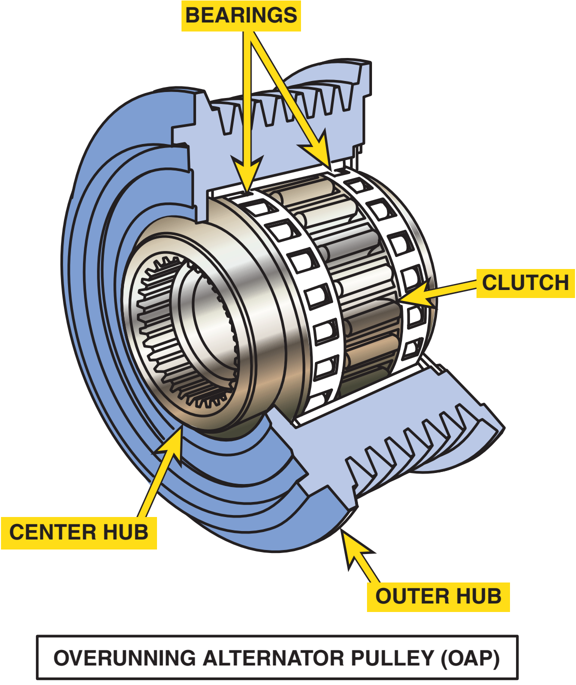

BEARINGS
CLUTCH
CENTER HUB
OUTER HUB
OVERUNNING ALTERNATOR PULLEY (OAP)

FIGURE 51–4 An exploded view of an overrunning alternator pulley showing all of the internal parts.

- Alternator Decoupler Pulley (ADP)
- Alternator Overrunning Decoupler Pulley
- **Overrunning Alternator Dampener (OAD)** (most common term)

FREQUENTLY ASKED QUESTION

Can I Install an OAP or an OAD to My Alternator?

Usually, no. An alternator needs to be equipped with the proper shaft to allow the installation of an OAP or OAD. This also means that a conventional pulley often cannot be used to replace a defective overrunning alternator pulley or dampener. Check service information for the exact procedure to follow.

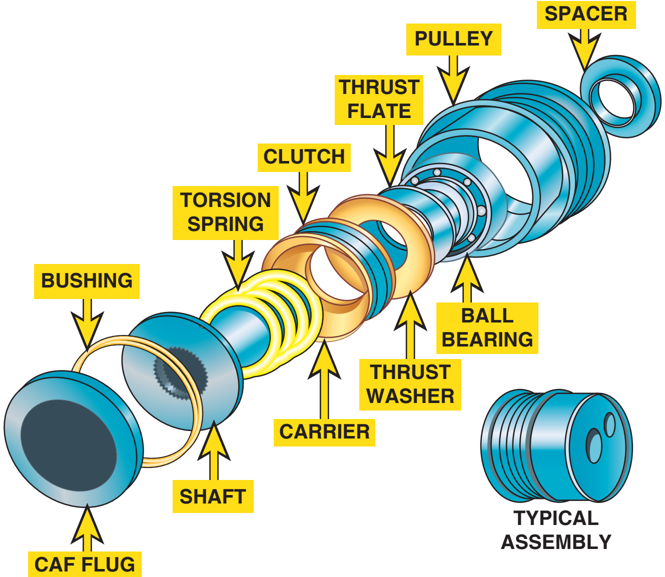

SPACER
PULLEY
THRUST FLATE
CLUTCH
TORSION SPRING
BUSHING
BALL BEARING
THRUST WASHER
CARRIER
SHAFT
CAF FLUG
TYPICAL ASSEMBLY

FIGURE 51–5 An overrunning alternator damper (OAD) is engineered to dampen noises and vibrations in the front accessory drive belt system.

ALTERNATOR COMPONENTS AND OPERATION

ROTOR CONSTRUCTION The **rotor** is the rotating part of the alternator and is driven by the accessory drive belt. The rotor creates the magnetic field of the alternator and produces a current by electromagnetic induction in the stationary stator windings. The rotor is constructed of many turns of copper wire coated with a varnish insulation wound over an iron core. The iron core is attached to the rotor shaft.

At both ends of the rotor windings are heavy-gauge metal plates bent over the windings with triangular fingers called **claw poles**. These pole fingers do not touch, but alternate or interlace, as shown in ● **FIGURE 51–6**.

HOW ROTORS CREATE MAGNETIC FIELDS The two ends of the rotor winding are connected to the rotor's slip rings. Current

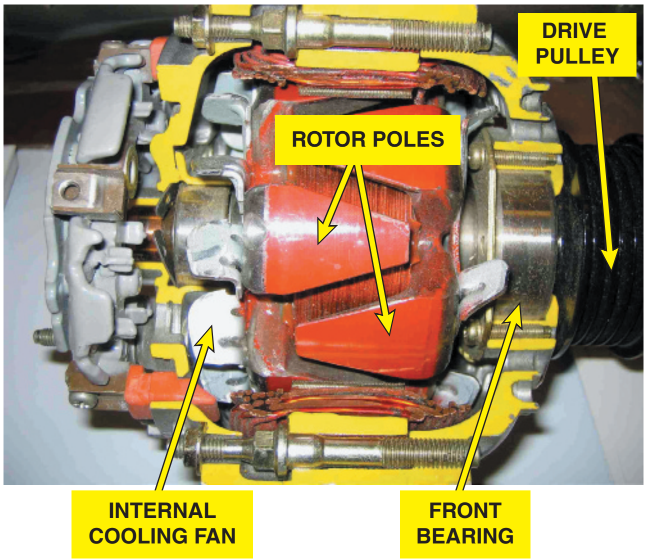

DRIVE PULLEY
ROTOR POLES
INTERNAL COOLING FAN
FRONT BEARING

FIGURE 51–6 A cutaway of an alternator, showing the rotor and cooling fan that is used to force air through the unit to remove the heat created when it is charging the battery and supplying electrical power for the vehicle.

for the rotor flows from the battery into one brush that rides on one of the slip rings, then flows through the rotor winding, then exits the rotor through the other slip ring and brush. One alternator brush is considered to be the "positive" brush and one is considered to be the "negative" or "ground" brush. The voltage regulator controls the field current through the rotor that controls the output of the alternator.

If current flows through the rotor windings, the metal pole pieces at each end of the rotor become electromagnets. Because the pole pieces are attached to each end of the rotor, one pole piece is a north pole magnet. The other pole piece is on the opposite end of the rotor, creating a south pole. Therefore, the rotor fingers are alternating north and south magnetic poles. These individual magnetic fields produce a current by electromagnetic induction in the stationary stator windings. ● **SEE FIGURE 51–7**.

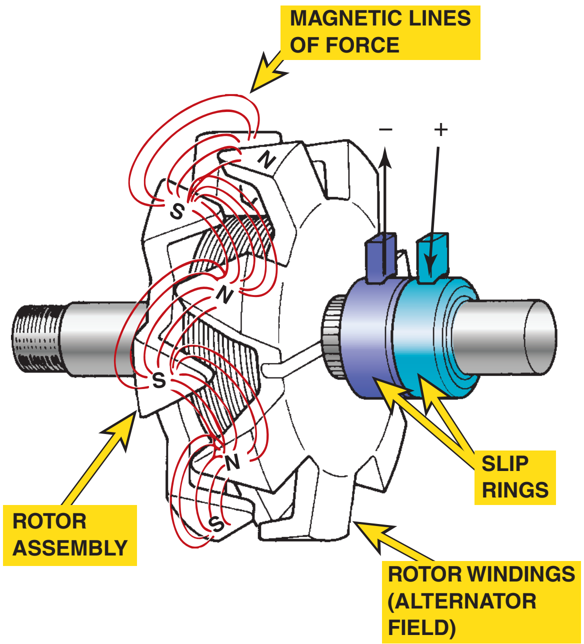


FIGURE 51–7 Rotor assembly of a typical alternator. Current through the slip rings causes the "fingers" of the rotor to become alternating north and south magnetic poles. As the rotor revolves, these magnetic lines of force induce a current in the stator windings.

ROTOR CURRENT The current necessary for the field (rotor) windings is conducted through slip rings with carbon brushes. The maximum rated alternator output in amperes depends on the number and gauge of the rotor windings.

The current for the field is controlled by the voltage regulator and is conducted to the slip rings through carbon brushes. The brushes conduct only the field current, which is usually between 2 and 5 amperes.

STATOR CONSTRUCTION The **stator** consists of the stationary coil windings inside the alternator. The stator is supported between the two halves of the alternator housing, with three copper wire windings that are wound on a laminated metal core.

As the rotor revolves, its moving magnetic field induces a current in the stator windings. ● **SEE FIGURE 51–8**.

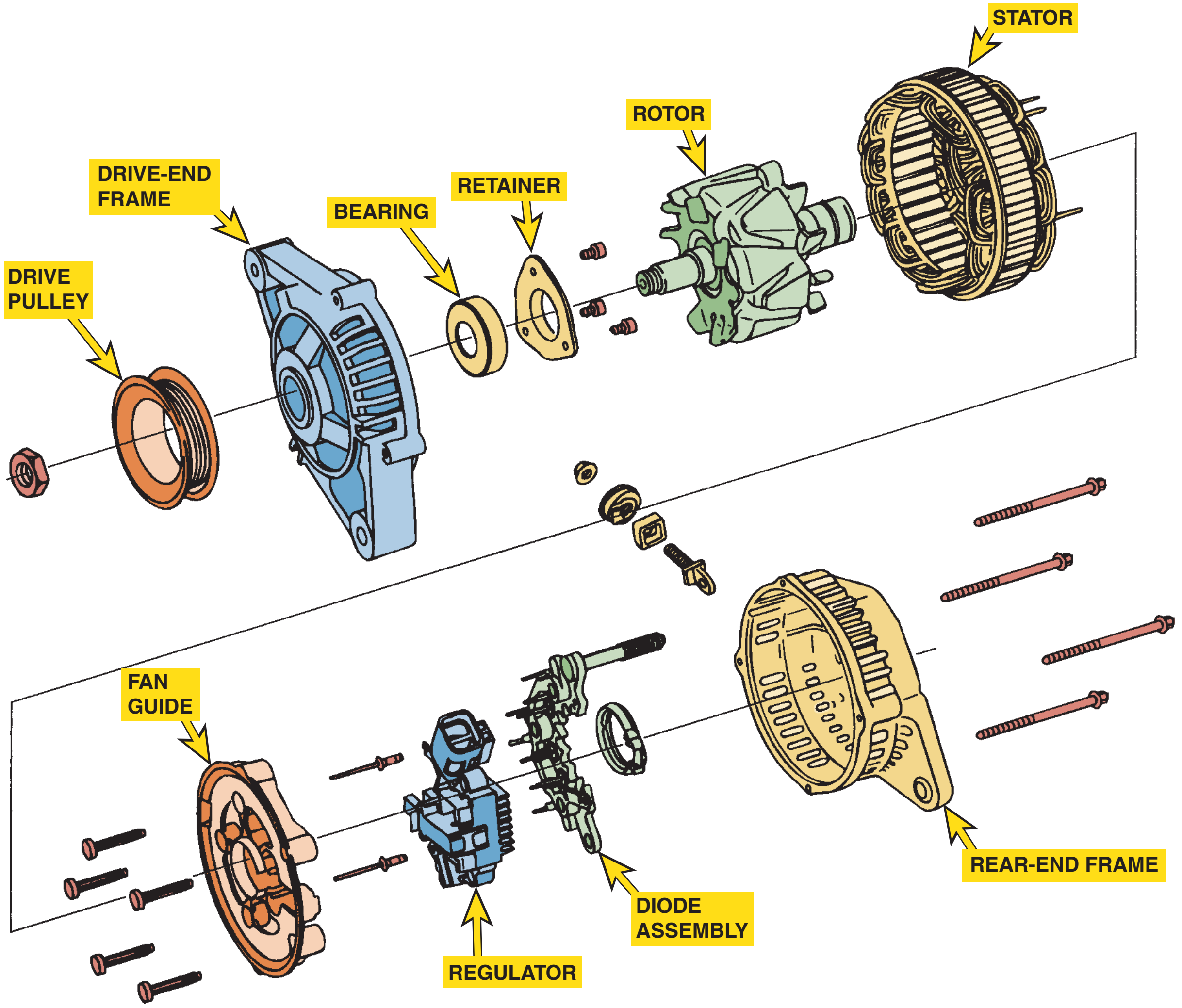


FIGURE 51–8 An exploded view of a typical alternator showing all of its internal parts including the stator windings.

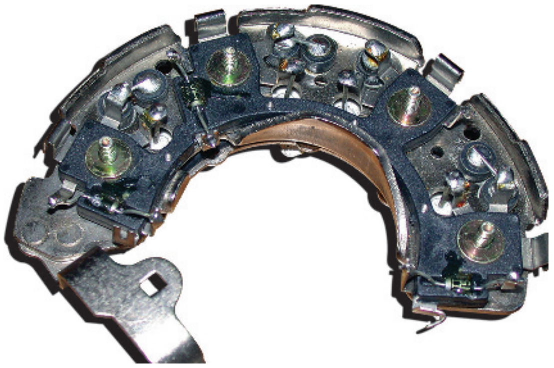


FIGURE 51–9 A rectifier usually includes six diodes in one assembly and is used to rectify AC voltage from the stator windings into DC voltage suitable for use by the battery and electrical devices in the vehicle.

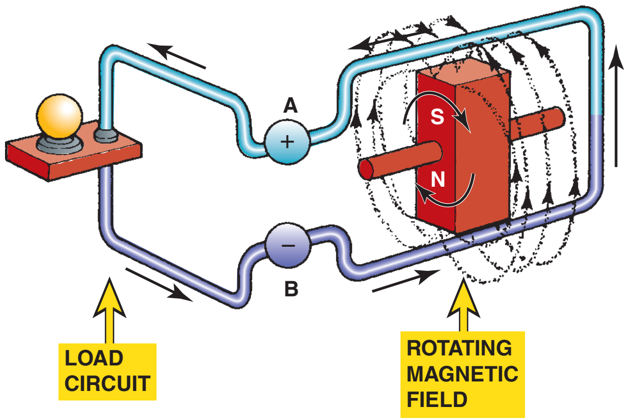


FIGURE 51–10 Magnetic lines of force cutting across a conductor induce a voltage and current in the conductor.

DIODES **Diodes** are constructed of a semiconductor material (usually silicon) and operate as a one-way electrical check valve that permits the current to flow in only one direction. Alternators often use six diodes (one positive and one negative set for each of the three stator windings) to convert alternating current to direct current.

Diodes used in alternators are included in a single part called a rectifier, or *rectifier bridge*. A rectifier includes not only the diodes (usually six), but also the cooling fins and connections for the stator windings and the voltage regulator. ● **SEE FIGURE 51–9**.

DIODE TRIO Some alternators are equipped with a diode trio that supplies current to the brushes from the stator windings. A diode trio uses three diodes in one housing, with one diode for each of the three stator windings and then one output terminal.

HOW AN ALTERNATOR WORKS

FIELD CURRENT IS PRODUCED A rotor inside an alternator is turned by a belt and drive pulley that are turned by the engine. Field current flowing through the slip rings to the rotor creates an alternating north and south pole on the rotor, with a magnetic field between each finger of the rotor. The magnetic field of the rotor generates a current in the stator windings by electromagnetic induction. ● **SEE FIGURE 51–10**.

CURRENT IS INDUCED IN THE STATOR The induced current in the stator windings is an alternating current because of the alternating magnetic field of the rotor. The induced current starts to increase as the magnetic field starts to induce current in each winding of the stator. The current then peaks when the magnetic field is the strongest and starts to decrease as the magnetic field moves away from the stator winding. Therefore, the current generated is described as being of a sine wave or alternating current pattern. ● **SEE FIGURE 51–11**.

As the rotor continues to rotate, this sine wave current is induced in each of the three windings of the stator.

Because each of the three windings generates a sine wave current, as shown in ● **FIGURE 51–12**, the resulting currents combine to form a three-phase voltage output.

The current induced in the stator windings connects to diodes (one-way electrical check valves) that permit the alternator output current to flow in only one direction, thereby changing AC voltage to DC voltage. All alternators contain at

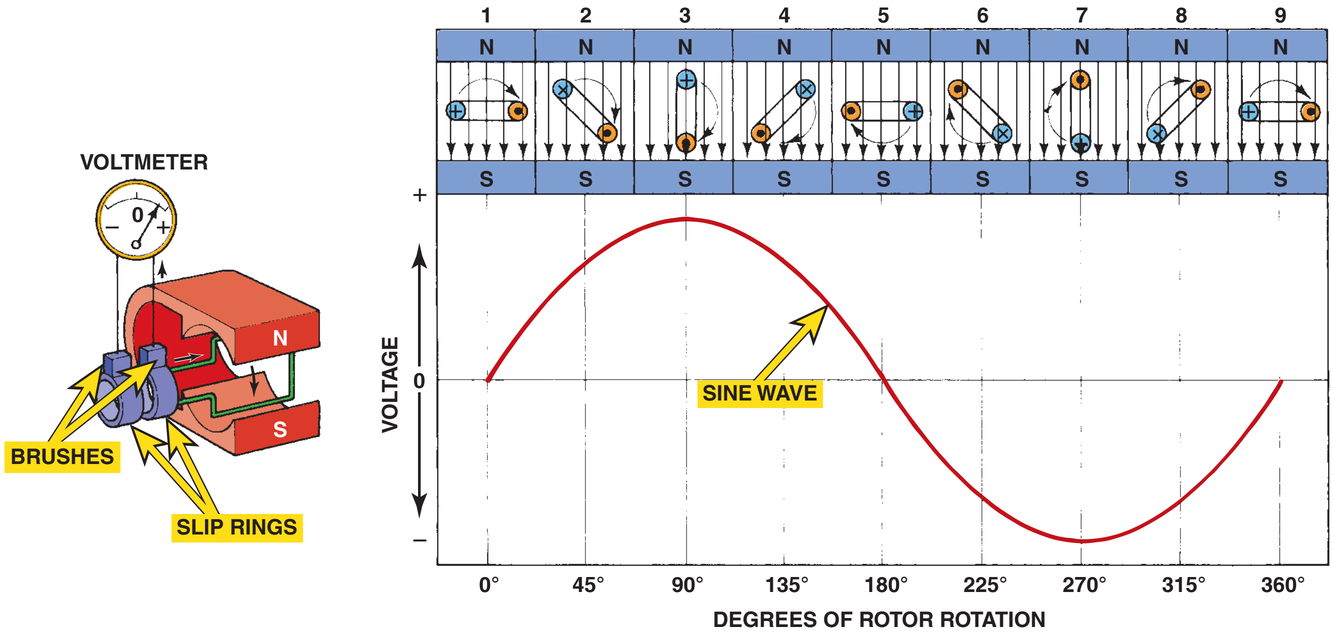


FIGURE 51–11 A sine wave (shaped like the letter *S* on its side) voltage curve is created by one revolution of a winding as it rotates in a magnetic field.

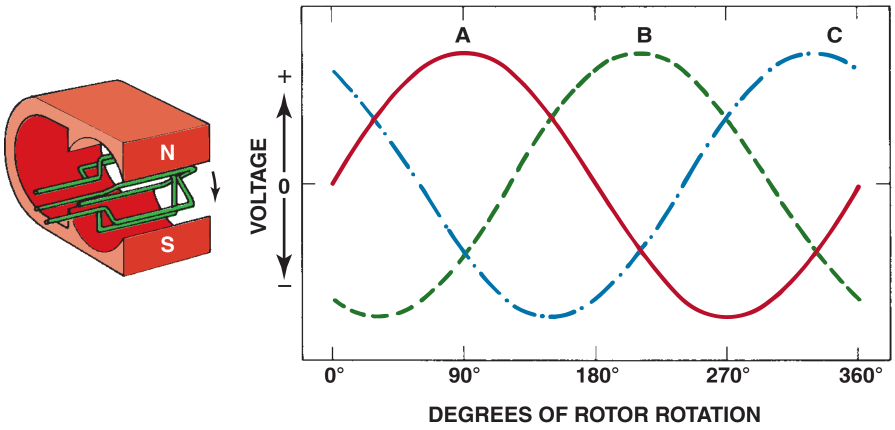


FIGURE 51–12 When three windings (A, B, and C) are present in a stator, the resulting current generation is represented by the three sine waves. The voltages are 120 degrees out of phase. The connection of the individual phases produces a three-phase alternating voltage.

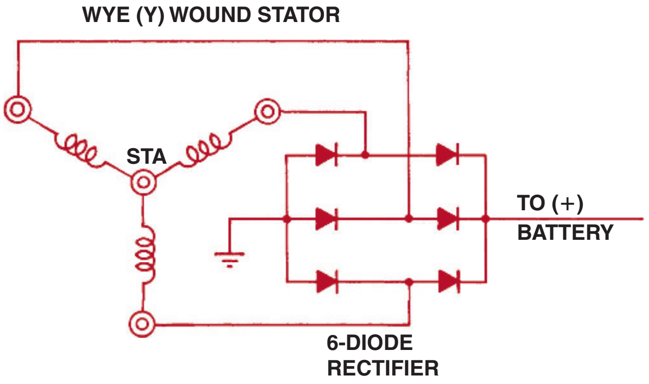


FIGURE 51–13 Wye-connected stator winding.

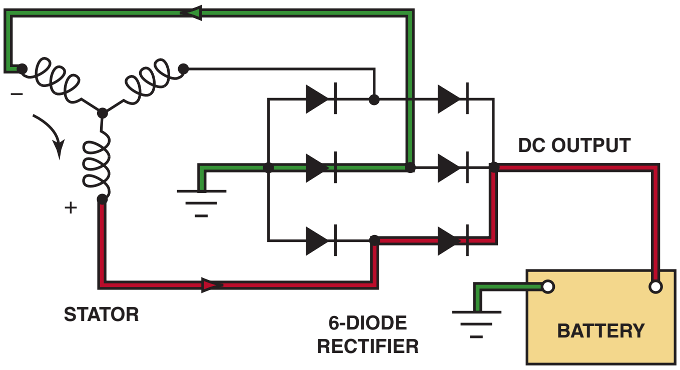


FIGURE 51–14 As the magnetic field, created in the rotor, cuts across the windings of the stator, a current is induced. Notice that the current path includes passing through one positive (+) diode on the way to the battery and one negative (–) diode as a complete circuit is completed through the rectifier and stator. It is the flow of current through the diodes that converts the AC voltage produced in the stator windings to DC voltage available at the output terminal of the alternator.

least six diodes, one pair (a positive and a negative diode) for each of the three stator windings. Some alternators contain eight diodes with another pair connected to the center connection of a wye-type stator.

WYE-CONNECTED STATORS The Y (pronounced "wye" and generally so written) type or star pattern is the most commonly used alternator stator winding connection. ● **SEE FIGURE 51–13.**

The output current with a wye-type stator connection is constant over a broad alternator speed range.

Current is induced in each winding by electromagnetic induction from the rotating magnetic fields of the rotor. In a wye-type stator connection, the currents must combine because two windings are always connected in series. ● **SEE FIGURE 51–14.**

The current produced in each winding is added to the other windings' current and then flows through the diodes to the alternator output terminal. One-half of the current produced is available at the neutral junction (usually labeled "STA" for stator).

DELTA-CONNECTED STATORS The **delta winding** is connected in a triangular shape. Delta is a Greek letter shaped like a triangle. ● **SEE FIGURE 51–15.**

Current induced in each winding flows to the diodes in a parallel circuit. More current can flow through two parallel circuits than can flow through a series circuit (as in a wye-type stator connection).

Delta-connected stators are used on alternators where high output at high-alternator revolutions per minute (RPM) is required. The delta-connected alternator can produce 73% more current than the same alternator with wye-type stator connections. For example, if an alternator with a wye-connected stator can produce 55 amperes, the *same* alternator with delta-connected stator windings can produce 73% more current, or 95 amperes (55 × 1.73 = 95). The delta-connected alternator, however, produces lower current at low speed and must be operated at high speed to produce its maximum output.

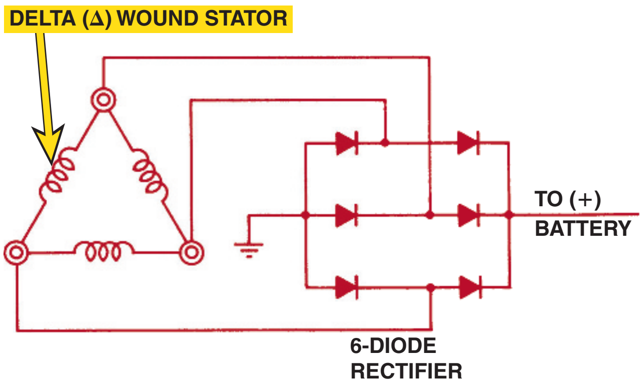


FIGURE 51–15 Delta-connected stator winding.

ALTERNATOR OUTPUT FACTORS

The output voltage and current of an alternator depend on the following factors:

1. **Speed of rotation.** Alternator output is increased with alternator rotational speed up to the alternator's maximum possible ampere output. Alternators normally rotate at a speed two to three times faster than engine speed, depending on the relative pulley sizes used for the belt drive. For example, if an engine is operating at 5,000 RPM, the alternator is rotating at about 15,000 RPM.
2. **Number of conductors.** A high-output alternator contains more turns of wire in the stator windings. Stator winding connections (whether wye or delta) also affect the maximum alternator output. ● **SEE FIGURE 51–16** for an example of a stator that has six, rather than three windings, which greatly increase the amperage output of the alternator.
3. **Strength of the magnetic field.** If the magnetic field is strong, a high output is possible because the current generated by electromagnetic induction is dependent on the number of magnetic lines of force that are cut.
    - **a.** The strength of the magnetic field can be increased by increasing the number of turns of conductor wire wound on the rotor. A higher output alternator rotor has more turns of wire than an alternator rotor with a low-rated output.
    - **b.** The strength of the magnetic field also depends on the current through the field coil (rotor). Because magnetic field strength is measured in ampere-turns, the greater the amperage or the number of turns, or both, the greater the alternator output.

ALTERNATOR VOLTAGE REGULATION

PRINCIPLES An automotive alternator must be able to produce electrical pressure (voltage) higher than battery voltage to charge the battery. Excessively high voltage can damage the battery, electrical components, and the lights of a vehicle. Basic principles include the following:

- If no (zero) amperes of current exists throughout the field coil of the alternator (rotor), alternator output is zero, because without field current, a magnetic field does not exist.

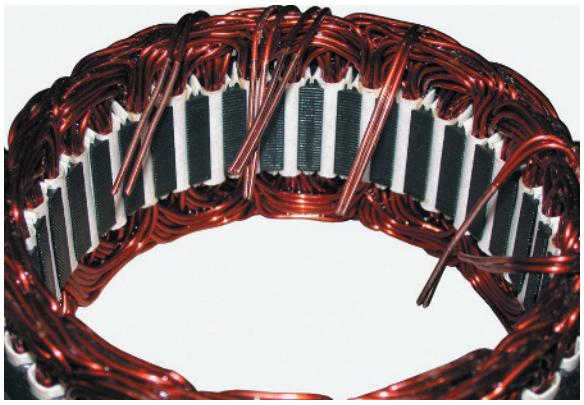


FIGURE 51–16 A stator assembly with six, rather than the normal three, windings.

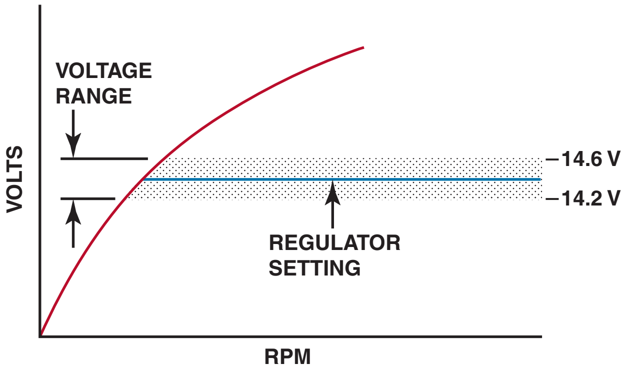


FIGURE 51–17 Typical voltage regulator range.

- The field current required by most automotive alternators is less than 3 amperes. It is the *control* of the *field* current that controls the output of the alternator.
- Current for the rotor flows from the battery positive post, through the rotor positive brush, into the rotor field winding, and exits the rotor winding through the rotor ground brush. Most voltage regulators control field current by controlling the amount of field current through the ground brush.
- The voltage regulator simply opens the field circuit if the voltage reaches a predetermined level, then closes the field circuit again, as necessary, to maintain the correct charging voltage. ● **SEE FIGURE 51–17**.
- The electronic circuit of the voltage regulator cycles between 10 and 7,000 times per second, as needed, to accurately control the field current through the rotor and, therefore, control the alternator output.

REGULATOR OPERATION

- The control of the field current is accomplished by opening and closing the *ground* side of the field circuit through the rotor on most alternators.
- The zener diode is a major electronic component that makes voltage regulation possible. A zener diode blocks current flow until a specific voltage is reached, then it permits current to flow. Alternator voltage from the stator and diodes is first sent through a thermistor, which changes resistance with temperature, and then to a zener diode. When the upper-limit voltage is reached, the zener diode conducts current to a transistor, which then opens the field (rotor) circuit. The electronics are usually housed in a separate part inside the alternator. ● **SEE FIGURES 51–18 AND 51–19**.

BATTERY CONDITION AND CHARGING VOLTAGE If the automotive battery is discharged, its voltage is lower than the voltage of a fully charged battery. The alternator supplies charging current, but it may not reach the maximum charging voltage. For example, if a vehicle is jump started and run at a fast idle (2,000 RPM), the charging voltage may be only 12 volts. In this case, the following may occur:

- As the battery becomes charged and the battery voltage increases, the charging voltage also increases, until the voltage regulator limit is reached.

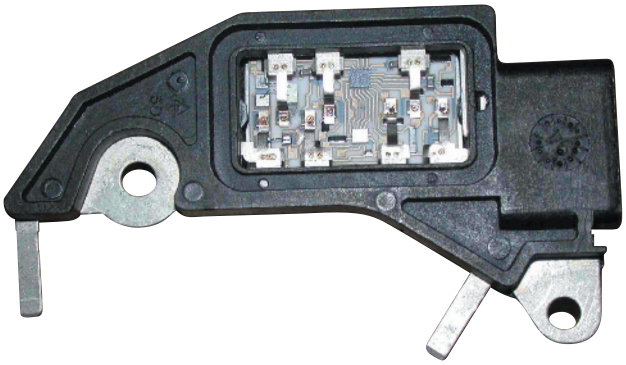


FIGURE 51–18 A typical electronic voltage regulator with the cover removed showing the circuits inside.

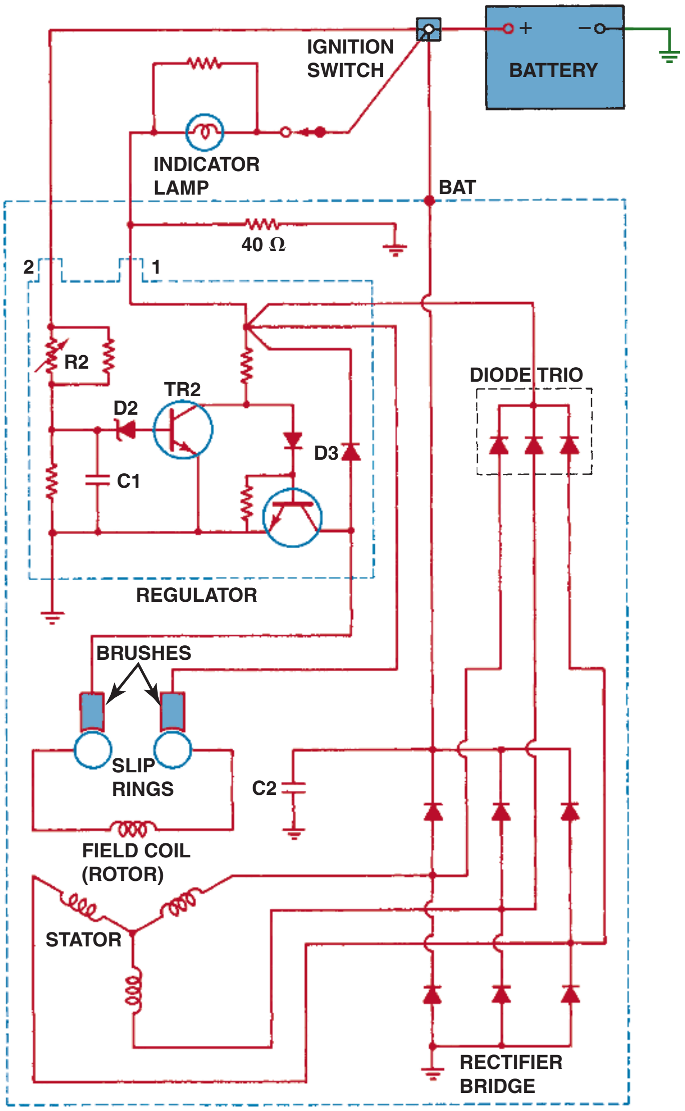


FIGURE 51–19 Typical General Motors SI-style alternator with an integral voltage regulator. Voltage present at terminal 2 is used to reverse bias the zener diode (D2) that controls TR2. The positive brush is fed by the ignition current (terminal 1) plus current from the diode trio.

- Then, the voltage regulator starts to control the charging voltage. A good, but discharged, battery should be able to convert into chemical energy all the current the alternator can produce. As long as alternator voltage is higher than battery voltage, current flows from the alternator (high voltage) to the battery (lower voltage).
- Therefore, if a voltmeter is connected to a discharged battery with the engine running, it may indicate charging voltage that is lower than normally acceptable.

In other words, the condition and voltage of the battery *do* determine the charging rate of the alternator. It is often stated that the battery is the true "voltage regulator" and that the voltage regulator simply acts as the upper-limit voltage control. This is the reason why all charging system testing *must* be performed with a reliable and known to be good battery, at least 75% charged, to be assured of accurate test results. If a discharged battery is used during charging system testing, tests could mistakenly indicate a defective alternator and/or voltage regulator.

TEMPERATURE COMPENSATION All voltage regulators (mechanical or electronic) provide a method for increasing the charging voltage slightly at low temperatures and for lowering the charging voltage at high temperatures. A battery requires a higher charging voltage at low temperatures because of the resistance to chemical reaction changes. However, the battery is overcharged if the charging voltage is not reduced during warm weather. Electronic voltage regulators use a temperature-sensitive resistor in the regulator circuit. This resistor, called a **thermistor**, provides lower resistance as the temperature increases. A thermistor is used in the electronic circuits of the voltage regulator to control charging voltage over a wide range of underhood temperatures.

NOTE: Voltmeter test results may vary according to temperature. Charging voltage tested at 32°F (0°C) is higher than for the same vehicle tested at 80°F (27°C) because of the temperature-compensation factors built into voltage regulators.

ALTERNATOR COOLING

Alternators create heat during normal operation and this heat must be removed to protect the components inside, especially the diodes and voltage regulator. The types of cooling include the following:

- External fan
- Internal fan(s)
- Both an external fan and an internal fan
- Coolant cooled (● **SEE FIGURE 51–20**)

COMPUTER-CONTROLLED CHARGING SYSTEMS

ADVANTAGES Computer control of the charging system has the following advantages:

1. The computer controls the field of the alternator, which can pulse it on or off, as needed, for maximum efficiency, thereby saving fuel.

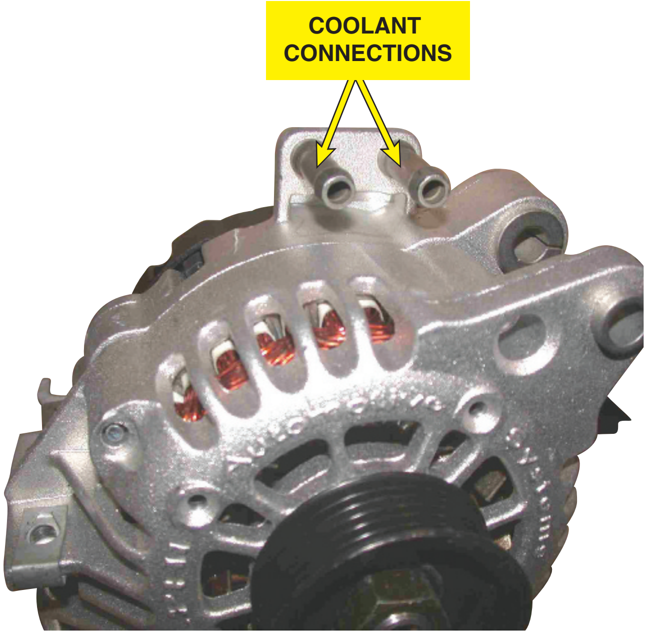


FIGURE 51–20 A coolant-cooled alternator showing the hose connections where coolant from the engine flows through the rear frame of the alternator.

NOTE: Some vehicle manufacturers, such as Honda/ Acura, use an electronic load control (ELC), which turns on the alternator when decelerating, where the additional load on the engine is simply used to help slow the vehicle. This allows the battery to be charged without placing a load on the engine, helping to increase fuel economy.

2. Engine idle can also be improved by turning on the alternator slowly, rather than all at once, if an electrical load is switched on, such as the air-conditioning system.
3. Most computers can also reduce the load on the electrical system if the demand exceeds the capacity of the charging system, by reducing fan speed, shutting off rear window defoggers, or increasing engine speed to cause the alternator to increase the amperage output.

NOTE: A commanded higher-than-normal idle speed may be the result of the computer compensating for an abnormal electrical load. This higher idle speed could indicate a defective battery or other electrical system faults.

4. The computer can monitor the charging system and set diagnostic trouble codes (DTCs) if a fault is detected. Many systems allow the service technician to control the charging of the alternator using a scan tool.
5. Because the charging system is computer controlled, it can be checked using a scan tool. Some vehicle systems allow the scan tool to activate the alternator field and then monitor the output to help detect fault locations. Always follow the vehicle manufacturer's diagnostic procedure.

TYPES OF SYSTEMS Computers can interface with the charging system in three ways.

1. The computer can *activate* the charging system by turning on and off the field current to the rotor. In other words, the computer, usually the powertrain control module (PCM), controls the field current to the rotor.
2. The computer can *monitor* the operation of the alternator and increase engine speed, if needed, during conditions when a heavy load is demanded by the alternator.
3. The computer can *control* the alternator by controlling alternator output to match the needs of the electrical system. This system detects the electrical needs of the vehicle and commands the alternator to charge only when needed to improve fuel economy.

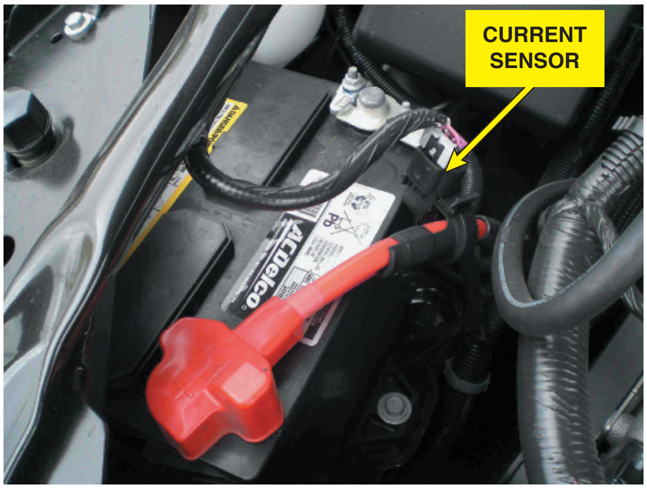


FIGURE 51–21 A Hall-effect current sensor attached to the positive battery cable is used as part of the EPM system.

GM ELECTRICAL POWER MANAGEMENT SYSTEM A typical system used on some General Motors vehicles is called **electrical power management (EPM)**. It uses a Hall-effect sensor attached to the negative or positive battery cable to measure the current leaving and entering the battery. ● **SEE FIGURE 51–21**.

The engine control module (ECM) controls the alternator by changing the on-time of the current through the rotor. ● **SEE FIGURE 51–22**.

The on-time, called **duty cycle**, varies from 5% to 95%. ● **SEE CHART 51–1**.

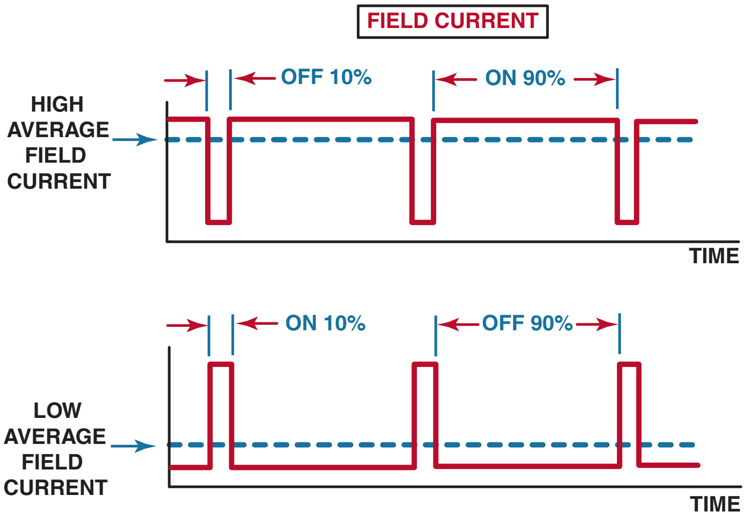


FIGURE 51–22 The amount of time current flowing through the field (rotor) determines the alternator output.

COMMAND DUTY CYCLE	ALTERNATOR OUTPUT VOLTAGE
10%	11.0 V
20%	11.6 V
30%	12.1 V
40%	12.7 V
50%	13.3 V
60%	13.8 V
70%	14.4 V
80%	14.9 V
90%	15.5 V

CHART 51–1

The output voltage is controlled by varying the duty cycle as controlled by the PCM.

This system has six modes of operation.

1. **Charge mode.** The charge mode is activated when any of the following occurs:
   - Electric cooling fans are on high speed.
   - Rear window defogger is on.
   - Battery state of charge (SOC) is less than 80%
   - Outside (ambient) temperature is less than 32°F (0°C).
2. **Fuel economy mode.** This mode reduces the load on the engine from the alternator for maximum fuel economy. This mode is activated when the following conditions are met:
   - Ambient temperature is above 32°F (0°C).
   - The SOC of the battery is 80% or higher.
   - The cooling fans and rear defogger are off.

   The target voltage is 13 volts and returns to the charge mode, if needed.
3. **Voltage reduction mode.** This mode is commanded to reduce the stress on the battery during low-load conditions. This mode is activated when the following conditions are met:
   - Ambient temperature is above 32°F (0°C).
   - Battery discharge rate is less than 7 amperes.
   - Rear defogger is off.
   - Cooling fans are on low or off.
   - Target voltage is limited to 12.7 volts.
4. **Start-up mode.** This mode is selected after engine start and commands a charging voltage of 14.5 volts for 30 seconds. After 30 seconds, the mode is changed, depending on conditions.
5. **Battery sulfation mode.** This mode is commanded if the output voltage is less than 13.2 volts for 45 minutes, which can indicate that sulfated plates could be the cause. The target voltage is 13.9 to 15.5 volts for three minutes. After three minutes, the system returns to another mode, based on conditions.
6. **Headlight mode.** This mode is selected when the headlights are on and the target voltage is 14.5 volts.

TECH TIP

The Voltage Display Can Be a Customer Concern

A customer may complain that the voltmeter reading on the dash fluctuates up and down. This may be normal as the computer-controlled charging system commands various modes of operation based on the operating conditions. Follow the vehicle manufacturer's recommended procedures to verify proper operation.

REVIEW QUESTIONS

1. How can a small electronic voltage regulator control the output of a typical 100 ampere alternator?
2. What are the component parts of a typical alternator?
3. How is the computer used to control an alternator?
4. How is AC voltage inside the alternator changed to DC voltage at the output terminal?
5. What is the purpose of an OAP or OAD?

CHAPTER QUIZ

1. Technician A says that the diodes regulate the alternator output voltage. Technician B says that the field current can be computer controlled. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A magnetic field created in the ____________ is used to induce a voltage in the ____________.
   a. stator; rear housing
   b. diodes; stator
   c. rotor; stator
   d. drive-end frame; OAD
3. How is the AC voltage produced in the alternator changed to DC voltage?
   a. Mechanical switches
   b. Alternating brushes
   c. Slip ring rotation
   d. Diodes inside the alternator
4. Technician A says that two diodes are required for each stator winding lead. Technician B says that diodes change alternating current into direct current. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

5. The alternator output current is produced in the ___________.
   - **a.** stator
   - **b.** rotor
   - **c.** brushes
   - **d.** diodes (rectifier bridge)
6. The output of an alternator can be increased by increasing the ______________ of the alternator.
   - **a.** speed of rotation
   - **b.** number of conductors in the starter
   - **c.** current in the rotor
   - **d.** Any of these would increase the output
7. How much current flows through the alternator brushes?
   - **a.** All of the alternator output flows through the brushes
   - **b.** 25 to 35 amperes, depending on the vehicle
   - **c.** 10 to 15 amperes
   - **d.** Less than 3 amperes
8. Technician A says that an alternator overrunning pulley is used to reduce vibration and noise. Technician B says that an overrunning alternator pulley or dampener uses a one-way clutch. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. What is/are used to help control the heat created in the alternator?
   - **a.** External fan
   - **b.** Internal fan
   - **c.** Coolant cooled
   - **d.** Any of the above
10. How does the computer interface with the alternator?
    - **a.** The computer can actuate the charging system
    - **b.** The computer can monitor the operation of the alternator
    - **c.** The computer can control the operation of the alternator
    - **d.** Any of the above

Chapter 52

CHARGING SYSTEM DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the various methods to test the charging system.
- Describe how to inspect and replace the drive belts.
- Describe the AC ripple voltage check.
- Describe how to test AC ripple current.
- Describe charging system voltage drop testing.
- Discuss the alternator output test.
- Discuss minimum required alternator output.
- Explain how to remove an alternator.
- Explain how to install an alternator.

KEY TERMS:

AC ripple voltage 597 • Charging voltage test 593

CHARGING SYSTEM TESTING AND SERVICE

BATTERY STATE OF CHARGE The charging system can be tested as part of a routine vehicle inspection or to determine the reason for a no-charge or reduced charging circuit performance. The battery *must* be at least 75% charged before testing the alternator and the charging system. A weak or defective battery causes inaccurate test results. If in doubt, replace the battery with a known good shop battery for testing.

CHARGING VOLTAGE TEST The **charging voltage test** is the easiest way to check the charging system voltage at the battery. Use a digital multimeter to check the voltage, as follows:

STEP 1 Select DC volts.

STEP 2 Connect the red meter lead to the positive (+) terminal of the battery and the black meter lead to the negative (−) terminal of the battery.

NOTE: The polarity of the meter leads is not too important when using a digital multimeter. If the meter leads are connected backward on the battery, the resulting readout simply has a negative (−) sign in front of the voltage reading.

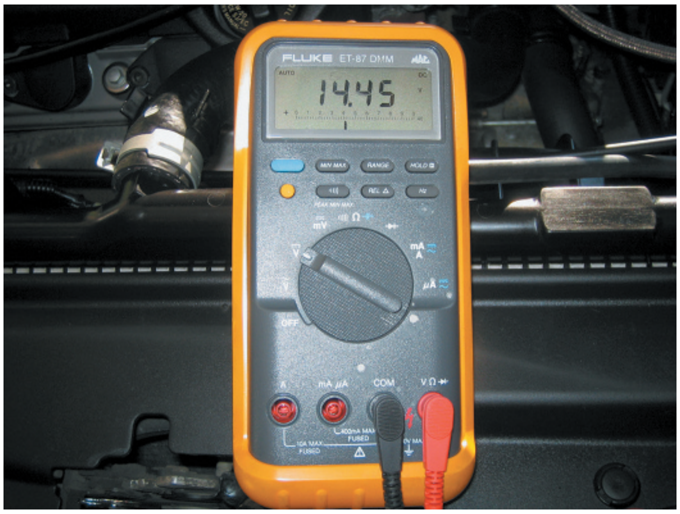


FIGURE 52–1 The digital multimeter should be set to read DC volts, with the red lead connected to the positive (+) battery terminal and the black meter lead connected to the negative (−) battery terminal.

STEP 3 Start the engine and increase the engine speed to about 2,000 RPM (fast idle) and record the charging voltage. ● **SEE FIGURE 52–1**.

Specifications for charging voltage = 13.5 to 15 volts

- If the voltage is too high, check that the alternator is properly grounded.
- If the voltage is lower than specifications, then there is a fault with the wiring or the alternator.
- If the wiring, fuses, and the connections are okay, then additional testing is required to help pinpoint the root cause. Replacement of the alternator and/or battery is often required if the charging voltage is not within factory specifications.
- If the alternator is computer-controlled, a defective current sensor or PCM could be the reason for a no-charge condition.

SCAN TESTING THE CHARGING CIRCUIT Most vehicles that use a computer-controlled charging system can be diagnosed using a scan tool. Not only can the charging voltage be monitored, but also, in many vehicles, the field circuit can be controlled and the output voltage monitored to check that the system is operating correctly. ● **SEE FIGURE 52–2.**

NOTE: Some charging systems, such as those on many Honda/Acura vehicles, use an electronic load detection circuit that energizes the field circuit only when an electrical load is detected. For example, if the engine is running and there are no accessories on, the voltage read at the battery may be 12.6 volts, which could indicate that the charging system is not operating. In this situation, turning on the headlights or an accessory should cause the computer to activate the field circuit, and the alternator should produce normal charging voltage.

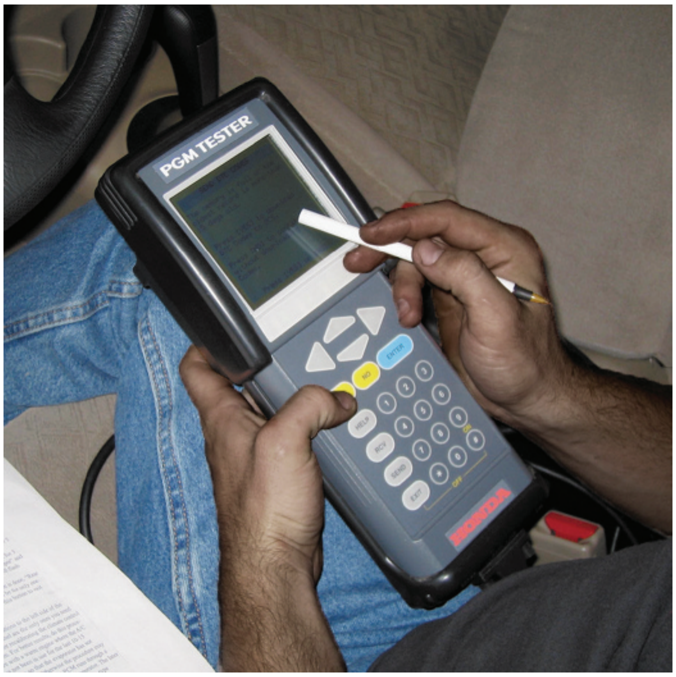


FIGURE 52–2 A scan tool can be used to diagnose charging system problems.

CASE STUDY

The Case of the Overcharging Chevrolet Truck

The owner of a Chevrolet Silverado 2500 HD, equipped with a 6.6 L diesel V8, stated that the ABS, Battery, and many other dash warning lights would come on when accelerating hard. The technician retrieved a C0800 diagnostic trouble code. (The module detects that the system voltage is greater than 16 volts.) The technician measured the voltage at the battery terminal with the engine operating above the idle speed and recorded a reading of a 17.7 volts. Because the voltage output of the alternator is controlled by the voltage regulator and it is built in the alternator, the technician replaced the alternator. The technician checked the charging voltage and it was now within factory specification. The diagnostic trouble code was cleared and the vehicle returned to the customer.

Summary:

Complaint—Customer asked to check the engine light and stated that several other warning lights would come on when accelerating rapidly.
Cause—The voltage regulator inside the alternator was not working as designed.
Correction—The alternator was replaced which corrected the customer concern.

FREQUENTLY ASKED QUESTION

What Is a Full-Fielding Test?

Full fielding is a procedure used on older noncomputerized vehicles for bypassing the voltage regulator that could be used to determine if the alternator is capable of producing its designed output. This test is no longer performed for the following reasons:

- The voltage regulator is built into the alternator, requiring that the entire assembly be replaced even if just the regulator is defective.
- When the regulator is bypassed, the alternator can produce a high voltage (over 100 volts in some cases), which could damage all of the electronic circuits in the vehicle.

Always follow the vehicle manufacturer's recommended testing procedures.

DRIVE BELT INSPECTION AND REPLACEMENT

BELT VISUAL INSPECTION It is generally recommended that all belts be inspected regularly and replaced as needed. Replace any serpentine belt that has more than three cracks in any one

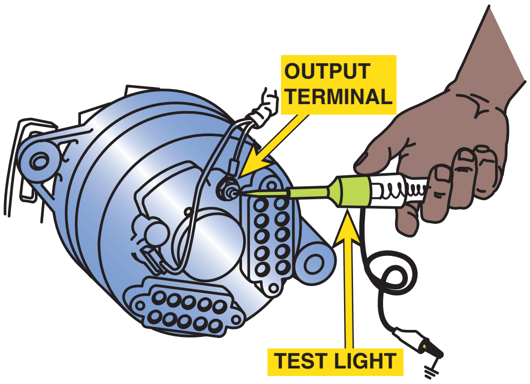


FIGURE 52–3 Before replacing an alternator, the wise technician checks that battery voltage is present at the output and battery voltage sense terminals. if no voltage is detected, then there is a fault in the wiring.

TECH TIP

Use a Test Light to Check for a Defective Fusible Link

Most alternators use a fusible link or mega fuse between the output terminal and the positive (+) terminal of the battery. If this fusible link or fuse is defective (blown), then the charging system does not operate at all. Many alternators have been replaced repeatedly because of a blown fusible link that was not discovered until later. A quick test that checks whether the fusible link is okay is to touch a test light to the output terminal with the other end of the test light attached to a good ground. The fusible link or mega fuse is okay if the light comes on. This test confirms that the circuit between the alternator and the battery has continuity. ● **SEE FIGURE 52–3**.

rib that appears in a 3 inch span. Check service information for the specified procedure and recommended replacement interval. ● **SEE FIGURE 52–4**.

BELT REPLACEMENT If the belt needs replacement, first make note of the belt routing. There may be a diagram under the hood. Use a tool to release the tensioner and then remove the belt. ● **SEE FIGURE 52–5**. Install the new belt and check it for the proper tension.

BELT TENSION MEASUREMENT If the vehicle does not use a belt tensioner, then a belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications or use the following table for an example of the proper tension based on the size of the belt.

There are four ways that vehicle manufacturers specify that the belt tension is within factory specifications:

1. **Belt tension gauge.** A belt tension gauge is needed to determine if it is at the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications, or see ● **CHART 52–1** for an example of the proper tension based on the size of the belt.

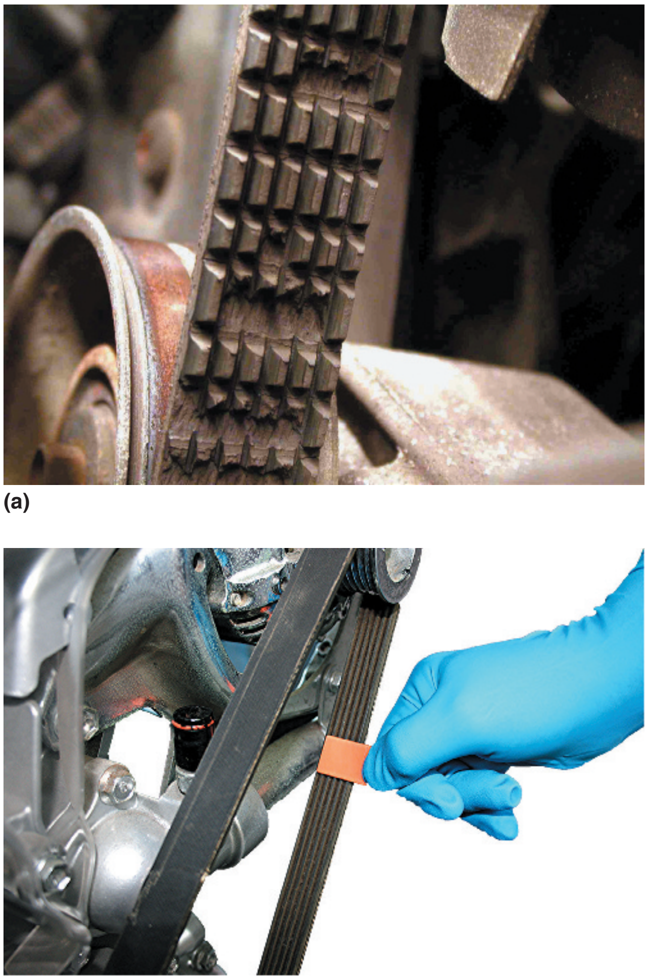

(a)
(b)

FIGURE 52–4 (a) This accessory drive belt is worn and requires replacement. Newer belts are made from ethylene propylene diene monomer (EPDM). This rubber does not crack like older belts and may not show wear, even though the ribs do wear and can cause slippage. (b) A belt wear gauge being used to check a belt. It should fit tightly but if it is able to be moved side to side, then the belt is worn and should be replaced.

SERPENTINE BELTS	
NUMBER OF RIBS USED	**TENSION RANGE (LB)**
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145
V-BELTS	
V-BELT TOP WIDTH (IN.)	**TENSION RANGE (LB)**
1/4	45–65
5/16	60–85
25/64	85–115
31/64	105–145

CHART 52–1

Typical belt tension for various widths of belts. Tension is the force needed to depress the belt as displayed on a belt tension gauge.

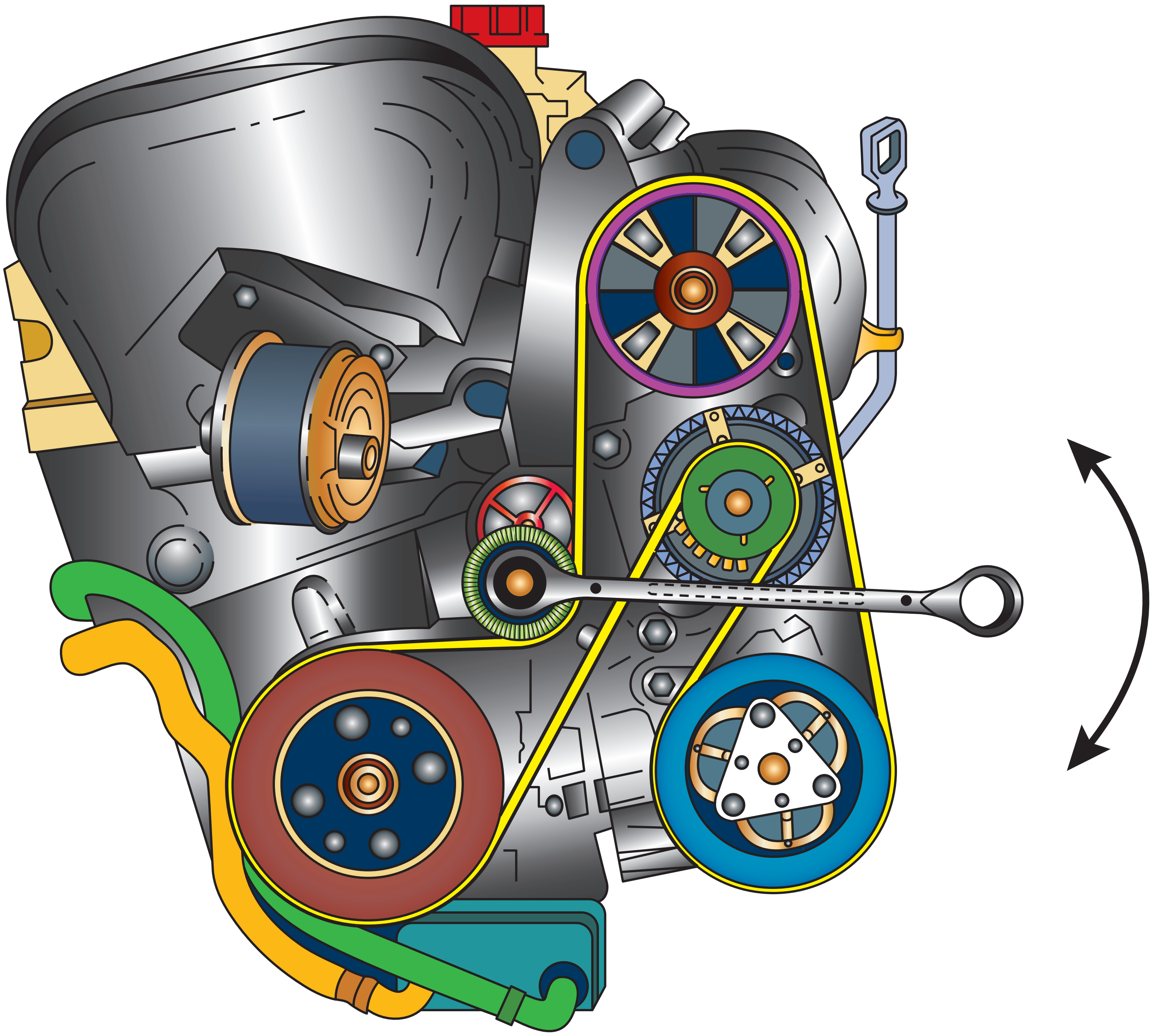


FIGURE 52–5 A wrench, breaker bar, or ratchet is used to release tension on the accessory drive belt, often called the front engine accessory drive (FEAD). Many experts recommend replacing the tensioner at the same time as the accessory drive belt.

2. **Marks on a tensioner.** Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the preferred location of the tensioner mark. ● **SEE FIGURE 52–6**.
3. **Torque wrench reading.** Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced.
4. **Deflection.** Depress the belt between the two pulleys that are the farthest apart; the flex or deflection should be 1/2 inch (13 mm).

OVERRUNNING CLUTCH If low or no alternator output is found, remove the alternator drive belt and check the overrunning alternator pulley (OAP) or overrunning alternator dampener (OAD) for proper operation. Both types of overrunning clutches use a one-way clutch. Therefore, the pulley should freewheel in

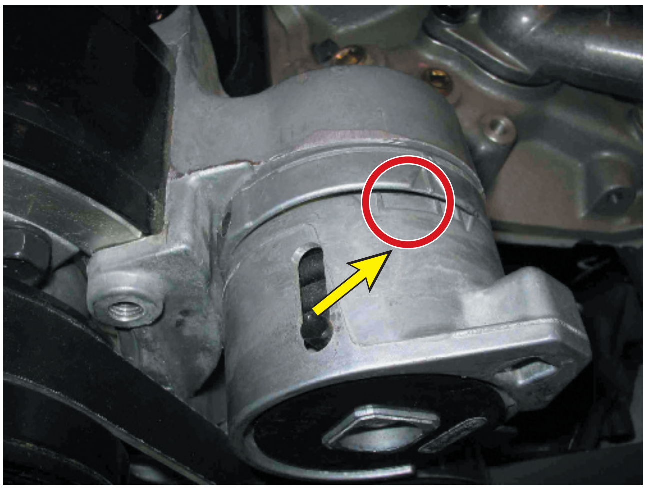


FIGURE 52–6 Check service information for where the tensioner marks should be located for proper belt tension.

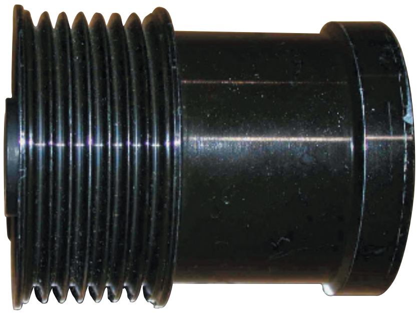


FIGURE 52–7 This overrunning alternator dampener (OAD) is longer than an overrunning alternator pulley (OAP) because it contains a dampener spring, as well as a one-way clutch. Be sure to check that it locks in one direction.

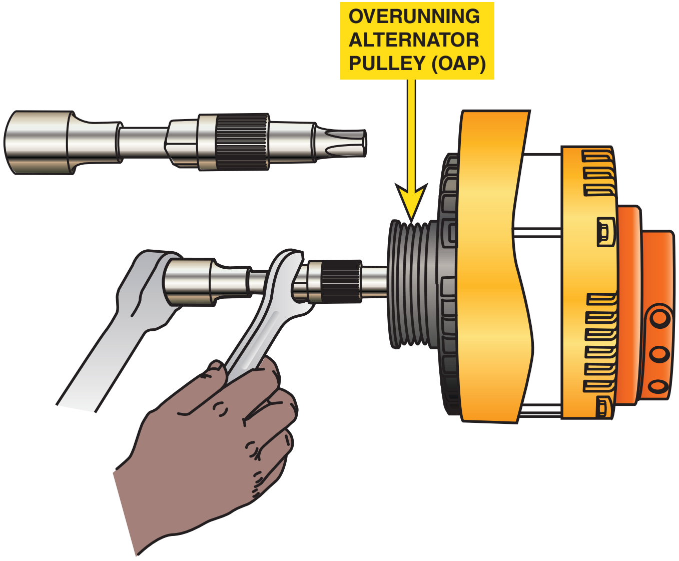


FIGURE 52–8 A special tool is needed to remove and install overrunning alternator pulleys or dampeners.

one direction and rotate the alternator rotor when rotated in the opposite direction. ● **SEE FIGURE 52–7.**

A special tool, such as Lisle No. 57650 or Gates No. 91024, is needed to repair the alternator. ● **SEE FIGURE 52–8.**

AC RIPPLE VOLTAGE CHECK

PRINCIPLES A good alternator should produce very little AC voltage or current output. It is the purpose of the diodes in the alternator to rectify or convert most AC voltage into DC voltage. While it is normal to measure some AC voltage from an alternator, excessive AC voltage, called AC ripple, is undesirable and indicates a fault with the rectifier diodes or stator windings inside the alternator.

TESTING AC RIPPLE VOLTAGE The procedure to check for **AC ripple voltage** includes the following steps:

STEP 1 Set the digital meter to read AC volts.

STEP 2 Start the engine and operate it at 2,000 RPM (fast idle).

MEASURING THE AC RIPPLE FROM THE ALTERNATOR TELLS A LOT ABOUT ITS CONDITION. IF THE AC RIPPLE IS ABOVE 500 MILLIVOLTS, OR 0.5 VOLT, LOOK FOR A PROBLEM IN THE DIODES OR STATOR. IF THE RIPPLE IS BELOW 500 MILLIVOLTS, CHECK THE ALTERNATOR OUTPUT TO DETERMINE ITS CONDITION.

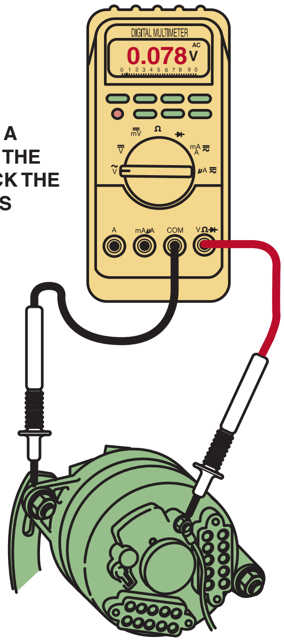


FIGURE 52–9 Testing AC ripple at the output terminal of the alternator is more accurate than testing at the battery due to the resistance of the wiring between the alternator and the battery. The reading shown on the meter, set to AC volts, is only 78 millivolts (0.078 volt), far below what the reading is if a diode is defective.

STEP 3 Connect the voltmeter leads to the positive and negative battery terminals.

STEP 4 Turn on the headlights to provide an electrical load on the alternator.

NOTE: A more accurate reading can be obtained by touching the meter lead to the output or "battery" terminal of the alternator. ● **SEE FIGURE 52–9.**

The results should be interpreted as follows: If the rectifier diodes are good, the voltmeter should read *less* than 400 millivolts (0.4 volt) AC. If the reading is over 500 millivolts (0.5 volt) AC, the rectifier diodes are defective.

NOTE: Many conductance testers, such as Midtronic and Snap-On, automatically test for AC ripple.

TECH TIP

The Lighter Plug Trick

Battery voltage measurements can be read through the lighter socket. Simply construct a test tool using a lighter plug at one end of a length of two-conductor wire and the other end connected to a double banana plug. The double banana plug fits most meters in the common (COM) terminal and the volt terminal of the meter. This is handy to use while road testing the vehicle under real-life conditions. Both DC voltage and AC ripple voltage can be measured. ● **SEE FIGURE 52–10.**

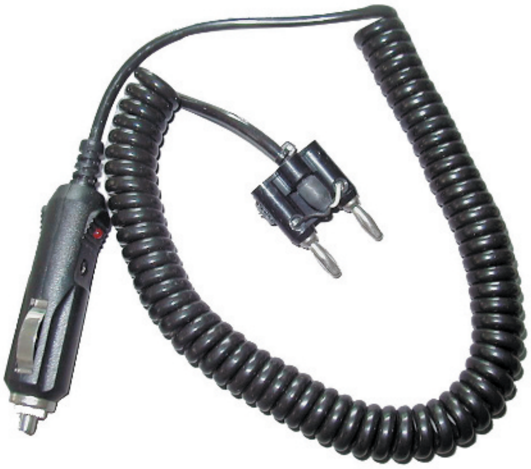


FIGURE 52–10 Charging system voltage can be easily checked at the lighter plug by connecting a lighter plug to the voltmeter through a double banana plug.

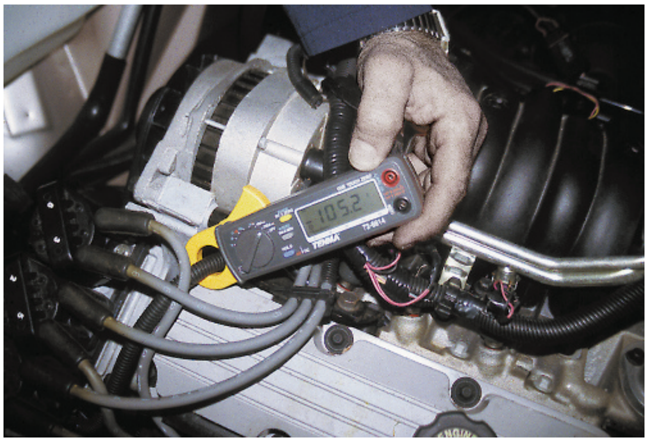


FIGURE 52–11 A mini clamp-on meter can be used to measure alternator output, as shown here (105.2 amperes). Then the meter can be used to check AC ripple by selecting AC amps on the rotary dial. AC ripple should be less than 10% of the DC output.

TESTING AC RIPPLE CURRENT

All alternators should create direct current (DC) if the diodes and stator windings are functioning correctly. A mini clamp-on meter capable of measuring AC amperes can be used to check the alternator. A good alternator should produce less than 10% of its rated amperage output in AC ripple amperes. For example, an alternator rated at 100 amperes should not produce more than 10 amperes AC ripple ($100 \times 10\% = 10$). It is normal for a good alternator to produce 3 or 4 amperes of AC ripple current to the battery. Only if the AC ripple current exceeds 10% of the rating of the alternator should the alternator be repaired or replaced.

TEST PROCEDURE To measure the AC current to the battery, perform the following steps:

STEP 1 Start the engine and turn on the lights to create an electrical load on the alternator.

STEP 2 Using a mini clamp-on digital multimeter, place the clamp around either all of the positive (+) battery cables or all of the negative (–) battery cables.

An AC/DC current clamp adapter can also be used with a conventional digital multimeter set on the DC millivolts scale.

STEP 3 To check for AC current ripple, switch the meter to read AC amperes and record the reading. Read the meter display.

STEP 4 The results should be less than 10% of the specified alternator rating. A reading of greater than 10 amperes AC indicates defective alternator diodes. ● **SEE FIGURE 52–11**.

CHARGING SYSTEM VOLTAGE DROP TESTING

ALTERNATOR WIRING For the proper operation of any charging system, there must be good electrical connections between the battery positive terminal and the alternator output terminal. The alternator must also be properly grounded to the engine block.

Many manufacturers of vehicles run the lead from the output terminal of the alternator to other connectors or junction blocks that are electrically connected to the positive terminal of the battery. If there is high resistance (a high voltage drop) in these connections or in the wiring itself, the battery is not properly charged.

VOLTAGE DROP TEST PROCEDURE When there is a suspected charging system problem (with or without a charge indicator light on), simply follow these steps to measure the voltage drop of the insulated (power-side) charging circuit.

STEP 1 Start the engine and run it at a fast idle (about 2,000 engine RPM).

STEP 2 Turn on the headlights to ensure an electrical load on the charging system.

STEP 3 Using any voltmeter set to read DC volts, connect the positive test lead (red) to the output terminal of the alternator. Attach the negative test lead (black) to the positive post of the battery.

The results should be interpreted as follows:

1. If there is less than a 0.4 volt (400 millivolts) reading, then all wiring and connections are satisfactory.
2. If the voltmeter reads higher than 0.4 volt, there is excessive resistance (voltage drop) between the alternator output terminal and the positive terminal of the battery.
3. If the voltmeter reads battery voltage (or close to battery voltage), there is an open circuit between the battery and the alternator output terminal.

To determine whether the alternator is correctly grounded, maintain the engine speed at 2,000 RPM with the headlights on. Connect the positive voltmeter lead to the case of the alternator and the negative voltmeter lead to the negative terminal of the battery. The voltmeter should read less than 0.2 volt (200 millivolts) if the alternator is properly grounded. If the reading is over 0.2 volt, connect one end of an auxiliary ground wire to the case of the alternator and the other end to a good engine ground. ● **SEE FIGURE 52–12**.

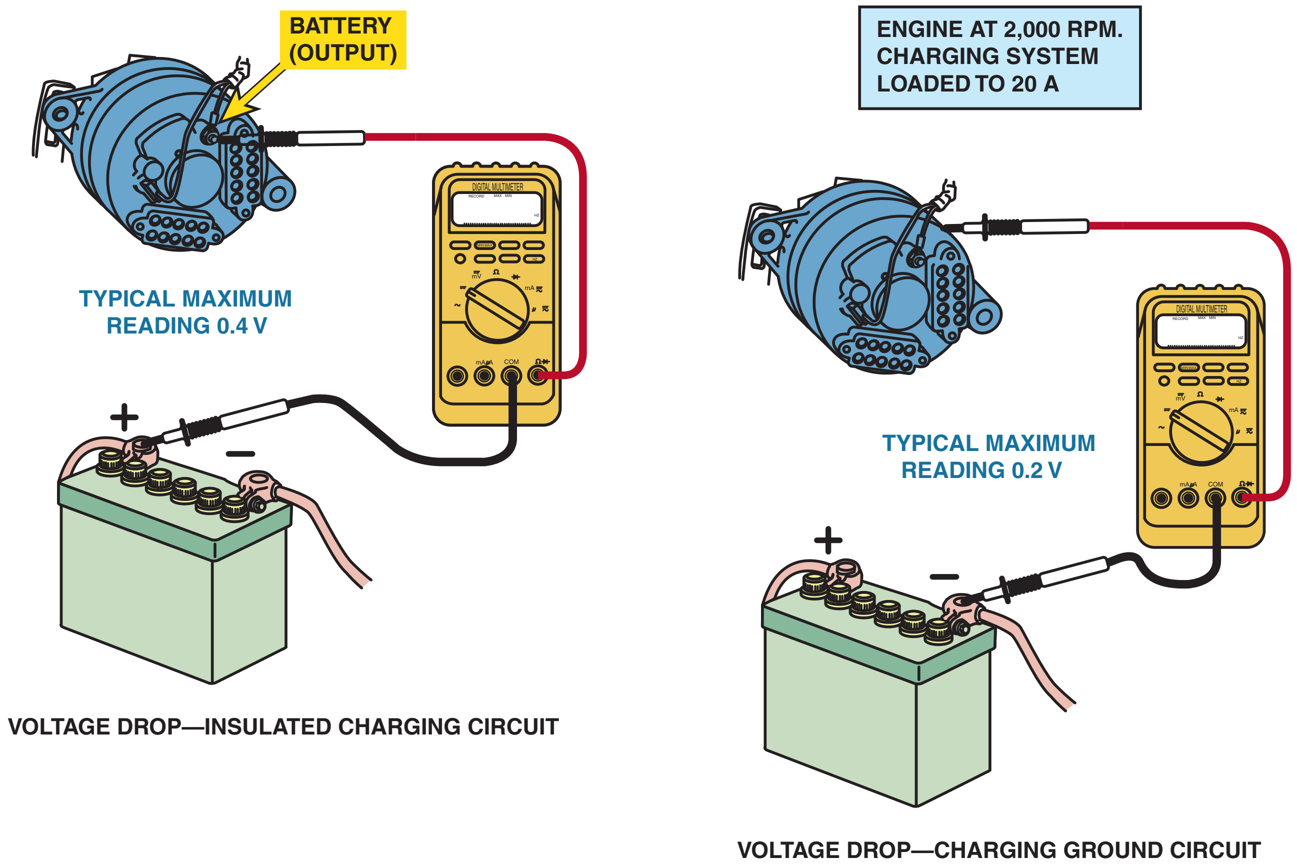

BATTERY (OUTPUT)
TYPICAL MAXIMUM READING 0.4 V
+
−
VOLTAGE DROP—INSULATED CHARGING CIRCUIT
ENGINE AT 2,000 RPM. CHARGING SYSTEM LOADED TO 20 A
TYPICAL MAXIMUM READING 0.2 V
+
−
VOLTAGE DROP—CHARGING GROUND CIRCUIT

FIGURE 52–12 Voltmeter hookup to test the voltage drop of the charging circuit.

TECH TIP

Use a Fused Jumper Wire as a Diagnostic Tool

When diagnosing an alternator charging problem, try using a fused jumper wire to connect the positive and negative terminals of the alternator directly to the positive and negative terminals of the battery. If a definite improvement is noticed, the problem is in the wiring of the vehicle. High resistance, due to corroded connections or loose grounds, can cause low alternator output, repeated regulator failures, slow cranking, and discharged batteries. A voltage drop test of the charging system can also be used to locate excessive resistance (high voltage drop) in the charging circuit, but using a fused jumper wire is often faster and easier.

ALTERNATOR OUTPUT TEST

PRELIMINARY CHECKS An alternator output test measures the current (amperes) of the alternator. A charging circuit may be able to produce correct charging circuit voltage, but not be able to produce adequate amperage output. If in doubt about charging system output, first check the condition of the alternator drive belt. With the engine off, attempt to rotate the fan of the alternator by hand. Replace or tighten the drive belt if the alternator fan can be rotated this way.

CARBON PILE TEST PROCEDURE A carbon pile tester uses plates of carbon to create an electrical load. A carbon pile test is used to load test a battery and/or an alternator. ● **SEE FIGURE 52–13**.

The testing procedure for alternator output is as follows:

STEP 1 Connect the starting and charging test leads according to the manufacturer's instructions, which usually include installing the amp clamp around the output wire near the alternator.

STEP 2 Turn off all electrical accessories to be sure that the tester is measuring the true output of the alternator.

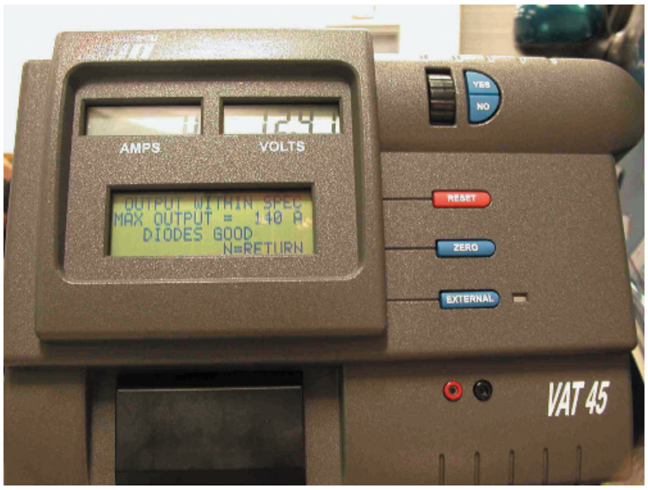

AMPS
VOLTS
OUTPUT WITHIN SPEC
MAX OUTPUT = 140 A
DIODES GOOD
N=RETURN
YES
NO
RESET
ZERO
EXTERNAL
VAT 45

FIGURE 52–13 A typical tester used to test batteries as well as the cranking and charging system. Always follow the operating instructions.

STEP 3 Start the engine and operate it at 2,000 RPM (fast idle). Turn the load increase control slowly to obtain the highest reading on the ammeter scale. Do not allow the voltage to drop below 12.6 volts. Note the ampere reading.

STEP 4 Add 5 to 7 amperes to the reading because this amount of current is used by the ignition system to operate the engine.

STEP 5 Compare the output reading to factory specifications. The rated output may be stamped on the alternator or can be found in service information.

CAUTION: *NEVER* disconnect a battery cable with the engine running. All vehicle manufacturers warn not to do this, because this was an old test, before alternators, to see if a generator could supply current to operate the ignition system without a battery. When a battery cable is removed, the alternator (or PCM) loses the battery voltage sense signal. Without a battery voltage sense circuit, the alternator does one of two things, depending on the make and model of vehicle:

- **The alternator output can exceed 100 volts. This high voltage may damage not only the alternator, but also electrical components in the vehicle, including the PCM and all electronic devices.**
- **The alternator stops charging as a fail-safe measure to protect the alternator and all of the electronics in the vehicle from being damaged due to excessively high voltage.**

MINIMUM REQUIRED ALTERNATOR OUTPUT

PURPOSE All charging systems must be able to supply the electrical demands of the electrical system. If lights and accessories are used constantly and the alternator cannot supply the necessary ampere output, the battery is drained. To determine the minimum electrical load requirements, connect an inductive ammeter probe around either battery cable or the alternator output cable. ● **SEE FIGURE 52–14.**

TECH TIP

Bigger Is Not Always Better

Many technicians are asked to install a higher output alternator to allow the use of emergency equipment or other high-amperage equipment, such as a high-wattage sound system.

Although many higher output units can be physically installed, it is important not to forget to upgrade the wiring and the fusible link(s) in the alternator circuit. Failure to upgrade the wiring could lead to overheating. The usual failure locations are at junctions or electrical connectors.

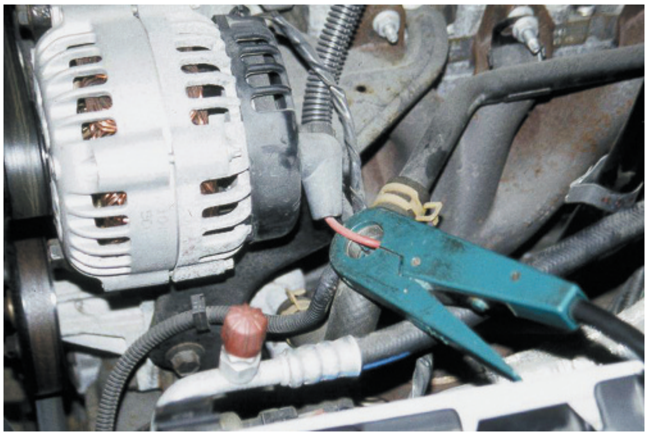


FIGURE 52–14 The best place to install a charging system tester amp probe is around the alternator output terminal wire, as shown in the figure.

NOTE: If using an inductive pickup ammeter, be certain that the pickup is over *all* the wires leaving the battery terminal.

Failure to include the small body ground wire from the negative battery terminal to the body or the small positive wire (if testing from the positive side) *greatly decreases* the current flow readings.

PROCEDURE After connecting an ammeter correctly in the battery circuit, continue as follows:

1. Start the engine and operate to about 2,000 RPM (fast idle).
2. Turn the heat selector to air-conditioning (if the vehicle is so equipped).
3. Turn the blower motor to high speed.
4. Turn the headlights on bright.
5. Turn on the rear defogger.
6. Turn on the windshield wipers.
7. Turn on any other accessories that may be used continuously (do not operate the horn, power door locks, or other units that are not used for more than a few seconds).
8. Observe the ammeter. The current indicated is the electrical load that the alternator is able to exceed to keep the battery fully charged.

TEST RESULTS The minimum acceptable alternator output is 5 amperes greater than the accessory load. A negative (discharge) reading indicates that the alternator is not capable of supplying the current (amperes) that may be needed.

ALTERNATOR REMOVAL

After diagnosis of the charging system has determined that there is a fault with the alternator, it must be removed safely from the vehicle. Always check service information for the exact procedure to follow on the vehicle being serviced. A typical removal procedure includes the following steps:

STEP 1 Disconnect the negative (–) terminal from the battery. (Use a memory saver to maintain radio, memory seats, and other functions.)

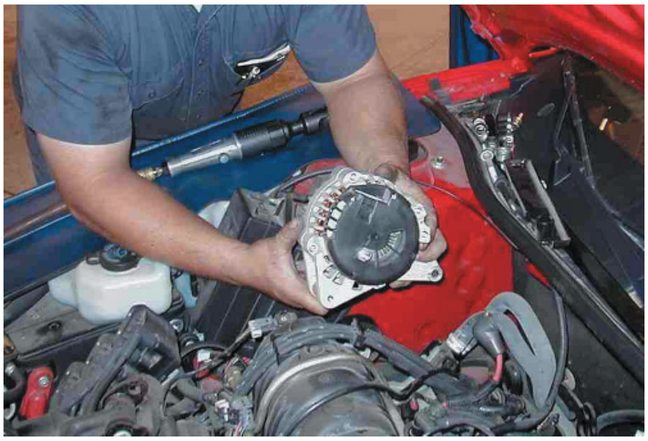


FIGURE 52–15 Replacing an alternator is not always as easy as it is from a Buick with a 3800 V-6, where the alternator is easy to access. Many alternators are difficult to access and require the removal of other components.

STEP 2 Remove the accessory drive belt that drives the alternator.

STEP 3 Remove electrical wiring, fasteners, spacers, and brackets, as necessary, and remove the alternator from the vehicle. ● **SEE FIGURE 52–15**.

ALTERNATOR INSTALLATION

Before installing a replacement alternator, check service information for the exact procedure to follow for the vehicle being serviced. A typical installation procedure includes the following steps:

STEP 1 Verify that the replacement alternator is the correct unit for the vehicle.

STEP 2 Install the alternator wiring on the alternator and install the alternator.

STEP 3 Check the condition of the drive belt and replace, if necessary. Install the drive belt over the drive pulley.

STEP 4 Properly tension the drive belt.

STEP 5 Tighten all fasteners to factory specifications.

STEP 6 Double-check that all fasteners are correctly tightened and remove all tools from the engine compartment area.

STEP 7 Reconnect the negative battery cable.

STEP 8 Start the engine and verify proper charging circuit operation.

CASE STUDY

The Two-Minute Alternator Repair

A Chevrolet pickup truck was brought to a shop for routine service. The customer stated that the battery required a jump start after a weekend of sitting. The technician tested the battery and the charging system voltage using a small handheld digital multimeter. The battery voltage was 12.4 volts (about 75% charged), but the charging voltage was also 12.4 volts at 2,000 RPM. Because normal charging voltage should be 13.5 to 15 volts, it was obvious that the charging system was not operating correctly.

The technician checked the dash and found that the "charge" light was *not* on. Before removing the alternator for service, the technician checked the wiring connection on the alternator. When the connector was removed, it was discovered to be rusty. After the contacts were cleaned, the charging system was restored to normal operation. The technician had learned that the simple things should always be checked first before tearing into a big or expensive repair.

Summary:

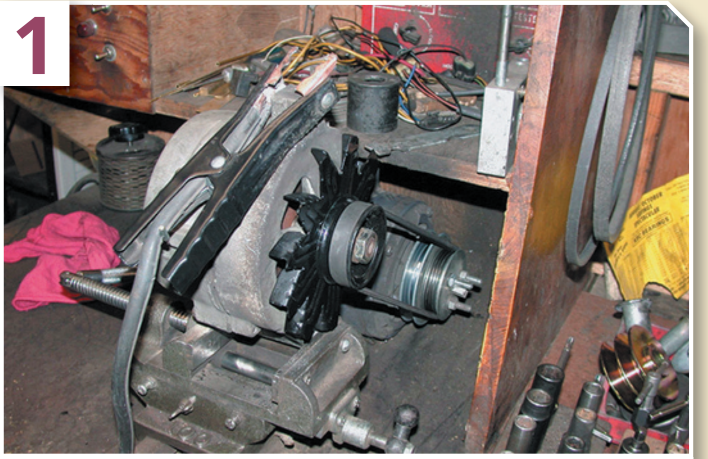
Complaint—Customer stated that the truck battery had to be jump-started after sitting for a weekend.

Cause—Tests confirmed that the alternator was not charging and a rusty connection at the alternator was found during a visual inspection.

Correction—Cleaning the electrical terminals at the alternator restored proper operation of the charging system.

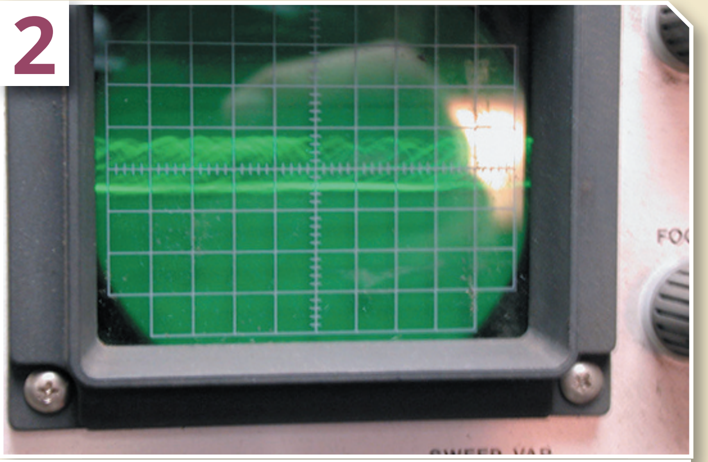
ALTERNATOR OVERHAUL

1



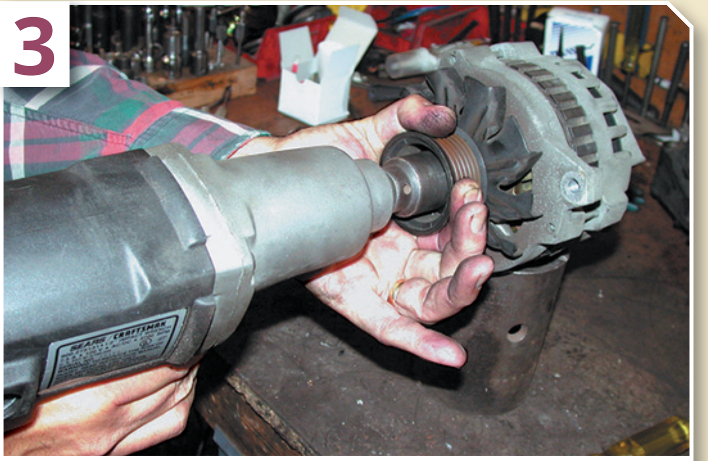
Before the alternator is disassembled, it is spin tested and connected to a scope to check for possible defective components.

2



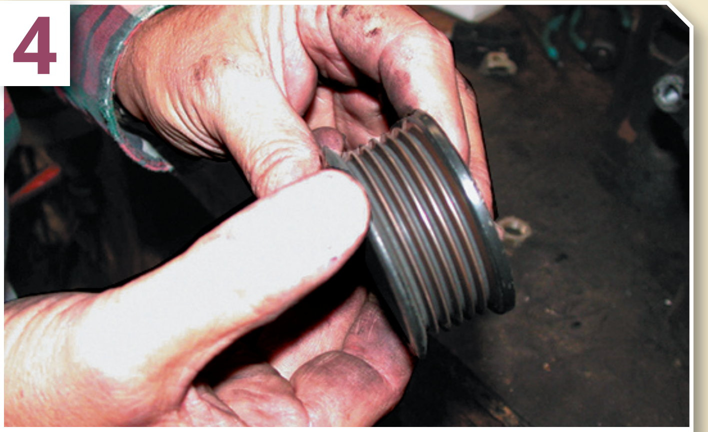
The scope pattern shows that the voltage output is far from being a normal pattern. This pattern indicates serious faults in the rectifier diodes.

3



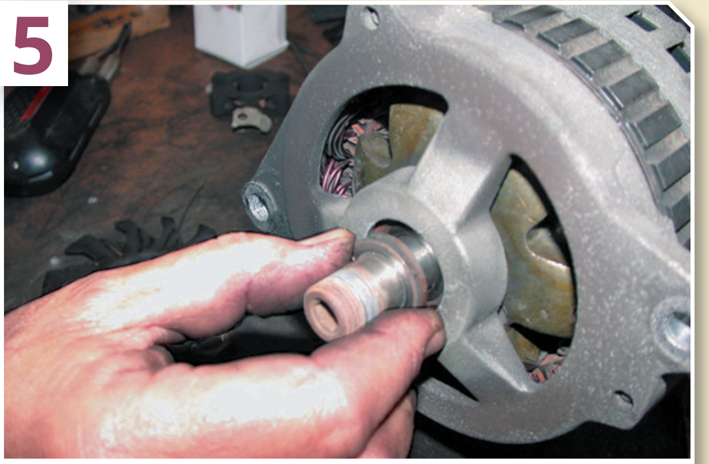
The first step is to remove the drive pulley. This rebuilder is using an electric impact wrench to accomplish the task.

4



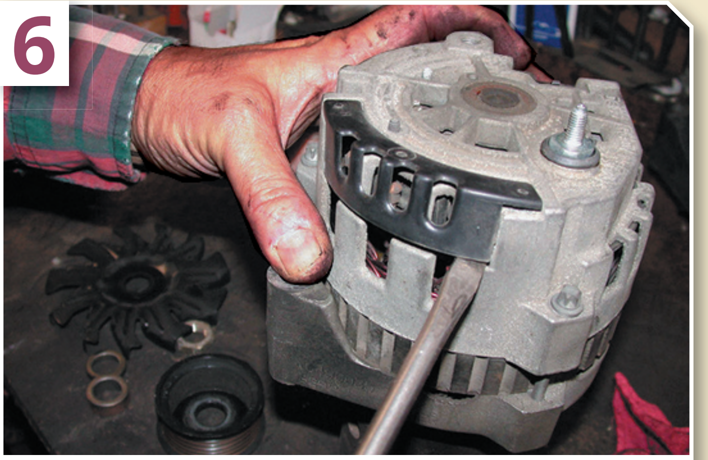
Carefully inspect the drive galley for damage of embedded rubber from the drive belt. The slightest fault can cause a vibration, noise, or possible damage to the alternator.

5



Remove the external fan (if equipped) and then the spacers, as shown.

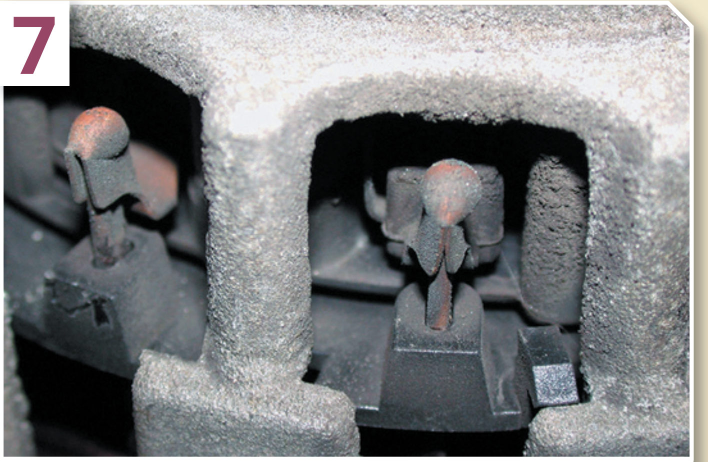
6



Next pop off the plastic cover (shield) covering the stator/rectifier connection.

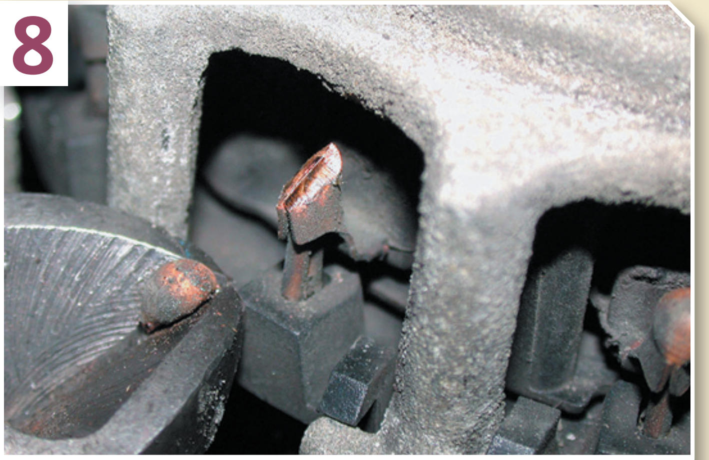
STEP BY STEP

7



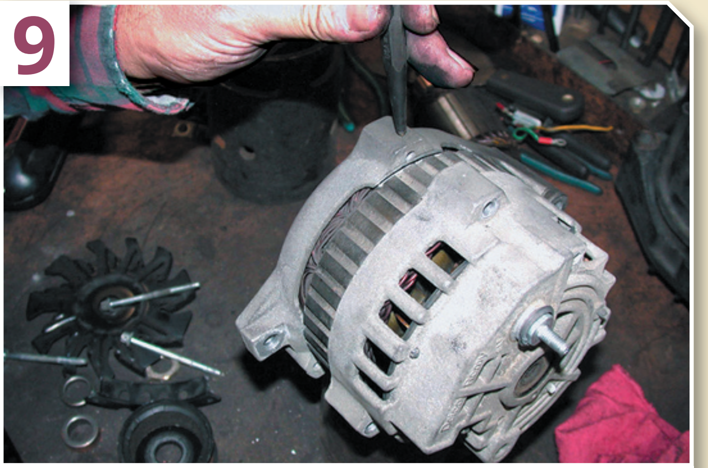
After the cover has been removed, the stator connections to the rectifier can be seen.

8



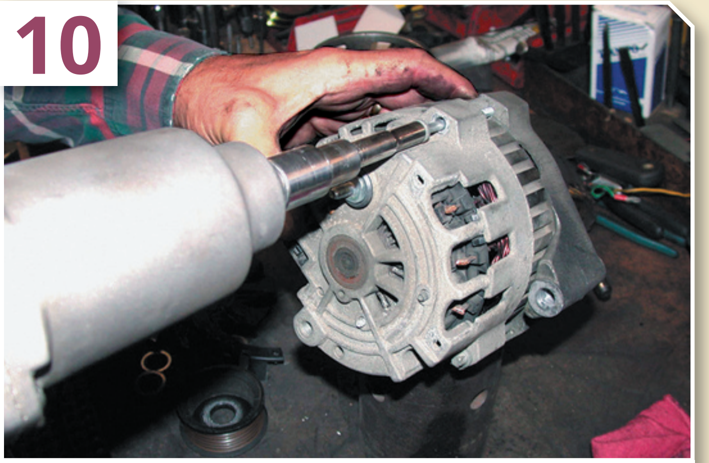
Using a diagonal cutter, cut the weld to separate the stator from the rectifier.

9



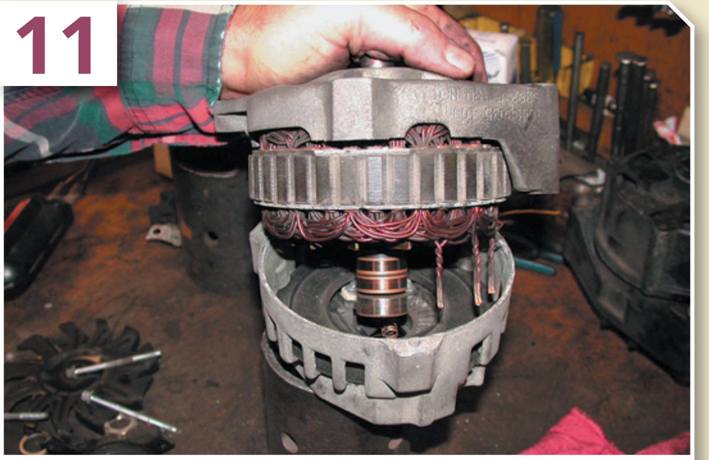
Before separating the halves of the case, this technician uses a punch to mark both halves.

10



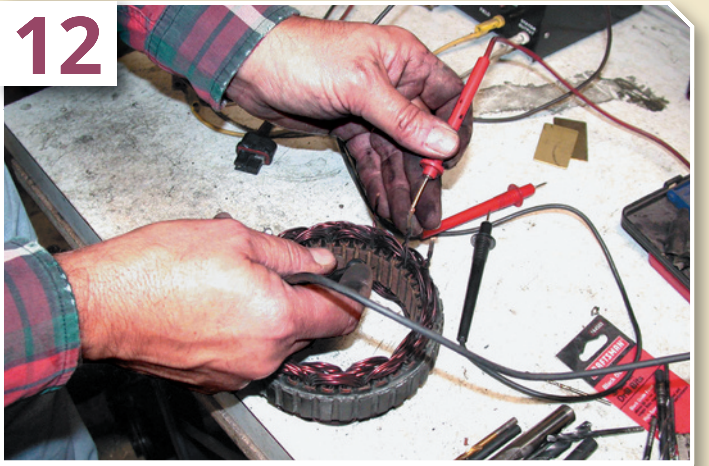
After the case has been marked, the through bolts are removed.

11



The drive-end (DE) housing and the stator are being separated from the rear (slip-ring-end) housing.

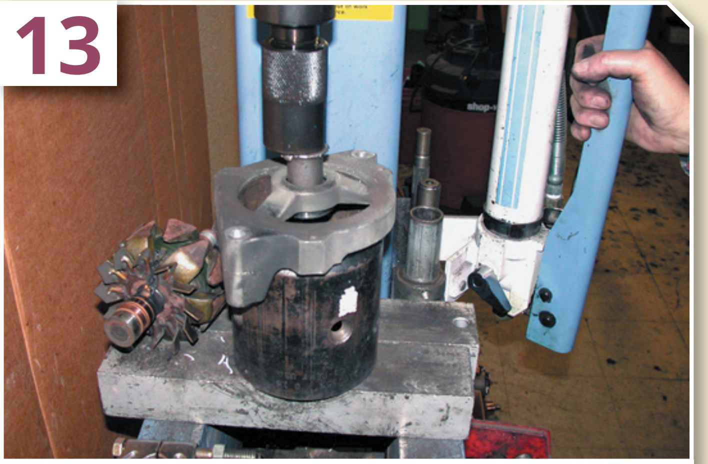
12



The stator is checked by visual inspection for discoloration or other physical damage, and then checked with an ohmmeter to see if the windings are shorted-to-ground.

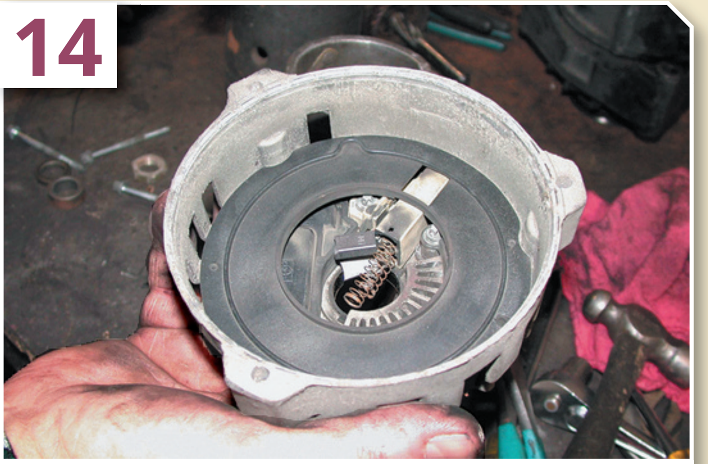
ALTERNATOR OVERHAUL

13



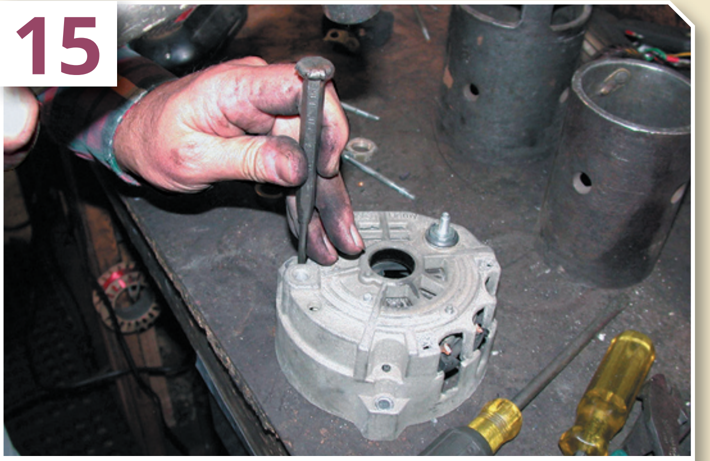
The front bearing is removed from the drive-end housing using a press.

14



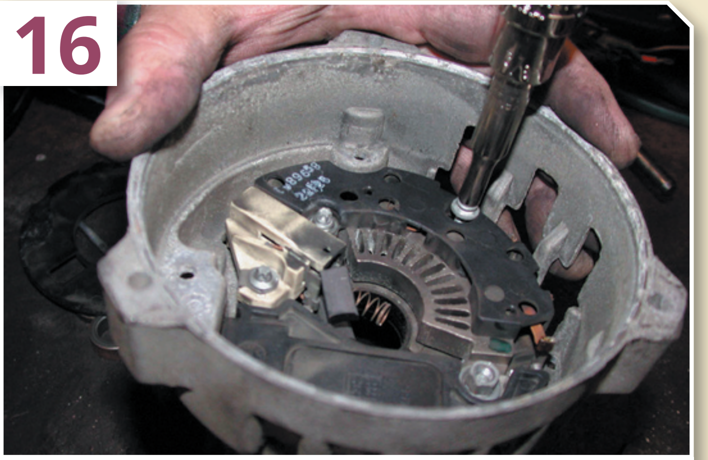
A view of the slip-ring-end (SRE) housing showing the black plastic shield, which helps direct air flow across the rectifier.

15



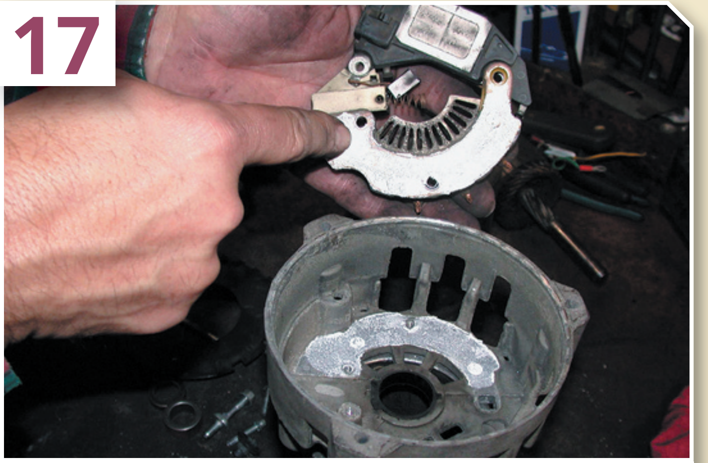
A punch is used to dislodge the plastic shield retaining clips.

16



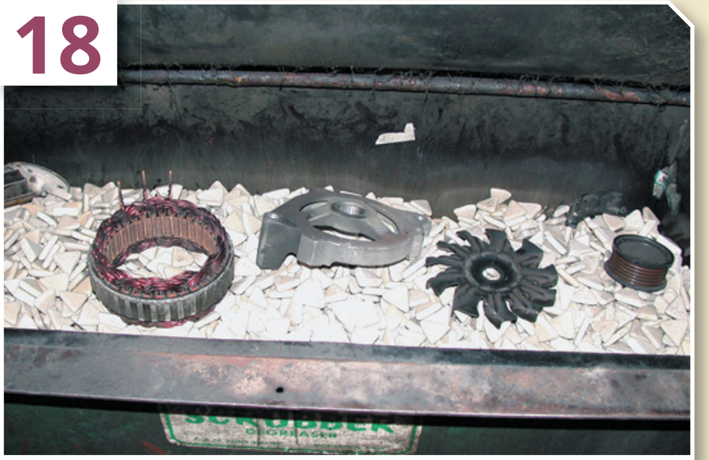
After the shield has been removed, the rectifier, regulator, and brush holder assembly can be removed by removing the retaining screws.

17



The heat transfer grease is visible when the rectifier assembly is lifted out of the rear housing.

18

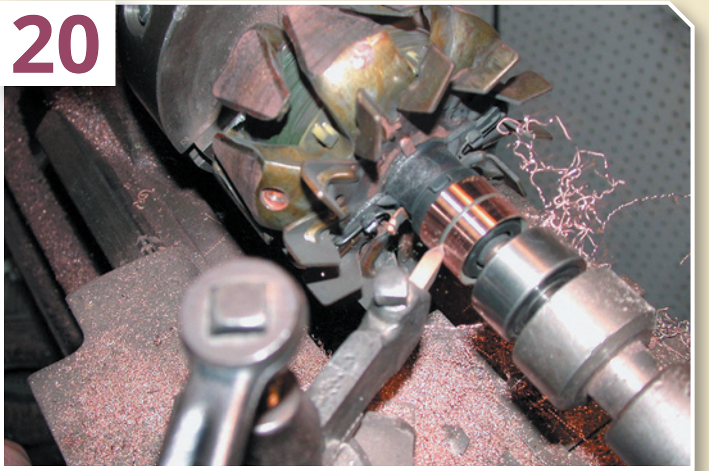


The parts are placed into a tumbler where ceramic stones and a water-based solvent are used to clean the parts.

19

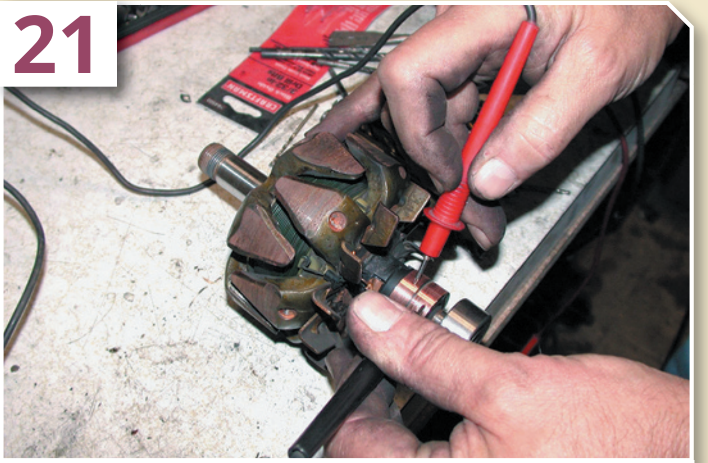
This rebuilder is painting the housing using a high-quality industrial grade spray paint to make the rebuilt alternator look like new.

20



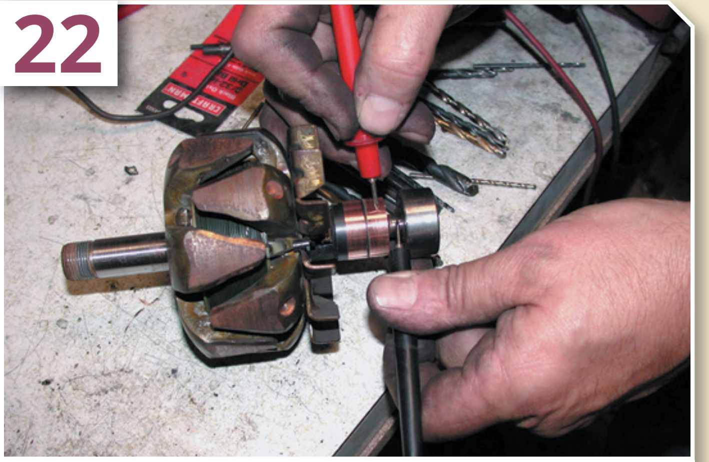
The slip rings on the rotor are being machined on a lathe.

21



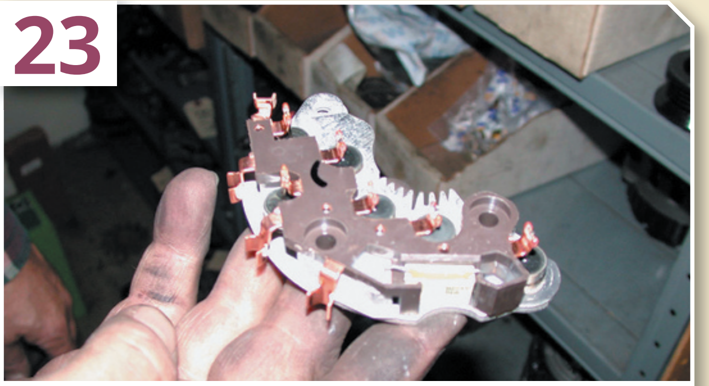
The rotor is being tested using an ohmmeter. The specifications for the resistance between the slip rings on the CS-130 are 2.2 to 3.5 ohms.

22



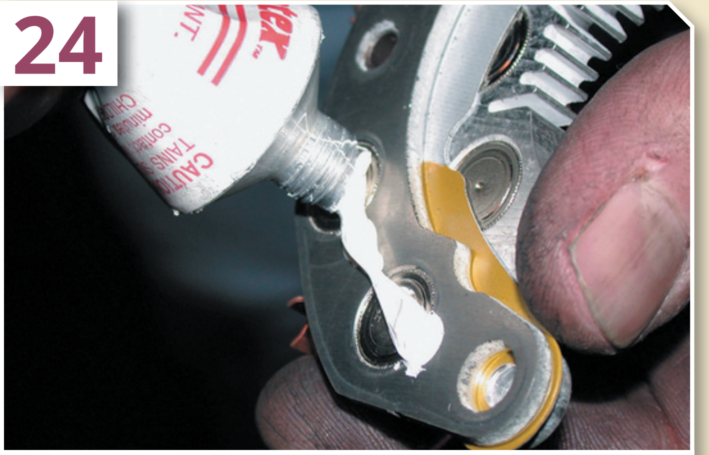
The rotor is also tested between the slip ring and the rotor shaft. This reading should be infinity.

23



A new rectifier. This replacement unit is significantly different than the original but is designed to replace the original unit and meets the original factory specifications.

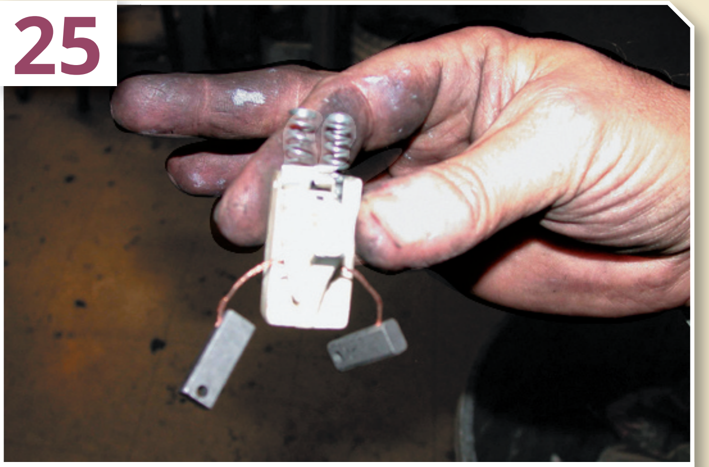
24



Silicone heat transfer compound is applied to the heat sink of the new rectifier.

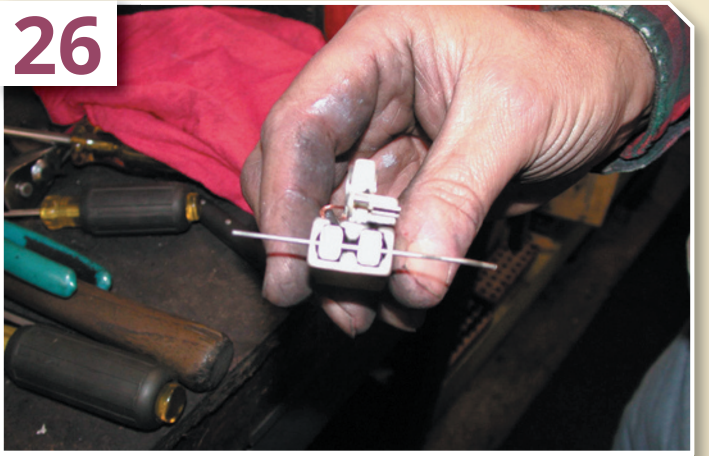
ALTERNATOR OVERHAUL

25



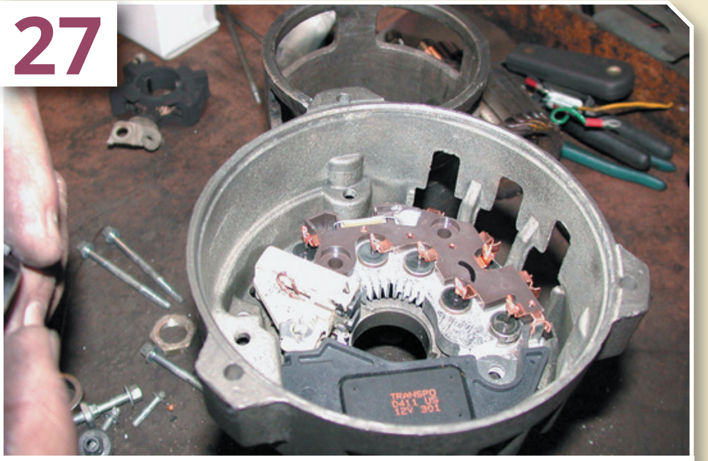
Replacement brushes and springs are assembled into the brush holder.

26



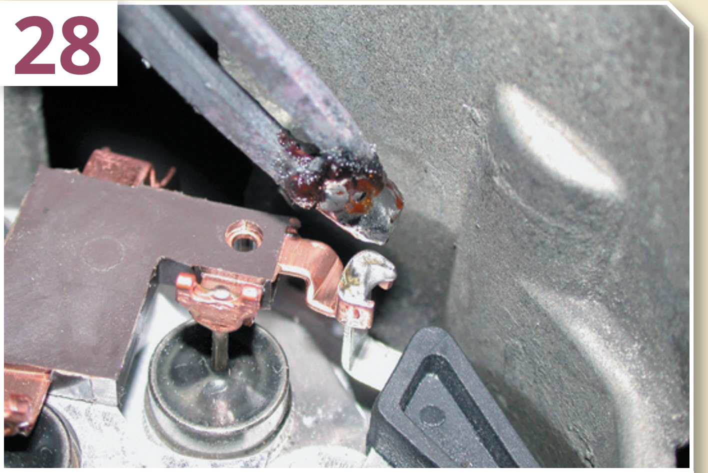
The brushes are pushed into the brush holder and retained by a straight wire, which extends through the rear housing of the alternator. This wire is then pulled out when the unit is assembled.

27



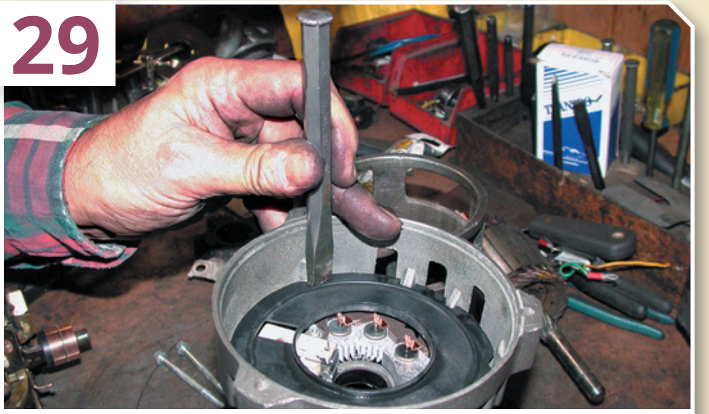
Here is what the CS alternator looks like after installing the new brush holder assembly, rectifier bridge, and voltage regulator.

28



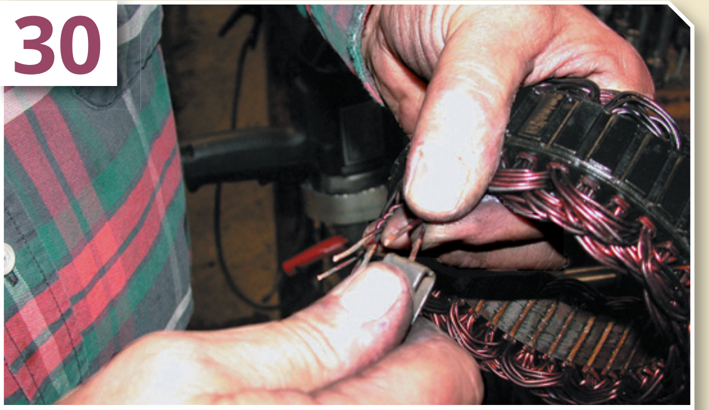
The junction between the rectifier bridge and the voltage regulator is soldered.

29



The plastic deflector shield is snapped back into location using a blunt chisel and a hammer. This shield directs the airflow from the fan over the rectifier bridge and voltage regulator.

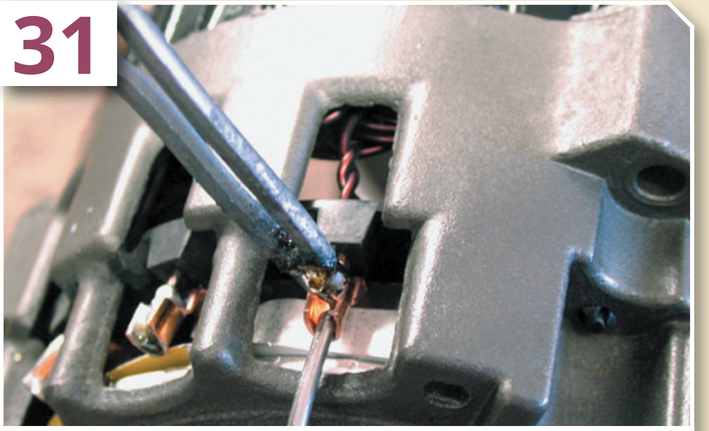
30



Before the stator windings can be soldered to the rectifier bridge, the varnish insulation is removed from the ends of the leads.

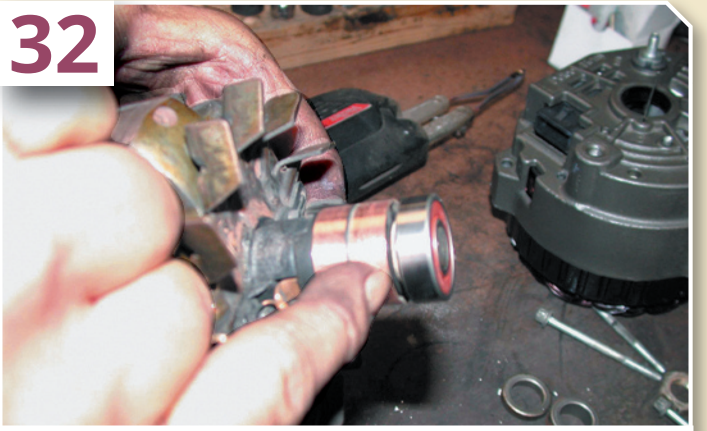
STEP BY STEP

31



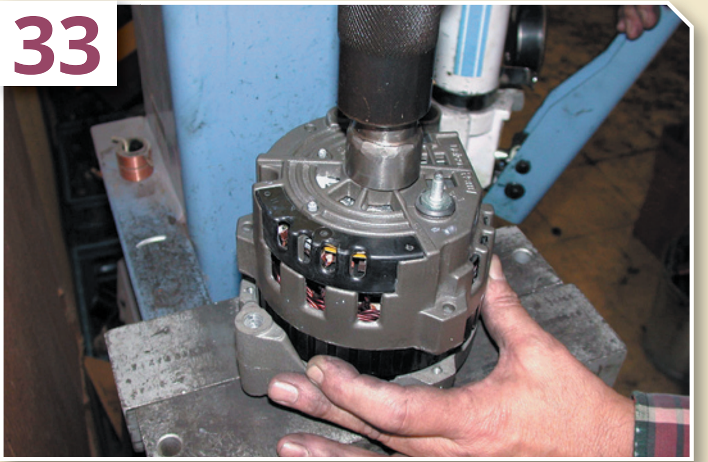
After the stator has been inserted into the rear housing, the stator leads are soldered to the copper lugs of the rectifier bridge.

32



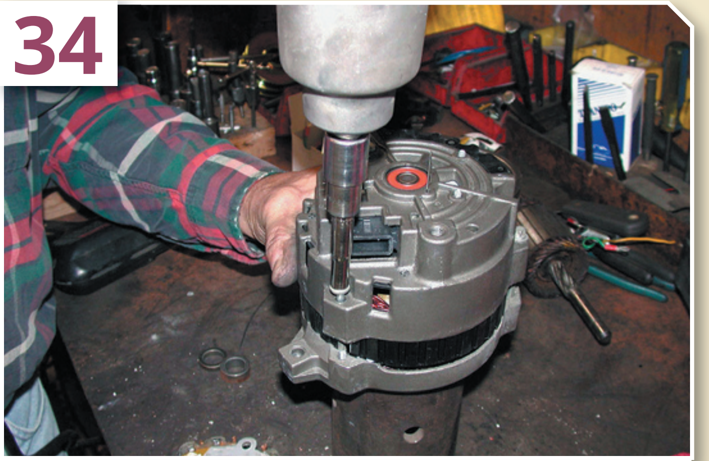
New bearings are installed. A spacer is placed between the bearing and the slip rings to help prevent the possibility that the bearing could move on the shaft and short against the slip ring.

33



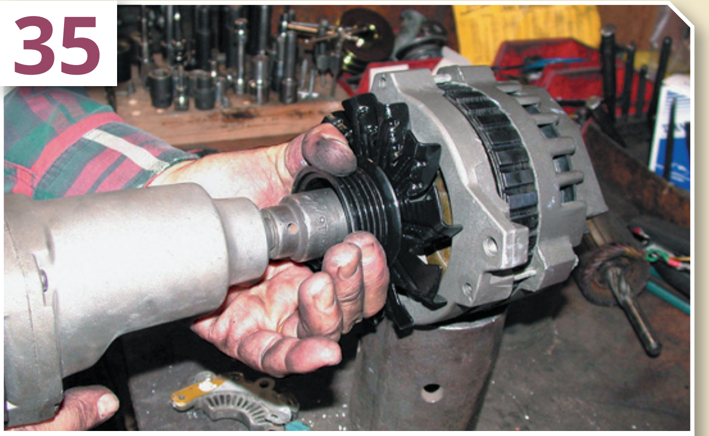
The slip-ring-end housing is aligned with the marks made during disassembly and is pressed into the drive-end housing.

34



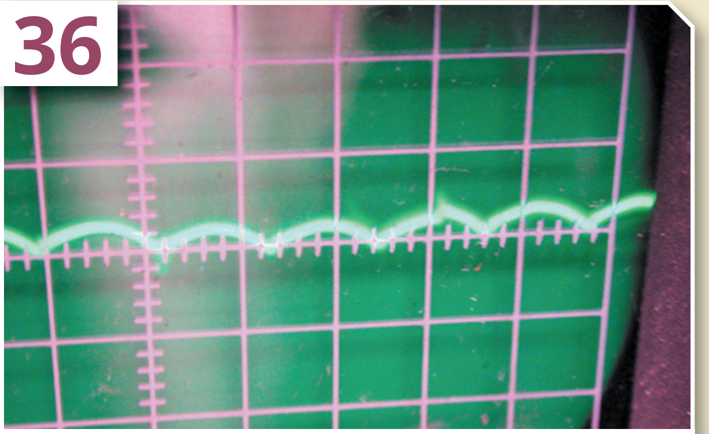
The retaining bolts, which are threaded into the drive-end housing from the back of the alternator, are installed.

35



The external fan and drive pulley are installed and the retaining nut is tightened on the rotor shaft.

36



The scope pattern shows that the diodes and stator are functioning correctly and voltage check indicates that the voltage regulator is also functioning correctly.

REVIEW QUESTIONS

1. How does a technician test the voltage drop of the charging circuit?
2. How does a technician measure the amperage output of an alternator?
3. What tests can be performed to determine whether a diode or stator is defective before removing the alternator from the vehicle?
4. Why could a defective overrunning alternator pulley (OAP) or dampener (OAD) cause a lack of proper charging?
5. What is procedure for replacing an alternator?

CHAPTER QUIZ

1. To check the charging voltage, connect a digital multimeter (DMM) to the positive (+) and the negative (–) terminals of the battery and select __________.
   - **a.** DC volts
   - **b.** AC volts
   - **c.** DC amps
   - **d.** AC amps
2. To check for ripple voltage from the alternator, connect a digital multimeter (DMM) and select __________ .
   - **a.** DC volts
   - **b.** AC volts
   - **c.** DC amps
   - **d.** AC amps
3. Which of the following would NOT be used to check drive belt wear?
   - **a.** Groove color change
   - **b.** A tension gauge
   - **c.** A belt wear gauge
   - **d.** Belt deflection between two pulleys
4. When performing an alternator output test, which tool should the technician choose?
   - **a.** An electronic torque wrench
   - **b.** An ohmmeter
   - **c.** A load tester
   - **d.** A vacuum gauge
5. An acceptable AC ripple current is __________ .
   - **a.** less than 100 amperes
   - **b.** 10 amperes or more
   - **c.** less than 10% of the rated output
   - **d.** None of the above
6. If the overrunning alternator pulley were to fail, what is the likely result?
   - **a.** Over charging
   - **b.** The alternator would not charge at all
   - **c.** The drive belt will become loose
   - **d.** Both a and c
7. Technician A says that a voltage drop test of the charging circuit should only be performed when current is flowing through the circuit. Technician B says to connect the leads of a voltmeter to the positive and negative terminals of the battery to measure the voltage drop of the charging system. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. When testing an alternator minimum required output, what is the acceptable reading?
   - **a.** 2 to 5 amperes
   - **b.** Five amperes greater than the accessory load
   - **c.** Over 100 amperes higher than the accessory load
   - **d.** Less than 3 amperes
9. What action should be performed when replacing an alternator?
   - **a.** Disconnect the negative battery cable.
   - **b.** Disconnect the positive battery cable.
   - **c.** Remove the drive belt.
   - **d.** Both a and c
10. What action should be performed when installing a replacement alternator?
    - **a.** Verify that the replacement alternator is the correct part.
    - **b.** Check the condition of the drive belt and replace if needed.
    - **c.** Tighten all fasteners to factory specifications.
    - **d.** All of the above

Chapter

53

LIGHTING AND SIGNALING CIRCUITS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain lighting systems in an automobile.
- List the advantages of using LED lights.
- Read and interpret a bulb chart.
- Discuss the operation of brake lights.
- Discuss the operation of turn signals.
- Describe daytime running lights.
- Describe headlights.
- Describe high-intensity discharge headlights.
- Describe LED headlights.
- Describe adaptive front lighting systems.
- Describe automatic headlights.
- Describe the headlight high-/low-beam switch.
- Describe auto-dimming headlights.
- Describe how to aim headlights.
- Describe fog lights and driving lights.
- Describe automatic dimming mirrors.
- Describe courtesy lights.
- Describe illuminated entry.
- Explain the procedures to inspect and troubleshoot the headlight system.
- Explain the procedures to diagnose the lighting and signaling system.

KEY TERMS:

Adaptive front lighting system (AFS) 619 • Automatic headlights 620 • Composite headlight 616 • Courtesy lights 623 • Daytime running lights (DRLs) 615 • Hazard warning 615 • High-intensity discharge (HID) 617 • Kelvin (K) 618 • Light-emitting diode (LED) 610 • Trade number 612 • Troxler effect 622

LIGHTING SYSTEMS

CIRCUITS INVOLVED A vehicle has many different lighting and signaling systems, each with its own specific components and operating characteristics. The major light-related circuits and systems covered in this chapter include the following:

- Exterior lighting
- Headlights
- Brake lights
- Turn signals and flasher units
- Courtesy lights
- Light-dimming rearview mirrors

NON-COMPUTER-CONTROLLED LIGHTING Older vehicles used the headlight switch to operate all the lights, including

1. Headlights
2. Taillights
3. Side-marker lights
4. Front parking lights
5. Dash lights
6. Interior (dome) light(s)

The headlight switch assembly on older vehicles carried a heavy current and was mechanical. Most contained a built-in circuit breaker for circuit protection. ● **SEE FIGURE 53–1**.

BODY CONTROL MODULE-CONTROLLED LIGHTING The **Body Control Module (BCM)** is often referred to as a *central organizational module*. Using a BCM results in the following benefits:

1. It simplifies the manufacturing and troubleshooting aspects of electronic modules.
2. It coordinates the operating functions of many related items, as well as security features.

All recent vehicles use a controller, usually the body control module (BCM), to control the lights. The switches to turn on the lights are simply a request from the switch to the BCM to turn

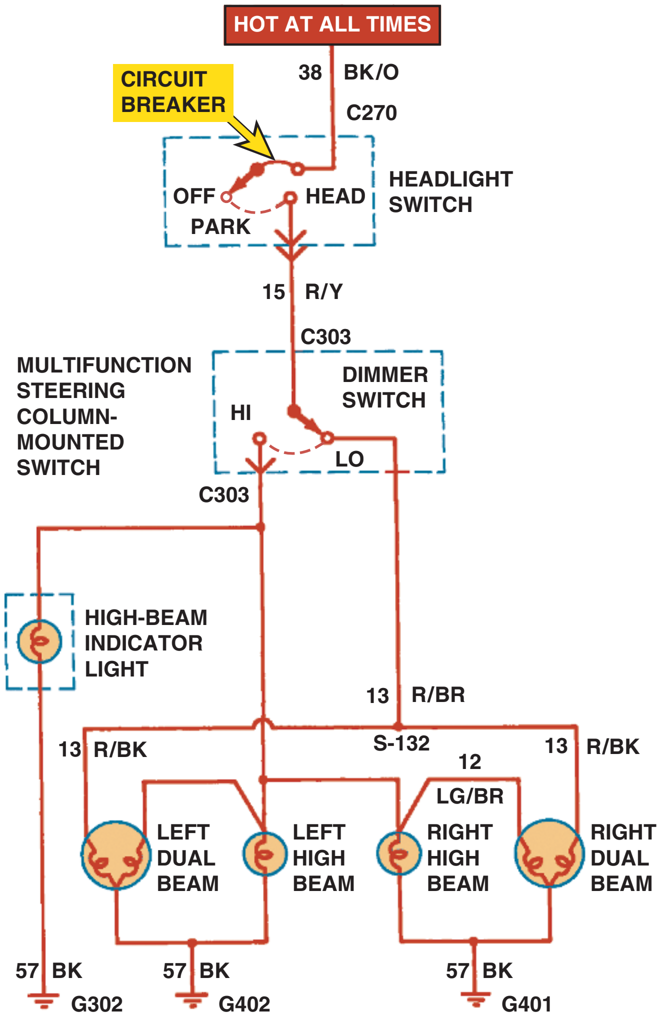


FIGURE 53–1 A typical headlight circuit diagram on an older vehicle that does not use a controller, such as the body control module (BCM) to control the operation of the lights. Note that the headlight switch is represented by a dotted outline indicating that other circuits (such as dash lights) also operate from the switch.

on the lights. The communication between the switches and the BCM is over serial data lines. Many vehicles use front and rear lighting modules, so the BCM sends a message over the data lines to the front or rear lighting module to turn on the commanded lights. The controller can control either the power side or the ground side of the circuit and performs the following:

- Monitors the current flow through the circuit and turns on a bulb failure warning light if it detects an open bulb or a fault in the circuit.
- After the ignition has been turned off, the modules turn off the lights after a time delay to prevent the battery from being drained.
- In the event of a communication failure, most module-controlled exterior lighting systems default to on position for safety.

Many electronic components are controlled by the BCM, including the following lighting circuits:

- Brake lights
- Courtesy lamps
- Dome lamps
- Exterior and interior lamps
- Fog lamps
- Hazard warning lamps
- Low- and high-beam head lamps
- Parking lamps
- Turn-signal lamps

● **SEE FIGURE 53–2.**

LED LIGHTING

PARTS AND OPERATION A **light-emitting diode (LED)** is a two-lead semiconductor light source. An LED is a P–N junction diode that emits light when a suitable voltage is applied to the leads. The electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. ● **SEE FIGURE 53–3.**

LED FEATURES LED lights are frequently used in newer vehicles for the following reasons:

1. **Faster illumination.** Using LEDs in brake lights light up 200 ms faster than an incandescent bulb, which requires some time to heat the filament before it is hot enough to create light. This faster illumination, when used in brake lights, can mean the difference in stopping distances at 60 MPH 60 MPH (100 km/h) by about 18 feet (6 m) due to the reduced reaction time for the driver of the vehicle behind.
2. **Longer service life.** LEDs are solid-state devices that do not use a filament to create light. As a result, they are less susceptible to vibration and often last the life of the vehicle.
3. **Lower current draw.** LEDs draw less current compared to incandescent bulbs and the result is less electrical drain from the charging system to operate all the lights in the vehicle. This helps improve fuel economy and lowers exhaust emissions by reducing the electrical load created by the alternator on the engine.

NOTE: Aftermarket replacement LED bulbs that are used to replace conventional bulbs may require the use of a different type of flasher unit due to the reduced current draw of the LED bulbs. ● **SEE FIGURE 53–4.**

TESTING BULBS Bulbs can be tested using two basic tests.

1. Perform a visual inspection of any bulb. Many faults, such as a shorted filament, a corroded connector, or moisture, can cause weird problems that are often thought to be wiring issues.
2. Bulbs can be tested using an ohmmeter and checking the resistance of the filament(s). Most bulbs read low resistance, between 0.5 and 20 ohms (incandescent bulbs), at room temperature, depending on the bulb. Test results include the following:
    - Normal resistance. The bulb is good. Check both filaments if it is a two-filament bulb.
    - Zero ohms. It is unlikely, but possible for the bulb filament to be shorted.
    - OL (electrically open). The reading indicates that the bulb filament is broken.

NOTE: If testing LED lights, check service information for the specified testing procedure.

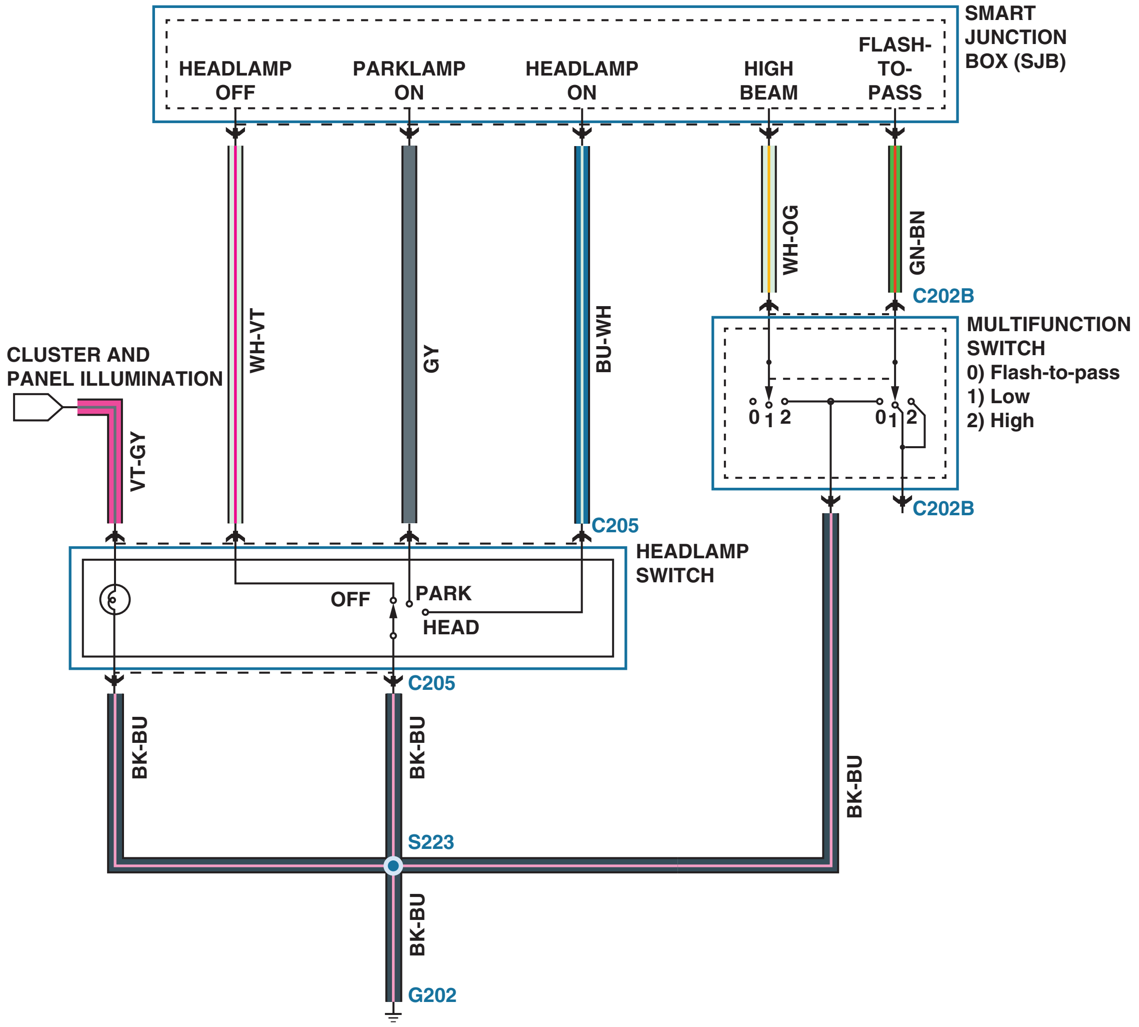

SMART JUNCTION BOX (SJB)
HEADLAMP OFF
PARKLAMP ON
HEADLAMP ON
HIGH BEAM
FLASH-TO-PASS
WH-VT
GY
BU-WH
WH-OG
GN-BN
C202B
MULTIFUNCTION SWITCH
0) Flash-to-pass
1) Low
2) High
0 1 2
0 1 2
C202B
CLUSTER AND PANEL ILLUMINATION
VT-GY
C205
HEADLAMP SWITCH
OFF
PARK
HEAD
C205
BK-BU
BK-BU
BK-BU
S223
BK-BU
G202

FIGURE 53–2 A schematic showing the inputs from the multifunction switch and the headlight switch to the smart junction box (SJB). The SJB then uses the body control module (BCM) to operate the lights.

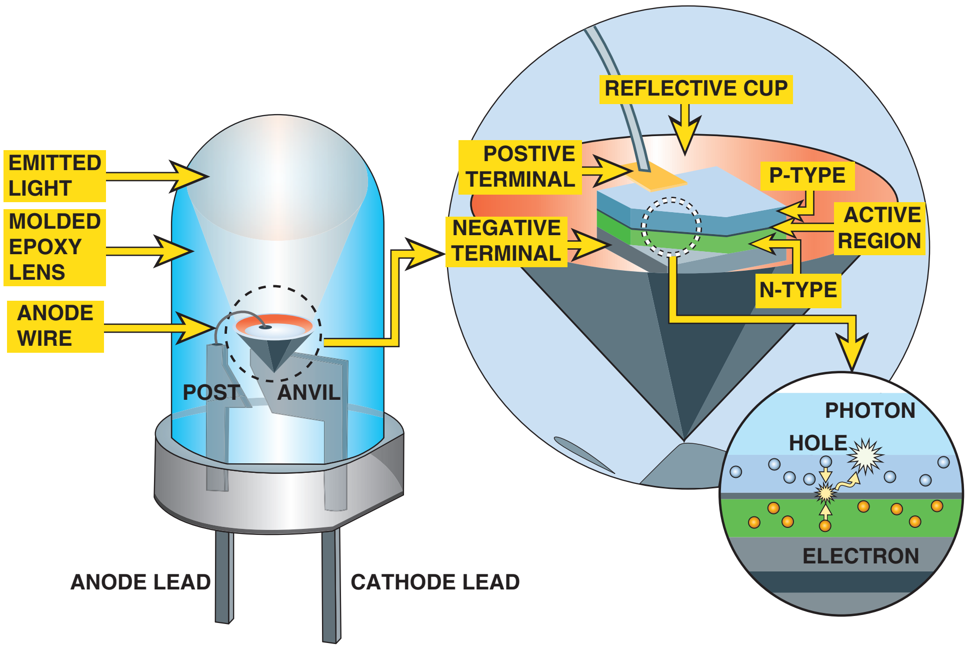

EMITTED LIGHT
MOLDED EPOXY LENS
ANODE WIRE
POST
ANVIL
ANODE LEAD
CATHODE LEAD
REFLECTIVE CUP
POSTIVE TERMINAL
NEGATIVE TERMINAL
P-TYPE
ACTIVE REGION
N-TYPE
PHOTON
HOLE
ELECTRON

FIGURE 53–3 An LED emits light when a photon is released at the P–N junction.

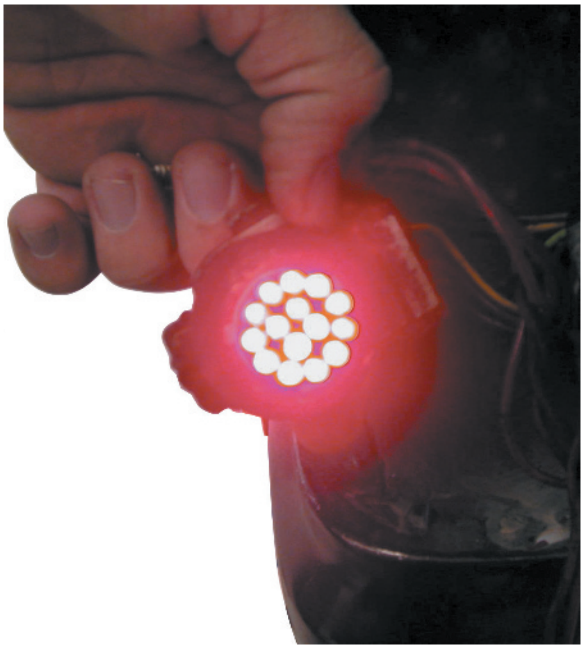


FIGURE 53–4 A replacement LED taillight bulb is constructed of many small, individual light-emitting diodes.

BULB NUMBERS

TRADE NUMBER The number used on automotive bulbs is called the bulb **trade number**, as recorded with the American National Standards Institute (ANSI). The number is the same regardless of the manufacturer. ● **SEE FIGURE 53–5.**

The amount of light produced by a bulb is determined by the resistance of the filament wire, which also affects the amount of current (in amperes) required by the bulb. The correct trade number of a bulb should always be used for replacement to prevent circuit or component damage. Check service information or the owner's manual for the exact replacement bulb to use. ● **SEE CHART 53–1**.

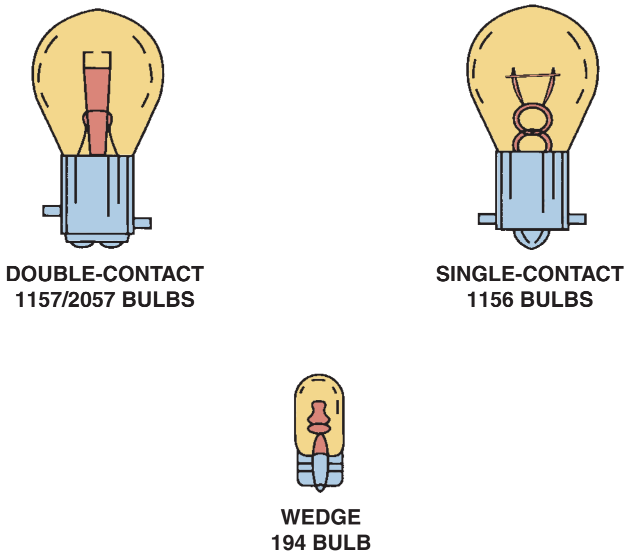


FIGURE 53–5 Dual-filament (double-contact) bulbs contain both a low-intensity filament for taillights or parking lights, and a high-intensity filament for brake lights and turn signals. Bulbs come in a variety of shapes and sizes. The numbers shown are the trade numbers.

BULB NUMBER	FILAMENTS	AMPERAGE	WATTAGE
1156	1	2.1	26.9
1157	2	0.6/2/1	8.3/26.9
2057	2	0.5/2.1	6.9/26.9
3057	2	0.5/2.1	6.7/26.9
4157	2	0.6/2/1	8.3/26.9
7440	1	1.8	21.0
7443	2	0.4/1.8	5.0/21.0
67	1	0.6	8.0
161	1	0.2	2.7
168	1	0.4	4.9
192	1	0.3	4.3
194	1	0.3	3.8
585	1	0.04	1.1
921	1	1.4	18
9003	2	4.6/5.0	55.0/60.0
9006	1	4.3	55.0

CHART 53–1

Some automotive bulb trade numbers with their amperage and wattage rating. Check service information for the exact bulb to use.

BULB NUMBER SUFFIXES Many bulbs have suffixes that indicate some feature of the bulb, while keeping the same size and light output specifications. Typical bulb suffixes include the following:

- A—amber (painted glass)
- B—blue
- G—green
- HD—heavy duty
- IF—inside frosted
- LL—long life
- NA—natural amber (amber glass)
- Q—quartz halogen
- R—red

● **SEE FIGURE 53–6.**

BRAKE LIGHTS

TERMINOLOGY Brake lights, also called *stop lights*, use the high-intensity filament of a double-filament bulb or LEDs. The brake lights are lit when the driver depresses the brake pedal. On older vehicles, the brake switch receives current from a fuse that is hot all the time. The brake light switch is a normally open (N.O.) switch, but is closed when the driver depresses the brake pedal. Newer brake switches have more than one set of contacts. In many cases, one set is normally open and the other set is normally closed.

- **One-Filament Stop/Turn Bulbs**—In some vehicles, the stop and turn signals are both provided by one filament.

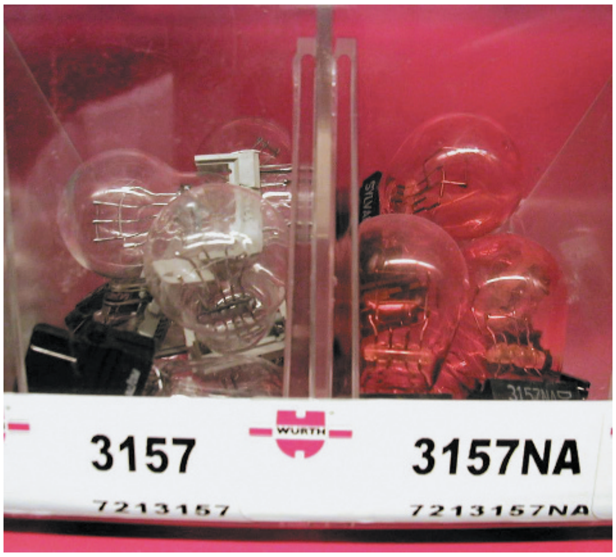

3157
WURTH
3157NA
7213157
7213157NA

FIGURE 53–6 Bulbs that have the same trade number have the same operating voltage and wattage. NA means that the bulb uses a natural amber glass ampoule with clear turn-signal lenses.

- **Two-Filament Stop/Turn Bulbs**—In systems using separate filaments for the stop and turn lamps, the brake and turn-signal switches are not connected.

All vehicles sold in the United States have a third brake light commonly referred to as the *center high-mounted stop light (CHMSL).* ● **SEE FIGURE 53–7**.

BCM-CONTROLLED BRAKE LIGHTS When the brake pedal is depressed, the signal is sent to the brake light controller, usually the BCM, which then signals the rear light module to actuate the brake lights. The input from the brake pedal switch or sensor is used by other systems in the vehicle as an input signal for the following systems:

1. **Shift interlock**—On vehicles equipped with an automatic transmission, the gear selector cannot be moved out of the park position unless the brake pedal is depressed.
2. **Push-button start**—Vehicles equipped with a push-button start do not start unless the brake pedal is depressed.
3. **Cruise control**—If the brake pedal is depressed, the cruise control function is disabled.

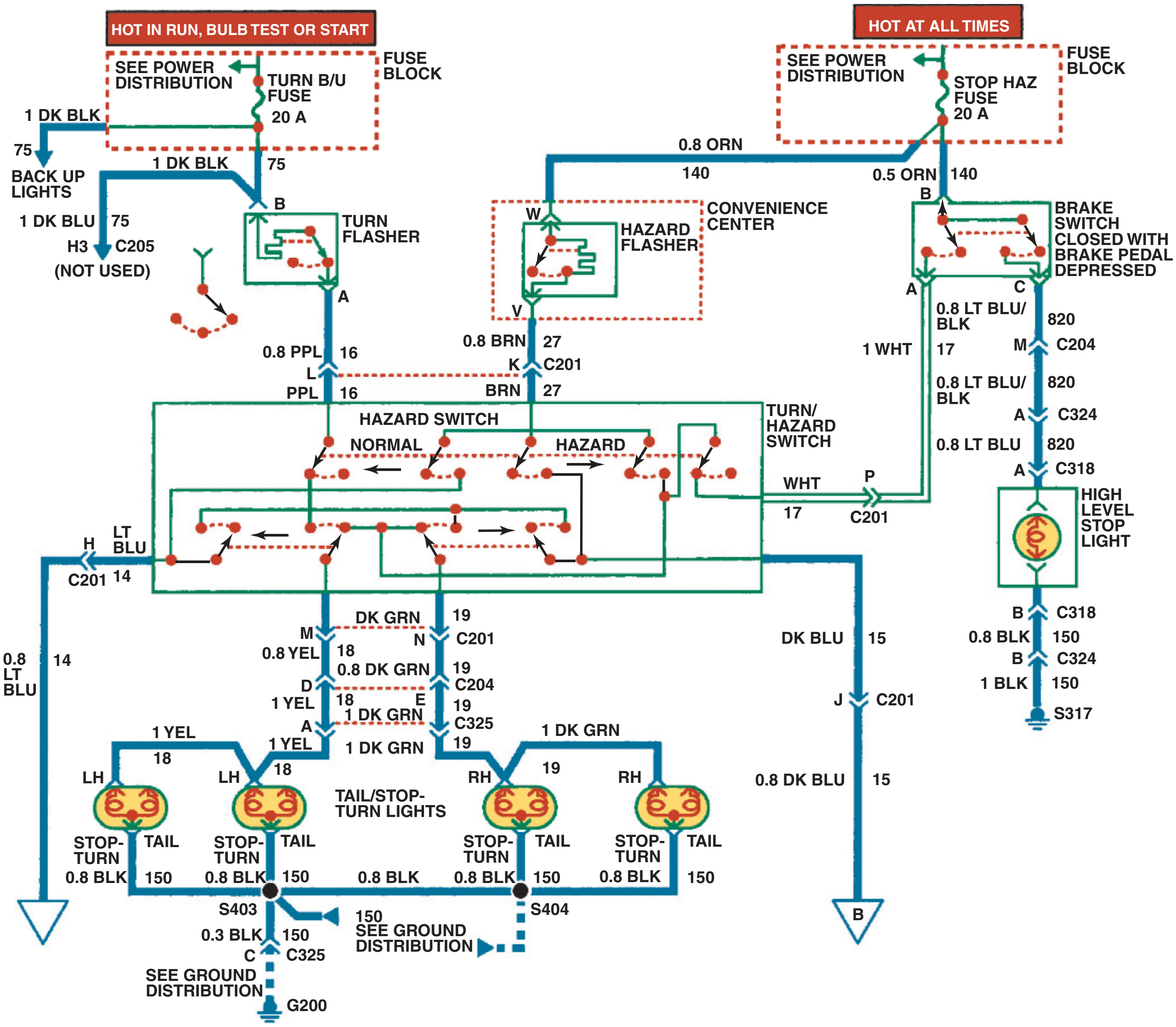

HOT IN RUN, BULB TEST OR START
SEE POWER DISTRIBUTION
TURN B/U FUSE 20 A
FUSE BLOCK
1 DK BLK
75
BACK UP LIGHTS
1 DK BLK
75
1 DK BLU
75
H3
C205
(NOT USED)
B
TURN FLASHER
A
HOT AT ALL TIMES
SEE POWER DISTRIBUTION
STOP HAZ FUSE 20 A
FUSE BLOCK
0.8 ORN
140
0.5 ORN
140
B
W
HAZARD FLASHER
CONVENIENCE CENTER
V
BRAKE SWITCH CLOSED WITH BRAKE PEDAL DEPRESSED
A
C
0.8 PPL
16
L
PPL
16
0.8 BRN
27
K
C201
BRN
27
1 WHT
0.8 LT BLU/ BLK
17
820
M
C204
0.8 LT BLU/ BLK
820
A
C324
0.8 LT BLU
820
A
C318
HAZARD SWITCH
NORMAL
HAZARD
TURN/ HAZARD SWITCH
WHT
P
17
C201
HIGH LEVEL STOP LIGHT
H
LT BLU
C201
14
0.8 LT BLU
14
DK GRN
19
M
N
C201
0.8 YEL
18
0.8 DK GRN
19
D
C204
1 YEL
18
E
19
1 DK GRN
A
C325
1 YEL
19
1 DK GRN
1 YEL
18
1 DK GRN
DK BLU
15
J
C201
B
C318
0.8 BLK
150
B
C324
1 BLK
150
S317
LH
18
LH
18
RH
19
19
RH
TAIL/STOP-TURN LIGHTS
0.8 DK BLU
15
STOP-TURN
TAIL
STOP-TURN
TAIL
STOP-TURN
TAIL
STOP-TURN
TAIL
0.8 BLK
150
0.8 BLK
150
0.8 BLK
0.8 BLK
150
0.8 BLK
150
S403
150
SEE GROUND DISTRIBUTION
S404
0.3 BLK
150
C
C325
SEE GROUND DISTRIBUTION
G200
B

FIGURE 53–7 A typical older-type brake light circuit showing the brake switch and all of the related circuit components.

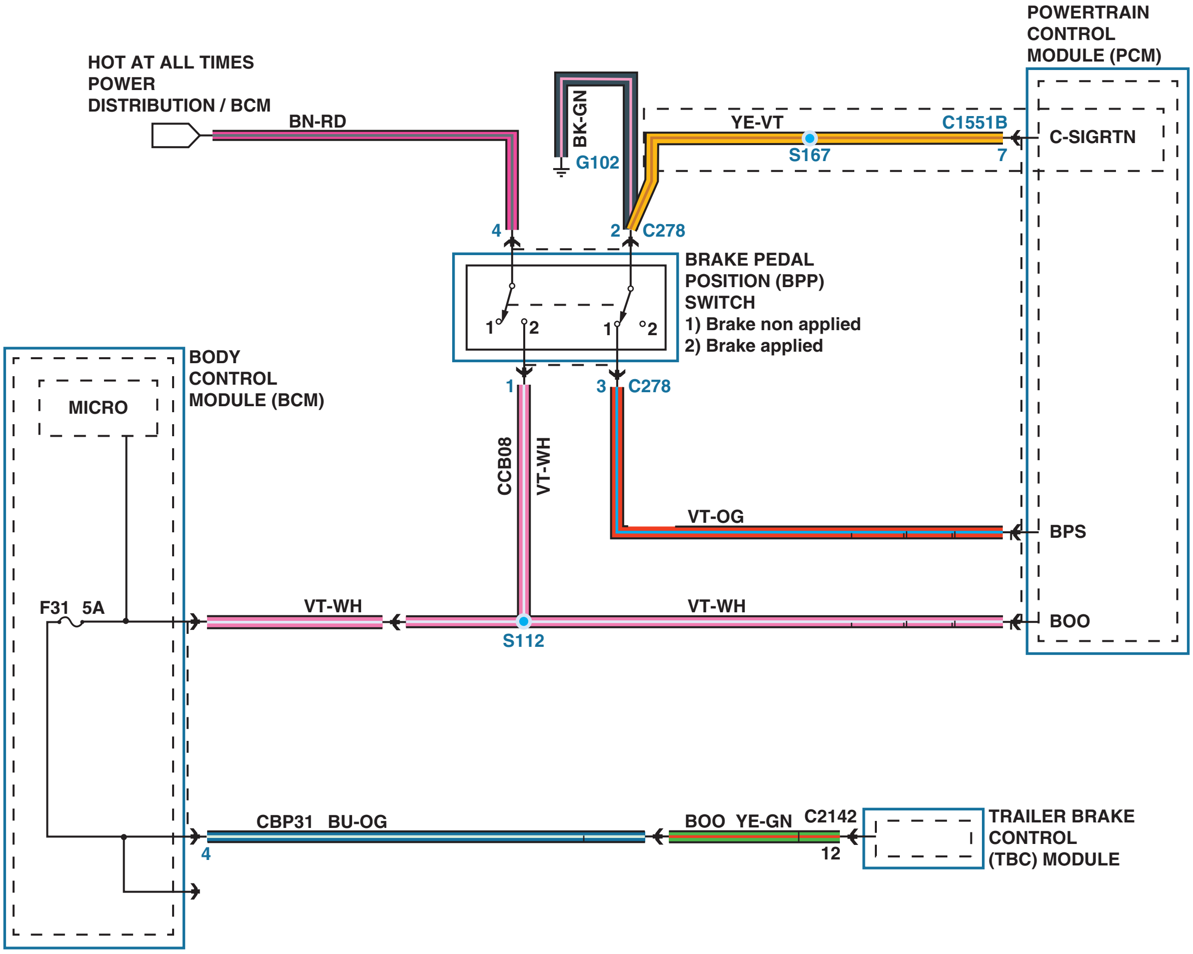

POWERTRAIN
CONTROL
MODULE (PCM)
HOT AT ALL TIMES
POWER
DISTRIBUTION / BCM
BN-RD
BK-GN
G102
YE-VT
C1551B
S167
7
C-SIGRTN
4
2
C278
BRAKE PEDAL
POSITION (BPP)
SWITCH
1) Brake non applied
2) Brake applied
1
2
1
2
BODY
CONTROL
MODULE (BCM)
MICRO
1
3
C278
CCB08
VT-WH
VT-OG
BPS
F31 5A
VT-WH
VT-WH
S112
BOO
CBP31 BU-OG
4
BOO YE-GN
C2142
12
TRAILER BRAKE
CONTROL
(TBC) MODULE

FIGURE 53–8 A schematic of the BCM-controlled brake light circuit that includes the brake pedal position (BPP) switch, which creates signals to the powertrain control module (PCM) with inputs labeled BPS (brake pedal position) and BOO (brake on-off).

4. **Antilock braking system (ABS)**—When the brake pedal is depressed, the ABS system is ready to intervene, if needed, to control wheel slippage.

On some vehicles, the key must be in the on position for all the brake lights to illuminate. This is particularly important to know when performing diagnostics. Check service information for the specified procedure to follow on the vehicle being tested. ● **SEE FIGURE 53–8**.

TURN SIGNALS

MECHANICAL SYSTEM OPERATION In older systems, the turn-signal circuit is supplied power from the flasher unit, which is powered from the ignition switch. When the turn-signal switch is moved in either direction, the corresponding turn-signal lamps receive current, and the flasher unit causes the current to start and stop.

A turn-signal flasher unit is a metal or plastic can, containing a switch that opens and closes the turn-signal circuit. It is often installed in a metal clip attached to the dash panel to allow the "clicking" noise of the flasher to be heard by the driver. ● **SEE FIGURE 53–9**.

BCM-CONTROLLED TURN SIGNALS Starting in the early 2000s, many vehicles use the turn signal as an input to the body control module (BCM). ● **SEE FIGURE 53–10**.

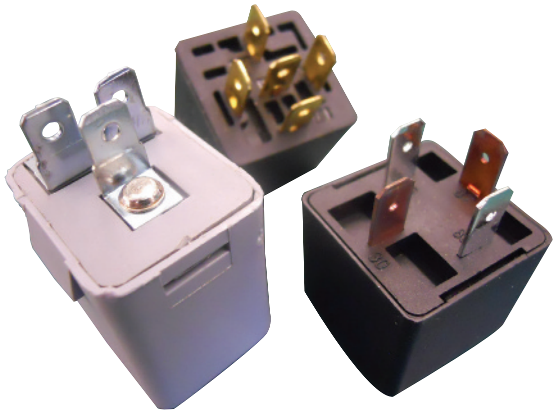


FIGURE 53–9 Three styles of flasher units.

The BCM sends a signal through the data lines to the lighting module(s) to flash the lights. With these systems, the BCM also sends a signal to the radio, which sends a clicking sound to the driver's side speaker, even if the radio is off.

BULB OUTAGE WARNING On some vehicles the lighting module, usually the BCM, monitors the current flow through all the lights. These circuits measure the current and, if there is a change that is not expected, they can turn on a warning light to warn the driver. If this current is below some threshold value, the bulb is assumed to be burned out. Some bulb failure

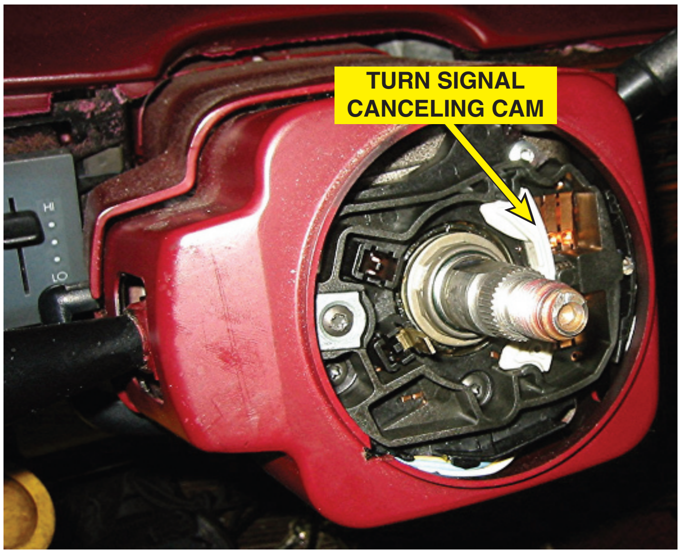


FIGURE 53–10 A steering column with the steering wheel removed, showing the turn signal canceling cam used to return the lever to the neutral position after a turn. The switches are an input to the body control module for left and right turn-signal operation.

systems work by sensing bulb resistances when the lamps are off. When diagnosing a bulb outage concern, perform the following steps:

STEP 1 Visually check the exterior lights for proper operation. Check all of the following:

- Backup light(s)
- Brake lights, including the center high-mounted stop light
- Driving lights, if equipped
- Fog lights, if equipped
- High-beam headlights
- License plate light(s)
- Low-beam headlights
- Park lights
- Puddle lights
- Side marker lights, front and rear, and left and right sides
- Taillights
- Turn signals front and rear

STEP 2 If one or more are not lighting, check or replace the bulb. Verify that the affected bulb is not an LED where a non-LED bulb is specified. ● **SEE FIGURE 53–11**.

STEP 3 If the warning lamp is still on, check the sockets for corrosion, proper voltage, and ground at the socket.

HAZARD WARNING LIGHTS

The **hazard warning**, also called *four-way flashers*, is a device installed in a vehicle lighting system with the primary function of causing both the left and right turn-signal lamps to flash when the hazard warning switch is activated. Secondary functions may include visible dash indicators for the hazard system and an audible signal to indicate when the flasher is operating. In older systems, a separate hazard warning flasher is used. Current vehicles use the BCM to operate all four turn-signal lights when the hazard (four-way) flasher switch is turned on by the driver.

COOL WHITE
2825
ALSO FITS: COMPATIBLE:
168/194
LED
For Off Road Use Only
12.8V, 0.5W

FIGURE 53–11 Replacement side marker LED lamps that could be used to replace standard bulbs. However, the current draw is lower and using these bulbs could cause the lamp outage warning lamp to be turned on.

DAYTIME RUNNING LIGHTS

PURPOSE AND FUNCTION

Daytime running lights (DRLs) are lights at the front of the vehicle that are on all the time the engine is running, unless they are turned off, or when the headlights are on. DRLs involve operation of the following:

- Front parking lights
- Separate DRL lamps
- Headlights (usually at reduced current and voltage) when the vehicle is running

Studies have shown that DRLs have reduced accidents where used. DRLs primarily use a control module that turns on either the low- or high-beam headlights wired in series or separate daytime running lights. The lights on some vehicles come on when the engine starts. Other vehicles turn on the lamps when the engine is running but delay their operation until a signal from the vehicle speed sensor indicates that the vehicle is moving. To avoid having the lights on during servicing, some systems turn off the headlights when the parking brake is applied, and the ignition switch is cycled off and then back on. Others only light the headlights when the vehicle is in a drive gear. ● **SEE FIGURE 53–12**.

The DRLs operate when the following conditions are met:

- The ignition is in the RUN or CRANK position
- The shift lever is out of the PARK position for vehicles equipped with automatic transmissions, or the parking brake is released for vehicles with manual transmissions
- The low- and high-beam headlamps are OFF

HEADLIGHTS

HEADLIGHT SWITCHES

Older vehicles use the headlight switch to operate the exterior and interior lights. On these systems, the headlight switch is connected directly to the battery

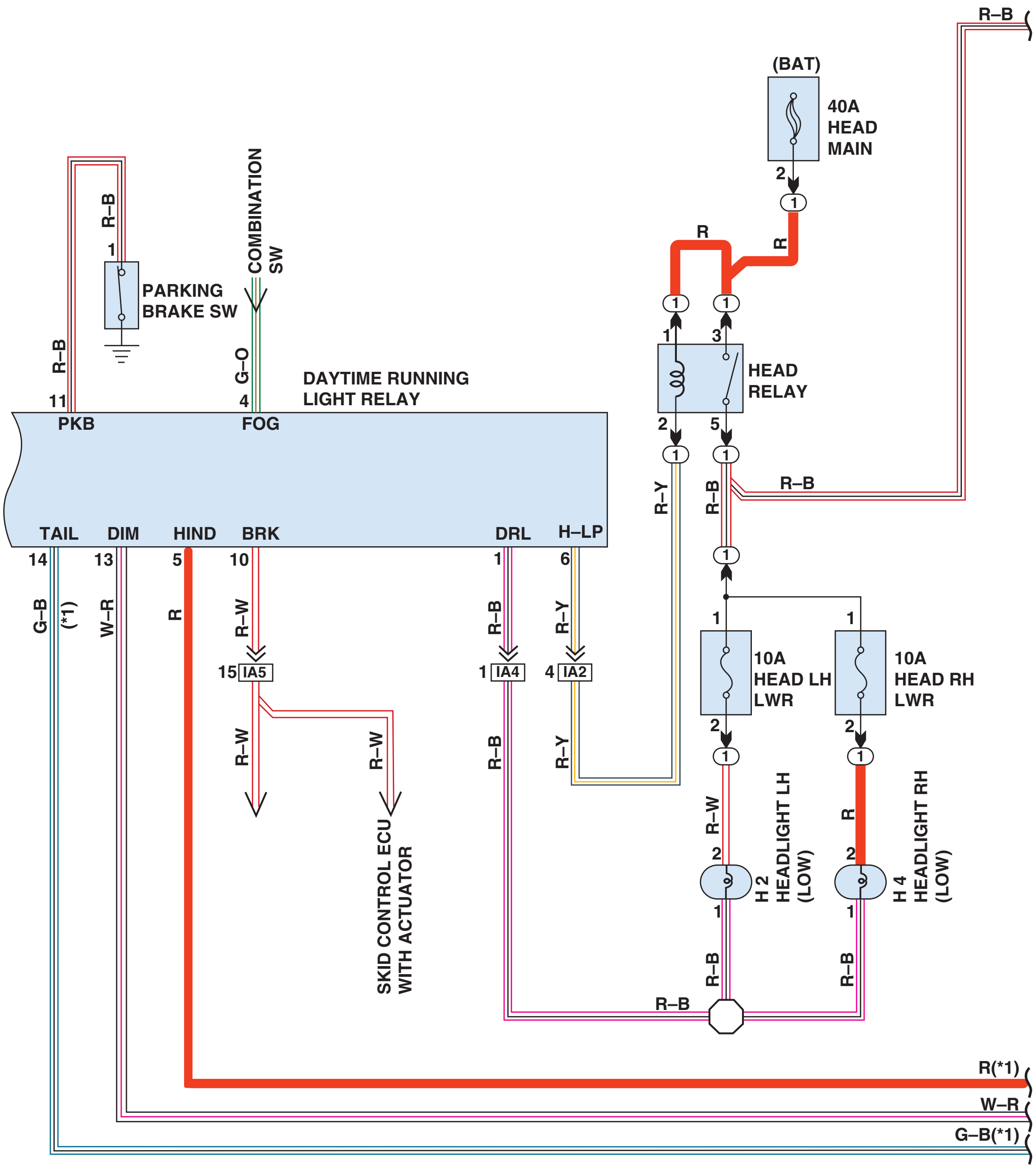

R–B
(BAT)
40A
HEAD
MAIN
2
1
R
R
1
1
1
3
HEAD
RELAY
2
5
1
1
R–Y
R–B
R–B
1
1
1
10A
HEAD LH
LWR
10A
HEAD RH
LWR
2
2
1
1
R–W
R
2
2
H 2
HEADLIGHT LH
(LOW)
H 4
HEADLIGHT RH
(LOW)
1
1
R–B
R–B
R–B
R–B
1
PARKING
BRAKE SW
COMBINATION
SW
R–B
G–O
11
4
DAYTIME RUNNING
LIGHT RELAY
PKB
FOG
TAIL
DIM
HIND
BRK
DRL
H–LP
14
13
5
10
1
6
G–B
(*1)
W–R
R
R–W
R–B
R–Y
15
IA5
1
IA4
4
IA2
R–W
R–W
R–B
R–Y
SKID CONTROL ECU
WITH ACTUATOR
R(*1)
W–R
G–B(*1)

FIGURE 53–12 A schematic showing a DRL circuit that uses the headlights. Also notice that each headlight has its own fuse to protect the circuit. Check service information for how the DRLs operate on the vehicle being serviced.

through a fusible link, and has continuous power or is "hot" all the time. ● **SEE FIGURE 53–13.**

HEADLIGHT SWITCH, BCM-CONTROLLED LIGHTING When the headlamp switch is placed in the HEAD or PARK position, a signal is sent to the body control module (BCM). The BCM responds by applying voltage to the park lamps, tail lamps, and license lamps control circuits illuminating the park, tail, and license lamps.

When the headlamp switch is placed in the HEADLAMP position, the BCM responds to the inputs by illuminating the park lamps and headlamps.

When placed in the AUTO position, the BCM monitors inputs from the ambient light sensor to determine whether headlamps are required or whether the daytime running lamps will be activated, based on outside lighting conditions.

COMPOSITE HEADLIGHTS Sealed beam headlights were used for many years and then, in the 1990s, were replaced with composite headlights. **Composite headlights** are constructed using a replaceable bulb and a fixed lens cover that is part of the vehicle. Composite headlights are the result of changes in the aerodynamic styling of vehicles where sealed beam lamps could no longer be used. ● **SEE FIGURE 53–14.**

The replaceable bulbs are usually bright halogen bulbs. Halogen bulbs get very hot during operation, between 500°F and 1,300°F (260°C and 704°C). It is important to never touch the glass of any halogen bulb with bare fingers because the natural oils of the skin on the glass bulb can cause the bulb to break when it heats during normal operation. ● **SEE FIGURE 53–15.**

BULB FAULTS Halogen bulbs can fail for various reasons. Some causes for halogen bulb failure and their indications include the following:

- **Gray color.** Low voltage to the bulb (check for corroded socket or connector)
- **White (cloudy) color.** Indication of an air leak
- **Broken filament.** Usually caused by excessive vibration
- **Blistered glass.** Indication that someone has touched the glass

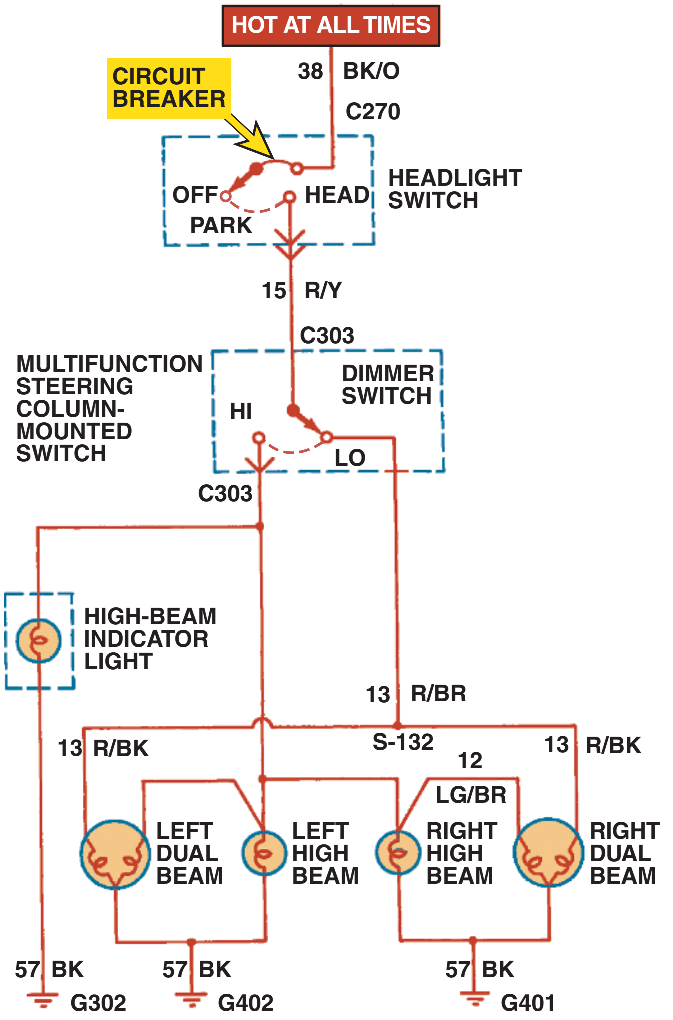

HOT AT ALL TIMES
CIRCUIT BREAKER
38
BK/O
C270
OFF
HEAD
PARK
HEADLIGHT SWITCH
15
R/Y
C303
MULTIFUNCTION STEERING COLUMN-MOUNTED SWITCH
DIMMER SWITCH
HI
LO
C303
HIGH-BEAM INDICATOR LIGHT
13
R/BR
13
R/BK
S-132
12
13
R/BK
LG/BR
LEFT DUAL BEAM
LEFT HIGH BEAM
RIGHT HIGH BEAM
RIGHT DUAL BEAM
57
BK
G302
57
BK
G402
57
BK
G401

FIGURE 53–13 A Typical headlight circuit diagram on an older vehicle that does not use a controller, such as the BCM, to control the operation of the lights. Note that the headlight switch is represented by a dotted outline, indicating that other circuits (such as dash lights) also operate from the switch.

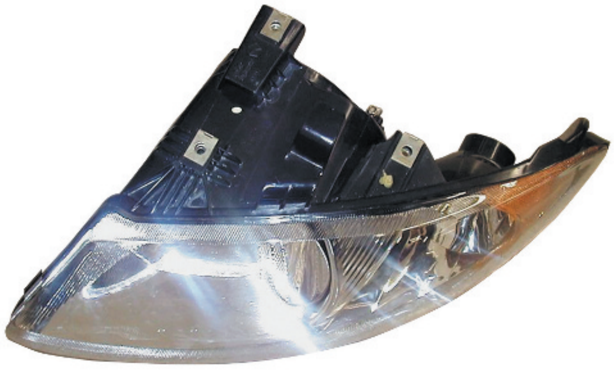


FIGURE 53–14 A typical composite headlamp assembly. The lens, housing, and bulb sockets are usually included as a complete assembly.

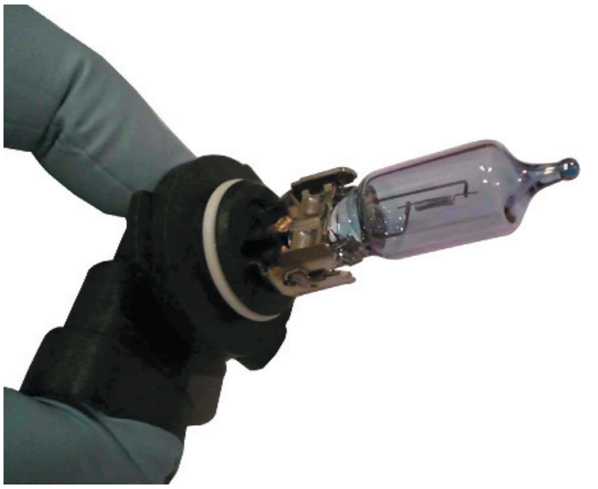


FIGURE 53–15 Handle a halogen bulb by the base to prevent the skin's oil from getting on the glass.

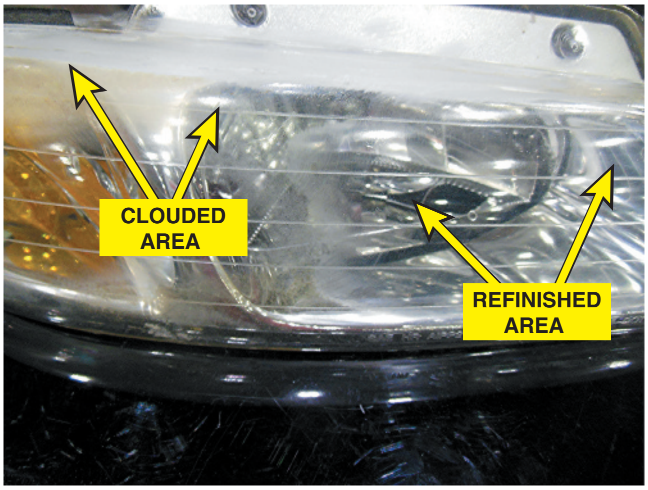

CLOUDED AREA
REFINISHED AREA

FIGURE 53–16 The right side of this headlight assembly has been restored, but still needs to be polished. The left side is cloudy and not yet restored.

CLOUDY HEADLIGHT RESTORATION The bulb covering of composite headlights is made from acrylic plastic. This material tends to fade, turn yellow, and discolor over a period of time due primarily to constant exposure to the sun's ultraviolet (UV) rays. The problem tends to be most serious in warmer, sunny climates. This clouding of the surface is more than a cosmetic issue because it can reduce the available light, reducing night vision. There are many brands and types of headlight restoration products available. Most products involve sanding the surface of the lens using fine sandpaper and applying a UV protectant to help prevent further damage to the plastic lens. Always follow the instructions for the product or procedure used to restore the headlights. ● **SEE FIGURE 53–16**.

HIGH-INTENSITY DISCHARGE HEADLIGHTS

PARTS AND OPERATION **High-intensity discharge (HID)** headlights produce light that is crisper, clearer, and brighter than light produced by a halogen headlight. HID lamps do not use a filament like conventional electrical bulbs, but contain two electrodes about 0.2 inch (5 mm) apart. A high-voltage pulse is sent to the bulb, which arcs across the tips of electrodes, producing light. It creates light from an electrical discharge between two electrodes in a gas-filled arc tube. A HID lamp produces twice

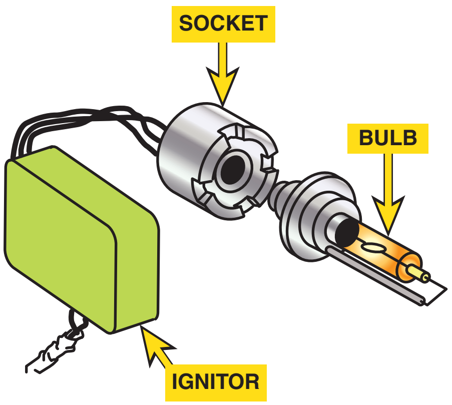


FIGURE 53–17 The igniter contains the ballast and transformer needed to provide high-voltage pulses to the arc-tube bulb.

the light with less electrical current (amperage) than conventional halogen bulbs. The HID lighting system consists of the discharge arc source, igniter, ballast, and headlight assembly. ● **SEE FIGURE 53–17**.

The two electrodes are contained in a tiny quartz capsule filled with xenon gas, mercury, and metal halide salts. HID headlights are also called *xenon* headlights. The lights and support electronics are expensive, but they should last the life of the vehicle, unless physically damaged. HID headlights produce a white light giving the lamp a blue-white color. The color of light is expressed in temperature using the Kelvin scale. **Kelvin (K)** temperature is the Celsius temperature plus 273 degrees. Typical color temperatures include the following:

- Daylight—5,400°K
- HID—4,100°K
- Halogen—3,200°K
- Incandescent (tungsten)—2,800°K

● **SEE FIGURE 53–18**.

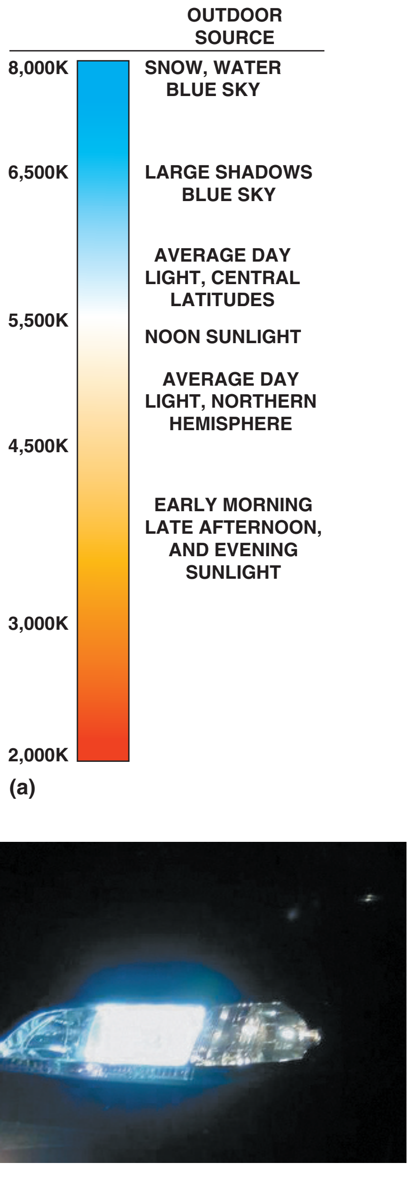


FIGURE 53–18 (a) The color of light is measured in degrees Kevin (K). The higher the temperature of the light, the bluer the appearance. (b) HID (xenon) headlights emit a whiter light than halogen headlights and usually look blue compared to halogen bulbs.

STAGES OF HID HEADLIGHT OPERATION The HID ballast is powered by voltage from the headlight switch or the BCM. The HID headlights operate in three stages or states:

1. **Start-up or stroke state**—When the headlight switch is turned to the on position, the ballast may draw up to 20 amperes at 12 volts. The ballast sends multiple high-voltage pulses to the arc tube to start the arc inside the bulb. The voltage provided by the ballast during the start-up state ranges from −600 to +600 volts, which is increased by a transformer to about 25,000 volts. The increased voltage is used to create an arc between the electrodes in the bulb.
2. **Run-up state**—After the arc is established, the ballast provides a higher-than-steady-state voltage to the arc tube to keep the bulb illuminated. On a cold bulb, this state could last as long as 40 seconds. On a hot bulb, the run-up state may last only 15 seconds. The current requirements during the run-up state are about 360 volts from the ballast and a power level of about 75 watts.
3. **Steady state**—The steady-state phase begins when the power requirement of the bulb drops to 35 watts. The ballast provides a minimum of 55 volts to the bulb during steady-state operation.

FREQUENTLY ASKED QUESTION

What Is the Difference between the Temperature of the Light and the Brightness of the Light?

The temperature of the light indicates the color of the light. The brightness of the light is measured in lumens. A standard 100 watt incandescent light bulb emits about 1,700 lumens. A typical halogen headlight bulb produces about 2,000 lumens, and a typical HID bulb produces about 2,800 lumens.

BI-XENON HEADLIGHTS Some vehicles are equipped with bi-xenon headlights, which use a shutter to block some of the

WARNING

Always adhere to all warnings because the high-voltage output of the ballast assembly can cause personal injury or death.

light during low-beam operation, and then mechanically move to expose more of the light from the bulb for high-beam operation. Because xenon lights are relatively slow to start working, vehicles equipped with bi-xenon headlights use two halogen lights for the "flash-to-pass" feature.

HID HEADLIGHT FAILURE SYMPTOMS The following symptoms indicate bulb failure.

- A light flickers
- Lights go out (caused when the ballast assembly detects repeated bulb restrikes)
- Color changes to a dim pink glow

Bulb failures are often intermittent and difficult to repeat. However, bulb failure is likely if the symptoms get worse over time. Always follow the vehicle manufacturer's recommended testing and service procedures.

DIAGNOSIS AND SERVICE HID headlights change slightly in color with age. This color shift is usually not noticeable unless one headlight arc-tube assembly has been replaced due to a collision repair, and then the difference in color may be noticeable. The difference in color gradually changes as the arc tube ages and should not be too noticeable by most customers. If the arc-tube assembly is near the end of its life, it may not light immediately if it is turned off and then back on immediately. This test is called a "hot restrike" and, if it fails, a replacement arc-tube assembly may be needed, or there is another fault, such as a poor electrical connection, that should be checked.

LED HEADLIGHTS

Many newer vehicles use LED headlights either as standard equipment or optional equipment. ● **SEE FIGURE 53–19**.

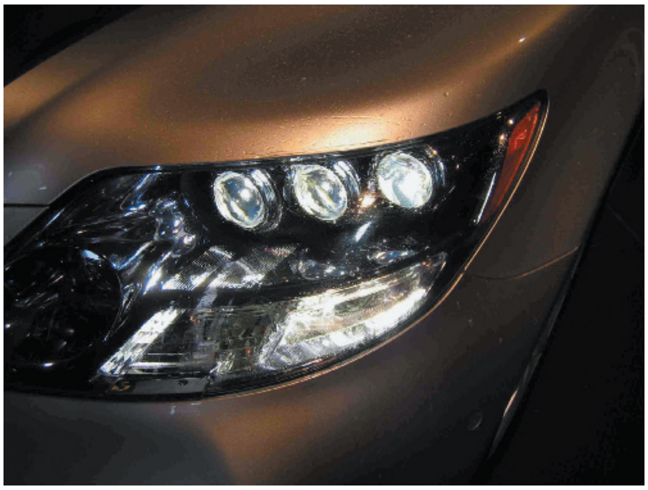


FIGURE 53–19 LED headlights usually require multiple units to provide the needed light, as seen on this Lexus LS600h.

The advantages of LED headlights compared to other types are as follows:

- Long service life
- Reduced electrical power required

The disadvantages of LED headlights are as follows:

- Higher cost
- Many small LEDs are required to create the necessary light output

ADAPTIVE FRONT LIGHTING SYSTEM

PURPOSE AND FUNCTION An **adaptive** (or **advanced**) **front lighting system**, or **AFS**, is a system that mechanically moves the headlights to follow the direction of the front wheels. The purpose is to provide improved lighting during cornering. The AFS headlights are usually capable of rotating 15 degrees to the left and 5 degrees to the right (some systems rotate 14 degrees and 9 degrees, respectively). Vehicles that use AFS include Lexus, Mercedes, and certain domestic models, usually as an extra cost option. ● **SEE FIGURE 53–20**.

AFS is often used in addition to self-leveling motors so that the headlights remain properly aimed, regardless of how the vehicle is loaded. Without self-leveling, headlights shine higher than normal if the rear of the vehicle is heavily loaded. ● **SEE FIGURE 53–21**.

NOTE: These angles are reversed on vehicles sold in countries that drive on the left side of the road, such as Great Britain, Japan, Australia, and New Zealand.

PARTS AND OPERATION The vehicle has to be moving above a predetermined speed, usually above 20 MPH (30 km/h), and the lights stop moving when the speed drops below about 3 MPH (5 km/h).

When a vehicle is equipped with an AFS, the lights are moved by the headlight controller outward and then inward, as well as up and down, as a test of the system. This action is quite noticeable to the driver and is a normal operation of the system.

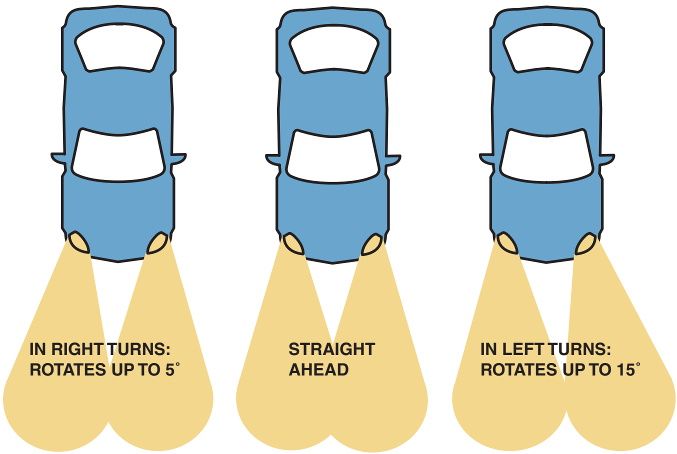


FIGURE 53–20 Adaptive front lighting systems rotate the low-beam headlight in the direction of travel.

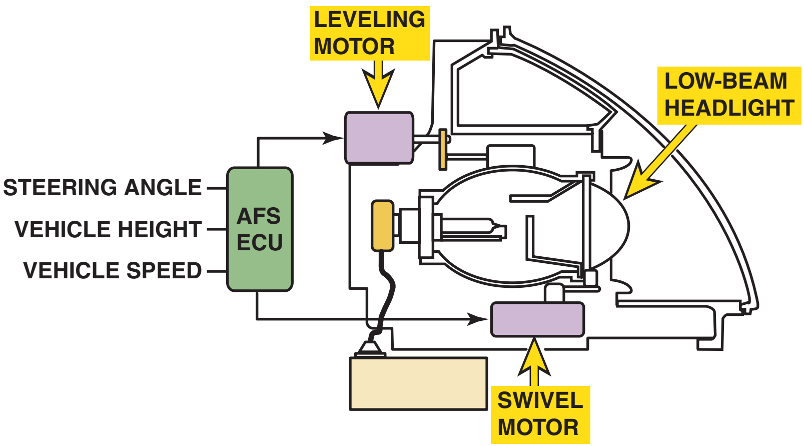


FIGURE 53–21 A typical adaptive front lighting system uses two motors: one for the up-and-down movement and the other for rotating the low-beam headlight to the left and right.

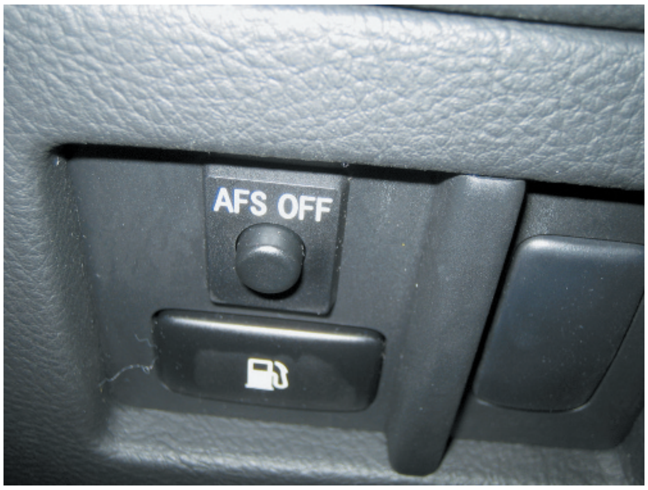


FIGURE 53–22 Typical dash-mounted switch that allows the driver to turn off the front lighting system.

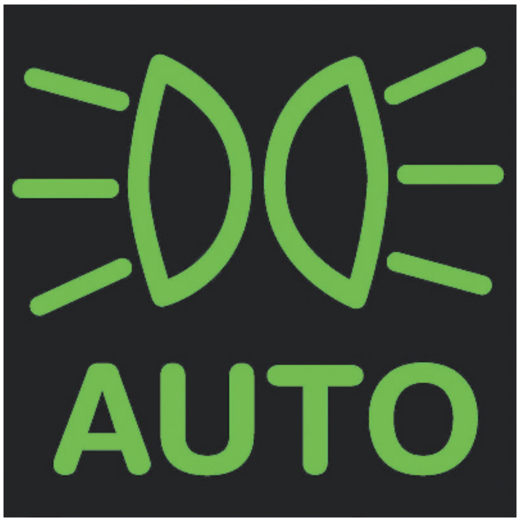


FIGURE 53–23 A dash symbol used to inform the driver that the automatic headlights are on.

DIAGNOSIS AND SERVICE The first step when diagnosing an AFS fault is to perform the following visual inspection:

- Start by checking that the AFS is switched on. Most AFS headlights are equipped with a switch that allows the driver to turn the system on and off. ● **SEE FIGURE 53–22**.
- Check that the system performs a self-test during start-up.
- Verify that both low-beam and high-beam lights function correctly. The system may be disabled if a fault with one of the headlights is detected.
- Use a scan tool to test for any AFS-related diagnostic trouble codes. Some systems allow the AFS to be checked and operated using a scan tool.

Always follow the recommended testing and service procedures as specified by the vehicle manufacturer in service information.

AUTOMATIC HEADLIGHTS

PURPOSE AND FUNCTION **Automatic headlights** automatically turn on the headlights when the light sensor detects low ambient light level. These sensors are usually located on the dash of the vehicle. If the light level is low, the headlights turn on automatically when the engine starts. The ambient light sensor is used to monitor outside lighting conditions. The ambient light sensor provides a voltage signal that varies between 0.2 and 4.9 volts, depending on outside lighting conditions. The BCM provides a 5 volt reference signal to the ambient light sensor. The BCM monitors the ambient light sensor signal circuit to determine if outside lighting conditions are correct for either daytime running lights, or automatic lamp control (ALC) when the headlamp switch is in the AUTO position.

CONTROLS Most vehicles allow the driver to select the headlights in the "AUTO" position or turn them on and off manually. If the headlights are on, a dash symbol is often displayed on the dash to inform the driver. ● **SEE FIGURE 53–23**.

HEADLIGHT HIGH-/LOW-BEAM SWITCH

DIMMER SWITCH Headlights use a high-intensity bulb or lamp and a low-intensity bulb or lamp. The switch used to switch between the two circuits is often called the *dimmer switch* or the high/low switch. An indicator light illuminates on the dash when the high beams are selected. The dimmer switch is usually hand-operated by a lever on the steering column.

AUTO DIMMING HEADLIGHTS

PURPOSE AND FUNCTION An **automatic headlight dimmer** (also called *automatic beam control* or *automatic high beams*) is a system that causes the headlights to switch from high-intensity beams to low-intensity beams when the system detects the headlights from an approaching vehicle.

TYPES OF SYSTEMS Types of automatic headlight dimming include the following:

- **Photo resistor-based system**—A system that uses a photo resistor is usually mounted at the top of the windshield inside the vehicle. This system automatically adjusts the headlight beams from “high-beam” to “low-beam” when approaching oncoming vehicles during nighttime driving. The system also switches back to high-beam after the vehicles have passed. Drivers can also use standard headlight dimmers to override the automatic headlight dimmer on vehicles so equipped.
- **Camera-based systems**—Some vehicles use the camera and lasers already fitted for collision avoidance. These systems can detect an oncoming vehicle from 400 yards (366 m) away, and detect the tail lights of a car in front from more than 120 yards (110 m).

CONDITIONS NEEDED TO FUNCTION For the automatic operation to turn on the high beams, the following conditions are usually required:

- Vehicle speed above 20 MPH
- Dark conditions with few streetlights
- There are no approaching vehicles with the headlights on
- There are no taillights from the vehicle in front

NOTE: High beams may not automatically turn off when an approaching vehicle is hidden from view due to a hill or a curve. This inability is not a fault with the system, but instead is due to the limiting factors of the system.

HEADLIGHT AIMING

According to U.S. federal law, all headlights, regardless of shape, must be able to be aimed using headlight-aiming equipment. The headlights are equipped with adjusting screws that can be used to aim the headlights. Some are also equipped with a bubble level to help make sure that the lights are level. Older vehicles equipped with sealed beam headlights used a headlight-aiming system that is attached to the headlight itself. Check service information for the exact procedure and specifications to follow when aiming headlights. ● **SEE FIGURE 53–24**.

FOG AND DRIVING LIGHTS

FOG LIGHTS The light from regular headlights can reflect off the fog, snow, or dust particles in the air, causing glare. When driving in fog, the use of fog lights reduces the glare. Fog lights have a unique beam that is flat and wide, and is positioned low on the vehicle, usually near the front bumper. Fog lights are also useful where there is dust and snow on the road, either

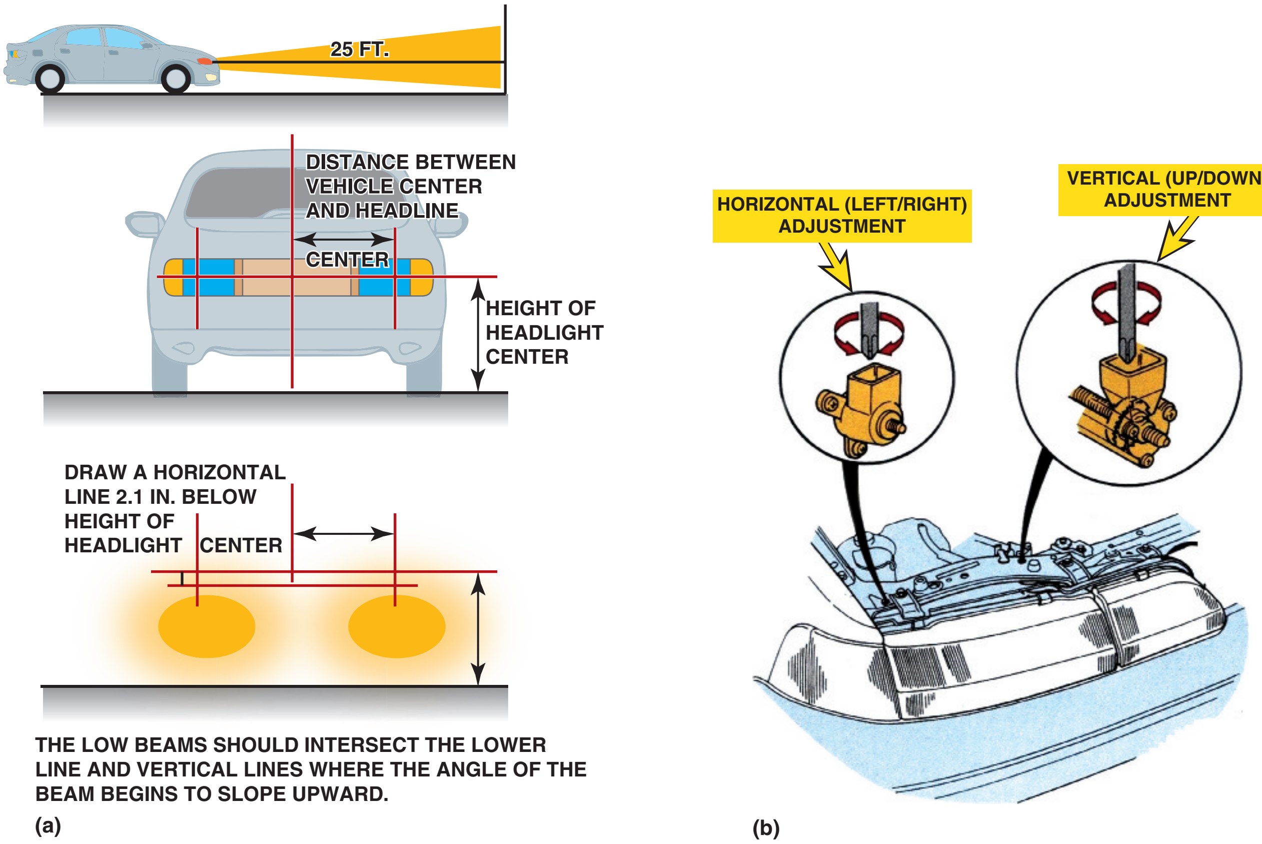

25 FT.
DISTANCE BETWEEN VEHICLE CENTER AND HEADLINE
CENTER
HEIGHT OF HEADLIGHT CENTER
DRAW A HORIZONTAL LINE 2.1 IN. BELOW HEIGHT OF HEADLIGHT
CENTER
THE LOW BEAMS SHOULD INTERSECT THE LOWER LINE AND VERTICAL LINES WHERE THE ANGLE OF THE BEAM BEGINS TO SLOPE UPWARD.
(a)
HORIZONTAL (LEFT/RIGHT) ADJUSTMENT
VERTICAL (UP/DOWN) ADJUSTMENT
(b)

FIGURE 53–24 (a) A typical headlight-aiming diagram as found in service information. (b) Adjustments to move the headlight-aiming point left or right or up and down are usually made using a screwdriver to move the headlight housing.

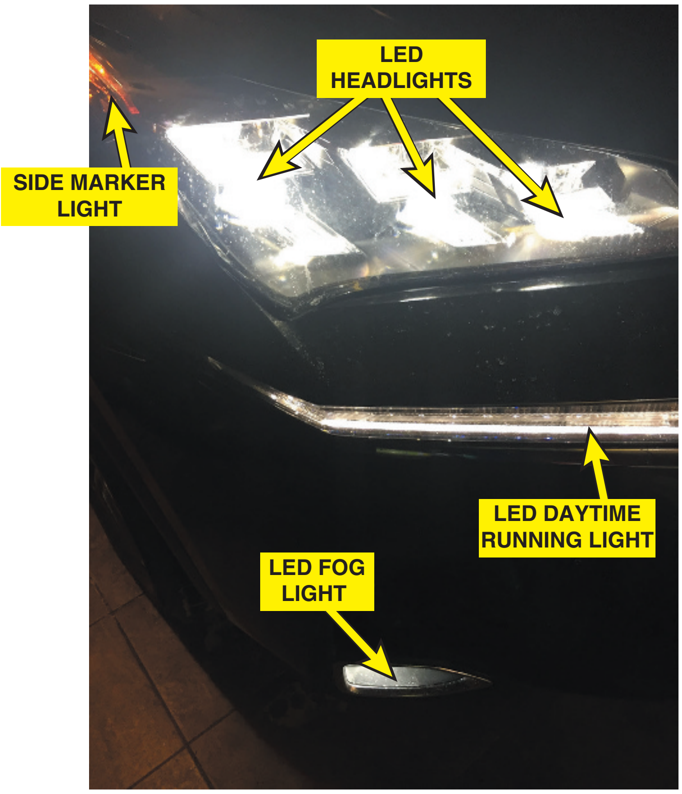


FIGURE 53–25 Fog lights are often included on many vehicles, such as these on a Lexus SUV.

drifting in through the air or being churned up from the surface of the road. Fog lights are usually white, though they can also be yellow or blue. Fog lights in the rear are always red. ● **SEE FIGURE 53–25**.

NOTE: Fog lights should only be used when poor visibility is present and then turned off.

DRIVING LIGHTS Driving lights have a narrow, straight beam, and are used while off-roading or traversing dark, deserted country roads. Driving lights are designed to send powerful beams far ahead, illuminating the next stretch of road. Driving lights are usually installed by the vehicle owner and are usually not available from the factory unless a special off-road equipment package is ordered. If installed, they should be wired to work only when the high beams are in use. Check local and state regulations in regards to the mounting and use of driving lights.

FREQUENTLY ASKED QUESTION

What Are Rear Fog Lights?

Some vehicles, usually European vehicles, are equipped with rear (red) fog lights. These are used so that drivers behind can see the vehicle in front. These could be on whenever the fog lights are turned on, or they could be on a separate switch. These rear fog lights are sometimes confused with brake lights being on because they are often as bright as brake lights. Check the owner's manual or service information if a fault is reported about the rear fog lights.

FREQUENTLY ASKED QUESTION

What Is the Troxler Effect?

The **Troxler effect**, also called *Troxler fading*, is a visual effect where an image remains on the retina of the eye for a short time after the image has been removed. The effect was discovered in 1804 by Ignaz Paul Vital Troxler (1780–1866), a Swiss physician. Because of the Troxler effect, headlight glare can remain on the retina of the eye and create a blind spot. At night, this fading away of the bright light from the vehicle in the rear reflected by the rearview mirror can cause a hazard.

AUTOMATIC DIMMING MIRRORS

PARTS AND OPERATION Automatic dimming mirrors use electrochromic technology to dim the mirror in proportion to the amount of headlight glare from other vehicles at the rear. The electrochromic technology developed by Gentex Corporation uses a gel that changes with light between two pieces of glass. One piece of glass acts as a reflector and the other has a transparent (clear) electrically conductive coating. The inside rearview mirror also has a forward-facing light sensor that is used to detect darkness. It signals the rearward-facing sensor to begin to check for excessive glare from headlights behind the vehicle. The rearward-facing sensor sends a voltage to the electrochromic gel in the mirror that is in proportion to the amount of glare detected. The mirror dims in proportion to the glare, and becomes like a standard rearview mirror when the glare is no longer detected. If automatic dimming mirrors are used on the exterior, the sensors in the interior mirror and electronics are used to control both the interior and exterior mirrors. ● **SEE FIGURE 53–26**.

DIAGNOSIS AND SERVICE If a customer concern states that the mirrors do not dim when exposed to bright headlights from the vehicle behind, the cause could be sensors or the mirror itself. Be sure that the mirror is getting electrical power. Most automotive dimming mirrors have a green light to indicate the presence of electrical power. If no voltage is found at the mirror, follow standard troubleshooting procedures to find the cause. If the mirror is getting voltage, start the diagnosis by placing a strip of tape over the forward-facing light sensor. Turn the ignition key on, engine off (KOEO), and observe the operation of the mirror when a flashlight or trouble light is directed onto the mirror. If the mirror reacts and dims, the forward-facing sensor is defective. Most often, the entire mirror assembly must be replaced, if any sensor or mirror faults are found.

One typical fault with automatic dimming mirrors is that a crack can occur in the mirror assembly, allowing the gel to escape from between the two layers of glass. This gel can drip onto the dash or center console and harm these surfaces. The mirror should be replaced at the first sign of any gel leakage.

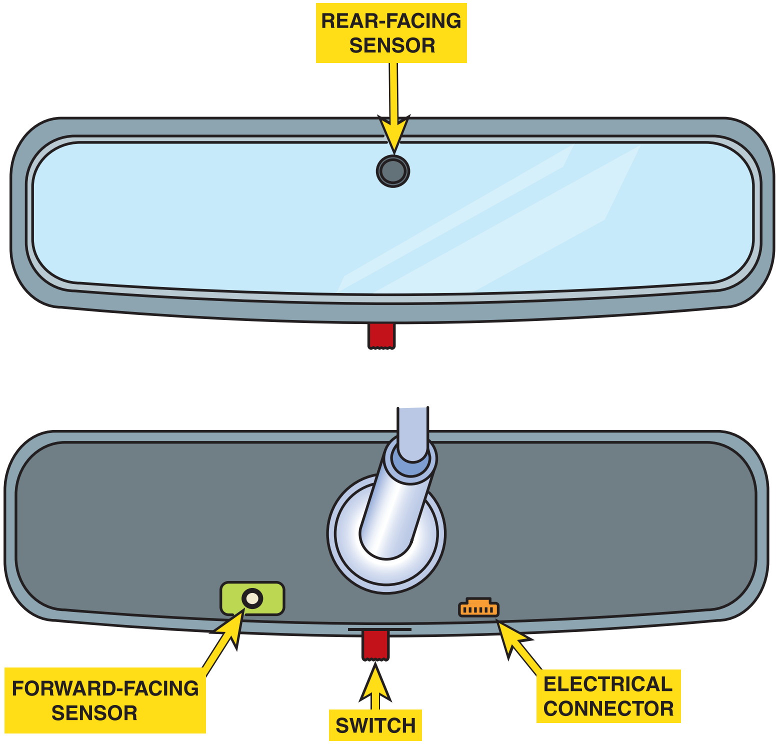


FIGURE 53–26 An automatic dimming mirror compares the amount of light toward the front of the vehicle to the rear of the vehicle and allows a voltage to cause the gel to darken the mirror.

COURTESY LIGHTS

Courtesy lights are a generic term primarily used for interior lights, including overhead (dome) and under-the-dash (courtesy) lights. These interior lights are controlled by switches located in the door handle of the vehicle or by a switch on the dash. Many newer vehicles operate the interior lights through the BCM or through an electronic module. Because the exact wiring and operation of these units differ, check the service information for the exact model of the vehicle being serviced.

ILLUMINATED ENTRY

Some vehicles are equipped with illuminated entry, meaning the interior lights are turned on for a given amount of time when the outside door handle or remote keyless entry (RKE) fob is operated while the doors are locked.

Most vehicles equipped with illuminated entry also light the exterior door lights, called “puddle lights,” that shine downward so people entering a vehicle in the dark can see the ground near the vehicle. The input from the door handle or key fob remote is used to “wake up” the power supply for the BCM and usually turns on the interior lights.

HEADLIGHT SYSTEM DIAGNOSIS

VISUAL INSPECTION All of the lights, including the operation of the headlights, should be a part of any vehicle inspection process. During a visual inspection, check the headlights for the following:

- Are they functioning as designed? (Check service information or a similar vehicle to make sure that the system is not working as designed.)
- Check the brightness to see if they are dim.
- Check if the headlights are too bright.

DIAGNOSTIC PROCEDURE If the headlights are not working at all, perform the following steps:

STEP 1 Use a factory or factory-level scan tool to turn the headlights on using the bidirectional command from the scan tool. If the headlights work, the headlights and the headlight circuit are working normally. The problem is likely the control input to the controller that operates the headlights.

STEP 2 Check the schematic for the headlight circuit and check for voltage at various parts to help pinpoint the location of the open circuit. Always follow the vehicle manufacturer’s specified procedures. ● **SEE FIGURE 53–27**.

- If the headlights are brighter than normal, the battery voltage may be higher than normal. Check the charging system voltage to make sure that it is less than 15.5 volts (on most vehicles). Check service information for the exact specifications.
- If the headlight(s) is/are dimmer than normal, check the electrical circuits to the headlights for excessive circuit resistance, such as any of the following:

  1. Loose electrical connector
  2. Corroded socket
  3. Poor electrical ground connection

LIGHTING SYSTEM DIAGNOSIS

Diagnosing any faults in the lighting and signaling systems usually includes the following steps:

STEP 1 Verify the customer concern.

STEP 2 Perform a visual inspection, checking for collision damage or other possible causes that would affect the operation of the lighting circuit.

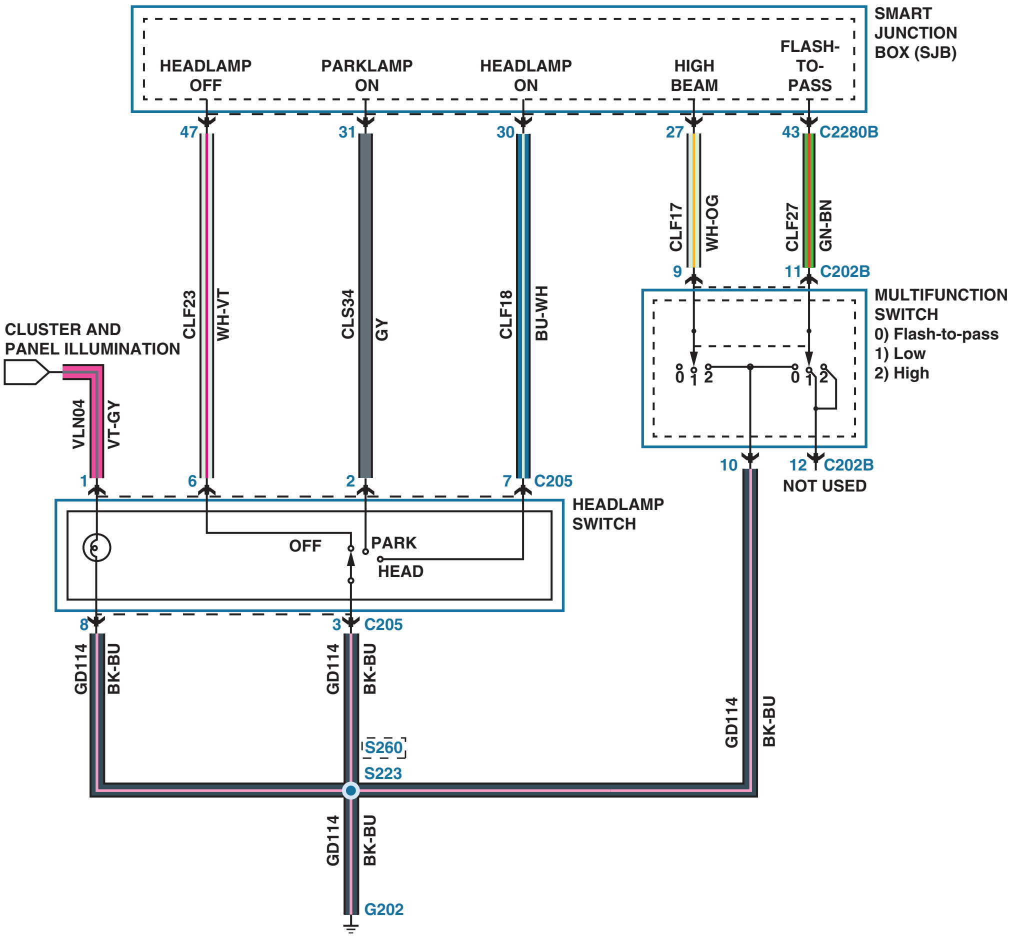

SMART JUNCTION BOX (SJB)
HEADLAMP OFF
PARKLAMP ON
HEADLAMP ON
HIGH BEAM
FLASH-TO-PASS
47
31
30
27
43
C2280B
CLF23
WH-VT
CLS34
GY
CLF18
BU-WH
CLF17
WH-OG
CLF27
GN-BN
9
11
C202B
MULTIFUNCTION SWITCH
0) Flash-to-pass
1) Low
2) High
0 1 2
0 1 2
CLUSTER AND PANEL ILLUMINATION
VLN04
VT-GY
1
6
2
7
C205
10
12
C202B
NOT USED
HEADLAMP SWITCH
OFF
PARK
HEAD
8
3
C205
GD114
BK-BU
GD114
BK-BU
GD114
BK-BU
S260
S223
GD114
BK-BU
G202

FIGURE 53–27 A Ford headlight circuit showing the control of the power side of the circuit comes from the smart junction box (SJB).

TECH TIP

The Weirder the Problem, the More Likely It Is a Poor Ground Connection

Bad grounds are often the cause for feedback or lamps operating at full or partial brilliance. At first, the problem looks weird, because often the switch for the lights that are on dimly is not even turned on. When an electrical device is operating, and it lacks a proper ground connection, the current tries to find ground and often causes other circuits to work. Check all grounds before replacing parts.

STEP 3 Connect a factory or enhanced scan tool with bidirectional control of the control modules to check for proper operation of the affected lighting circuit.

STEP 4 Follow the diagnostic procedure, as found in service information, to determine the root cause of the problem.

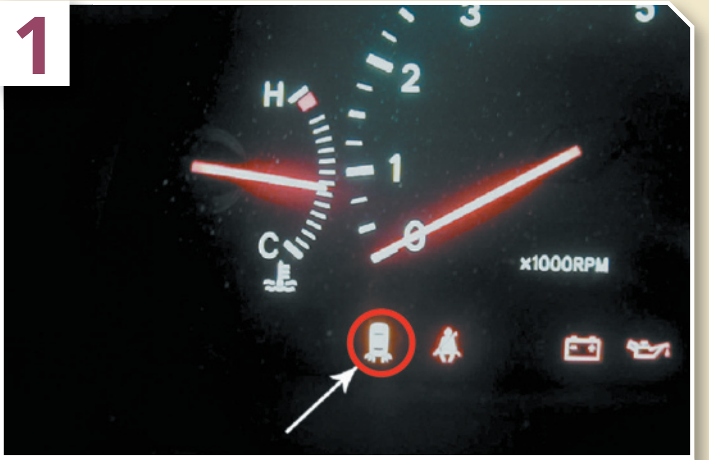
LIGHTING SYSTEM SYMPTOM GUIDE The following list assists technicians in determining lighting systems faults by symptom.

PROBLEM/CONCERN	POSSIBLE CAUSE
One headlight dim	1. Poor ground connection on body 2. Corroded connector
One headlight out (low or high beam)	1. Burned out headlight filament (Check the headlight with an ohmmeter. There should be a low ohm reading between the power-side connection and the ground terminal of the bulb.) 2. Open circuit (no 12 volts to the bulb)
Both high- and low-beam headlights out	1. Burned out bulbs 2. Open circuit (Check for voltage at the wiring connector to the headlights for a possible open circuit to the headlights or open [defective] dimmer switch.)

PROBLEM/CONCERN	POSSIBLE CAUSE
All headlights inoperative	1. Burned out filaments in all headlights (Check for excessive charging-system voltage.) 2. Defective dimmer switch 3. Defective headlight switch
Slow turn-signal operation	1. Defective flasher unit (if equipped) 2. High resistance in sockets or ground wire connections 3. Incorrect bulb numbers
Turn signals operating on one side only	1. Burned out bulb on the affected side 2. Poor ground connection or defective socket on the affected side 3. Incorrect bulb number on the affected side 4. Defective turn-signal switch
Interior light(s) inoperative	1. Burned out bulb(s) 2. Open in the power-side circuit (blown fuse) 3. Open in door switch(es)
Brake lights inoperative	1. Defective brake switch 2. Defective turn-signal switch (mechanical system) 3. Burned out brake light bulbs 4. Open circuit or poor ground connection 5. Blown fuse
Hazard warning lights inoperative	1. Defective hazard flasher unit (if equipped) 2. Open in hazard circuit 3. Blown fuse 4. Defective hazard switch

TAILLIGHT BULB REPLACEMENT

1

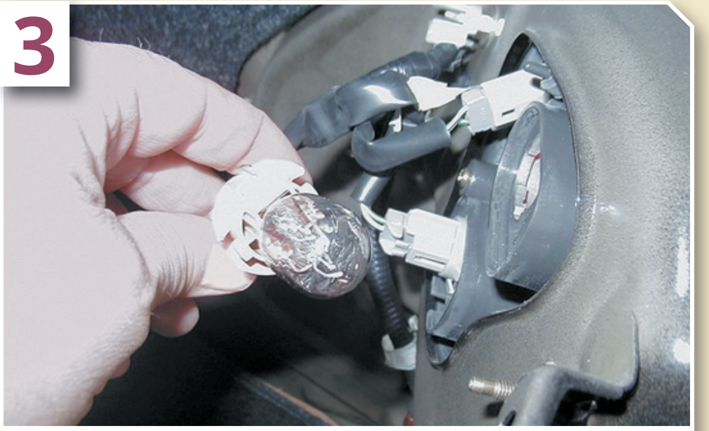


The driver noticed that the taillight fault indicator (icon) on the dash was on any time the lights were on.

2

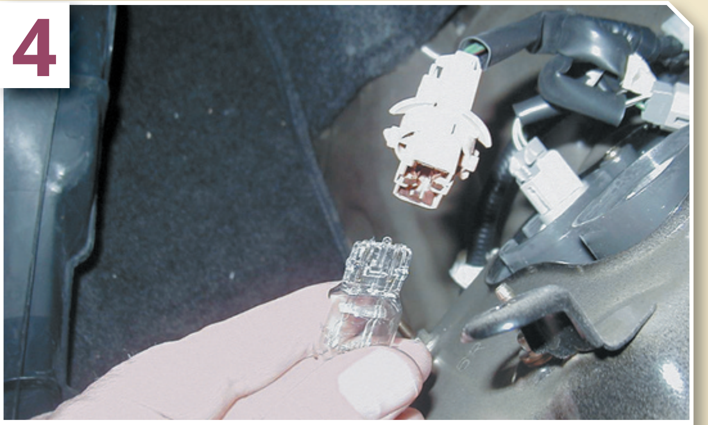
A visual inspection at the rear of the vehicle indicated that the right rear taillight bulb did not light. Removing a few screws from the plastic cover revealed the taillight assembly.

3



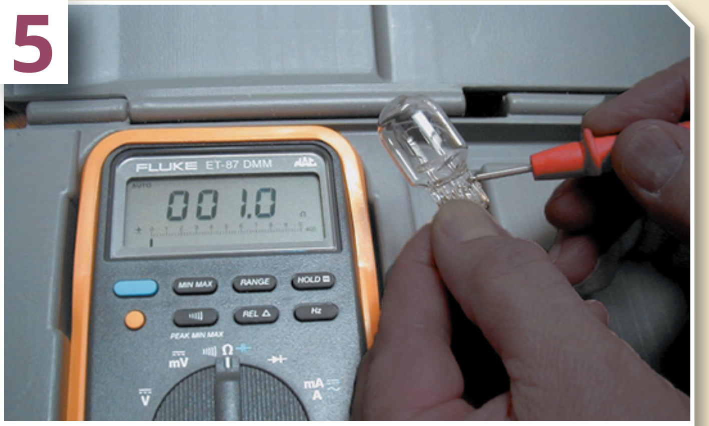
The bulb socket is removed from the taillight assembly by gently twisting the base of the bulb counterclockwise.

4



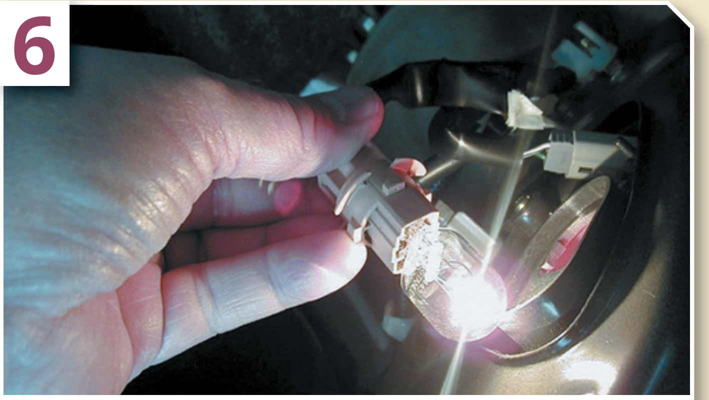
The bulb is removed from the socket by gently grasping the bulb and pulling the bulb straight out of the socket. Many bulbs required that you rotate the bulb 90 degrees (1/4 turn) to release the retaining bulbs.

5



The new 7443 replacement bulb is being checked with an ohmmeter to be sure that it is okay before it is installed in the vehicle.

6



The replacement bulb is inserted into the taillight socket and the lights are turned on to verify proper operation before putting the components back together.

REVIEW QUESTIONS

1. Why should the exact same trade number of bulb be used as a replacement?
2. Why is it important to avoid touching a halogen bulb with your fingers?
3. What are the advantages of LED lights?
4. Why are lights controlled by the BCM in many vehicles?
5. What are the conditions needed for an auto dimming headlight system to work?

CHAPTER QUIZ

1. Technician A says that the bulb trade number is the same for all bulbs of the same size. Technician B says that a dual-filament bulb has different wattage ratings for each filament. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. Light-emitting diodes (LEDs) are used for lighting because they __________.
   - **a.** light quicker (faster illumination)
   - **b.** have longer service life
   - **c.** have lower current draw
   - **d.** Any of the above
3. Which statement is true?
   - **a.** Daytime running lights can be separate lights or use the headlights.
   - **b.** Automatic headlights, auto-dimming headlights, and adaptive headlights are different terms for the same system.
   - **c.** The high- and low-beam switch is used to control the current through the low or high filament.
   - **d.** Both a and c are correct
4. Which of the following is used when the brakes lights or turn signal is used?
   - **a.** A brake light switch
   - **b.** The high filament in a dual filament bulb
   - **c.** A turn signal lamp
   - **d.** All of the above
5. Vehicles equipped with the illuminated entry feature typically use the __________ to command the interior lights ON.
   - **a.** BCM
   - **b.** RKE fob
   - **c.** outside door handle
   - **d.** Any of the above
6. Which of the lighting systems could result in an electrical shock hazard if proper precautions are not followed?
   - **a.** LED lights
   - **b.** HID lights
   - **c.** Rear fog lights
   - **d.** Driving lights
7. What type of light bulb should not be touched using bare hands?
   - **a.** 1157 or 2057 bulbs
   - **b.** Halogen bulbs
   - **c.** LED bulbs
   - **d.** HID bulbs
8. The "color" of light produced by a light bulb is measured in what unit?
   - **a.** Kelvin degrees
   - **b.** Amperes
   - **c.** Watts
   - **d.** Volts
9. An automatically dimming mirror is used to __________.
   - **a.** automatically dim the headlights
   - **b.** help prevent the Troxler effect
   - **c.** operate the fog lights when needed
   - **d.** operate the daytime running lights (DRLs)
10. Technician A says that a scan tool is usually needed to aim headlights. Technician B says that the keyless entry key fob is used to wake up the BCM, which usually is responsible to turn on the interior (courtesy) lights. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter

54

DRIVER INFORMATION AND NAVIGATION SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Identify the meaning of dash warning symbols.
- Describe steering wheel controls.
- Describe voice activation.
- Describe maintenance indicators.
- Describe analog and digital displays.
- Discuss the operation of a head-up display.
- Discuss the operation of night vision systems.
- Discuss the operation of electronic displays.
- Discuss the operation of virtual displays.
- Discuss the operation of touch screens.
- Describe how speedometers and odometers work.
- Discuss the diagnosis of oil pressure lamp, temperature lamp, brake warning lamp, and other analog dash instruments.
- Describe how a navigation system works.
- Explain the operation and diagnosis of Telematics systems.
- Explain the operation of a backup camera.

KEY TERMS:

Analog display 631 • Backup camera 641 • Bulb test 628 • Digital display 631 • EEPROM 635 • Global positioning system (GPS) 637 • Head-up display (HUD) 632 • Instrument panel (IP) 628 • Instrument panel cluster (IPC) 631 • Liquid crystal display (LCD) 633 • Night vision 632 • Nonvolatile random access memory (NVRAM) 635 • OnStar 639 • Steering wheel controls 630 • Stepper motor 631 • Telematics 639 • Thin-film-transistor (TFT) 633 • Touch screen 634 • Virtual display 634 • Voice activation 630 • WOW display 634

DASH WARNING SYMBOLS

PURPOSE AND FUNCTION All vehicles are equipped with warning lights on the **instrument panel (IP)** and they are often confusing to drivers. Symbols are used instead of words because they are universal in a global vehicle market. The dash warning lights are often called *telltale* lights as they are used to notify the driver of a situation or fault.

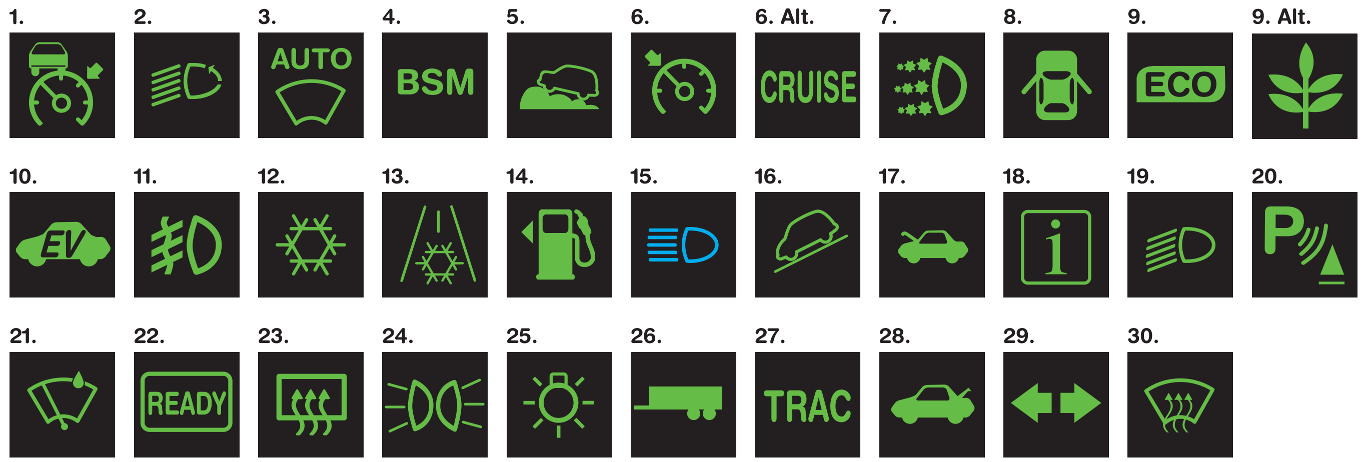
NOTE: Not all vehicles use all the symbols. Check the owner's manual or service information for the symbols used on the vehicle being checked.

BULB TEST A **bulb test** is performed when the ignition is first turned on. All of the warning lights come on as part of a self-test, and to help the driver or technician spot any warning light that may be burned out or not operating. Technicians or drivers who are familiar with what lights should light may be able to determine if one or more warning lights are not on when the ignition is first turned on. Most factory scan tools can be used to command all of the warning lights on to help determine if one is not working.

GREEN OR WHITE SYMBOLS Green or white symbols are used to notify the driver that certain functions are working, such as the headlights are on or the turn signals have been activated. None of the green or white symbols need any further action by the driver. The blue symbol is used to indicate the high-beam headlights are on. ● **SEE FIGURE 54–1**.

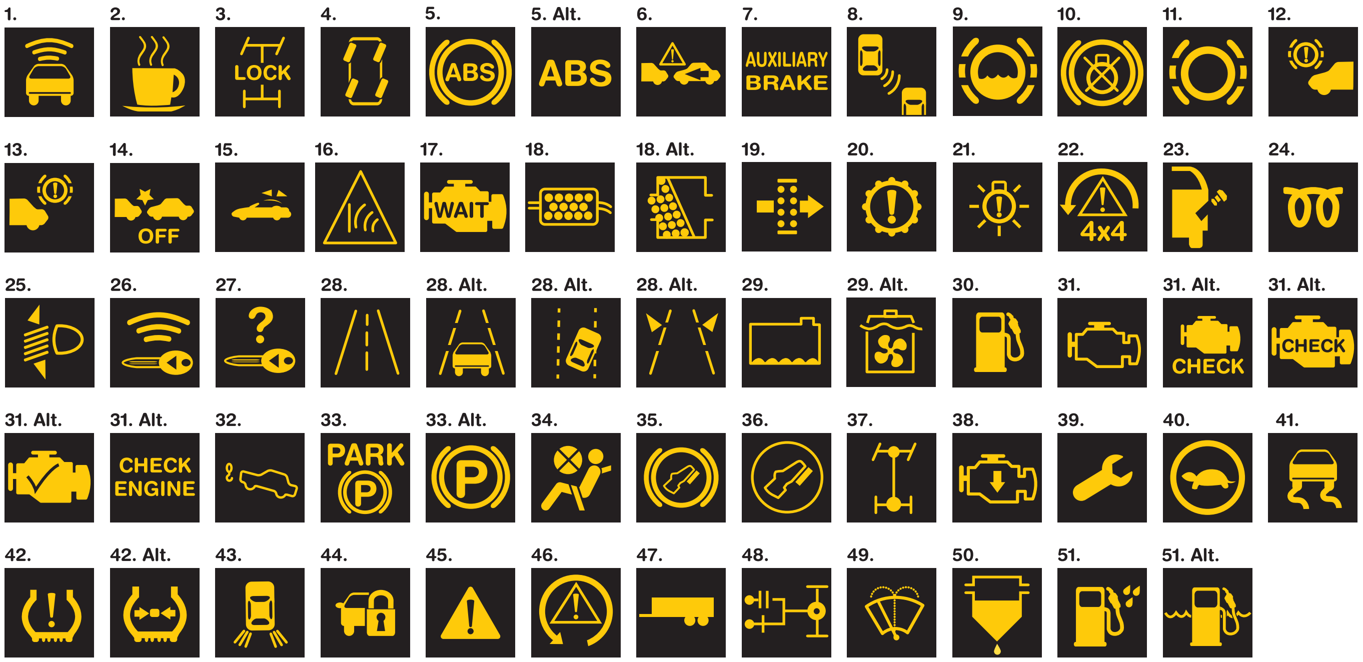
AMBER SYMBOLS Amber-colored symbols mean that a fault or an issue has occurred that may require attention soon. These can include a warning of low air pressure in a tire, or that the powertrain control module (PCM) has detected a fault in the engine that could affect the exhaust emissions.

While these issues should be addressed, there is no urgency and it is not necessary to stop the vehicle. ● **SEE FIGURE 54–2**.



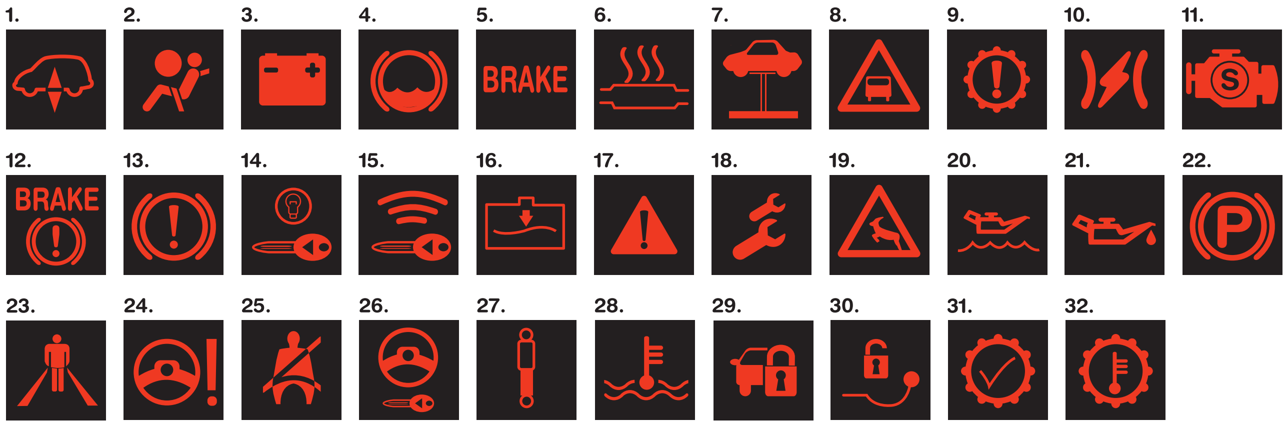
1. Adaptive Cruise Control
2. Adaptive Lighting
3. Automatic Wipers
4. Blind Spot Monitor
5. Crawl Control Indicator
6. Cruise Control On
7. Daytime Running Lights
8. Door Open
9. Eco Driving Indicator
10. EV Mode
11. Fog Lights - Front
12. Freeze Warning
13. Frost Warning
14. Fuel Fill Side Indicator
15. High Beam Headlights
16. Hill Descent Control
17. Hood Open
18. Information Indicator
19. Low Beam Headlights
20. Parking Assist
21. Rain Sensor
22. Ready Indicator
23. Rear Window Defrost
24. Parking Light
25. Tail Light Indicator
26. Tow Mode Selected
27. Traction Control
28. Trunk Open
29. Turn Signal Indicator
30. Windshield Defrost

FIGURE 54–1 Green and blue symbols are used to inform the driver what is in operation.



1. Adaptive Cruise Control
2. Alert Notice
3. All Wheel Lock
4. All Wheel Steer
5. Anti-Lock Brake System Warning
6. Auto Braking Indicator
7. Auxiliary Brake Active
8. Blind Spot Indicator
9. Brake Fluid Low
10. Brake Warning Light Fault
11. Brake Pad Wear Warning
12. Brake Pad Warning - Front
13. Brake Pad Warning - Rear
14. Collision Warning Off
15. Convertible Top Warning
16. Crosswind Assist
17. Diesel Engine Preheat
18. Diesel Particulate Filter Warning
19. Dirty Air Filter
20. Electric Shift Malfunction
21. Exterior Light Fault
22. Four-Wheel-Drive Fault
23. Gas Cap Loose
24. Glow Plug
25. Headlight Range Control
26. Key Fob Battery Low
27. Key Not In Vehicle
28. Lane Departure Warning
29. Low Coolant Level Detected
30. Low Fuel
31. Malfunction Indicator Lamp (MIL)
32. Needs To Be Towed
33. Parking Brake
34. Passenger Airbag Deactivated
35. Press Brake Pedal
36. Press Clutch Pedal
37. Rear Differential Lock
38. Reduced Power
39. Service Required
40. Speed Reduced
41. Stability Control Activated
42. TPMS Warning Lamp
43. Tail Light Out
44. Theft Deterrent
45. Time for Maintenance Indicator
46. Traction Control Fault
47. Trailer Towing Mode
48. Transmission Warning
49. Washer Fluid Low
50. Water in Diesel Fuel
51. Water in Fuel Filter

FIGURE 54–2 Amber warning symbols inform the driver of a potential concern.



1. Air Suspension Warning
2. Airbag Warning
3. Battery/Alternator Warning
4. Brake Fluid Low
5. Brake Warning
6. Catalytic Converter Warning
7. Chassis System Warning
8. Distance Warning
9. Drivetrain Trouble Indicator
10. Electronic Throttle Control
11. Engine Fault Stop
12. Handbrake Warning
13. Hydraulic Brake Fault
14. Ignition Switch Warning
15. Key Fob Battery Low
16. Low Coolant Level Warning
17. Master Warning
18. Mechanical Fault Warning
19. Night Vision Warning
20. Oil Level Low
21. Oil Pressure Low
22. Parking Brake Light
23. Pedestrian Warning
24. Power Steering Warning
25. Seat Belt Not On
26. Steering Lock Warning
27. Suspension Fault Detected
28. Temperature Warning
29. Theft Deterrent Fault
30. Trailer Tow Hitch Warning
31. Transmission Fault Do Not Shift
32. Transmission Fluid Temp Warning

FIGURE 54–3 Red dash symbols are used to warn the driver of a fault requiring immediate action.

FREQUENTLY ASKED QUESTION

How to Rest Maintenance Indicators?

In most cases, the maintenance required indicators symbols are used only as a reminder that routine maintenance is needed, such as an oil change. For most vehicles, the resetting procedure is often easily done such as: “Depress the accelerator pedal three times to the floor, in less than 10 seconds.” Then when the ignition is turned off, and the light will go out, resetting the indicator. Check service information the owner's manual or perform an Internet search to find the exact procedure to follow for the vehicle being serviced.

RED WARNING SYMBOLS Red symbols mean that a serious fault has been detected and that immediate attention is required. An example of a serious fault that requires the driver’s attention is the red brake warning light or the oil pressure warning light. Both of these indicate that a fault has been detected and the vehicle should not be driven further until the cause has been found and corrected. ● **SEE FIGURE 54–3**.

STEERING WHEEL CONTROLS

PURPOSE **Steering wheel controls** are steering wheels that include buttons to allow the driver to control certain audio, vehicle information, and HVAC functions. The purpose of having steering wheel controls is to allow the driver to keep their hands on the wheel and their eyes on the road at all times. Steering wheels that have controls are often called *multi-function steering wheels*. ● **SEE FIGURE 54–4**.

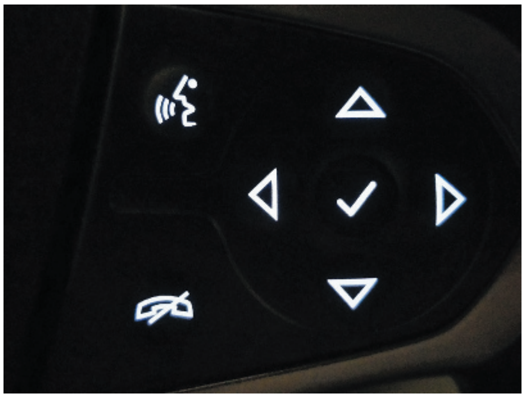


FIGURE 54–4 Steering wheel controls allow the driver to select a function while keeping their hands on the wheel and their eyes on the road.

FUNCTIONS Some of the functions on the steering wheel include the following:

- Radio controls, such as volume up and down and mode selection
- Cruise control
- Telephone answering and calling
- Voice commands

Check service information for the specified tests and procedures to follow if the steering wheel controls do not operate as designed.

VOICE ACTIVATION

PURPOSE Most recent vehicles include *voice commands*, commonly called **voice activation**, that can be used to perform various functions or settings in the vehicle. Most systems include a list of phrases to use to achieve the best results.

FUNCTIONS The typical functions that can be performed using voice commands include the following:

- Phone calls with outgoing or incoming calls usually tied by Bluetooth to a cell phone in the vehicle
- Text messages can be read, and a response sent, using Bluetooth
- Climate-control settings, including desired temperature, in many vehicles
- Select source of audio, such as radio, USB, or satellite
- Navigation system, including destination and points of interest

Check service information for the specified tests and procedures to follow if the voice commands or the controls do not operate as designed.

MAINTENANCE INDICATORS

PURPOSE AND FUNCTION The purpose of the maintenance reminders is to inform the driver that routine maintenance is needed. The message can include what type of maintenance is needed, such as a minor or a major service, but most messages simply state that service is required soon or service is required now. ● **SEE FIGURE 54–5**.

RESET MAINTENANCE INDICATORS To reset the maintenance reminder light or message, check the owner's manual or service information.

ANALOG AND DIGITAL DISPLAYS

TERMINOLOGY Vehicle information is displayed on the **instrument panel cluster (IPC)**:

- An **analog display** uses a needle to show the values, such as engine RPM
- A **digital display** uses numbers to indicate values, such as vehicle speed

Analog electromagnetic dash instruments use small electromagnetic coils that are connected to a sending unit for such things as fuel level, water temperature, and oil pressure. The sensors are the same, regardless of the type of display used. The resistance of the sensor varies with what is being measured.

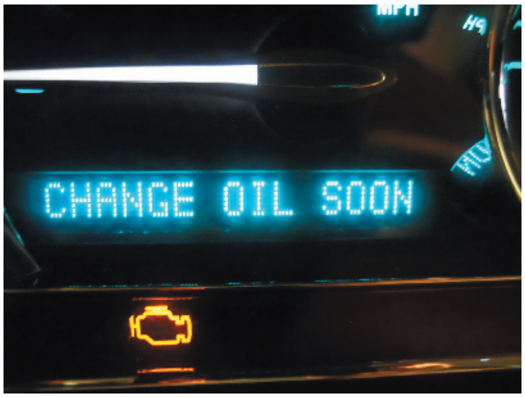


FIGURE 54–5 Maintenance reminders are often messages displayed on the instrument panel informing the driver of needed service, such as the need to change the engine oil.

STEPPER MOTOR ANALOG GAUGES Most analog dash displays use a stepper motor to move the needle. A **stepper motor** is a type of electric motor that is designed to rotate in small steps based on the signal from a computer. This type of gauge is very accurate. A digital output is used to control stepper motors. Stepper motors are direct current motors that move in fixed steps or increments from de-energized (no voltage) to fully energized (full voltage). A stepper motor often has as many as 120 steps of motion.

A typical stepper motor uses a permanent magnet and two electromagnets. Each of the two electromagnetic windings is controlled by the computer. The computer pulses the windings and changes the polarity of the windings to cause the armature of the stepper motor to rotate a degree at a time. Each degree pulse is recorded by the computer as a "count" or "step," which explains the name given to this type of motor. ● **SEE FIGURE 54–6**.

NOTE: Many electronic-gauge clusters are checked when the ignition is first turned on; the dash display needles are commanded to 1/4, 1/2, 3/4, and full positions before returning to their normal readings. This self-test allows the service technician to check the operation of each individual gauge, even though replacing the entire instrument panel cluster is usually necessary to repair an inoperative gauge.

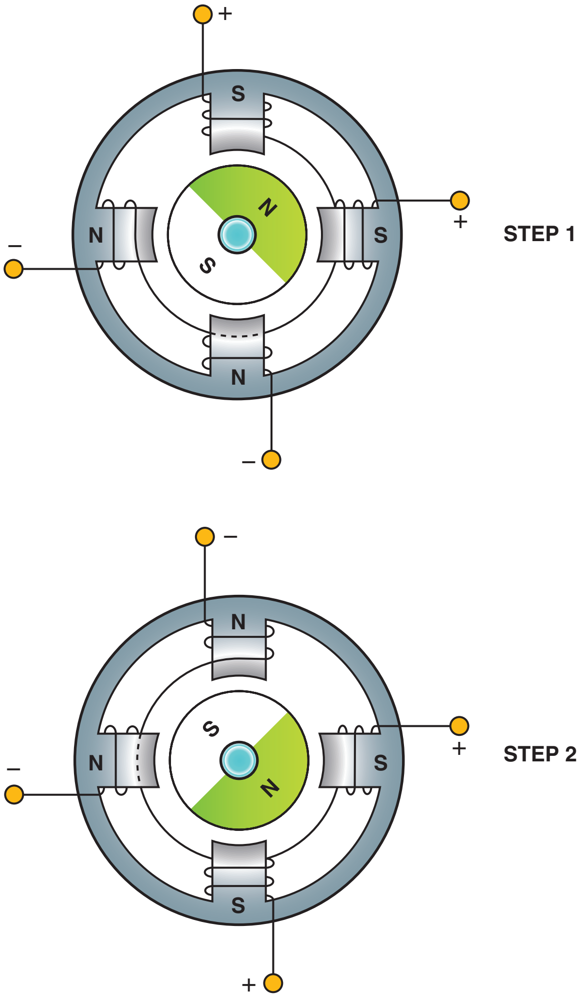


FIGURE 54–6 Most stepper motors use four wires that are pulsed by the computer to rotate the armature in steps.

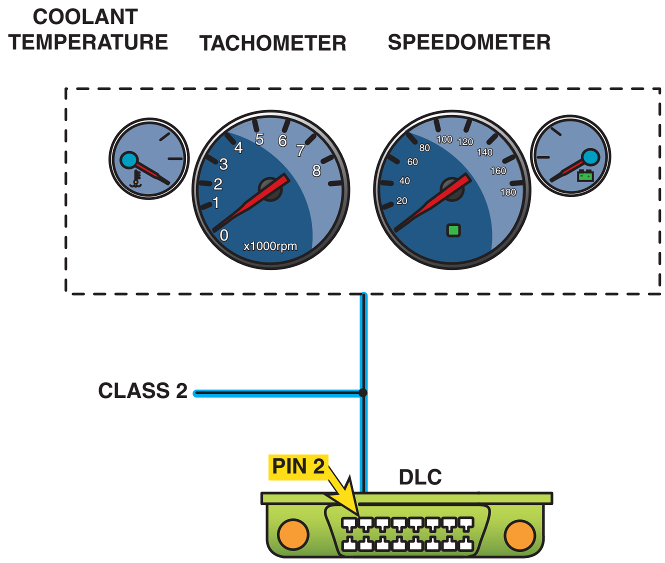


FIGURE 54–7 A typical instrument display uses data from the sensors over serial data lines to the individual gauges.

NETWORK COMMUNICATION Many instrument panels are operated by electronic control units that communicate with the powertrain control module (PCM) for engine data, such as revolutions per minute (RPM) and engine coolant temperature (ECT). The PCM uses the voltage changes from variable-resistance sensors, such as that of the fuel gauge, to determine fuel level. The data is transmitted to the instrument cluster, as well as to the PCM through serial data lines. Because all sensor inputs are interconnected, the technician should always follow the factory recommended diagnostic procedures. ● **SEE FIGURE 54–7**.

HEAD-UP DISPLAY

PURPOSE The **head-up display (HUD)**, also called a *heads-up display*, is a supplemental display that projects the vehicle speed and sometimes other data, such as turn-signal information, onto the windshield. The projected image looks as if it is some distance ahead, making it easy for the driver to see without having to refocus on a closer dash display. ● **SEE FIGURES 54–8 AND 54–9**.

OPERATION On many vehicles, the brightness of the head-up display can be controlled to make it easier for the driver to see the information. The HUD unit is installed in the instrument panel (IP) and uses a mirror to project vehicle information onto the inside surface of the windshield. ● **SEE FIGURE 54–10**.

Follow the vehicle manufacturer's recommended diagnostic and testing procedures if any faults are found with the head-up display.

NIGHT VISION

PURPOSE AND FUNCTION **Night vision** systems use a camera that is capable of observing objects in the dark to assist the driver while driving at night. The primary night-viewing illumination devices are the headlights. The night vision option uses a HUD to improve the vision of the driver beyond the scope of the headlights. Using a HUD allows the driver to keep eyes on

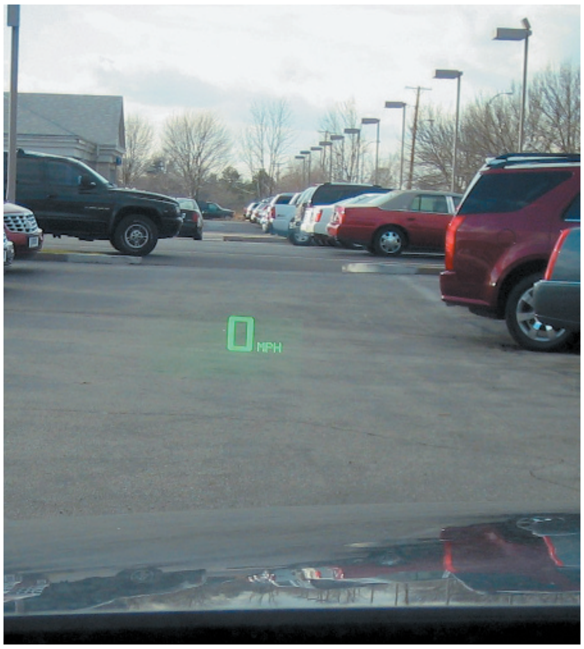


FIGURE 54–8 A typical head-up display showing zero miles per hour, which is actually projected on the windshield from the head-up display in the dash.

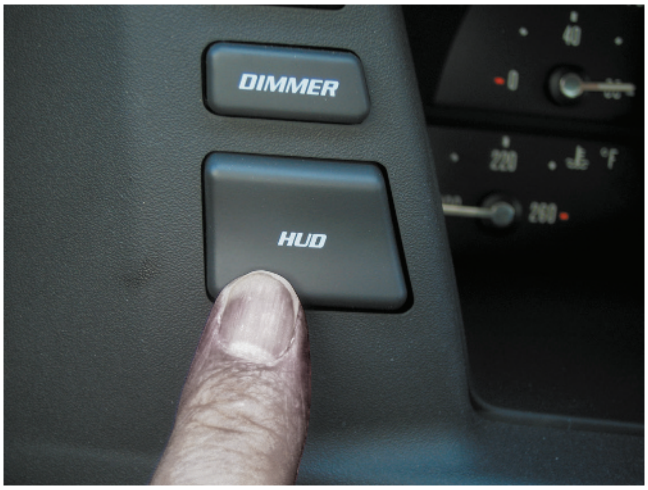


FIGURE 54–9 The dash-mounted control for the head-up display on this Cadillac allows the driver to move the image up and down on the windshield for best viewing.

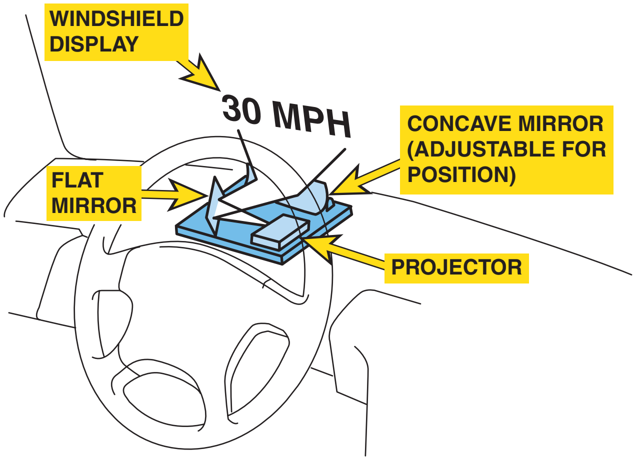


FIGURE 54–10 A typical head-up display (HUD) unit.

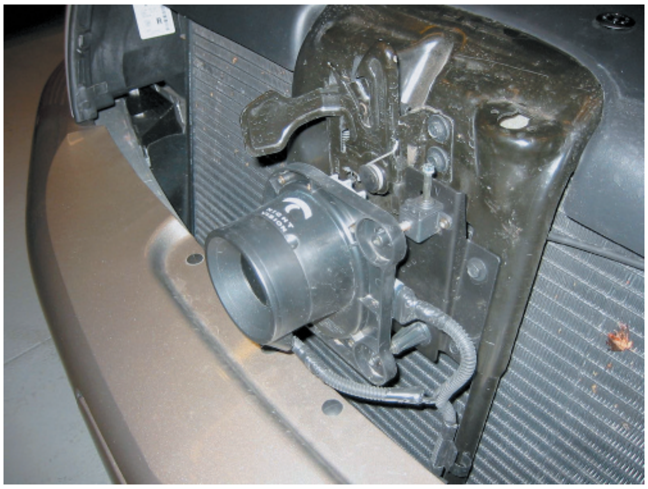


FIGURE 54–11 A night vision camera behind the grille of a Cadillac.

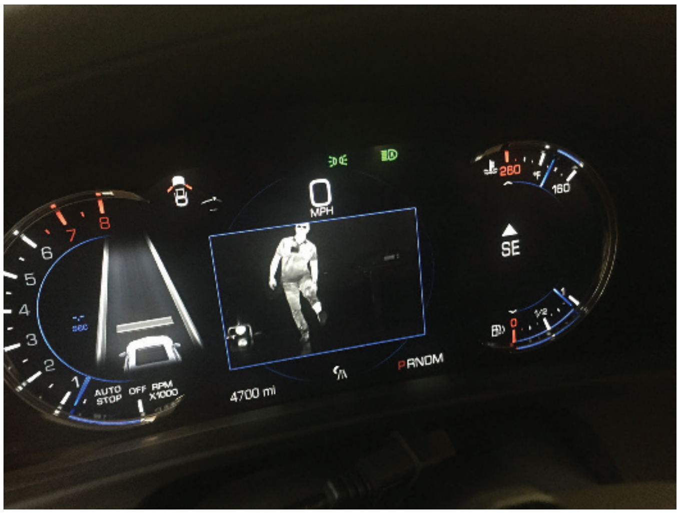


FIGURE 54–12 A view of a person walking in front of a Cadillac equipped with night vision.

the road and hands on the wheel for maximum safety. Besides the HUD, the night vision camera uses a special thermal imaging or infrared technology. The camera is mounted behind the grille in the front of the vehicle. ● **SEE FIGURES 54–11 AND 54–12**.

OPERATION The camera creates pictures based on the heat energy emitted by objects, rather than from light reflected on an object, as in a normal optical camera. The image looks like a black and white photo negative when hot objects (higher thermal energy) appear light or white, and cool objects appear dark or black. Other parts of the night vision system include the following:

- On/off and dimming switch. This allows the driver to adjust the brightness of the display and to turn it on or off, as needed.
- Up/down switch. The night vision HUD system has an electric tilt-adjust motor that allows the driver to adjust the image up or down on the windshield within a certain image.

CAUTION: Becoming accustomed to night vision can be difficult and may take several nights to get used to looking at the HUD.

DIAGNOSIS AND SERVICE The first step when diagnosing a fault with the night vision system is to verify the concern. Check the owner's manual or service information for proper operation. For example, the Cadillac night vision system requires the following actions to function:

1. The ignition has to be in the on (run) position.
2. The Twilight Sentinel photo cell must indicate that it is dark.
3. The headlights must be on.
4. The switch for the night vision system must be on and the brightness adjusted so the image is properly displayed.

Even though the night vision system camera is protected from road debris by a grille, small stones or other debris can get past the grille and damage the lens of the camera. The operation of the night vision can also be affected by an accumulation of heavy ice or snow. If the camera is damaged, it must be replaced as an assembly because no separate parts are available. Always follow the vehicle manufacturer's recommended testing and servicing procedures.

ELECTRONIC DISPLAYS

LIQUID CRYSTAL DISPLAYS A **liquid crystal display (LCD)** can be arranged into a variety of forms, letters, numbers, and bar graph displays.

- LCD construction consists of a special fluid sandwiched between two sheets of polarized glass. The special fluid between the glass plates permit light to pass if a small voltage is applied to the fluid through a conductive film laminated to the glass plates.
- The light from a very bright halogen bulb behind the LCD shines through those segments of the LCD that have been polarized to let the light through, which then show numbers or letters.
- **Thin-film-transistor (TFT)** LCD is a type of a LCD that uses TFT technology. This type of display has enhanced image qualities and contrast compared to simple light-driven LCDs.
- LCD displays can be used to present data in the form of numbers, text messages, or graphical gauges. The high-resolution screen can be programmed to show several functions, such as navigation, radio and media, as well as Google Earth 3-D graphics, and traffic data. This is in addition to the usual functions of showing speed, engine revolutions, outside temperature, and fuel level.

CAUTION: When cleaning an LCD, be careful not to push on the glass plate covering the special fluid. If excessive pressure is exerted on the glass, the display may be permanently distorted. If the glass breaks, the fluid escapes and could damage other components in the vehicle, due to its strong alkaline nature. Use only a soft, damp cloth to clean these displays.

- The major disadvantage of an LCD digital dash is that the numbers or letters are slow to react or change at low temperatures. ● **SEE FIGURE 54–13**.

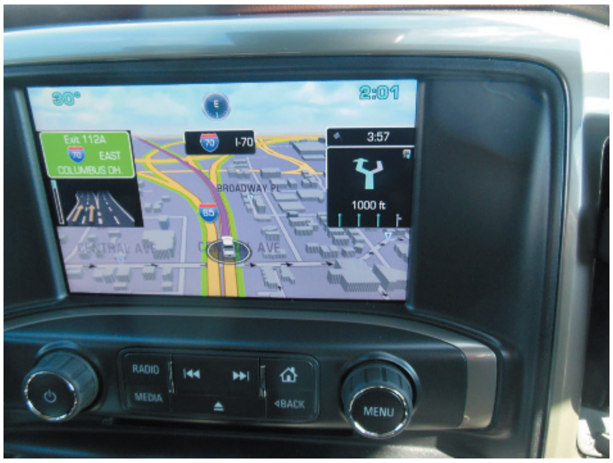


FIGURE 54–13 A typical LCD navigation system display.

FREQUENTLY ASKED QUESTION

What Is the WOW Display?

When a vehicle equipped with a digital dash is started, all segments of the electronic display are turned on at full brilliance for 1 or 2 seconds. This is commonly called the **WOW display** and is used to show off the brilliance of the display. If numbers are part of the display, the number 8 is shown, because this number uses all segments of a number display. Technicians can also use the WOW display to determine if all segments of the electronic display are functioning correctly.

VIRTUAL DISPLAY

PURPOSE AND FUNCTION A **virtual display** is a dash that allows the driver to select what data is being displayed. Many vehicles are equipped with an LCD dash display that can be changed to display various functions based on the driver's preference. This allows the dash display to be totally customized to what the driver wishes to see displayed. For example, a typical display can show any four of the following:

- Coolant temperature
- Voltmeter
- Oil pressure
- Vehicle speed (speedometer)
- Engine speed (tachometer)
- Automatic transmission fluid temperature
- Tire pressures for all four tires

OPERATION The dash display is all that is really different because all the data comes to the IPC on the data bus. The only difference is that the display can be changed to meet the needs of the driver. For example, if a driver is towing a trailer, displaying the automatic transmission fluid temperature is very helpful so that overheating of the transmission is avoided. ● **SEE FIGURE 54–14**.

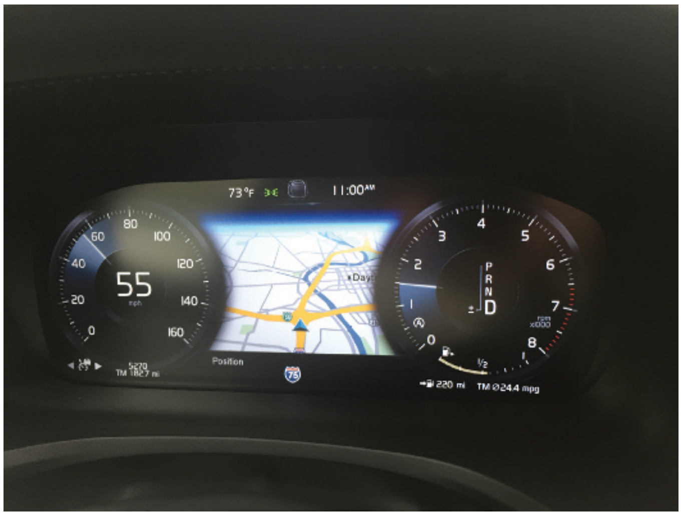


FIGURE 54–14 A virtual dash on this Volvo is able to display a speedometer (left) in both analog (needle-type) and digital (number) as well as a tachometer on the right. In the center of the display, this virtual dash is displaying the navigation screen. What is displayed can be changed by the driver to match what is important to them.

TOUCH SCREENS

PURPOSE A **touch screen** is a dash display, usually LCD, that allows the driver or passenger to use a finger to perform functions that are displayed on the screen.

OPERATION A capacitive touchscreen panel consists of an insulator, such as glass, coated with a transparent conductor, such as indium tin oxide (ITO). Because the human body is also an electrical conductor, touching the surface of the screen results in a distortion of the screen's electrostatic field. The location is then sent to the controller for processing. Placing a finger near the electric fields adds conductive surface area to the capacitive system. This is measurable as a change in capacitance. The capacitance can be changed and measured at every individual point on the grid (intersection). ● **SEE FIGURE 54–15**.

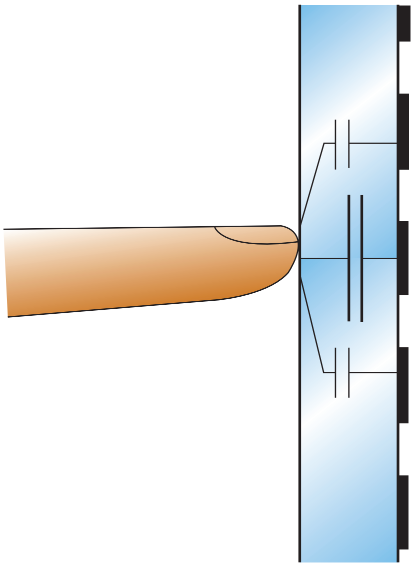


FIGURE 54–15 Schematic of a capacitive touchscreen.

TECH TIP

Touch Screen Tip

Most vehicle navigation systems use a touch screen for use by the driver (or passenger) to input information or other on-screen prompts. Most touch screens use a change in capacitance at the surface of the screen to determine when and where some action is being performed. Do not push harder on the display if the unit does not respond, or the display unit may be damaged. If no response is detected when lightly touching the screen, rotate the finger to cause the capacitance area to increase so it can be easily detected.

TOUCH SCREEN FEEDBACK Many touch screens include feedback to the user by either using a beep or a small vibration when the screen is touched. This is called *haptic* response system and helps improve the user experience by giving immediate feedback.

SPEEDOMETERS/ODOMETERS

OPERATION Dash displays use an electric vehicle speed sensor on the output of the transmission or from the input from the wheel speed sensors (WSS). Some vehicles use the ABS wheel speed sensors to get vehicle speed, rather than a dedicated vehicle speed sensor. Many speed sensors contain a permanent magnet and generate a voltage in proportion to the vehicle speed. These speed sensors are commonly called permanent magnet (PM) generators. ● **SEE FIGURE 54–16**.

The output of a PM generator speed sensor is an AC voltage that varies in frequency and amplitude with increasing vehicle speed. The PM generator speed signal is sent to the instrument cluster electronic circuits. These specialized electronic circuits include a buffer amplifier circuit that converts the variable sine wave voltage from the speed sensor to an on/off signal that can be used by other electronic circuits to indicate a vehicle's speed. The vehicle speed is then displayed by either an electronic needle-type speedometer or by numbers on a digital display.

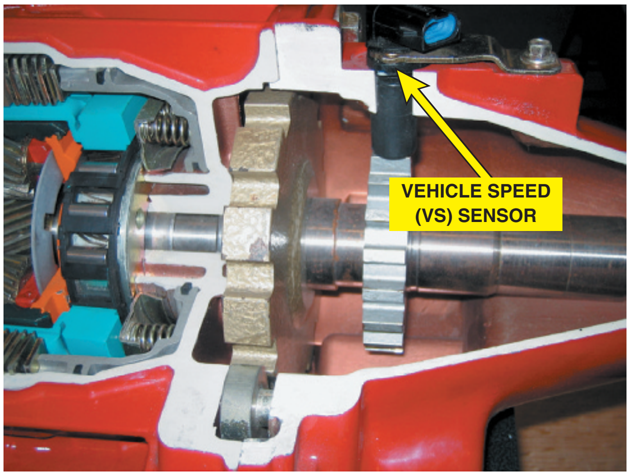


FIGURE 54–16 A vehicle speed sensor located in the extension housing of the transmission. Some vehicles use the wheel speed sensors for vehicle speed information.

ODOMETERS An odometer is a dash display that indicates the total miles traveled by the vehicle. Electronic dash displays can use either an electrically driven mechanical odometer or a digital display odometer to indicate miles traveled. On mechanical-type odometers, a small electric motor, called a stepper motor, is used to turn the number wheels of a mechanical-style odometer. A pulsed voltage is fed to this stepper motor, which moves in relation to the miles traveled. ● **SEE FIGURE 54–17**.

Digital odometers use LED, LCD, or VTF displays to indicate miles traveled in the instrument cluster. Because total miles must be retained when the ignition is turned off or the battery is disconnected, a special electronic chip must be used that retains the miles traveled. These special chips are called **nonvolatile random access memory (NVRAM)**. *Nonvolatile* means that the information stored in the electronic chip is not lost when electrical power is removed. Some vehicles use a chip called electronically erasable programmable read-only memory (**EEPROM**). Most digital odometers can read up to 999,999.9 miles or kilometers (km), and then the display indicates error. If the chip is damaged or exposed to static electricity, it may fail to operate and "error" may appear.

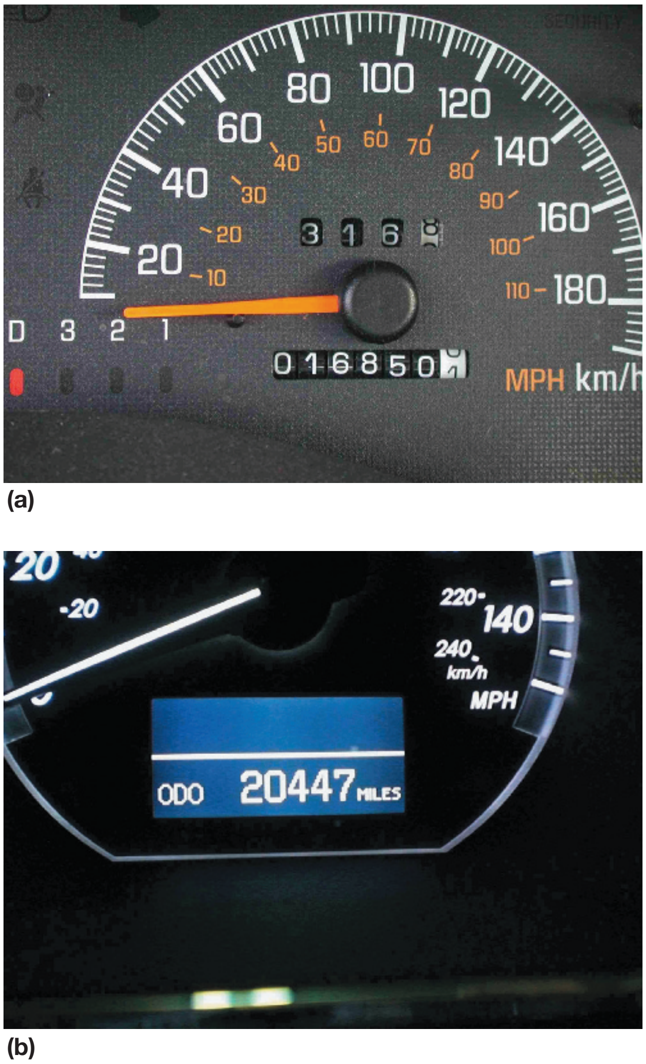


FIGURE 54–17 (a) Some odometers are mechanical and are operated by a stepper motor. (b) Many vehicles are equipped with an electronic odometer.

TECH TIP

Keep the Same Overall Tire Diameter

Whenever larger (or smaller) wheels or tires are installed, the speedometer and odometer calibration are thrown off. This can be summarized as follows:

- **Larger diameter tires.** The speed showing on the speedometer is slower than the actual speed.

  The odometer reading shows fewer miles than actual.
- **Smaller diameter tires.** The speed showing on the speedometer is faster than the actual speed. The odometer reading shows more miles than actual.

  To avoid speedometer and odometer issues, select a wheel/tire combination that has the same outside diameter (OD) of the original wheel/tire combination. Many newer vehicles can use the scan tool to change the tire size (from a select group of sizes) to minimize the effects of tires size change on odometer and speedometer readings.

  To determine the exact effects of a replacement size wheel or tire, perform an Internet search for a tire size comparison chart.

CASE STUDY

The Speedometer Works as if It Is a Tachometer

The owner of a Ford F-150 pickup truck complained that all of a sudden the speedometer needle went up and down with engine speed, rather than vehicle speed. In fact, the speedometer needle went up and down with engine speed, even though the gear selector was in "park" and the vehicle was not moving. After hours of troubleshooting, the service technician went back and started checking the basics and discovered that the alternator had a bad diode. The technician measured over 1 volt AC and over 10 ampere AC ripple current using a clamp-on AC/DC ammeter. Replacing the alternator restored the proper operation of the speedometer.

Summary:

Complaint—Customer stated that the speedometer moves in relation to engine speed and not vehicle speed.
Cause—Tests confirmed that the alternator was producing excessive AC voltage due to a bad diode.
Correction—Replacing the alternator restored proper operation of the speedometer.

SPEEDOMETER/ODOMETER SERVICE If the speedometer and odometer fail to operate, check the following:

- Use a scan tool and monitor the vehicle speed as displayed on the scan tool. If the speed is zero, then check the output from the vehicle speed sensor. With the vehicle safely raised off the ground and supported so the drive wheels rotate, check the vehicle speed using a scan tool.
- If a scan tool is not available, disconnect the wires from the speed sensor near the output shaft of the transmission. Connect a multimeter set on AC volts to the terminals of the speed sensor, and rotate the drive wheels with the transmission in neutral. A good speed sensor should indicate approximately 2 volt AC if the drive wheels are rotated by hand.
- If the speed sensor is working, check the wiring from the speed sensor to the dash cluster. If the wiring is good, the instrument panel (IP) should be sent to a specialized repair facility.
- If the speedometer operates correctly, but the mechanical odometer does not work, the odometer stepper motor, the number wheel assembly, or the circuit controlling the stepper motor is defective. If the digital odometer does not operate, but the speedometer operates correctly, the dash cluster must be removed and sent to a specialized repair facility.

DASH GAUGES

FUEL LEVEL Fuel level gauges use a fuel tank sending unit that consists of a float attached to a variable resistor. When the fuel level changes, the resistance of the fuel level sending unit also changes. As the resistance of the tank unit changes, the dash-mounted gauge also changes to show the level of the fuel in the tank.

OIL PRESSURE The oil pressure lamp operates through use of an oil pressure sending unit, which is a switch screwed into the engine block, and grounds the electrical circuit. It lights the dash warning lamp in the event of low oil pressure, that is, 3 to 7 PSI (20 to 50 kPa). Normal oil pressure is generally between 10 and 60 PSI (70 and 400 kPa). Some vehicles are equipped with variable-voltage oil pressure sensors rather than a simple pressure switch. ● **SEE FIGURE 54–18**.

To test the operation of the oil pressure warning circuit, unplug the wire from the oil pressure sending unit, usually located

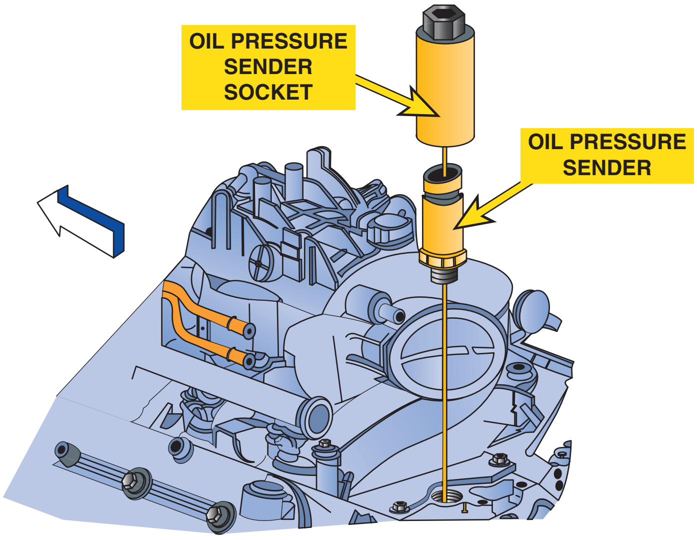


FIGURE 54–18 A sending unit socket being used to remove an oil pressure sender unit.

CASE STUDY

Electronic Devices Cannot Swim

The owner of a Dodge minivan complained that after the vehicle was cleaned inside and outside, the temperature gauge, fuel gauge, and speedometer stopped working. The vehicle speed sensor was checked and found to be supplying a square wave signal that changed with vehicle speed. A scan tool indicated a speed, yet the speedometer displayed zero all the time. Finally, the service technician checked the body control module (BCM) to the right of the accelerator pedal and noticed that it had been wet, from the interior cleaning. Drying the BCM did not fix the problem, but a replacement BCM fixed all the problems. The owner discovered that electronic devices do not like water and that computers cannot swim.

Summary:

Complaint—Customer complained that many gauges stopped working after the vehicle was cleaned.
Cause—The body control module (BCM) was found to be wet from interior cleaning.
Correction—Replacing the BCM fixed all the problems.

FREQUENTLY ASKED QUESTION

What Does the Arrow Mean?

Many fuel gauges have an arrow next the symbol of a fuel pump. The arrow points to the side where the fill cap is located. This is very helpful if using a rental vehicle as it indicates which side to pull up to a filling station pump. ● **SEE FIGURE 54–19**.

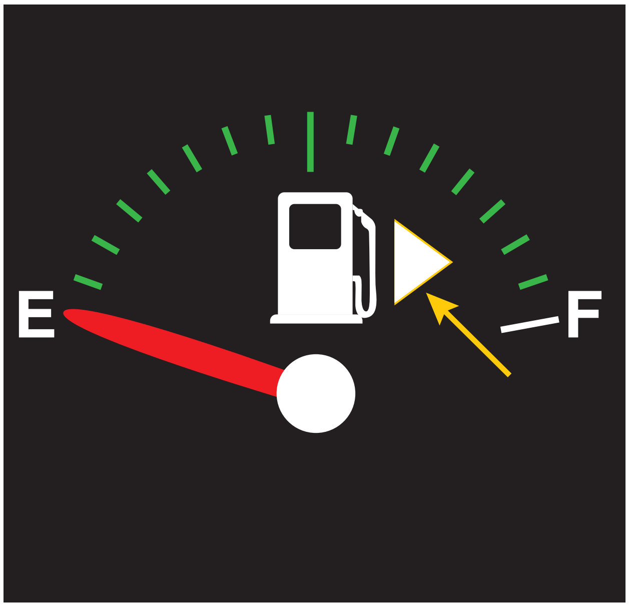


FIGURE 54–19 The arrow next to the fuel pump symbol shows which side of the vehicle the fuel cap is located.

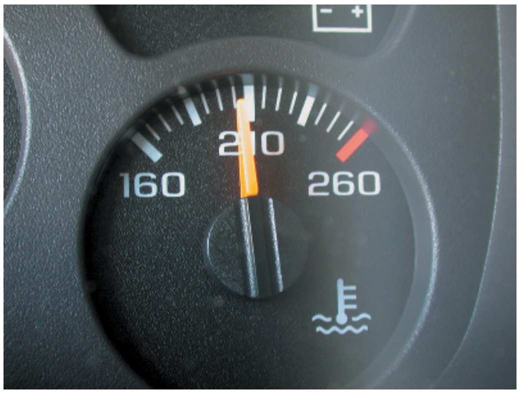


FIGURE 54–20 A temperature gauge showing normal operating temperature between 180°F and 215°F, depending on the specific vehicle and engine.

near the oil filter, with the ignition switch on. With the wire disconnected from the sending unit, the warning lamp should be off. If the wire is touched to a ground, the warning lamp should be on. If there is *any* doubt of the operation of the oil pressure warning lamp, always check the actual engine oil pressure, using a mechanical gauge that can be screwed into the opening that is left after unscrewing the oil pressure sending unit. For removing the sending unit, special sockets are available at most auto parts stores, or a 1 inch or 1 1/16 inch 6-point socket may be used for most sending units.

COOLANT TEMPERATURE The "hot" lamp, or engine coolant overheat warning lamp, warns the driver whenever the engine coolant temperature is between 248°F and 258°F (120°C and 126°C). Most vehicles use the engine coolant temperature (ECT) sensor for engine temperature gauge operation. To test this sensor, use a scan tool to verify proper engine temperature and follow the vehicle manufacturer's recommended testing procedures. ● **SEE FIGURE 54–20**.

DASH INSTRUMENT DIAGNOSIS If one or more electronic dash gauges do not work correctly, first perform a bulb check. The electronic dash instruments can be tested using the following procedure:

1. Use a factory or factory-level scan tool to check for any "B" (body) or "C" (chassis) diagnostic trouble codes (DTCs) that may be set and stored. If a DTC is stored, follow the service information instructions to find the root cause.
2. Use the bidirectional control features on the scan tool to actuate the dash display to see if they function. If not, the replacement of the entire IPC may be required.

Always follow the specified testing and diagnostic procedures found in service information for the vehicle being tested.

NAVIGATION AND GPS

PURPOSE AND FUNCTION The **global positioning system (GPS)** uses 24 satellites in orbit around the earth to provide signals for navigation devices. GPS is funded and controlled by the U.S. Department of Defense (DOD). While the system can be used by anyone with a GPS receiver, it was designed for and is operated by the U.S. military. ● **SEE FIGURE 54–21**.

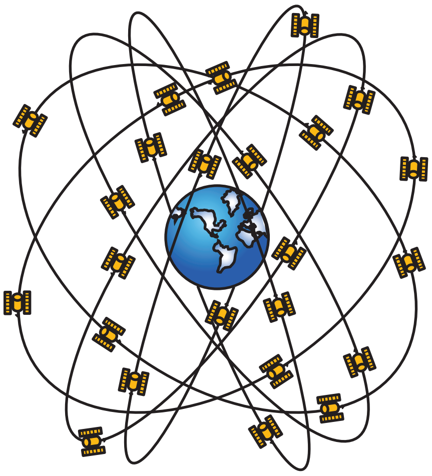


FIGURE 54–21 Global positioning systems use 24 satellites in high earth orbit whose signals are picked up by navigation systems. The navigation system computer then calculates the location based on the position of the satellite overhead.

NAVIGATION SYSTEM PARTS AND OPERATION Navigation systems use the GPS satellites for basic location information. The navigation controller uses other sensors, including a digitized map to display the location of the vehicle.

- **GPS satellite signals.** Signals from at least three satellites are needed to locate the vehicle.
- **Yaw sensor.** This sensor is often used inside the navigation unit to detect movement of the vehicle during cornering. This sensor is also called a *"g" sensor* because it measures force; 1 g is the force of gravity.
- **Vehicle speed sensor.** A yaw sensor is a device, usually a chip that measures the movement of a vehicle around its vertical axis. This sensor input is used by the navigation controller to determine the speed and distance the vehicle travels. This information is compiled and compared to the digital map and GPS satellite inputs to locate the vehicle.
- **Audio output/input.** Voice-activated factory units use a built-in microphone at the center top of the windshield and the audio speakers speech output.

Navigation systems include the following components:

1. Screen display ● **SEE FIGURE 54–22**.
2. GPS antenna
3. Navigation control unit, usually with map information on a DVD or memory card.

The memory card includes street names and the following information:

1. Points of interest (POI), including automated teller machines (ATMs), restaurants, schools, colleges, museums, shopping mall, and airports, as well as vehicle dealer locations.
2. Business addresses and telephone numbers, including hotels and restaurants. (If the telephone number is listed in the business telephone book, it can usually be displayed on the navigation screen. If the telephone number of the business is known, the location can be displayed.)

NOTE: Private residences or cellular telephone numbers are not included in the database of telephone numbers stored on the navigation system memory card.

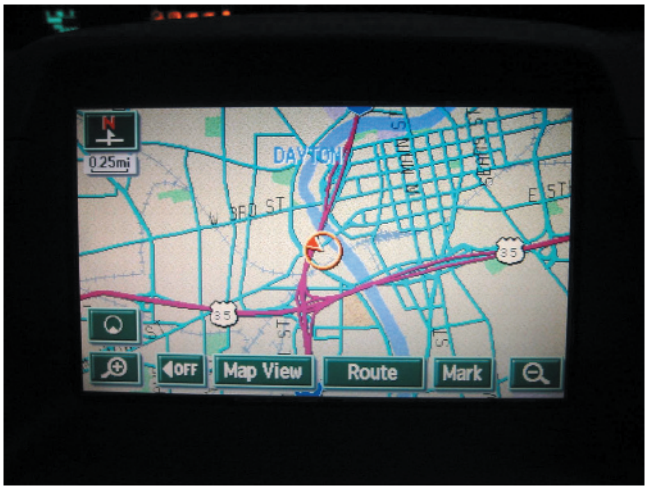


FIGURE 54–22 A typical GPS display screen showing the location of the vehicle.

FREQUENTLY ASKED QUESTION

What Is Navigation-Enhanced Climate Control?

Some vehicles use data from the navigation system to help control the automatic climate control system. Data about the location of the vehicle includes

- Time and date. This information allows the automatic climate control system to determine where the sun is located.
- Direction of travel. The navigation system can also help the climate control system determine the direction of travel.

As a result of the input from the navigation system, the automatic climate control system can control cabin temperature, in addition to various other sensors in the vehicle. For example, if the vehicle is traveling south in the late afternoon in July, the climate control system could assume that the passenger side of the vehicle is warmed more by the sun than the driver's side, and could increase the airflow to the passenger side to help compensate for the additional solar heating.

3. Turn-by-turn directions to addresses that are selected by:
    - Points of interest (POI)
    - Typed in using a keyboard shown on the display

The navigation unit then often allows the user to select the fastest way to the destination, as well as the shortest way, or assists in how to avoid toll roads. ● **SEE FIGURE 54–23**.

DIAGNOSIS AND SERVICE For the correct functioning of the navigation system, three inputs are needed:

- Location
- Direction
- Speed

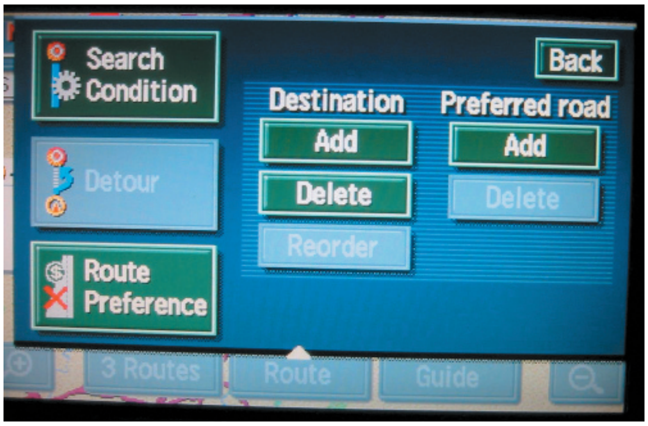
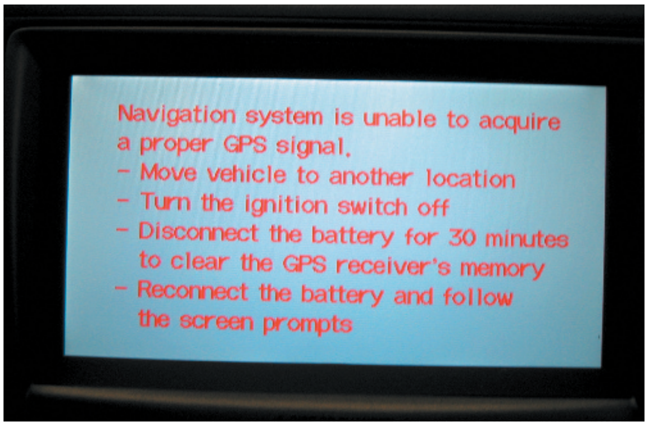


FIGURE 54–23 A typical navigation display showing various options. Some systems do not allow access to these if the vehicle is in gear and/or moving.

The navigation system uses the GPS satellite and map data to determine a location. Direction and speed are determined by the navigation computer from inputs from the satellite, plus the yaw sensor and vehicle speed sensor. The following symptoms may occur and be a customer complaint. Knowing how the system malfunctions helps to determine the most likely cause:

- If the vehicle symbol jumps down the road, a fault with the vehicle speed (VS) sensor input is usually indicated.
- If the symbol rotates on the screen, but the vehicle is not being driven in circles, a fault with the yaw sensor or yaw sensor input to the navigation controller is likely.
- If the symbol goes off course and shows the vehicle on a road that it is not on, a fault with the GPS antenna is the most common reason.
- Most factory-installed navigation systems use a GPS antenna inside the rear back glass or under the rear package shelf. If a metalized window tint is applied to the rear glass, the signal strength from the GPS satellites can be reduced. If the customer concern includes inaccurate or nonfunctioning navigation, check for window tint.

Sometimes the navigation system itself displays a warning that views from the satellite are not being received. Always follow the displayed instructions. ● **SEE FIGURE 54–24**.



Navigation system is unable to acquire a proper GPS signal.
- Move vehicle to another location
- Turn the ignition switch off
- Disconnect the battery for 30 minutes to clear the GPS receiver's memory
- Reconnect the battery and follow the screen prompts

FIGURE 54–24 A screen display of a navigation system that is unable to acquire usable signals from GPS satellites.

TELEMATICS

WHAT IS TELEMATICS?

Telematics is an interconnected system that combines telecommunications (cellular systems) and GPS navigation satellite system technology. Telematics is a method of monitoring a vehicle by combining a GPS system with on-board diagnostic systems. It is possible to record and map exactly where a vehicle is located and how fast it's traveling.

A typical telematics system includes

- Telecommunications, such as cell phone communication
- Vehicle technologies, such as self-diagnostics
- Electrical sensors, instrumentation, wireless communications
- Multimedia and Internet

Telematics, such as **OnStar**, can be a manufacturer-installed system or an aftermarket-installed system. The systems offer a variety of features, including the following:

1. **Vehicle tracking**—Used by the GPS, an onboard telematics system can track the vehicle location.
2. **User-based Insurance (UBI)**—Insurance companies want to control their cost, so many offer a discount if the vehicle owner allows a tracking device to be installed on their vehicle. This unit usually plugs into the data link connector (DLC) under the dash for its power and ground, as well as some of the data that is available on the data stream, such as throttle position and vehicle speed.

NOTE: This type of add-on tracking devices are sometimes responsible for some false diagnostic trouble codes. The devices should be removed when diagnosing any suspected vehicle network faults.

3. **Security Services**—Services, such as vehicle-collision notification and emergency services, are the core telematics features found on all systems. When an airbag deploys or other sensors are triggered, the vehicle-collision notification sends an alert to a telematics command center. An operator then contacts the vehicle's occupants through the telematics system's built-in cellular modem to assess the situation. Once the occupants confirm there's been an accident—or if the operator doesn't get a response—the command center dispatches emergency-response personnel. A telematics system also pinpoints the vehicle's location using GPS.
4. **Convenience Services**—Telematics systems offer various convenience features to help vehicle owners out of a nonemergency jam, or just make their lives easier. The system can remotely unlock a car's door after you've accidentally left the keys inside, for example. A telematics system can also flash a car's lights and sound the horn in a crowded parking lot to help you find it.

TELEMATICS SYSTEMS

There are many brand names for what is considered to be a telematics system, including

- Acura Link
- Audi Connect
- Blue Link (Hyundai)
- BMW Assist
- Care Track (Volvo)
- Car-Net (VW)

- CUE (Cadillac)
- Honda Link
- InControl (Jaguar)
- IntelliLink (Buick and GMC)
- Lexus Enform
- Mbrace (Mercedes)
- OnStar (Chevrolet and others)
- Porsche Car Connect
- Starlink (Subaru)
- Sync (Ford)
- T Connect (Toyota)
- UVO (Kia)

PARTS AND OPERATION One example of a telematics system is OnStar. OnStar was first introduced in 1996 as an option on some Cadillac models. This is a system that includes the following functions:

1. Cellular telephone
2. Global positioning antenna and computer

The cellular telephone is used to communicate with the driver from advisors at service centers. The advisor at the service center is able to see the location of the vehicle as transmitted from the GPS antenna and computer system in the vehicle on a display.

OnStar does not display the location of the vehicle to the driver unless the vehicle is also equipped with a navigation system. Unlike most navigation systems, the OnStar system requires a monthly fee. The driver interface unit is a group of three buttons mounted on the inside rearview mirror and a hands-free cellular telephone. ● **SEE FIGURE 54–25**.

The OnStar system includes the following features, which can vary, depending on the level of service desired and cost per month:

- **Automatic notification of airbag deployment.** If the airbag is deployed, the advisor is notified immediately and attempts to call the vehicle. If there is no reply or if the occupants report an emergency, the advisor contacts emergency services and gives them the location of the vehicle.
- **Emergency services.** If the red button is pushed, OnStar immediately locates the vehicle and contacts the nearest emergency service agency.
- **Stolen vehicle location assistance.** If a vehicle is reported stolen, a call-center advisor can track the vehicle.
- **Remote door unlock.** An OnStar advisor can send a cellular telephone message to the vehicle to unlock the vehicle, if needed.
- **Roadside assistance.** When called, an OnStar advisor can locate a towing company or locate a provider who can bring gasoline or change a flat tire.
- **Accident assistance.** An OnStar advisor is able to help with the best way to handle an accident. The advisor can supply a step-by-step checklist of the things that should be done, plus call the insurance company, if desired.
- **Remote horn and lights.** The OnStar system is tied into the lights and horn circuits, so an advisor can activate them, if requested, to help the owner locate the vehicle in a parking lot or garage.
- **Vehicle diagnosis.** Because the OnStar system is tied to the PCM, an OnStar advisor can help with diagnosis if there is a fault detected. The system works as follows:
    - The malfunction indicator light (MIL) (check engine) comes on to warn the driver that a fault has been detected. The driver can depress the OnStar button to talk to an advisor and ask for a diagnosis.
    - The OnStar advisor sends a signal to the vehicle requesting the status from the powertrain control module, as well as the controller for the antilock brakes and the airbag module.
    - The vehicle then sends any diagnostic trouble codes (DTCs) to the advisor. The advisor can then inform the driver about the importance of the problem and give advice as to how to resolve the problem.

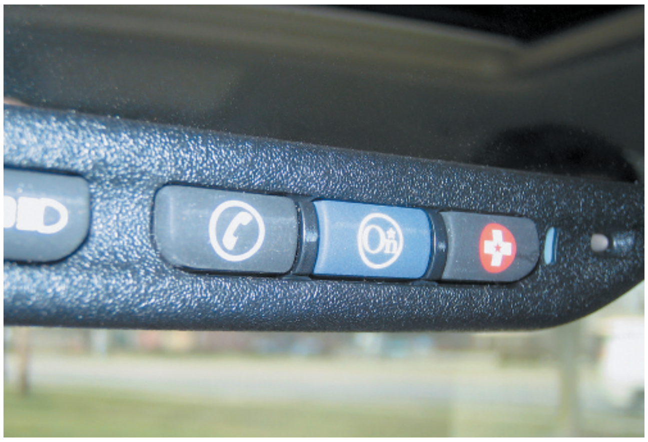


FIGURE 54–25 The three-button OnStar control is located on the inside rearview mirror. The left button (telephone handset icon) is pushed if a hands-free cellular call is to be made. The center button is depressed to contact an OnStar advisor and the right emergency button is used to request that help be sent to the vehicle's location.

DIAGNOSIS AND SERVICE The OnStar system can fail to meet the needs of the customer if any of the following conditions occur:

1. Lack of cellular telephone service in the area
2. Poor global positioning system (GPS) signals, which can prevent an OnStar advisor from determining the position of the vehicle
3. Transport of the vehicle by truck or ferry so that it is out of contact with the GPS satellite for an advisor to properly track the vehicle

If all of the above are normal and the problem still exists, follow service information diagnostic and repair procedures. If a new vehicle communication interface module (VCIM) is installed in the vehicle, the electronic serial number (ESN) must be tied to the vehicle. Check service information instructions for the exact procedures to follow.

BACKUP CAMERA

PARTS AND OPERATION

A **backup camera** is used to display the area at the rear of the vehicle in a screen display on the dash, or in the inside rear-view mirror when the gear selector is placed in reverse. Backup cameras are also called:

- *Reversing cameras*
- *Rearview cameras*

Backup cameras are different from normal cameras because the image displayed on the dash is flipped, so it is a mirror image of the scene at the rear of the vehicle. This reversing of the image is needed because the driver and the camera are facing in opposite directions. Backup cameras were first used in large vehicles with limited rearward visibility, such as motor homes. Many vehicles equipped with navigation systems today include a backup camera for added safety while reversing. ● **SEE FIGURE 54–26**.

The backup camera contains a wide-angle or fisheye lens to give the largest viewing area. Most backup cameras are pointed downward so that objects on the ground, as well as walls, are displayed. ● **SEE FIGURE 54–27**.

REAR CAMERA IMAGE ISSUES

The quality of the image projected on the display may be not be clear if any of the following conditions occur:

- Dark conditions
- Damage to the rear camera or the rear of the vehicle, affecting the aiming of the camera
- Dirt, mud, ice, or snow blocking the camera view
- Excessive high or low temperature that could affect the camera or lens
- Glare caused by the sun or a nearby bright light source, such as headlights of another vehicle

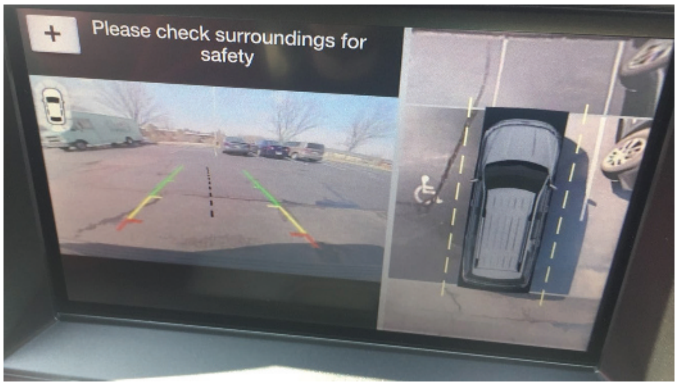


FIGURE 54–26 A dash display on a Ford F-150 pickup truck showing the backup camera image on the left side of the screen and a bird's eye view on the right side showing the vehicle next to the truck on the right and the handicap parking stop on the left. The bird's eye view is created by combining the images from the front, side mirror, and rear cameras together to create the virtual image.

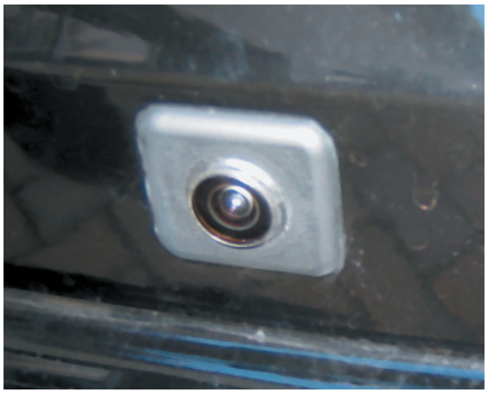


FIGURE 54–27 A typical fisheye-type backup camera usually located near the center on the rear of the vehicle near the license plate.

DIAGNOSIS AND SERVICE

Faults in the backup camera system can be related to the camera itself, the display, or the connecting wiring. The main input to the display unit comes from the transmission range switch, which signals the backup camera when the transmission is shifted into reverse.

To check the transmission range switch, perform the following:

1. Check if the backup (reverse) lights function when the gear selector is placed in reverse with the key on, engine off (KOEO).
2. Check that the transmission/transaxle is fully engaged in reverse when the selector is placed in reverse.

Most of the other diagnosis involves visual inspection:

1. Check the backup camera for damage.
2. Check the screen display for proper operation.
3. Check that the wiring from the rear camera to the body is not cut or damaged.
4. Always follow the vehicle manufacturer's recommended diagnosis and repair procedures.

REVIEW QUESTIONS

1. How does a stepper motor analog dash gauge work?
2. What do the colors of the dash symbols mean?
3. Night vision is used to detect what type of objects?
4. What is meant by the term telematics?
5. How does a navigation system determine the location of the vehicle?

CHAPTER QUIZ

1. Which color symbol requires immediate attention by the driver?
   - **a.** Red
   - **b.** Amber
   - **c.** Green
   - **d.** White
2. Technician A says that LCDs may be slow to work at low temperatures. Technician B says that an LCD dash display can be damaged if pressure is exerted on the front of the display during cleaning. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Technician A says that metal-type tinting can affect the navigation system. Technician B says most telematic systems require a monthly payment for full use of their system. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Technician A says that the data displayed on the dash can or in the windshield (head up display) can come from the powertrain control module (PCM). Technician B says that a virtual display can be set to show what the driver wishes to see displayed.
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Which of the following is NOT included on a vehicle using a steering wheel control system?
   - **a.** Power window control
   - **b.** Cruise control
   - **c.** Radio controls
   - **d.** HVAC functions
6. What is the minimum oil pressure required to keep the oil pressure warning light turned OFF?
   - **a.** 10 PSI (70 kPa)
   - **b.** 3 to 7 PSI (20 to 50 kPa)
   - **c.** 60 PSI (400 kPa)
   - **d.** None of these
7. Where are the total miles traveled stored in a vehicle equipped with an electronic odometer?
   - **a.** LCD
   - **b.** NVRAM
   - **c.** LED
   - **d.** VTF
8. A backup camera can show a poor quality image on the interior display if what occurs?
   - **a.** Ice or snow on the camera
   - **b.** Bright lights aimed at the camera
   - **c.** Extreme temperatures
   - **d.** Any of the above
9. The vehicle voice activation system can be used to control ____________.
   - **a.** text messages
   - **b.** phone calls
   - **c.** the sound system
   - **d.** All of the above
10. What system uses a special camera?
   - **a.** Touch screens
   - **b.** Night vision system
   - **c.** Electronic displays
   - **d.** Any of the above

Chapter

55

SECURITY AND IMMOBILIZER SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the purpose and function of a security system.
- Explain how an immobilizer system works and identify its major components.
- Describe immobilizer systems in Chrysler vehicles.
- Describe the Ford passive antitheft system.
- Describe the General Motors antitheft system.
- Explain how to diagnose a fault with an immobilizer system.

KEY TERMS:

Key fob 644 • Radio frequency identification (RFID) 644 • Remote keyless entry (RKE) 644 • Transceiver 644 • Transponder 644

VEHICLE SECURITY SYSTEMS

PURPOSE AND FUNCTION The purpose and function of a security system on a vehicle is to prevent the unauthorized use (theft) of the vehicle. This function is accomplished by installing the following locks:

1. A lock on the doors to help prevent unauthorized entry to the interior of the vehicle.
2. A lock for the ignition so a key is needed to crank and start the engine and unlock the steering wheel, starting in 1970.

While these locks have worked, vehicles can still be easily stolen if access to the interior and the ignition switch is accessible. It is the purpose and function of an immobilizer system to prevent the vehicle from being started if the correct ignition key is not used, even if an intruder gets access to the interior of the vehicle and tries to use a key that fits the lock cylinder.

POSSIBLE IMMOBILIZER CAUSED FAULTS Faults with the immobilizer system can be the cause of one of the following

FREQUENTLY ASKED QUESTION

What Is Content Thief Protection?

Content Thief protection is a security system that includes sensors that detect glass breakage or entry into the vehicle and sounds an alarm when these occur. The purpose of the content theft system is to prevent the theft of objects inside the vehicle and sound an alarm when someone enters the vehicle without using the proper remote or key. Most systems use a motion detector for content theft protection, as well as switches in the doorjambs, trunk, and hood that provide an input signal to the control module. Some antitheft systems are more complex and also have electronic sensors that trigger the alarm if glass is broken or a change in battery current draw occurs. These sensors also provide an input signal to the control module, which may be a separate antitheft unit, or may be incorporated into the PCM or BCM. ● **SEE FIGURE 55–1**.

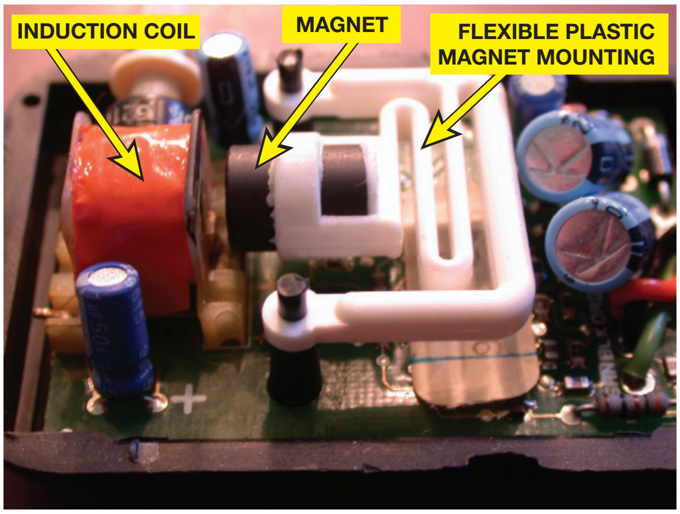


FIGURE 55–1 A shock sensor used in alarm and antitheft systems. If the vehicle is moved, the magnet moves relative to the coil, inducing a small voltage that triggers the alarm.

conditions depending on the exact make and model of a vehicle:

- No crank condition (the starter motor does not operate)
- The engine cranks but does not start (fuel disabled in most vehicles)
- The engine starts but then almost immediately stalls

Therefore, if a customer concern involves any of these situations, a fault in the immobilizer system is a possible cause, rather than a fault with the ignition or fuel system.

IMMOBILIZER SYSTEMS

NORMAL OPERATION A vehicle equipped with an immobilizer system operates normally as follows:

- When a valid key is used and is rotated to the start position, the engine cranks and starts and the immobilizer symbol on the dash flashes on and off for about two seconds, and then goes off. ● **SEE FIGURE 55–2**.

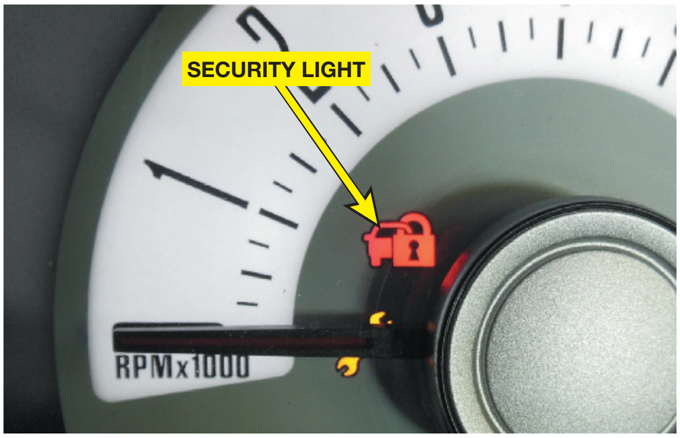


FIGURE 55–2 The security system symbol used on a Ford. The symbol varies by make, model, and year, so check service information to determine what symbol is used on the vehicle being diagnosed.

- If there is a fault with an invalid key, the dash symbol flashes continuously and the engine does not start or, if it does crank and start, the engine does not continue to run.

IMMOBILIZER SYSTEM PARTS Most security systems today use a **Radio Frequency Identification (RFID)** security system, which has two main components:

1. A **key fob** is the object that is a decoration on a key ring and usually contains a transmitter used to unlock a vehicle. While the **remote keyless entry (RKE)** part of the key fob has a battery to power the transmitter, the RFID chip part of the key fob does not require a battery to function. The **transponder** is mounted in the key or the body of the key fob. A transponder has an antenna, which consists of a coil of wire, as well as a circuit board containing the processing electronics and data memory. ● **SEE FIGURE 55–3**.
2. The transponder key has the transponder electronics integrated in its plastic body. It consists of the following components:
    - A microchip contains the unique internal identification (ID) number. To prevent an unauthorized scanning of the ID number, the code changes with each transfer and uses several million different coding possibilities. ● **SEE FIGURE 55–4**.
    - The coil antenna in the key consists of a copper coil wound up in a ring case and an integrated circuit to create a high-frequency alternating voltage for the inductive coupling. Through inductive (electromagnetic) coupling, the data from the key is transferred to the immobilizer module.
    - Another coil is installed around the lock cylinder and connected to the control module of the immobilizer system. This coil transfers and receives all data signals to and from the immobilizer control module using the coil antenna/transceiver. It does not need to be reprogrammed to the immobilizer system in case of replacement.
    - A **transceiver** is inside the vehicle and receives the signal transmitted by the transponder in the key. A "transceiver"

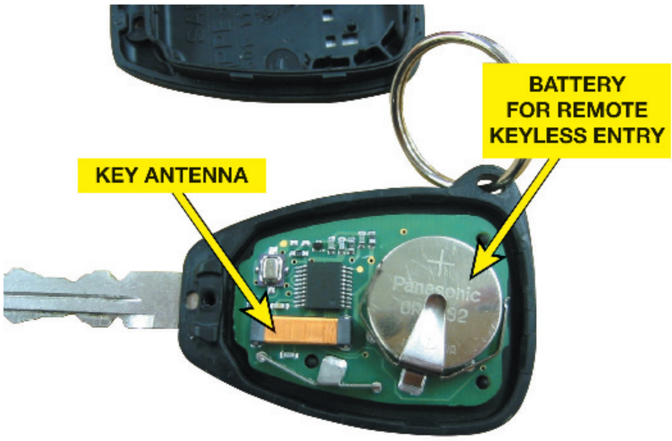


FIGURE 55–3 A typical key with the cover removed showing the battery used to power the door lock and the antenna used for the immobilizer system.

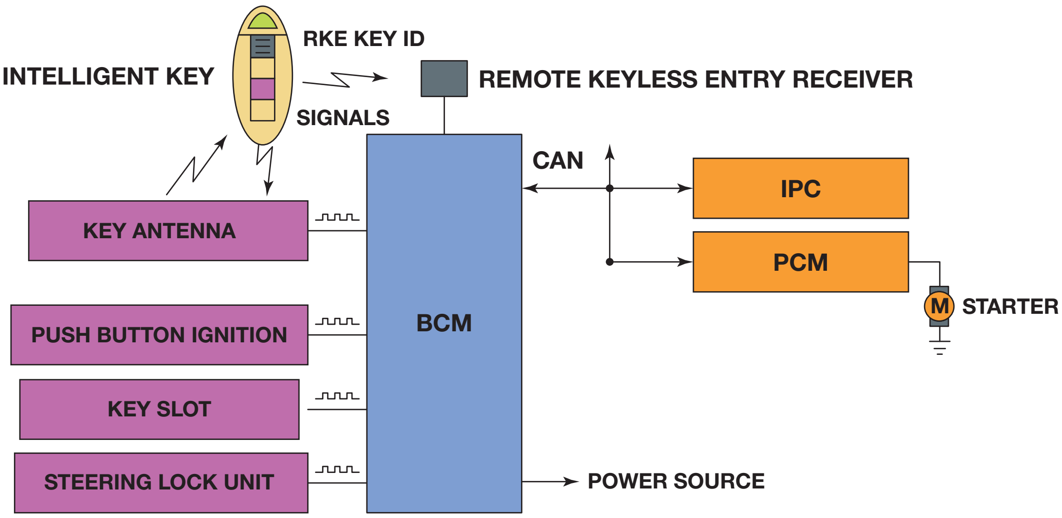

INTELLIGENT KEY
RKE KEY ID
SIGNALS
REMOTE KEYLESS ENTRY RECEIVER
CAN
IPC
PCM
M
STARTER
KEY ANTENNA
PUSH BUTTON IGNITION
KEY SLOT
STEERING LOCK UNIT
BCM
POWER SOURCE

FIGURE 55–4 The remote keyless entry is used to unlock the doors as well as create the signals to the powertrain control module (PCM) used to control the starter motor and/or the fuel system and the warning lamp on the instrument panel cluster (IPC).

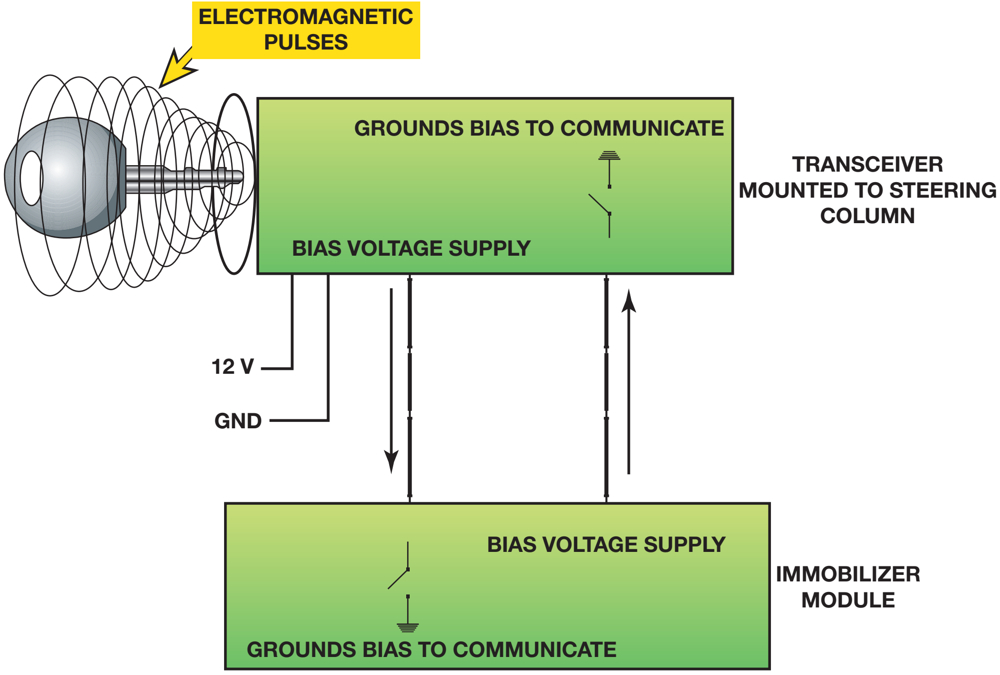

ELECTROMAGNETIC PULSES
GROUNDS BIAS TO COMMUNICATE
BIAS VOLTAGE SUPPLY
TRANSCEIVER MOUNTED TO STEERING COLUMN
12 V
GND
BIAS VOLTAGE SUPPLY
GROUNDS BIAS TO COMMUNICATE
IMMOBILIZER MODULE

FIGURE 55–5 A typical immobilizer circuit showing the communication between the key and the transceiver. The transceiver then communicates with the immobilizer module over data lines.

functions as both a reviewer and a transmitter. The transceiver is usually mounted on the steering column assembly. The antenna for the transceiver is a coil of wire mounted within the plastic ring that mounts around the lock cylinder. ● **SEE FIGURE 55–5**.

IMMOBILIZER SYSTEM OPERATION When the ignition key in inserted, the transceiver sends out an electromagnetic energy pulse. This energy pulse is received by the coil inside the key transponder, which creates a voltage. The information or data in the magnetic pulses is in the form of a frequency modulated signal.

A typical immobilizer system consists of transponder key, coil antenna, key reminder switch, separate immobilizer module, PCM, and security light. Most immobilizer systems work as follows:

- The key identification (ID) numbers are stored in a nonvolatile memory of the immobilizer module. At each start, the module compares the ID number of the transponder key used with those stored in the memory.
- If the verification has been successful, the immobilizer module sends a request signal to the PCM to compare the key ID number with the numbers registered in the PCM.
- Each immobilizer module has its unique code word that is stored in the PCM. After the verification of the ID number, the immobilizer module requests the code word from the PCM.
- The immobilizer module controls the starter circuit and the security light and signals the PCM to activate fuel injection and ignition when the ID number and code word verification have been successful.
- The signals between immobilizer module and PCM are transmitted via a serial data line.

SECURITY LIGHT OPERATION Normal operation of the security light includes a self-test and flashes a few times, then goes out. However, if a fault is detected, the security light continues to flash and the engine may not start. If a fault occurs with the immobilizer system when the engine is running, then the security

TECH TIP

Do Not Have Other Keys Near

Whenever diagnosing an immobilizer system, keep other key fobs away from the area. If another key fob were close, it could be transmitting a signal that is not recognized by the vehicle and the security system could prevent proper vehicle operation. Even having other metal objects near the key can affect the strength of the electromagnetic pulses and could interfere with the immobilizer system and prevent it from working as designed. ● **SEE FIGURE 55–6**.

light comes on, but the engine is not shut off, as this condition is not a theft attempt.

PRECAUTIONS To avoid damage to the key, do not allow the key to:

- Be dropped onto a hard surface
- Get wet
- Be exposed to any kind of magnetic field
- Be exposed to high temperatures on places, such as the top of the dash under direct sunlight.

A system malfunction may occur if any of the following items are touching the key or are near the key head:

- A metal object
- Spare keys or keys for other vehicles equipped with an immobilizer system
- An electronic device, such as cards with magnetic strips

TYPICAL IMMOBILIZER CIRCUITS The diagnostic process involved with positively identifying the defective security system component can be quick and accurate. At the transceiver, check for power, ground, and proper communication on data transmission lines. ● **SEE FIGURE 55–7**.

CAUTION: Do not leave the key in the ignition, as this often keeps the immobilizer system alive and drains the vehicle battery. If leaving the vehicle, take the key out of the ignition and place it 15 feet (5 meters) away to help avoid possible issues.

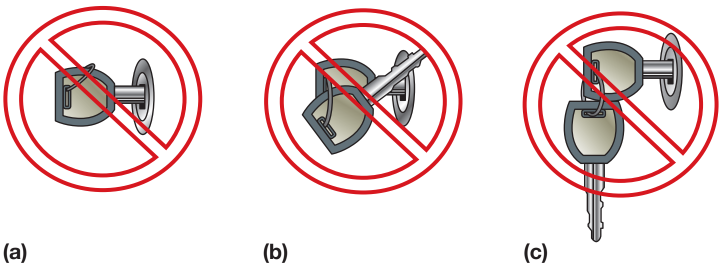


FIGURE 55–6 (a) Avoid using a key where the key ring is over the top of the key, which can interfere with the operation of the immobilizer system. (b) Do not angle another key upward from the key being used to help prevent interference with the magnetic field used to energize the key. (c) Do not have the keys from another vehicle near the key being used.

CHRYSLER IMMOBILIZER SYSTEM

BACKGROUND Beginning in 1998, Chrysler started a security system known as the **Sentry Key Immobilizer System (SKIS)**. When an attempt to start a vehicle arises, the onboard computer sends out a radio-frequency (RF) signal that is read by the electronic transponder chip embedded in the key. The transponder then returns a unique signal back to the SKIM, giving it the okay signal for the vehicle to start and continue to run. This all happens in under a second and is completely transparent to the vehicle driver. For additional security, two preprogrammed keys are needed in order to register additional keys into the system. In the event of the loss of all keys, special programming equipment is needed to register new keys into the system.

CHRYSLER SELF-PROGRAMMING ADDITIONAL SENTRY KEYS (REQUIRES TWO ORIGINAL KEYS)

Quick steps:

STEP 1 Purchase a blank key and have it cut to fit the lock cylinder.

STEP 2 Insert the original key #1 into the ignition and turn to ON.

STEP 3 Wait five seconds and turn the key to OFF.

STEP 4 Immediately insert the original key #2 into the ignition and turn to ON.

STEP 5 Wait 10 seconds for the SKIS indicator in the dash to start to flash.

STEP 6 Turn the ignition off, insert the new blank key, and turn the ignition back on.

STEP 7 Once the SKIS light stops flashing and turns off, the new key is programmed.

FORD PATS SYSTEM

BACKGROUND Ford uses a responder key for their antitheft system, which is called the **Passive Antitheft System** (**PATS**).

FORD PROGRAMMING FOR ADDITIONAL (PATS) KEYS This procedure works only if two or more programmed ignition keys are available. The steps include

STEP 1 Insert the first programmed ignition key into the ignition lock cylinder. Turn the ignition switch from the LOCK to RUN position (ignition switch must stay in the run position for one second). Turn the ignition switch to the LOCK position and remove the ignition key from the ignition lock cylinder.

STEP 2 Within five seconds of turning the ignition switch to the LOCK position, insert the second programmed ignition key into the ignition lock cylinder. Turn the ignition switch from the LOCK to RUN position (ignition switch must stay in the RUN position for one second). Turn the ignition switch to the LOCK position and remove the second ignition key from the ignition lock cylinder.

STEP 3 Within five seconds of turning the ignition switch to the LOCK position, insert a new unprogrammed ignition key into the ignition lock cylinder. Turn the ignition switch

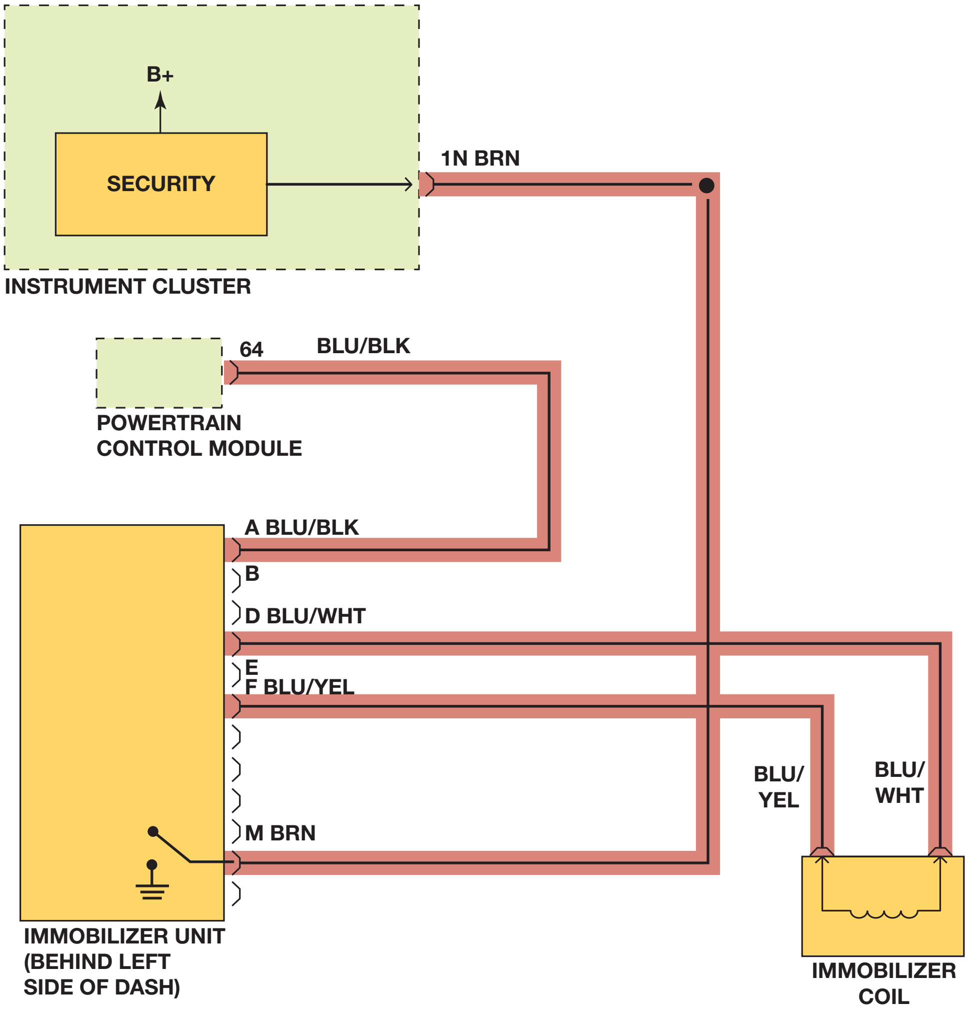

B+
SECURITY
1N BRN
INSTRUMENT CLUSTER
64
BLU/BLK
POWERTRAIN
CONTROL MODULE
A BLU/BLK
B
D BLU/WHT
E
F BLU/YEL
BLU/
YEL
BLU/
WHT
M BRN
IMMOBILIZER UNIT
(BEHIND LEFT
SIDE OF DASH)
IMMOBILIZER
COIL

FIGURE 55–7 Check service information for the exact wiring diagram (schematic) for the vehicle being tested. Highlighting the wires and noting their color helps when following the specified testing procedures.

from the LOCK to RUN position (the ignition switch must stay in the RUN position for one second). Turn the ignition switch to the LOCK position and remove the ignition key from the ignition lock cylinder. The new ignition key should now be programmed. To program additional key(s), repeat the key programming procedure from Step 1.

GENERAL MOTORS ANTITHEFT SYSTEM

BACKGROUND The type of antitheft system used on General Motors vehicles has included many different systems, starting with an antitheft system that used a resistor pellet in the ignition key. If the key fit the lock cylinder and the resistance was the correct value, the engine would crank and start. This system was called the **Vehicle Antitheft System** or **(VATS)**. A special tester was required to test this system. ● **SEE FIGURE 55–8**.

Newer systems include the **Passkey I** and **Passkey II**, which also use a resistor pellet in the ignition key. **Passlock I**, **Passlock II,** and **Passlock truck** systems use a Hall-effect sensor and magnets in the lock cylinder with a conventional key. ● **SEE FIGURE 55–9**.

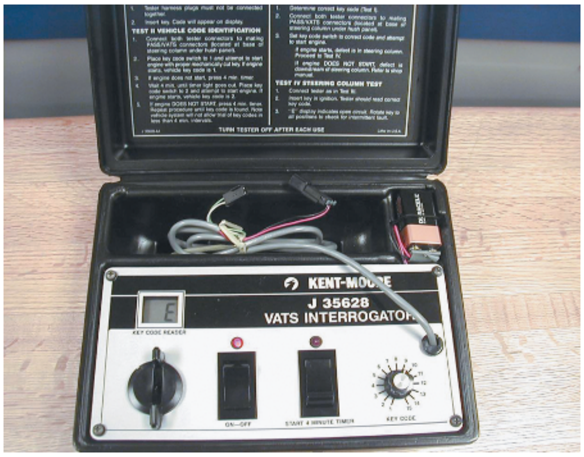

KENT-MOORE
J 35628
VATS INTERROGATOR

FIGURE 55–8 A special tool is needed to diagnose a General Motors VATS security system and special keys that contain a resistor pellet.

Passkey III systems use a transponder embedded into the head of the key, which is stamped "SK3." Most of the systems disable the starter and the fuel injectors, but Passlock I disables fuel after the engine starts, and the security light then flashes. Due to the various systems, service information must be used and followed to diagnose and repair a fault in these systems.

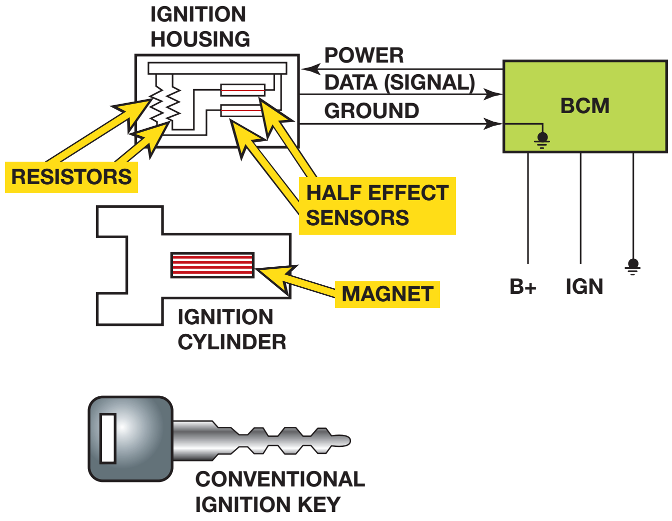
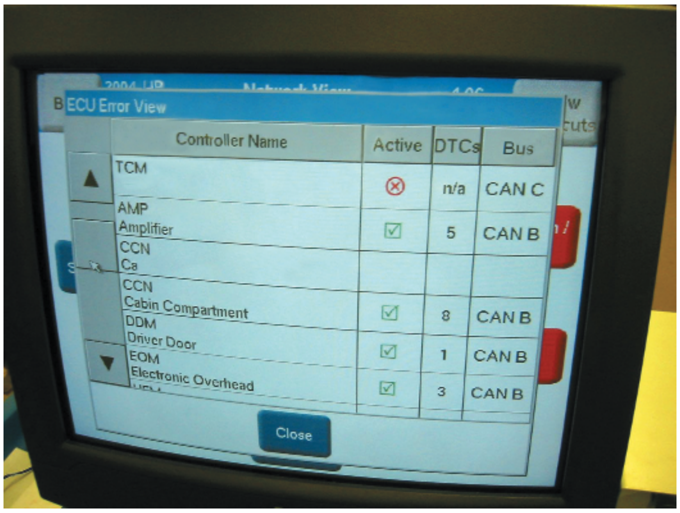


FIGURE 55–9 The Passlock series of General Motors security systems uses a conventional key. The magnet is located in the ignition lock cylinder and triggers the Hall-effect sensors.


ECU Error View

Controller Name	Active	DTCs	Bus
TCM	⊗	n/a	CAN C
AMP Amplifier	☑	5	CAN B
CCN Ca			
CCN Cabin Compartment	☑	8	CAN B
DDM Driver Door	☑	1	CAN B
EOM Electronic Overhead	☑	3	CAN B

FIGURE 55–10 Scan tools, such as this factory tool being used on a BMW, are capable of many diagnostic functions that can help the technician zero in on the root cause of a problem.

TESTING IMMOBILIZER SYSTEMS

DIAGNOSTIC STEPS Most vehicle manufacturers recommend a series of steps that a technician should follow when diagnosing a fault with the immobilizer system:

STEP 1 **Verify the Customer Concern**—A fault with the immobilizer system often causes the engine to not start or start, then stall. Faults can also be intermittent because many systems "time out" after 20 minutes if an error occurs, and then works normally after the wait period. A "no-start" condition can also occur that is not associated with the immobilizer system and should be handled using normal diagnostic procedures as specified by the vehicle manufacturer for a no-start condition.

STEP 2 **Visual Inspection—**Most vehicle manufacturers specify that the first step after the customer concern has been verified is that a visual inspection be performed. A visual inspection includes checking the security light status. A typical security light status includes the following:

- **Normal**—The security dash lamp comes on for two to five seconds for a bulb check when the ignition is turned on, then goes out.
- **Tamper mode**—The security lamp flashes about once per second if the system detects a bad key, lock cylinder, or security-related wiring problem. The engine does not start or, if it does start, does not continue to run.
- **Fail enable mode**—If a fault with the security system occurs when the vehicle is running, the security light remains on, but the immobilizer system is disabled because it is apparently not a theft attempt. Therefore, the engine starts and runs as normal, except that the security warning light on the dash is on all the time.

Check for the presence of aftermarket accessories, such as an add-on remote starter system. These systems require the use of a spare key that is held near the lock cylinder, thereby allowing the engine to start using a remote control. A fault with the aftermarket system could have an effect on the proper operation of the immobilizer system.

TECH TIP

Look for DTCs in "Body" and "Chassis"

Whenever diagnosing a customer concern with the immobilizer system, check for diagnostic trouble codes (DTCs) under chassis and body systems. A global or generic scan tool that can read only "P" codes is not suitable for diagnosing many faults with the immobilizer system. These codes are most often found under chassis or body systems. Chassis-related codes are labeled "C" and body system-related codes are labeled "B" codes and these can cause an immobilizer issue if they affect a sensor that is used by the system. ● **SEE FIGURE 55–10**.

STEP 3 **Check for Diagnostic Trouble Codes**—Use a factory or enhanced factory-level aftermarket scan tool and retrieve diagnostic trouble codes. Check service information for the exact codes for the vehicle being checked. ● **SEE CHART 55–1** for some sample DTCs and their meaning.

STEP 4 **Check for Technical Service Bulletins**—Technical service bulletins (TSBs) are issued by vehicle and aftermarket manufacturers to inform technicians of a situation or technical problem and give the corrective steps and a list of parts needed to solve the problem. Any diagnostic trouble codes should be retrieved before looking at the technical service bulletins because many bulletins include what DTCs may or may not be present. ● **SEE FIGURE 55–11**.

DTC	DESCRIPTION OF FAULT
P0513	Incorrect immobilizer key
P1570	Fault in antenna detected
P1517	Reference code not compatible with ECM
P1572	Communications failure with ECM
B2957	Security system data circuit low
B2960	Security system data wrong but valid

CHART 55–1

Sample diagnostic trouble codes for an immobilizer system. These codes vary by make, model, and year of manufacture, so check service information for the exact vehicle being diagnosed.

FIGURE 55–11 After checking for stored diagnostic trouble codes (DTCs), the wise technician checks service information for any technical service bulletins (TSBs) that may relate to the vehicle being serviced.

While some of these TSBs concern minor problems covering few vehicles, many contain very helpful solutions to hard-to-find problems that cover many vehicles. TSBs can also be purchased through aftermarket companies that are licensed and available on a website. Visit the National Automotive Service Task Force (NASTF) website (www.NASTF.org) for a list of the Web addresses for all vehicle manufacturers' sites where the full text of TSBs can be purchased directly. Factory TSBs can often save the technician many hours of troubleshooting.

STEP 5 **Perform Pinpoint Tests**—Following the specified diagnostic steps found in service information, check for the system for proper voltage at each of the components.

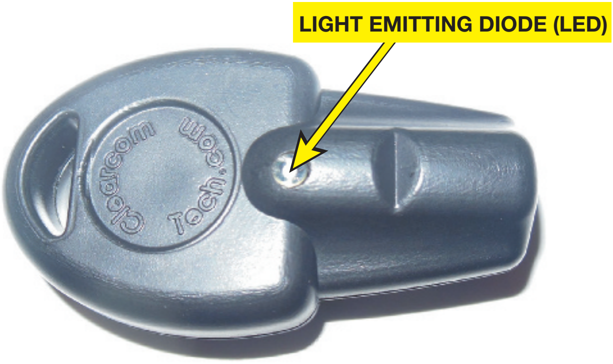


FIGURE 55–12 Immobilizer coil detectors can be found online by searching for immobilizer transponder coil detector.

TECH TIP

Use an Antenna Coil Tester to Save Time

The procedure for testing the antenna coil using an antenna tester includes the following:

- Insert the ignition key into the ignition lock cylinder. On some vehicles, inserting the key causes the transceiver to activate. On some vehicles, the key must be rotated to the ON position.
- Use a handheld tester to check that the transceiver is able to transmit a signal. A coil detector is used to check the immobilizer coil that surrounds the lock cylinder. The coil is working normally if the LED lights up as the key is inserted into the lock cylinder. If the coil is defective, this can save the technician a lot of time troubleshooting the system. The coil can be replaced without the need to reprogram the keys. ● **SEE FIGURE 55–12**.

STEP 6 **Determine the Root Cause**—By following the specified diagnostic routine, the root cause can often be determined. If a module is replaced, it usually must be programmed to accept the ignition key and this can be a huge problem if a used module is chosen instead of a new one. Always check service information for the exact procedure to follow.

STEP 7 **Verify the Repair**—After the repairs or service procedures have been performed, verify that the system is working as designed. If needed, operate the vehicle under the same conditions that it was when the customer concern was corrected to verify the repair. Document the work order and return the vehicle to the customer in clean condition.

REVIEW QUESTIONS

1. What faults will an immobilizer system cause?
2. How is the security information transferred from the key to the vehicle?
3. A typical immobilizer system consists of what parts?
4. To avoid damage to the key, what precautions are needed to be performed?
5. An antenna coil tester is used to test what part of the immobilizer system?

CHAPTER QUIZ

1. What is the purpose and function of an immobilizer system?
   - **a.** Prevents entry inside the vehicle
   - **b.** Only allows the use of the ignition key that is properly matched to the lock cylinder
   - **c.** Prevents the vehicle from starting or running if the correct key is not used
   - **d.** Requires that the driver enter a password to start the vehicle
2. What does the battery in the key fob power?
   - **a.** The shock sensor
   - **b.** The remote keyless entry (RKE)
   - **c.** The immobilizer circuit
   - **d.** Both the remote keyless entry and the immobilizer circuit
3. What can occur if the immobilizer system is not working as designed?
   - **a.** No crank condition (the starter motor does not operate)
   - **b.** The engine cranks but does not start
   - **c.** The engine starts but then almost immediately stalls
   - **d.** Any of the above
4. An immobilizer fault may occur if the ____________.
   - **a.** key is dropped onto a hard surface
   - **b.** key gets wet
   - **c.** key is exposed to any kind of magnetic field
   - **d.** Any of the above
5. How is data transmitted between the key and the steering column (lock cylinder)?
   - **a.** By inductive coupling
   - **b.** By electrical contacts inside the lock cylinder
   - **c.** Transmitted from the key to the vehicle using the battery inside the key
   - **d.** Transferred from the key to the BCM using a small transmitter in the key
6. A typical Ford immobilizer system is called ____________.
   - **a.** VATS
   - **b.** PATS
   - **c.** Passlock
   - **d.** SKIS
7. A typical Chrysler immobilizer system is called ____________.
   - **a.** VATS
   - **b.** PATS
   - **c.** Passlock
   - **d.** SKIS
8. The security dash lamp comes on for two to five seconds and then goes out. This indicates what condition?
   - **a.** A fault has been detected in the key transponder
   - **b.** A fault has been detected in the wiring near the ignition lock cylinder
   - **c.** Normal security light operation
   - **d.** The system has entered tamper mode
9. Immobilizer diagnostic trouble codes are often found under what area?
   - **a.** Engine-related “P” codes
   - **b.** Body-related “B” codes
   - **c.** Chassis-related “C” codes
   - **d.** Any of the above
10. If an immobilizer-related fault occurs, what symbol is likely to be displayed on the dash?
    - **a.** “IM”
    - **b.** A padlock symbol
    - **c.** The “check engine” light
    - **d.** The “service engine soon” light

Chapter

56

AIRBAG AND PRETENSIONER CIRCUITS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain how safety belts and retractors function.
- Explain the operation of front airbags.
- Describe the procedures to diagnose common faults in airbag systems.
- Describe the procedures to repair common faults in airbag systems.
- Discuss driver side airbag module replacement.
- Discuss safety issues when manually deploying airbags.
- Explain how the passenger presence system works.
- Describe how seat and side curtain airbags function.
- Describe the data recorded by an event data recorder when an airbag is deployed.

KEY TERMS:

Airbag 653 • Arming sensor 653 • Clockspring 656 • Deceleration sensors 654 • Dual-stage airbags 655 • EDR 662 • Integral sensors 654 • Occupant detection system (ODS) 660 • Passenger presence system (PPS) 660 • Pretensioners 652 • SAR 653 • SIR 653 • Squib 653 • SRS 653

SAFETY BELTS AND RETRACTORS

SAFETY BELTS Safety belts are used to keep the driver and passengers secured to the vehicle in the event of a collision. Most safety belts include three-point support and are constructed of nylon webbing about 2 inches (5 cm) wide. The three support points include two points on either side of the seat for the belt over the lap and one crossing over the upper torso, which is attached to the "B" pillar or seat back. Every crash consists of three types of collisions:

Collision 1: The vehicle strikes another vehicle or object.

Collision 2: The driver and/or passengers hit objects inside the vehicle if unbelted.

Collision 3: The internal organs of the body hit other organs or bones, which causes internal injuries.

If a safety belt is being worn, the belt stretches, absorbing a lot of the impact, thereby preventing collision with other objects in the vehicle and reducing internal injuries. ● **SEE FIGURE 56–1**.

BELT RETRACTORS Safety belts are also equipped with one of the following types of retractors:

- Emergency locking retractors, which lock the position of the safety belt in the event of a collision or rollover
- Emergency and web speed-sensitive retractors, which allow freedom of movement for the driver and passenger, but lock if the vehicle is accelerating too fast or if the vehicle is decelerating too fast

● **SEE FIGURE 56–2** for an example of an inertia-type seat belt locking mechanism.

SAFETY BELT LIGHTS AND CHIMES All late-model vehicles are equipped with a safety belt warning light on the dash and a chime that sounds if the belt is not fastened. ● **SEE FIGURE 56–3**.

Some vehicles intermittently flash the reminder light and sound a chime until the driver, and sometimes the front passenger, fasten their safety belts.

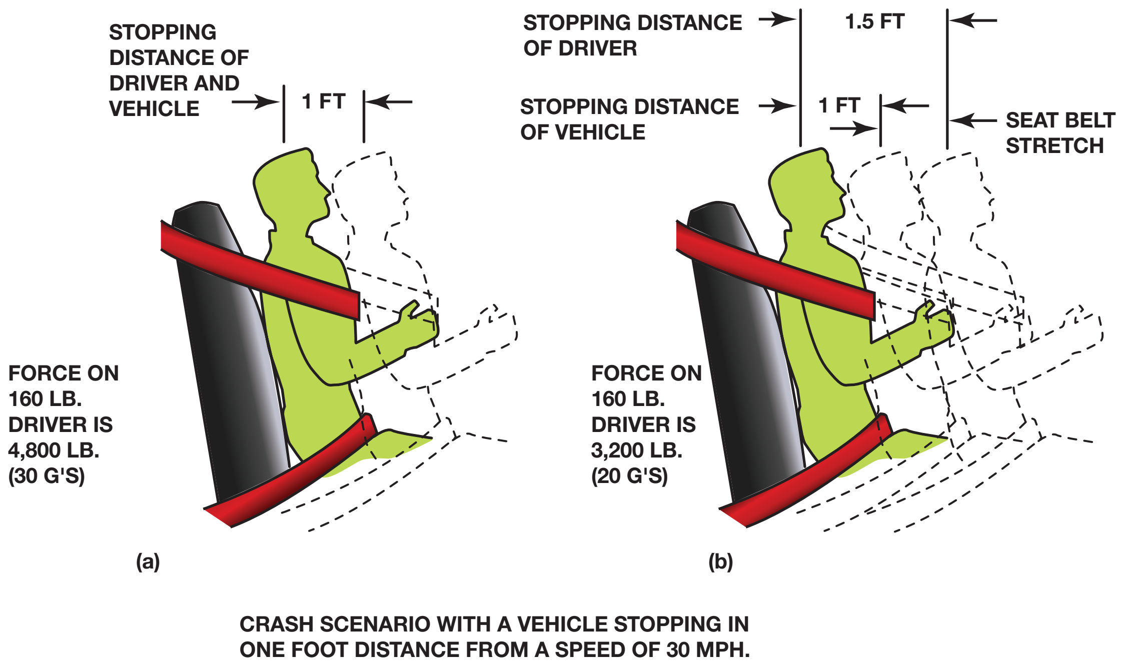

STOPPING DISTANCE OF DRIVER AND VEHICLE
1 FT
FORCE ON 160 LB. DRIVER IS 4,800 LB. (30 G'S)
(a)
STOPPING DISTANCE OF DRIVER
1.5 FT
STOPPING DISTANCE OF VEHICLE
1 FT
SEAT BELT STRETCH
FORCE ON 160 LB. DRIVER IS 3,200 LB. (20 G'S)
(b)
CRASH SCENARIO WITH A VEHICLE STOPPING IN ONE FOOT DISTANCE FROM A SPEED OF 30 MPH.

FIGURE 56–1 (a) Safety belts are the primary restraint system. (b) During a collision, the stretching of the safety belt slows the impact to help reduce bodily injury.

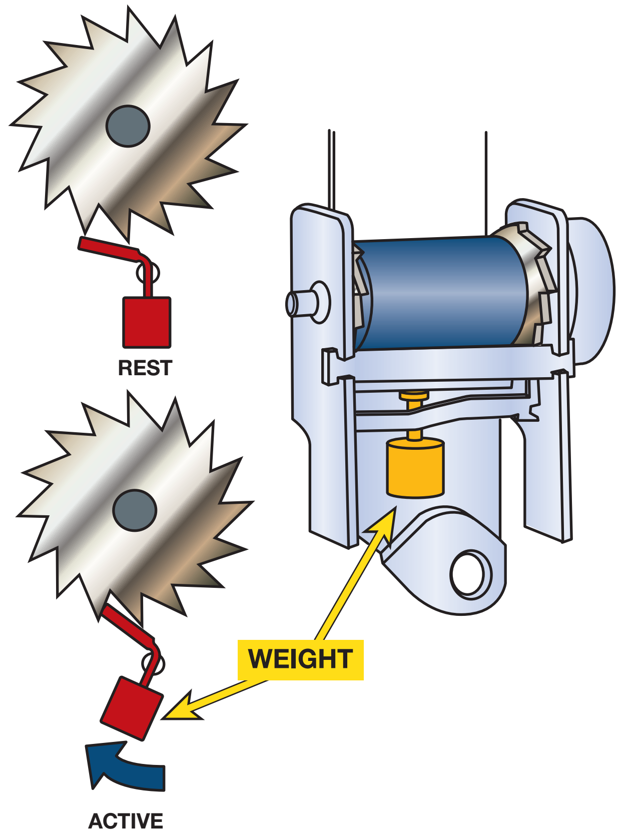

REST
WEIGHT
ACTIVE

FIGURE 56–2 Most safety belts have an inertia-type mechanism that locks the belt in the event of rapid movement.

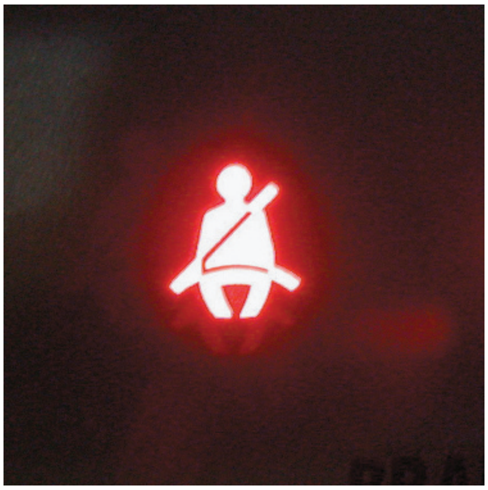


FIGURE 56–3 A typical safety belt warning light.

PRETENSIONERS A **pretensioner** is an explosive (pyrotechnic) device that is part of the seat belt retractor assembly and tightens the seat belt as the airbag is being deployed. The purpose of the pretensioning device is to force the occupant back into position against the seat back and to remove any slack in the seat belt. ● **SEE FIGURE 56–4**.

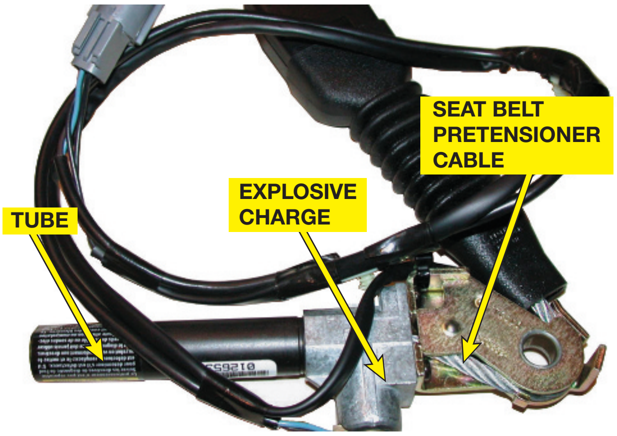

SEAT BELT PRETENSIONER CABLE
EXPLOSIVE CHARGE
TUBE

FIGURE 56–4 A small explosive charge in the pretensioner forces the end of the seat belt down the tube, which removes any slack in the seat belt.

CAUTION: The seat belt pretensioner assemblies must be replaced in the event of an airbag deployment. Always follow the vehicle manufacturer's recommended service procedure. Pretensioners are explosive devices that could be ignited if voltage is applied to the terminals. Do not use a jumper wire or powered test light around the seat belt latch wiring. Always follow the vehicle manufacturer's recommended test procedures.

FRONT AIRBAGS

PURPOSE AND FUNCTION

Airbag passive restraints are designed to cushion the driver (or passenger, if the passenger side is so equipped) during a frontal collision. The system consists of one or more nylon bags folded up in compartments located in the steering wheel, dashboard, interior panels, and/or side pillars of the vehicle. During a crash of sufficient force, pressurized gas instantly fills the airbag and then deploys out of the storage compartment to protect the occupant from serious injury. These airbag systems may be known by many different names, including the following:

1. **Supplemental restraint system (SRS)**
2. **Supplemental inflatable restraints (SIR)**
3. **Supplemental air restraints (SAR)**

Most airbags are designed to supplement the safety belts in the event of a collision, and front airbags are meant to be deployed only in the event of a frontal impact within 30 degrees of center. Front (driver and passenger side) airbag systems are *not* designed to inflate during side or rear impact. The force required to deploy a typical airbag is approximately equal to the force of a vehicle hitting a wall at over 10 MPH (16 km/h).

The force required to trigger the sensors within the system prevents accidental deployment if curbs are hit or the brakes are rapidly applied. The system requires a substantial force to deploy the airbag to help prevent accidental inflation.

PARTS INVOLVED

● **SEE FIGURE 56–5** for an overall view of the parts included in a typical airbag system.

The parts include:

1. Sensors
2. Airbag (inflator) module
3. Clockspring wire coil in the steering column
4. Control module
5. Wiring and connectors

OPERATION

To cause inflation, the following events must occur:

- To cause a deployment of the airbag, two sensors must be triggered at the same time. The **arming sensor** is used to provide electrical power, and a *forward* or *discriminating sensor* is used to provide the ground connection.
- The arming sensor provides the electrical power to the airbag heating unit, called a **squib**, inside the inflator module.
- The squib uses electrical power and converts it into heat for ignition of the propellant used to inflate the airbag.

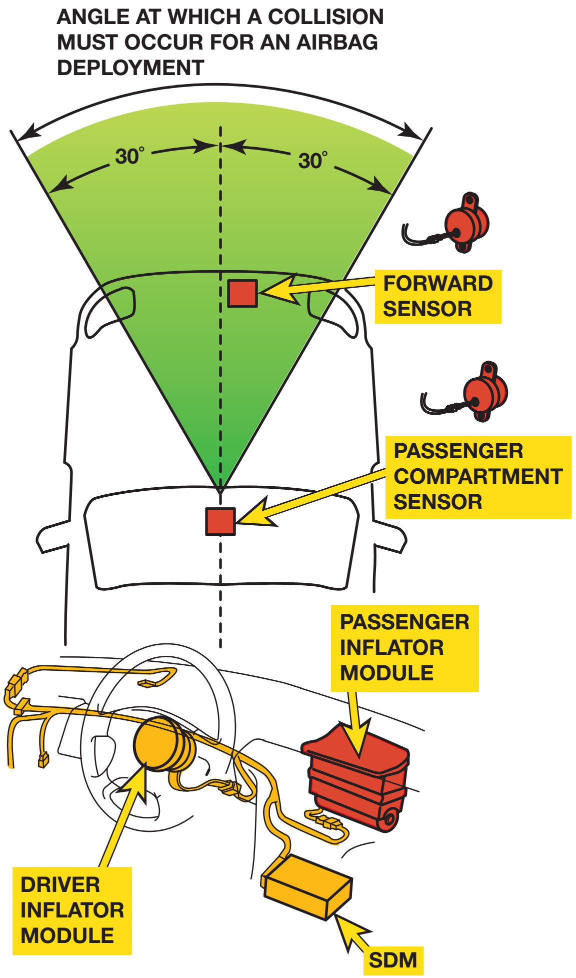

ANGLE AT WHICH A COLLISION MUST OCCUR FOR AN AIRBAG DEPLOYMENT
30°
30°
FORWARD SENSOR
PASSENGER COMPARTMENT SENSOR
PASSENGER INFLATOR MODULE
DRIVER INFLATOR MODULE
SDM

FIGURE 56–5 A typical airbag system showing many of the components. The SDM is the "sensing and diagnostic module" and includes the arming sensor, as well as the electronics that keep checking the circuits for continuity and the capacitors that are discharged to deploy the airbags.

- Before the airbag can inflate, however, the squib circuit also must have a ground provided by the forward or the discriminating sensor. In other words, two sensors (arming and forward sensors) *must* be triggered *at the same time* before the airbag is deployed. ● **SEE FIGURE 56–6**.

TYPES OF AIRBAG INFLATORS

There are two different types of inflators used in airbags:

1. **Solid fuel.** This type uses sodium azide pellets, and when ignited, generates a large quantity of nitrogen gas that quickly inflates the airbag. This was the first type used and is still commonly used in driver and passenger side airbag inflator modules. ● **SEE FIGURE 56–7**. The squib is the electrical heating element used to ignite the gas-generating material, usually sodium azide. It requires about 2 amperes of current to heat the heating element and ignite the inflator.
2. **Compressed gas.** Commonly used in passenger side airbags and roof-mounted systems, the compressed gas system uses a canister filled with argon gas, plus a small percentage of helium at 3,000 PSI (435 kPa). A small igniter ruptures a burst disc to release the gas when energized. The compressed gas inflators are long cylinders that can be installed inside the instrument panel, seat back, door panel, or along any side rail or pillar of the vehicle. ● **SEE FIGURE 56–8**.

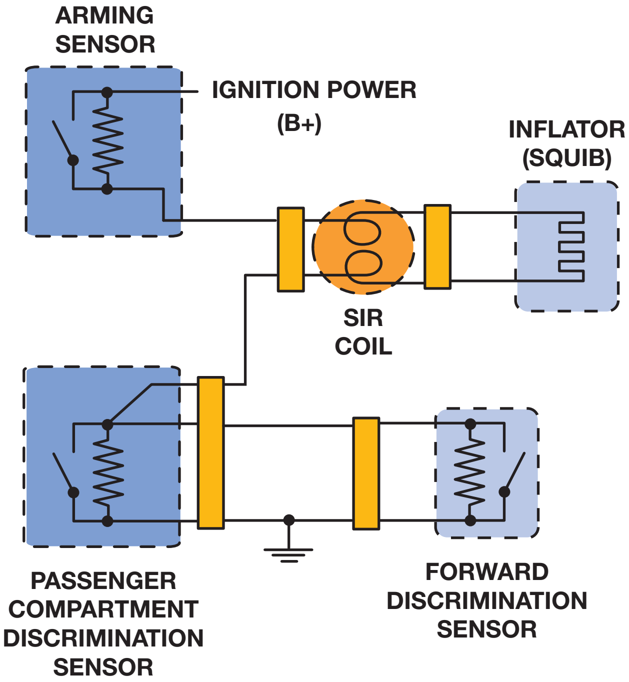

ARMING SENSOR
IGNITION POWER (B+)
INFLATOR (SQUIB)
SIR COIL
PASSENGER COMPARTMENT DISCRIMINATION SENSOR
FORWARD DISCRIMINATION SENSOR

FIGURE 56–6 A simplified airbag deployment circuit. Note that both the arming sensor and at least one of the discriminating sensors must be activated at the same time. The arming sensor provides the power, and either one of the discriminating sensors can provide the ground for the circuit.

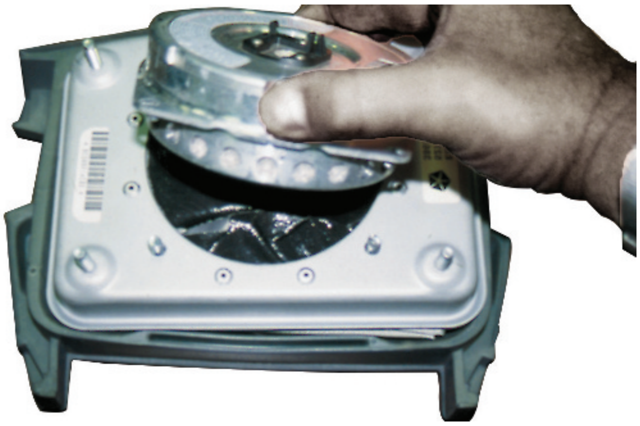


FIGURE 56–7 The inflator module is being removed from the airbag housing. The squib, inside the inflator module, is the heating element that ignites the pyrotechnic gas generator that rapidly produces nitrogen gas to fill the airbag.

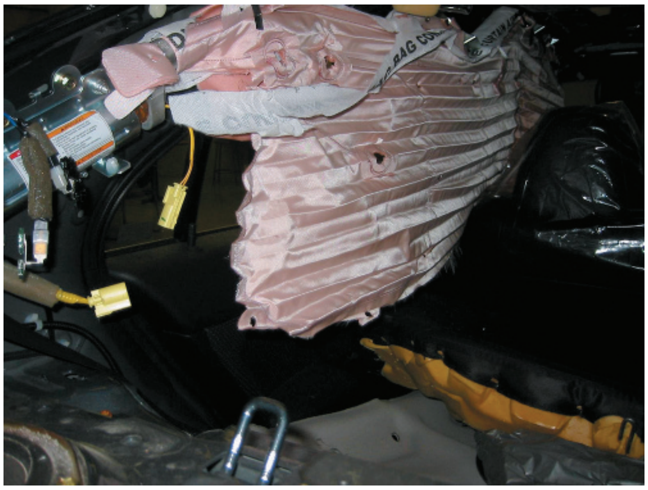


FIGURE 56–8 This figure shows a deployed side curtain airbag on a training vehicle.

Once the inflator is ignited, the nylon bag quickly inflates (in about 30 milliseconds or 0.030 second) with nitrogen gas generated by the inflator. During an actual frontal collision accident, the driver is being thrown forward by the driver's own momentum toward the steering wheel. The strong nylon bag inflates at the same time. Personal injury is reduced by the spreading of the stopping force over the entire upper-body region. The normal collapsible steering column remains in operation and collapses in a collision when equipped with an airbag system. The bag is equipped with two large side vents that allow the bag to deflate immediately after inflation, once the bag has cushioned the occupant in a collision.

TIMELINE FOR AIRBAG DEPLOYMENT Following are the times necessary for an airbag deployment in milliseconds (each millisecond is equal to 0.001 second or 1/1,000 of a second):

1. Collision occurs: 0.0 millisecond
2. Sensors detect collision: 16 milliseconds (0.016 second)
3. Airbag is deployed and seam cover rips: 40 milliseconds (0.040 second)
4. Airbag is fully inflated: 100 milliseconds (0.100 second)
5. Airbag deflated: 250 milliseconds (0.250 second)

In other words, an airbag deployment occurs and is over in about a quarter of a second. ● **SEE FIGURE 56–9**.

SENSOR OPERATION All three sensors are basically switches that complete an electrical circuit when activated. The sensors are similar in construction and operation, and the *location* of the sensor determines its name. All airbag sensors are rigidly mounted to the vehicle and *must* be mounted with the arrow pointing toward the front of the vehicle to ensure that the sensor can detect rapid forward deceleration.

There are three basic styles (designs) of airbag sensors:

1. **Magnetically retained gold-plated ball sensor.** This sensor uses a permanent magnet to hold a gold-plated steel ball away from two gold-plated electrical contacts. ● **SEE FIGURE 56–10**.

   If the vehicle (and the sensor) stops rapidly enough, the steel ball is released from the magnet because the inertia force of the crash was sufficient to overcome the magnetic pull on the ball and then makes contact with the two gold-plated electrodes. The steel ball only remains in contact with the electrodes for a relatively short time because the steel ball is drawn back into contact with the magnet.
2. **Rolled up stainless-steel ribbon-type sensor.** This sensor is housed in an airtight package with nitrogen gas inside to prevent harmful corrosion of the sensor parts. If the vehicle (and the sensor) stops rapidly, the stainless-steel roll "unrolls" and contacts the two gold-plated contacts. Once the force is stopped, the stainless-steel roll rolls back into its original shape. ● **SEE FIGURE 56–11**.
3. **Integral sensor.** Some vehicles use electronic **deceleration sensors** built into the inflator module, called **integral sensors**. For example, General Motors uses the term *sensing and diagnostic module* (SDM) to describe their integrated sensor/module assembly. These units contain an accelerometer-type sensor that measures the rate of deceleration and, through computer logic, determines if the airbags should be deployed. ● **SEE FIGURE 56–12**.

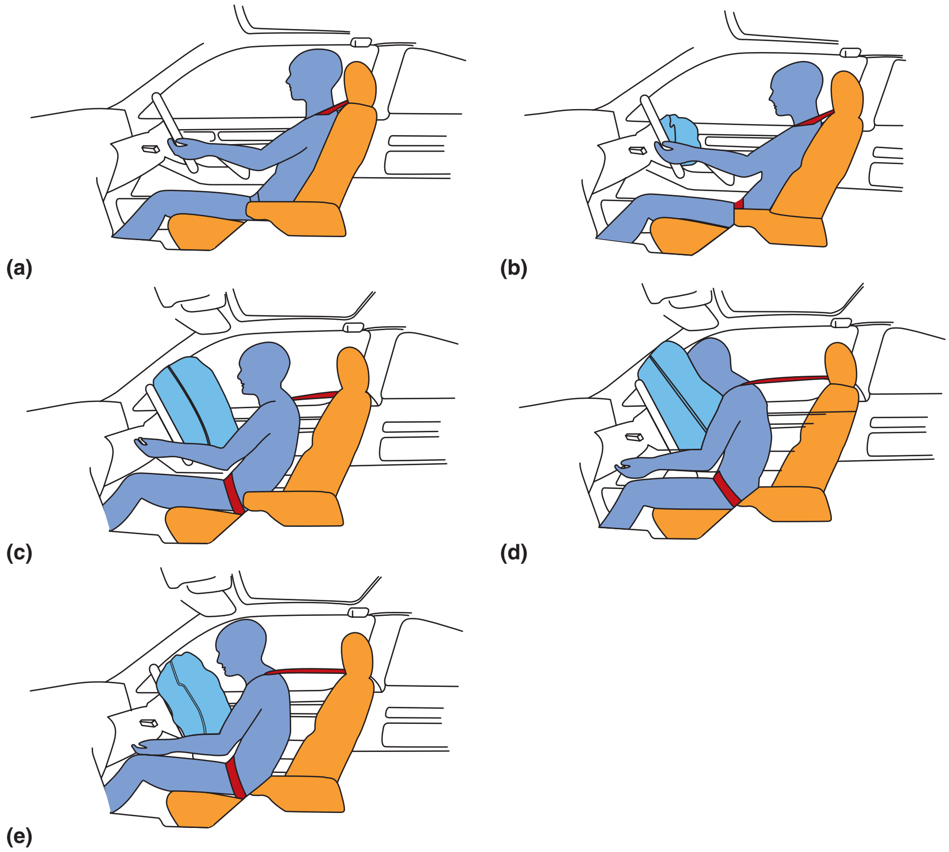


FIGURE 56–9 The sequence of deployment of a typical airbag includes the following:
(a) The driver is sitting in a normal driving position.
(b) About 16 milliseconds (0.016 second) after an impact with a solid object that results in a rapid deceleration causing the triggering of the airbag.
(c) About 40 milliseconds after impact, the airbag deploys and the driver's body is moving forward.
(d) At 100 milliseconds after impact, the airbag has fully inflated and the driver's body is being slowed by the airbag and by the seat belt.
(e) Starting at about 120 milliseconds, the driver's body will start to move back toward the seat and the airbag will be deflated by 250 milliseconds after the impact.

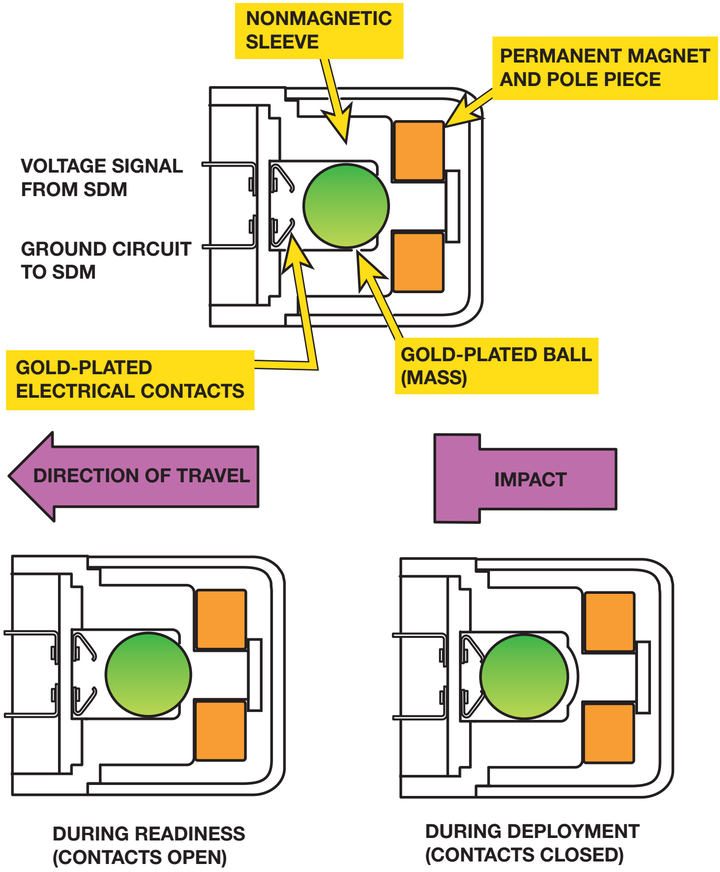

NONMAGNETIC SLEEVE
PERMANENT MAGNET AND POLE PIECE
VOLTAGE SIGNAL FROM SDM
GROUND CIRCUIT TO SDM
GOLD-PLATED ELECTRICAL CONTACTS
GOLD-PLATED BALL (MASS)
DIRECTION OF TRAVEL
IMPACT
DURING READINESS (CONTACTS OPEN)
DURING DEPLOYMENT (CONTACTS CLOSED)

FIGURE 56–10 An airbag magnetic sensor.

TWO-STAGE AIRBAGS Two-stage airbags, often called advanced airbags or smart airbags, use an accelerometer-type of sensor to detect force of the impact. This type of sensor measures the actual amount of deceleration rate of the vehicle and is used to determine whether one or both elements of a two-stage airbag should be deployed.

- **Low-stage deployment.** This lower-force deployment is used if the accelerometer detects a low-speed crash.

SAFETY TIP

Dual-Stage Airbag Caution

Many vehicles are equipped with **dual-stage airbags** (two-stage airbags) that actually contain two separate inflators, one for less severe crashes and one for higher-speed collisions. These systems are sometimes called *smart airbag systems* because the accelerometer-type sensor used can detect how severe the impact is and deploy one or both stages. If one stage is deployed, the other stage is still active and could be accidentally deployed. A service technician cannot tell by looking at the airbag whether both stages have deployed. Always handle a deployed airbag as if it has not been deployed, and take all precautions necessary to keep any voltage source from getting close to the inflator module terminals.

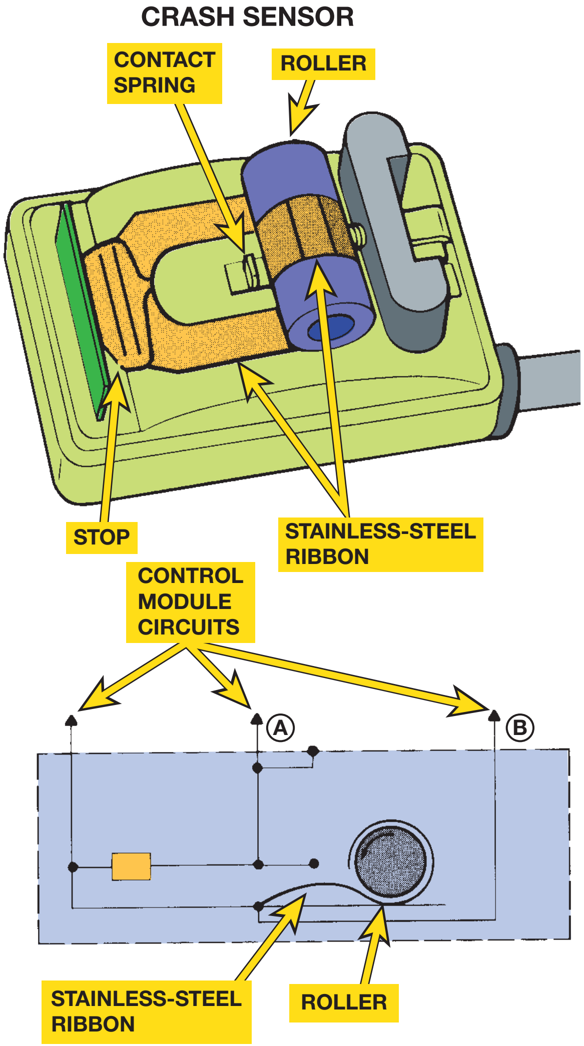


FIGURE 56–11 Some vehicles use a ribbon-type crash sensor.

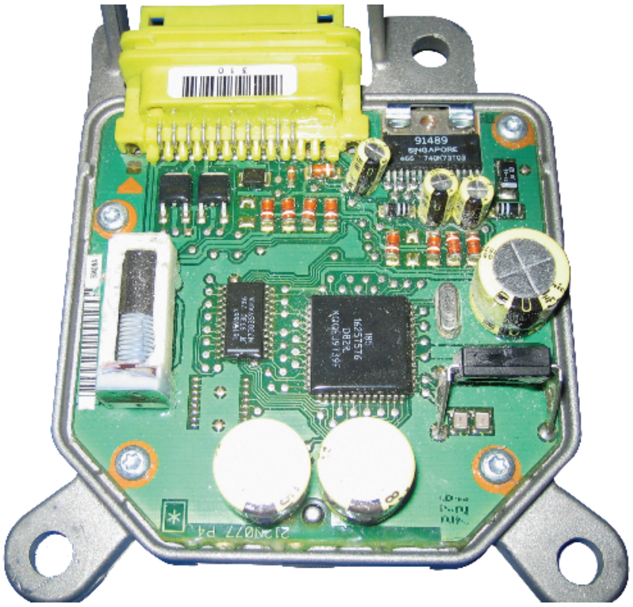


FIGURE 56–12 A sensing and diagnostic module that includes an accelerometer.

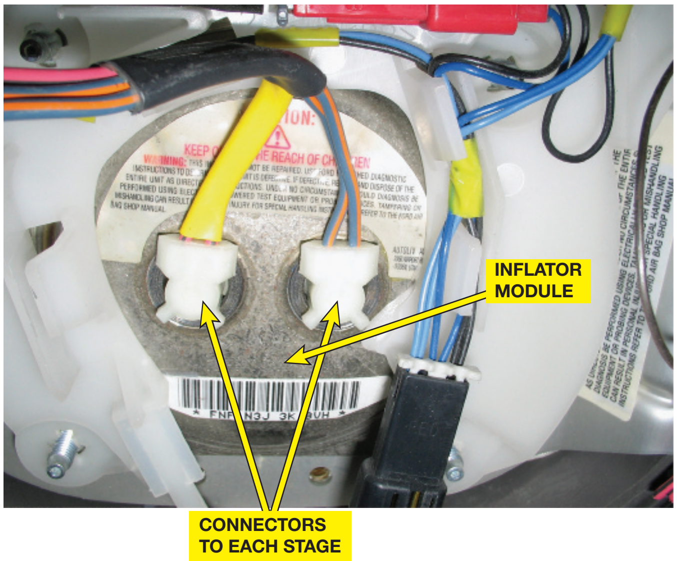


FIGURE 56–13 A driver's side airbag showing two inflator connectors. One is for the lower-force inflator and the other is for the higher-force inflator. Either can be ignited, or both at the same time if the deceleration sensor detects a severe impact.

- **High-stage deployment.** This stage is used if the accelerometer detects a higher-speed crash or a more-rapid deceleration rate.
- **Both low- and high-stage deployment.** Under severe high-speed crashes, both stages can be deployed.

● **SEE FIGURE 56–13**.

WIRING Wiring and connectors are very important for proper identification and long life. Airbag-related circuits have the following features:

- All electrical wiring connectors and conduit for airbags are colored yellow.
- To ensure proper electrical connection to the inflator module in the steering wheel, a coil assembly is used in the steering column. This coil is a ribbon of copper wires that operates much like a window shade when the steering wheel is rotated. As the steering wheel is rotated, this coil, usually called a **clockspring**, prevents the lack of continuity between the sensors and the inflator assembly that might result from a horn-ring type of sliding conductor.
- Inside the yellow plastic airbag connectors are gold-plated terminals that are used to prevent corrosion.

● **SEE FIGURE 56–14**.

Most airbag systems also contain a diagnostic unit that often includes an auxiliary power supply, which is used to provide the current to inflate the airbag if the battery is disconnected from the vehicle during a collision. This auxiliary power supply normally uses capacitors that are discharged through the squib of the inflation module. When the ignition is turned off, these capacitors are discharged. Therefore, after a few minutes, an airbag system does not deploy if the vehicle is hit while parked.

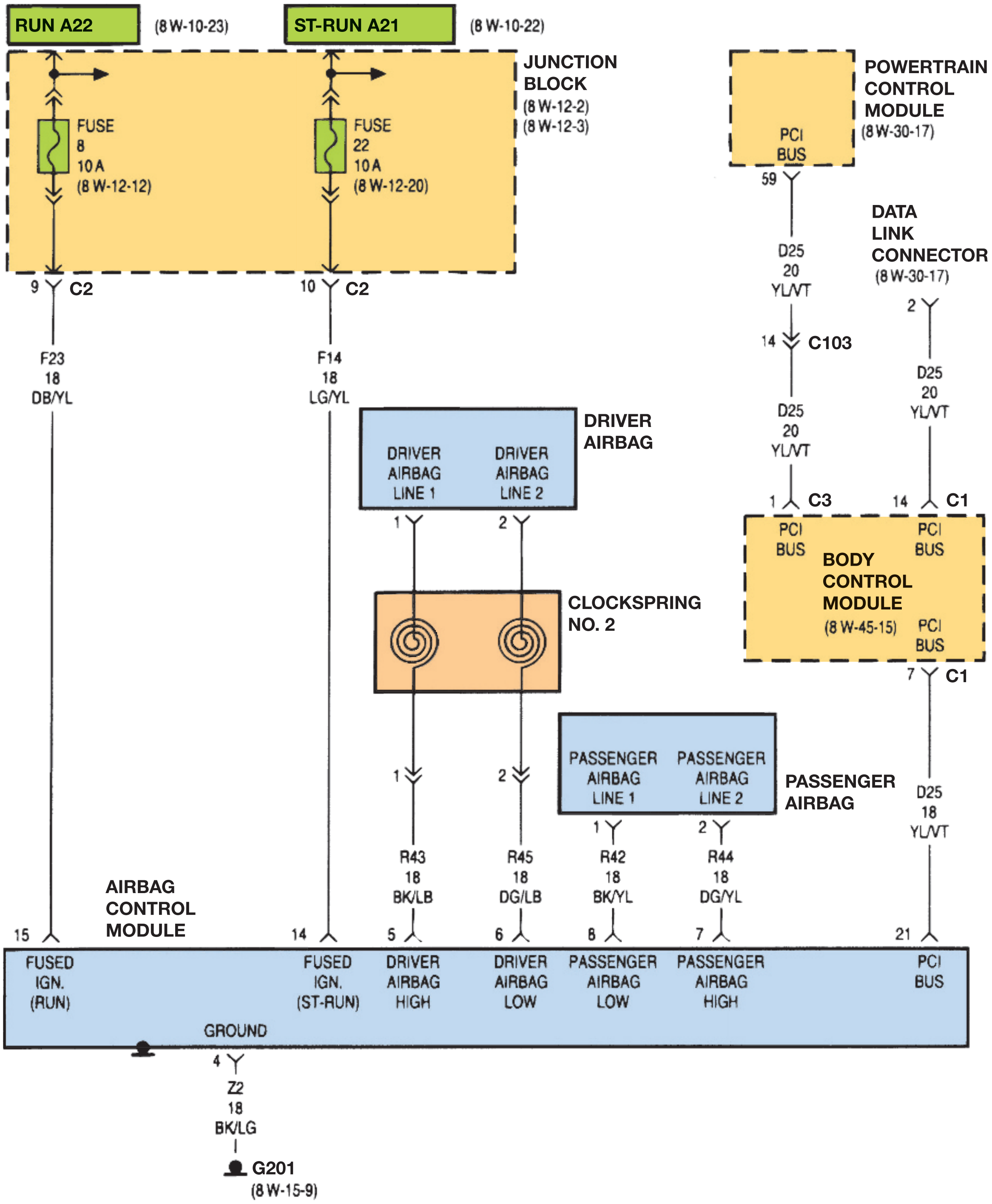

RUN A22
(8 W-10-23)
ST-RUN A21
(8 W-10-22)
JUNCTION BLOCK
(8 W-12-2)
(8 W-12-3)
FUSE 8 10 A (8 W-12-12)
FUSE 22 10 A (8 W-12-20)
POWERTRAIN CONTROL MODULE
(8 W-30-17)
PCI BUS
59
D25 20 YL/VT
DATA LINK CONNECTOR
(8 W-30-17)
2
14 C103
D25 20 YL/VT
9 C2
10 C2
F23 18 DB/YL
F14 18 LG/YL
DRIVER AIRBAG
DRIVER AIRBAG LINE 1
DRIVER AIRBAG LINE 2
1
2
1 C3
14 C1
PCI BUS
PCI BUS
BODY CONTROL MODULE
(8 W-45-15)
PCI BUS
7 C1
CLOCKSPRING NO. 2
PASSENGER AIRBAG LINE 1
PASSENGER AIRBAG LINE 2
PASSENGER AIRBAG
D25 18 YL/VT
1
2
R43 18 BK/LB
R45 18 DG/LB
R42 18 BK/YL
R44 18 DG/YL
AIRBAG CONTROL MODULE
15
14
5
6
8
7
21
FUSED IGN. (RUN)
FUSED IGN. (ST-RUN)
DRIVER AIRBAG HIGH
DRIVER AIRBAG LOW
PASSENGER AIRBAG LOW
PASSENGER AIRBAG HIGH
PCI BUS
GROUND
4
Z2 18 BK/LG
G201
(8 W-15-9)

FIGURE 56–14 The airbag control module is linked to the powertrain control module (PCM) and the body control module (BCM) on this Chrysler system. Notice the airbag wire connecting the module to the airbag through the clockspring. Both power, labeled "driver airbag high," and ground, labeled "driver airbag low," are conducted through the clockspring.

AIRBAG DIAGNOSIS TOOLS AND EQUIPMENT

SELF-TEST PROCEDURE The electrical portion of airbag systems is constantly checked by the circuits within the airbag-energizing power unit or through the airbag controller. The electrical airbag components are monitored by applying a small-signal voltage from the airbag controller through the various sensors and components. Each component and sensor uses a resistor in parallel with the load or open sensor switch for use by the diagnostic signals. If continuity exists, the testing circuits measure a small voltage drop. If an open or short circuit occurs, a dash warning light is lighted and a possible diagnostic trouble code (DTC) is stored. Follow exact manufacturer's recommended procedures for accessing and erasing airbag DTCs.

Diagnosis and service of airbag systems usually require some or all of the following items:

- Digital multimeter (DMM)
- Airbag simulator, often called a load tool
- Scan tool
- Shorting bar or shorting connector(s)
- Airbag system tester

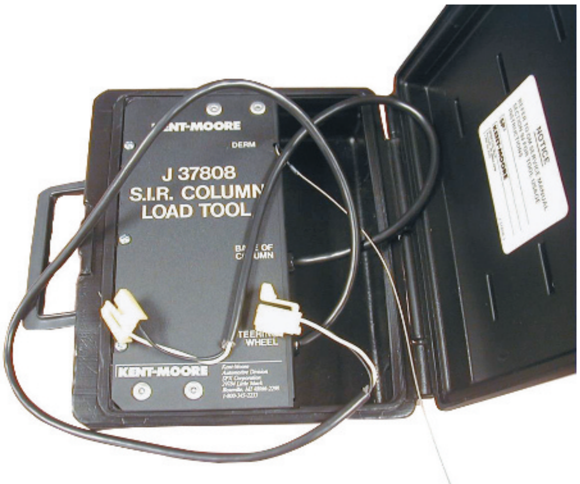


FIGURE 56–15 An airbag diagnostic tester. Included in the plastic box are electrical connectors and a load tool that substitutes for the inflator module during troubleshooting.

- Vehicle-specific test harness
- Special wire repair tools or connectors, such as crimp-and-seal weatherproof connectors

● **SEE FIGURE 56–15.**

CAUTION: Most vehicle manufacturers specify that the negative battery terminal be removed when testing or working around airbags. Be aware that a memory saver device used to keep the computer and radio memory alive can supply enough electrical power to deploy an airbag.

PRECAUTIONS Take the following precautions when working with or around airbags:

1. Always follow all precautions and warning stickers on vehicles equipped with airbags.
2. Maintain a safe working distance from all airbags to help prevent the possibility of personal injury in the unlikely event of an unintentional airbag deployment:
   - Side impact airbag: 5 inches (13 cm) distance
   - Driver front airbag: 10 inches (25 cm) distance
   - Passenger front airbag: 20 inches (50 cm) distance
3. In the event of a collision in which the bag(s) is deployed, the inflator module *and* all sensors usually must be replaced to ensure proper future operation of the system.
4. Avoid using a self-powered test light around the yellow airbag wiring. Even though it is highly unlikely, a self-powered test light could provide the necessary current to accidentally set off the inflator module and cause an airbag deployment.
5. Use care when handling the inflator module section when it is being removed from the steering wheel. Always hold the inflator away from your body.
6. If handling a deployed inflator module, always wear gloves and safety glasses to avoid the possibility of skin irritation from the sodium hydroxide dust, which is used as a lubricant on the bag(s), that remains after deployment.
7. Never jar or strike a sensor. The contacts inside the sensor may be damaged, preventing the proper operation of the airbag system in the event of a collision.
8. When mounting a sensor in a vehicle, make certain that the arrow on the sensor is pointing toward the front of the vehicle. Also be certain that the sensor is securely mounted.

TECH TIP

Pocket the Ignition Key to Be Safe

When replacing any steering gear, such as a rack-and-pinion steering unit, be sure that no one accidentally turns the steering wheel. If the steering wheel is turned without being connected to the steering gear, the airbag wire coil (clockspring) can become off center. This can cause the wiring to break when the steering wheel is rotated after the steering gear has been replaced. To help prevent this from occurring, simply remove the ignition key from the ignition and keep it in your pocket while servicing the steering gear.

FREQUENTLY ASKED QUESTION

What Are Smart Airbags?

Smart airbags use the information from sensors to determine the level of deployment. Sensors used include the following:

- **Vehicle speed (VS) sensors.** This type of sensor has a major effect on the intensity of a collision. The higher the speed is, the greater is the amount of impact force.
- **Seat belt fastened switch.** If the seat belt is fastened, as determined by the seat belt buckle switch, the airbag system deploys accordingly. If the driver or passenger is not wearing a seat belt, the airbag system deploys with greater force compared to when the seat belt is being worn.
- **Passenger seat sensor.** The sensor in the seat on the passenger's side determines the force of deployment. If there is not a passenger detected, the passenger side airbag does not deploy on the vehicle equipped with a passenger seat sensor system.

AIRBAG SYSTEM SERVICE

DIS-ARMING The airbags should be disarmed (temporarily disconnected) whenever performing service work on any of the following locations:

- Steering wheel
- Dash or instrument panel
- Glove box (instrument panel storage compartment)

Check service information for the exact procedure, which usually includes the following steps:

STEP 1 Disconnect the negative battery cable.

STEP 2 Remove the airbag fuse (has a yellow cover).

STEP 3 Disconnect the yellow electrical connector located at the base of the steering column to disable the driver's-side airbag.

STEP 4 Disconnect the yellow electrical connector for the passenger-side airbag.

This procedure is called "disabling airbags" in most service information. Always follow the vehicle manufacturer's specified procedures.

DIAGNOSTIC AND SERVICE PROCEDURE Airbag system components and their location in the vehicle vary according to system design, but the basic principles of testing are the same as for other electrical circuits. Use service information to determine how the circuit is designed and the correct sequence of tests to be followed.

- Some airbag systems require the use of special testers. The built-in safety circuits of such testers prevent accidental deployment of the airbag.
- If such a tester is not available, follow the recommended alternative test procedures specified by the manufacturer.
- Access the self-diagnostic system and check for DTC records.
- The scan tool is needed to access the data stream on most systems.

SELF-DIAGNOSIS All airbag systems can detect system electrical faults and, if found, disables the system and notifies the driver through an airbag warning lamp in the instrument cluster. Depending on circuit design, a system fault may cause the warning lamp to fail to illuminate, remain lit continuously, or flash. Some systems use a tone generator that produces an audible warning when a system fault occurs, or if the warning lamp is inoperative.

The warning lamp should illuminate with the ignition key on and engine off as a bulb check. If not, the diagnostic module is likely disabling the system. If the airbag warning light remains on, the airbags may or may not be disabled, depending on the specific vehicle and the fault detected. Some warning lamp circuits have a timer that extinguishes the lamp after a few seconds. The airbag system generally does not require service unless there is a failed component. However, a steering wheel–mounted airbag module is routinely removed and replaced in order to service switches and other column-mounted devices.

FREQUENTLY ASKED QUESTION

Why Change Knee Bolsters If Switching to Larger Wheels?

Larger wheels and tires can be installed on vehicles, but the powertrain control module (PCM) needs to be reprogrammed so the speedometer and other systems that are affected by a change in wheel/tire size can work effectively. When 20 inch wheels are installed on General Motors trucks or sport utility vehicles (SUVs), GM specifies that replacement knee bolsters be installed. Knee bolsters are the padded area located on the lower part of the dash where a driver or passenger's knees would hit in the event of a front collision. The reason for the need to replace the knee bolsters is to maintain the crash testing results. The larger 20 inch wheels tend to be forced further into the passenger compartment in the event of a front-end collision. Therefore, to maintain the frontal crash rating standard, the larger knee bolsters are required.

WARNING

Failure to perform the specified changes when changing wheels and tires could result in the vehicle not being able to provide occupant protection as designed by the crash test star rating that the vehicle originally achieved.

KNEE AIRBAGS Some vehicles are equipped with knee airbags usually on the driver's side. Use caution if working under the dash and always follow the vehicle manufacturer's specified service procedures.

DRIVER SIDE AIRBAG MODULE REPLACEMENT

For the specific model being serviced, carefully follow the procedures provided by the vehicle manufacturer to disable and remove the airbag module. Failure to do so may result in serious injury and extensive damage to the vehicle. Replacing a discharged airbag is costly. The following procedure reviews the basic steps for removing an airbag module. Do not substitute these general instructions for the specific procedure recommended by the manufacturer:

1. Turn the steering wheel until the front wheels are positioned straight ahead. Some components on the steering column are removed only when the front wheels are straight.
2. Switch the ignition off and disconnect the negative battery cable, which cuts power to the airbag module.
3. Once the battery is disconnected, wait as long as recommended by the manufacturer before continuing. When in doubt, wait at least 10 minutes to make sure the capacitor is completely discharged.
4. Loosen and remove the nuts or screws that hold the airbag module in place. On some vehicles, these fasteners are located on the back of the steering wheel. On other vehicles, they are located on each side of the steering wheel. The fasteners may be concealed with plastic finishing covers that must be pried off with a small screwdriver to access them.
5. Carefully lift the airbag module from the steering wheel and disconnect the electrical connector. Connector location varies: Some are below the steering wheel behind a plastic trim cover; others are at the top of the column under the module. ● **SEE FIGURES 56–16 AND 56–17**.

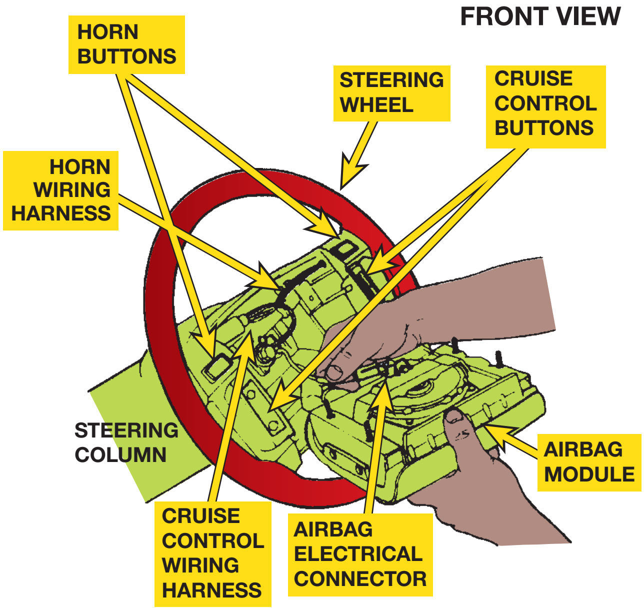


FIGURE 56–16 After disconnecting the battery and the yellow connector at the base of the steering column, the airbag inflator module can be removed from the steering wheel and the yellow airbag electrical connector at the inflator module be disconnected.

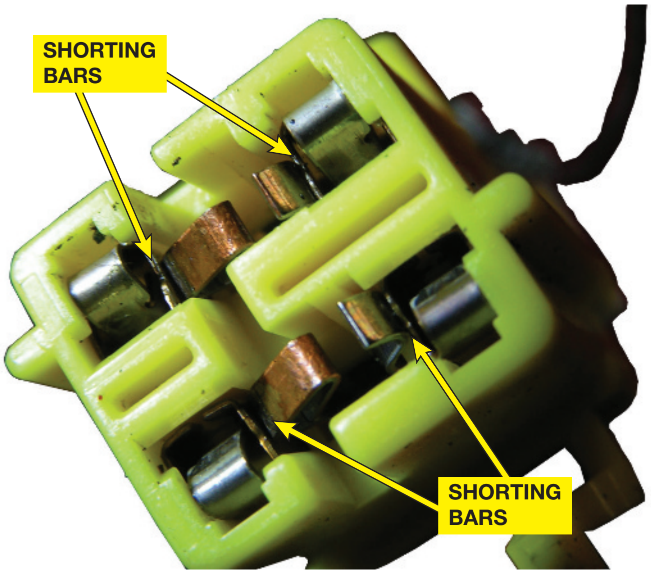


FIGURE 56–17 Shorting bars are used in most airbag connectors. These spring-loaded clips short across both terminals of an airbag connector when it is disconnected to help prevent accidental deployment of the airbag. If electrical power is applied to the terminals, the shorting bars simply provide a low-resistance path to the other terminal and do not allow current to flow past the connector. The mating part of the connector has a tapered piece that spreads apart the shorting bars when the connector is reconnected.

6. Store the module pad side up in a safe place where it cannot be disturbed or damaged while the vehicle is being serviced. Do not attempt to disassemble the airbag module. If the airbag is defective, replace the entire assembly.

When installing the airbag module, make sure the clockspring is correctly positioned to ensure module-to-steering-column continuity. ● **SEE FIGURE 56–18**.

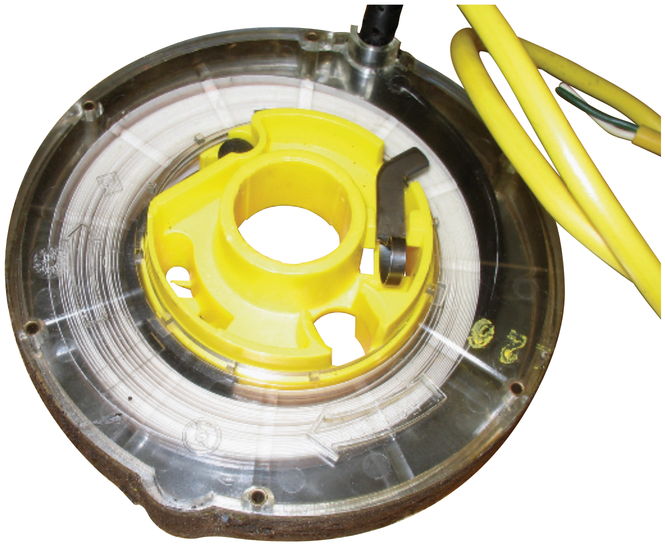


FIGURE 56–18 An airbag clockspring showing the flat conductor wire. It must be properly positioned to ensure proper operation.

Always route the wiring exactly as it was before removal. Also, make sure the module seats completely into the steering wheel. Secure the assembly using new fasteners, if specified.

SAFETY WHEN MANUALLY DEPLOYING AIRBAGS

Airbag modules cannot be disposed of unless they are deployed. Do the following to prevent injury when manually deploying an airbag:

- When possible, deploy the airbag outside of the vehicle. Follow the vehicle manufacturer's recommendations.
- Follow the vehicle manufacturer's procedures and equipment recommendations.
- Wear the proper hearing and eye protection.
- Deploy the airbag with the trim cover facing up.
- Stay at least 20 feet (6 m) from the airbag. (Use long jumper wires attached to the wiring and routed outside the vehicle to a battery.)
- Allow the airbag module to cool.

● **SEE FIGURE 56–19**.

OCCUPANT DETECTION SYSTEMS

PURPOSE AND FUNCTION The U.S. Federal Motor Vehicle Safety Standard 208 (FMVSS) specifies that the passenger side airbag be disabled or deployed with reduced force under the following conditions. This system is referred to as an **occupant detection system (ODS)** or the **passenger presence system (PPS)**.

- When there is no weight on the seat and no seat belt is fastened, the passenger-side airbag does not deploy and the passenger airbag light should be off. ● **SEE FIGURE 56–20**.

FIGURE 56–19 An airbag being deployed as part of a demonstration in an automotive laboratory.

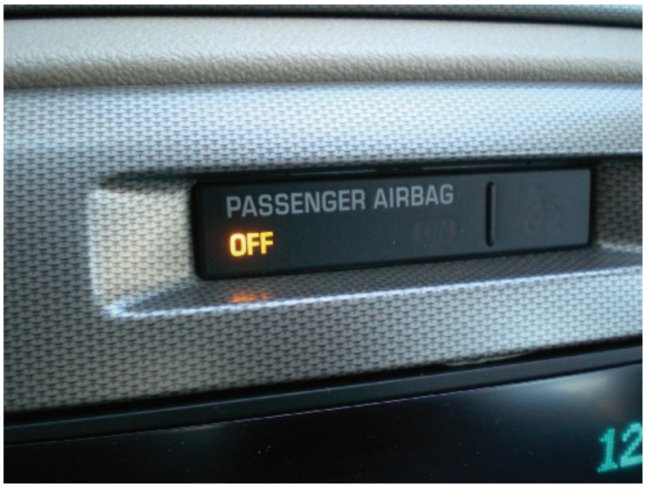


FIGURE 56–20 A dash warning lamp lights if the passenger side airbag is off because no passenger was detected by the seat sensor.

- The passenger-side airbag is disabled and the disabled airbag light is "on" only if at least 10 to 37 pounds (4.5 to 17 kg) is on the passenger seat, which generally represents a seated child.
- If 38 to 99 pounds (17 to 45 kg) is detected on the passenger seat, which represents a child or small adult, the airbag deploys at a decreased force.
- If 99 pounds (45 kg) or more is detected on the passenger seat, the airbag deploys at full force, depending on the severity of the crash, speed of the vehicle, and other factors, which may result in the airbag deploying at a reduced force.
  ● **SEE FIGURE 56–21**.

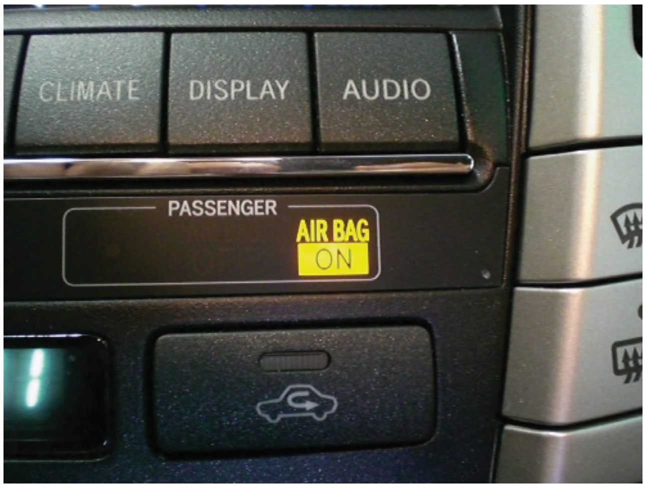


FIGURE 56–21 The passenger side airbag "on" lamp lights if a passenger is detected on the passenger seat.

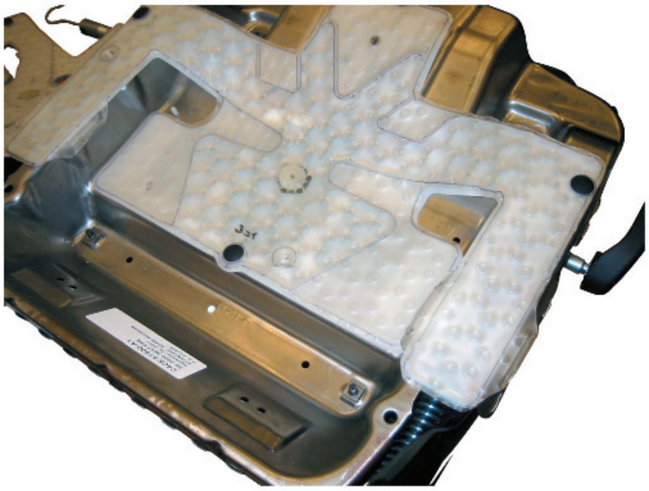


FIGURE 56–22 A gel-filled (bladder-type) occupant detection sensor showing the pressure sensor and wiring.

TYPE OF SEAT SENSOR The passenger presence system uses one of three types of sensors:

- **Gel-filled bladder sensor.** This type of occupant sensor uses a silicone-filled bag that has a pressure sensor attached. The weight of the passenger is measured by the pressure sensor, which sends a voltage signal to the module controlling the airbag deployment. A safety belt tension sensor is also used with a gel-filled bladder system to monitor the tension on the belt. The module then uses the information from both the bladder and the seat belt sensor to determine if a tightened belt may be used to restrain a child seat. ● **SEE FIGURE 56–22**.
- **Capacitive strip sensors.** This type of occupant sensor uses several flexible conductive metal strips under the seat cushion. These sensor strips transmit and receive a low-level electric field, which changes due to the weight of the front passenger seat occupant. The module determines the weight of the occupant based on the sensor values.
- **Force-sensing resistor sensors.** This type of occupant sensor uses resistors, which change their resistance based on the stress that is applied. These resistors are part of the

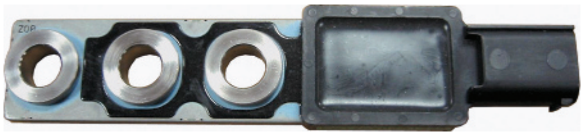


FIGURE 56–23 A resistor-type occupant detection sensor. The weight of the passenger strains these resistors, which are attached to the seat, thereby signaling to the module the weight of the occupant.

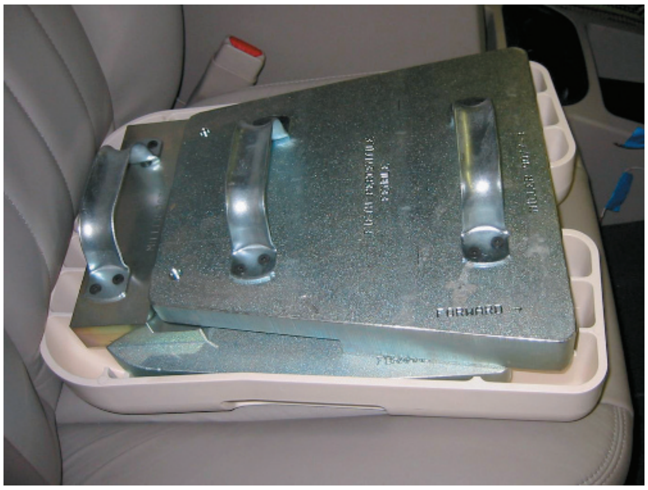


FIGURE 56–24 A test weight is used to calibrate the occupant detection system on a Chrysler vehicle.

seat structure, and the module can determine the weight of the occupant based on the change in the resistance of the sensors. ● **SEE FIGURE 56–23**.

CAUTION: Because the resistors are part of the seat structure, it is very important that all seat fasteners be torqued to factory specifications to ensure proper operation of the occupant detection system. A *seat track position* (STP) *sensor* is used by the airbag controller to determine the position of the seat. If the seat is too close to the airbag, the controller may disable the airbag.

DIAGNOSING OCCUPANT DETECTION SYSTEMS A fault in the system may cause the passenger side airbag light to turn on when there is no weight on the seat. A scan tool is often used to check or calibrate the seat, which must be empty, by commanding the module to rezero the seat sensor. Some systems, such as those on Chrysler vehicles, use a unit that has various weights along with a scan tool to calibrate and diagnose the occupant detection system. ● **SEE FIGURE 56–24**.

SEAT AND SIDE CURTAIN AIRBAGS

SEAT AIRBAGS Side and/or *curtain airbags* use a variety of sensors to determine if they need to be deployed. Side airbags are mounted in one of two general locations:

- In the side bolster of the seat (● **SEE FIGURE 56–25**.)
- In the door panel

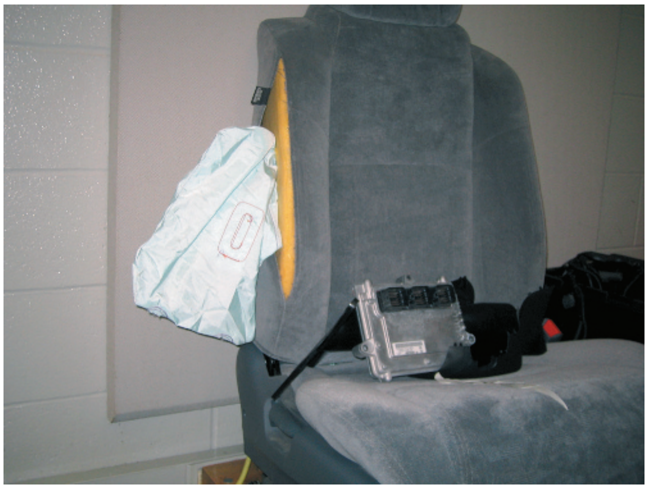


FIGURE 56–25 A typical seat (side) airbag that deploys from the side of the seat.

TECH TIP

Aggressive Driving and OnStar

If a vehicle equipped with the OnStar system is being driven aggressively and the electronic stability control system has to intercede to keep the vehicle under control, OnStar may call the vehicle to see if there has been an accident. The need for a call from OnStar is usually determined if the accelerometer registers slightly over 1 g-force, which could be achieved while driving on a race track.

Most side airbag sensors use an electronic accelerometer to detect when to deploy the airbags, which are usually mounted to the bottom of the left and right "B" pillars (where the front doors latch) behind a trim panel on the inside of the vehicle.

CAUTION: Avoid using a lockout tool (e.g., a "slim jim") in vehicles equipped with side airbags to help prevent damage to the components and wiring in the system.

SIDE CURTAIN AIRBAGS Side curtain airbags are usually deployed by a module based on input from many different sensors, including a lateral acceleration sensor and wheel speed sensors. For example, in one system used by Ford, the ABS controller commands that the brakes on one side of the vehicle be applied, using down pressure while monitoring the wheel speed sensors. If the wheels slow down with little brake pressure, the controller assumes that the vehicle could roll over, thereby deploying the side curtain airbags.

EVENT DATA RECORDERS

PARTS AND OPERATION As part of the airbag controller on many vehicles, the **event data recorder (EDR)** is used to record parameters just before and slightly after an airbag deployment. The following parameters are recorded:

- Vehicle speed
- Brake on/off

- Seat belt fastened
- G-forces as measured by the accelerometer

Unlike an airplane event data recorder, a vehicle unit is not a separate unit and does not record voice conversations nor include all crash parameters. This means that additional crash data, such as skid marks and physical evidence at the crash site, is needed to fully reconstruct the incident.

The EDR is embedded into the airbag controller and receives data from many sources and at varying sample rates. The data are constantly being stored in a memory buffer and are not recorded into the EPROM unless an airbag deployment has been commanded. The combined data are known as an *event file.* The airbag is commanded on, based on input mainly from the accelerometer sensor. This sensor, usually built into the airbag controller, is located inside the vehicle. The accelerometer calculates the rate of change of the speed of the vehicle. This determines the acceleration rate and is used to predict if that rate is high enough to deploy the frontal airbags. The airbags are deployed if the threshold g-value is exceeded. The passenger side airbag is also deployed unless it is suppressed by either of the following:

- No passenger is detected.
- The passenger side airbag switch is off.

DATA EXTRACTION Data extraction from the event data recorder in the airbag controller can only be achieved using a piece of equipment known as the Crash Data Retrieval System, manufactured by Vetronics Corporation. This is the only authorized method for retrieving event files and only certain organizations are allowed access to the data. These groups or organizations include:

- Original equipment manufacturer's representatives
- National Highway Traffic Safety Administration
- Law enforcement agencies
- Accident reconstruction companies

Crash data retrieval must only be done by a trained crash data retrieval (CDR) technician or analyst. A technician undergoes specialized training and must pass an examination. An analyst must attend additional training beyond that of a technician to achieve CDR analyst certification.

REVIEW QUESTIONS

1. What are the safety precautions to follow when working around an airbag?
2. What sensor(s) must be triggered for an airbag deployment?
3. How should deployed inflation modules be handled?
4. What is the purpose of pretensioners?
5. What is the purpose of the event data recorder?

CHAPTER QUIZ

1. A vehicle is being repaired after an airbag deployment. Technician A says that the inflator module should be handled as if it is still live. Technician B says gloves should be worn to prevent skin irritation. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A seat belt pretensioner is ___________.
   a. a device that contains an explosive charge
   b. used to remove slack from the seat belt in the event of a collision
   c. used to force the occupant back into position against the seat back in the event of a collision
   d. All of the above
3. The occupant detection system measures the ___________ of the person in the passenger seat.
   a. height
   b. weight
   c. age
   d. distance from the seat belt
4. Two technicians are discussing dual-stage airbags. Technician A says that a deployed airbag is safe to handle, regardless of which stage caused the deployment of the airbag. Technician B says that both stages ignite, but at different speeds, depending on the speed of the vehicle. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Where are shorting bars used?
   a. In pretensioners
   b. At the connectors for airbags
   c. In the crash sensors
   d. In the airbag controller
6. Technician A says that a deployed airbag can be repacked, reused, and reinstalled in the vehicle. Technician B says that a deployed airbag should be discarded and replaced with an entire new assembly. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. What color are the airbag electrical connectors and conduit?
  - **a.** Blue
  - **b.** Red
  - **c.** Yellow
  - **d.** Orange

8. On some vehicles, the side curtain airbags use which of the following devices to determine when to deploy?
  - **a.** Wheel speed sensors
  - **b.** Lateral acceleration sensor
  - **c.** Passenger presence system (PPS) seat sensor
  - **d.** Seat belt sensor

9. How many sensors must be triggered at the same time to cause an airbag deployment?
  - **a.** One
  - **b.** Two
  - **c.** Three
  - **d.** Four

10. Which parameters might be stored in the airbag controller in the event of a deployment?
  - **a.** Voice recordings
  - **b.** A 10-second video of the driver
  - **c.** Whether the windows were open or closed
  - **d.** Seat belt fastened

Chapter

57

BODY ELECTRICAL ACCESSORIES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe how the horn operates.
- Diagnose faulty horn operation.
- Explain the testing and diagnosis of windshield wipers.
- Explain the testing and diagnosis of windshield washers.
- Describe how rain-sense wipers operate and are serviced.
- Describe the operation of the blower motor.
- Describe the operation of cruise control.
- Discuss electrically heated rear window defogger systems.
- Explain the operation and testing procedures for power windows.
- Discuss electric power door locks and trunk/lift gate locks.
- Discuss the operation of power sun roofs/moon roofs and sun shades.
- Describe the operation of power seats.
- Describe the operation of electrically heated seats and cooled seats.
- Describe the operation of heated steering wheels.
- Describe the operation of heated mirrors.
- Explain the operation of adjustable pedals and folding outside mirrors.
- Describe the operation and diagnosis of remote keyless entry.
- Describe the operation and diagnosis of garage door openers.
- Discuss remote start systems.
- Explain the diagnosis of body electrical communications systems and describe the process to reprogram electronic modules.

KEY TERMS:

Automatic reversal systems (ARS) 678 • Cruise control 675 • Electric adjustable pedals (EAP) 685 • Heated rear window defogger 676 • Heated seats 684 • Heated steering wheel 685 • Horns 665 • Moon roof 681 • Over the air (OTA) 690 • Passive entry, passive starting (PEPS) 688 • Power windows 678 • Pulse wipers 668 • Rain-sense wipers 672 • Remote start 689 • Sun roof 681 • Sun shades 681 • Variable-delay wipers 668 • Windshield wipers 666

HORNS

PURPOSE AND FUNCTION **Horns** are electric devices that emit a loud sound used to alert other drivers or persons in the area. Horns are manufactured in several different tones, ranging from 1,800 to 3,550 Hz, and must be heard from a minimum distance of 200 feet (60 m). Vehicle manufacturers select from various horn tones for a particular vehicle sound. ● **SEE FIGURE 57–1**.

When two horns are used, each has a different tone, yet the sound combines when both are operated. Most horns since 2000 have used the body control module (BCM) to control the actual operation.

HORN CIRCUITS Automotive horns usually operate on full battery voltage wired from the battery, through a fuse. Older vehicles use a horn relay with a horn button on the steering wheel or column that completes a circuit to ground that closes the control side of the relay. The heavy current flow required to operate the horn travels through the load side of the relay to the horn. ● **SEE FIGURE 57–2**.

FIGURE 57–1 Two horns are used on this vehicle. Many vehicles use only one horn, often hidden underneath the vehicle.

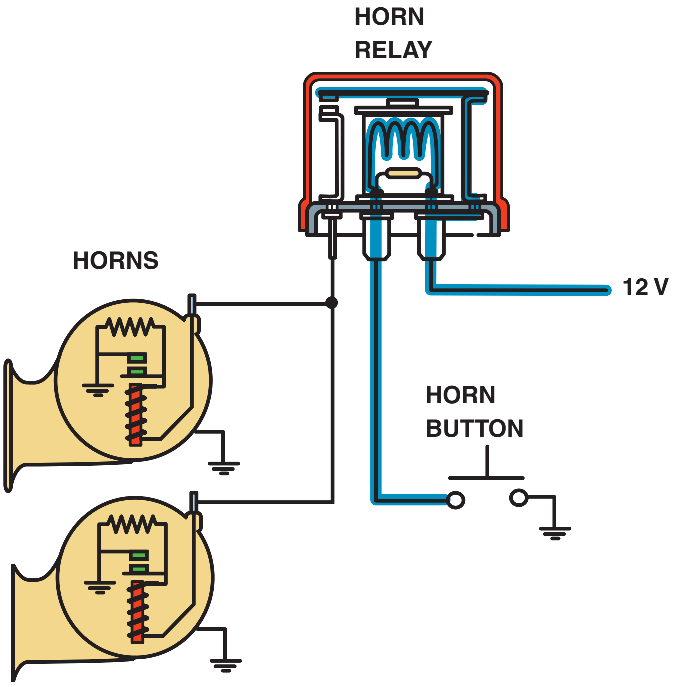


FIGURE 57–2 A simplified horn circuit where the horn button completes the ground circuit of the relay coil.

COMPUTER-CONTROLLED HORNS On most recent model vehicles, the horn button is an input to the body control module (BCM) or electronic control unit (ECU). The BCM controls the operation of the horn relay. The horn relay may also be controlled by the BCM, which "beeps" the horn when the vehicle is locked or unlocked, using the key fob remote, and can be sounded by the alarm system. Check service information for the exact details about the horn circuit for the vehicle being checked. ● **SEE FIGURE 57–3.**

HORN OPERATION A vehicle horn is an actuator that converts an electrical signal to sound. The horn circuit has an armature (a coil of wire) and contacts that are attached to a diaphragm. When energized, the armature causes the diaphragm to move up, which then opens a set of contact points that de-energize the armature circuit. As the diaphragm moves down, the contact points close, re-energizing the armature circuit, and the diaphragm moves up again. This rapid opening and closing of the contact points causes the diaphragm to vibrate at an audible frequency. The sound created by the diaphragm is magnified as it travels through a trumpet attached to the diaphragm chamber. Most horn systems typically use one or two horns, but some have up to four. Those with multiple horns use both high- and low-pitch units to achieve a harmonious tone. Only a high-pitched unit is used in single-horn applications. The horn assembly is marked with an "H" or "L" for pitch identification.

HORN DIAGNOSIS

SCAN TOOL TESTING A scan tool can be used to test a horn that is computer controlled by using the bidirectional feature of a factory or factory-level aftermarket scan tool. Because most horn buttons are an input to the BCM or similar module, a scan tool can often be used to command the horn to sound. Check service information for the vehicle being tested for the exact tests and testing procedures to follow.

HORN CIRCUIT TESTING Once the cause of an inoperative horn has been reduced to the horn wiring circuit, the wiring needs to be checked. Typically, a digital multimeter (DMM) is used to perform voltage drop and continuity checks to isolate the failure. A momentary contact switch, horn button, is used to sound the horn. The horn switch is mounted to the steering wheel in or near the center of the steering column.

CAUTION: If the steering wheel needs to be removed for diagnosis or repair of the horn circuit, follow service information procedures for disarming the airbag circuit prior to removing the steering wheel, and for the specified test equipment to use.

On most recent-model vehicles, the horn relay is in a centralized power distribution center along with other relays, circuit breakers, and fuses. Check the relay to determine if the coil is being energized and if current passes through the power circuit when the horn switch is depressed. Check service information for the exact diagnosis and horn replacement procedures to follow.

HORN REPLACEMENT Horns are generally mounted on the radiator core support by bolts and nuts or sheet metal screws. To replace a horn, remove the fasteners and lift the old horn from its mounting bracket. Clean the attachment area on the mounting bracket and chassis before installing the new horn. Some models use a corrosion-resistant mounting bolt to ensure a ground connection.

WINDSHIELD WIPERS

PURPOSE AND FUNCTION **Windshield wipers** are used to keep the viewing area of the windshield clear of rain. Windshield wiper systems and circuits vary greatly between manufacturers as well as between models. Some vehicles combine the windshield wiper and windshield washer functions into a single system. Many minivans and sport utility vehicles (SUVs) also have a rear window wiper and washer system that works independently of the windshield system. Generally, all windshield and rear window wiper and washer systems operate in a similar fashion. Wiper control switches are installed on the steering column, usually as part of a multifunction switch that controls several other functions.

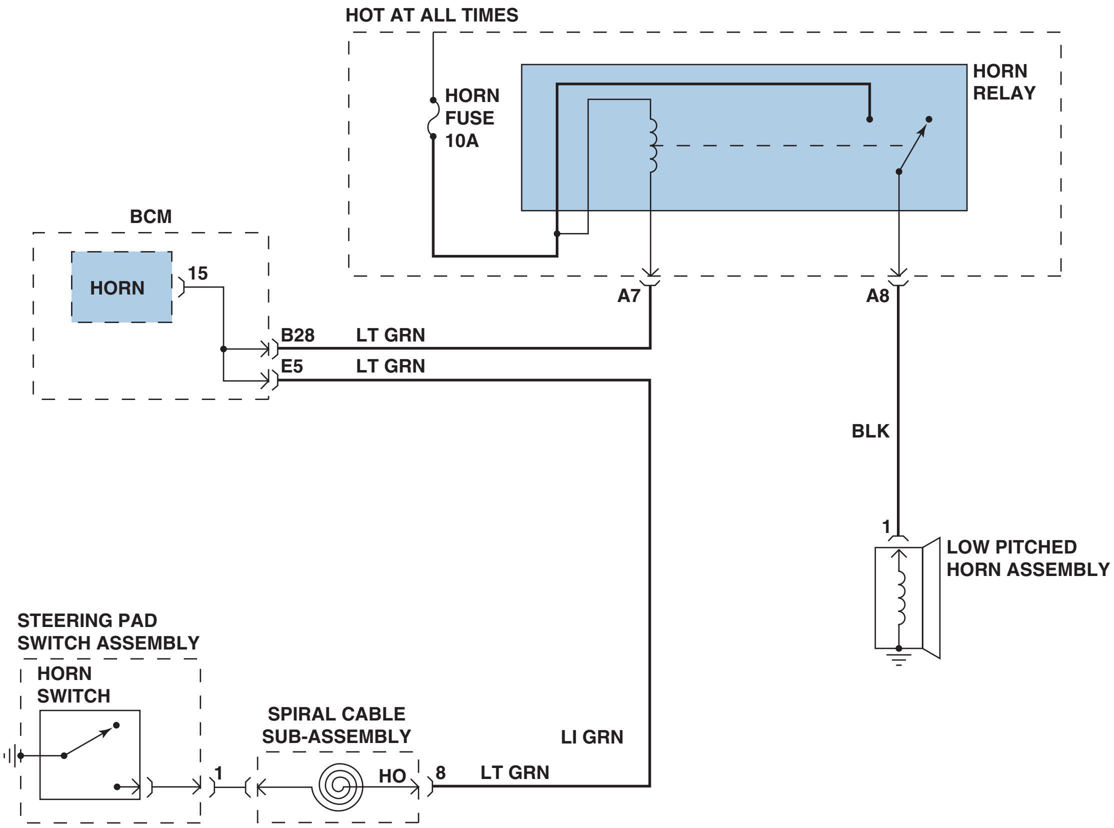

HOT AT ALL TIMES
HORN FUSE 10A
HORN RELAY
BCM
HORN
15
B28
LT GRN
E5
LT GRN
A7
A8
BLK
1
LOW PITCHED HORN ASSEMBLY
STEERING PAD SWITCH ASSEMBLY
HORN SWITCH
SPIRAL CABLE SUB-ASSEMBLY
LI GRN
1
HO
8
LT GRN

FIGURE 57–3 A typical schematic of a horn circuit. Note that the horn relay can be activated by either the horn switch in the steering wheel or by the body control module (BCM).

COMPUTER CONTROLLED WIPERS Most wipers, since the 1990s, have used the BCM to control the actual operation of the wiper. The wiper controls are an input to the control module and may also turn on the headlights whenever the wipers are on, which is the law in some states. ● **SEE FIGURE 57–4**.

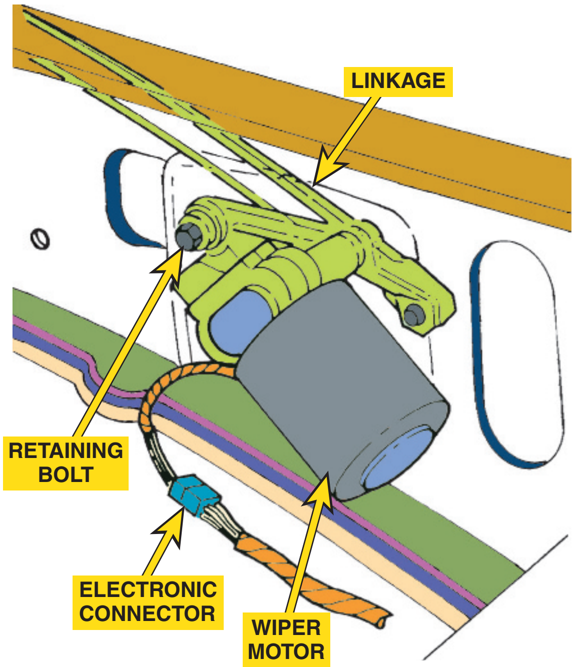

LINKAGE
RETAINING BOLT
ELECTRONIC CONNECTOR
WIPER MOTOR

FIGURE 57–4 The motor and linkage bolt to the body and connect to the switch with a wiring harness.

WIPER AND WASHER COMPONENTS A typical combination wiper and washer system consists of the following:

- Wiper motor(s)
- Gearbox
- Wiper arms and linkage
- Wiper blades
- Washer pump
- Hoses and jets (nozzles)
- Fluid reservoir
- Combination switch
- Wiring and electrical connectors

● **SEE FIGURE 57–5**.

WINDSHIELD WIPER MOTORS The windshield wipers ordinarily use a special two-speed electric motor. Some are compound-wound motors, a motor type that provides for two different speeds.

- Series-wound field
- Shunt field

One speed is achieved in the series-wound field and the other speed in the shunt-wound field. Other wiper motors are of the permanent magnet type. ● **SEE FIGURE 57–6**.

WIPER MOTOR OPERATION Wiper motors using a permanent magnet motor have a low-speed positive brush, a high-speed positive brush, and a ground (negative) brush. The brushes connect the battery to the internal windings of the motor, and the

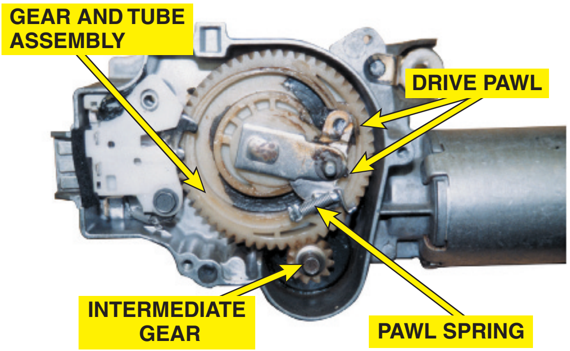


FIGURE 57–5 A typical wiper motor with the housing cover removed. The motor itself has a worm gear on the shaft that turns the small intermediate gear, which then rotates the gear and tube assembly, which rotates the crank arm (not shown) that connects to the wiper linkage.

FREQUENTLY ASKED QUESTION

How Do Wipers Park?

Some vehicles have wiper arms that park lower than the normal operating position, so they are hidden below the hood when not in operation. This is called a *depressed park position.* When the wiper motor is turned off, the park switch allows the motor to continue to turn until the wiper arms reach the bottom edge of the windshield. Then the park switch reverses the current flow through the wiper motor, which makes a partial revolution in the opposite direction.

The wiper linkage pulls the wiper arms down below the level of the hood and the park switch is opened, stopping the wiper motor.

two brushes provide for two different motor speeds. The ground brush is directly opposite the low-speed brush. The high-speed brush is off to the side of the low-speed brush. When current flows through the high-speed brush, there are fewer turns on the armature between the hot and ground brushes and, therefore, the resistance is less. With less resistance, more current flows and the armature revolves faster.

PARK POSITION Windshield wiper motor park operation is controlled by the wiper motor module using an input from the park switch within the wiper motor assembly. When the windshield wiper/washer switch is turned to the OFF position while the wiper blades are somewhere on the windshield, the wiper motor module continues to operate the wiper motor until the wipers reach the park position. Check service information for the exact operation for the vehicle being serviced.

VARIABLE WIPERS The **variable-delay wipers** (also called **pulse wipers**) is a term used to describe the operation of the wipers that operate on an interval that can be delayed when the rain is light. Older vehicles use an electronic circuit with a variable resistor that controls the time of the charge and discharge of a capacitor. The charging and discharging of the capacitor controls the circuit for the operation of the wiper motor. On newer vehicles, the wipers are controlled by the BCM with input from the driver using a knob or dial to adjust the wiper interval.

WINDSHIELD WIPER DIAGNOSIS If the windshield wipers are not working, use a factory or factory-level scan tool and check for operation using the bidirectional controls.

- If the wipers function when commanded by the scan tool, check service information for the exact procedures to follow when checking the switch input and BCM connections.
- If the wipers do not function when being commanded by the scan tool, perform circuit testing, which usually includes determining if the fault is electrical or mechanical. ● **SEE FIGURE 57–7**.

To determine if there is an electrical or mechanical problem, access the motor assembly and disconnect the wiper arm linkage

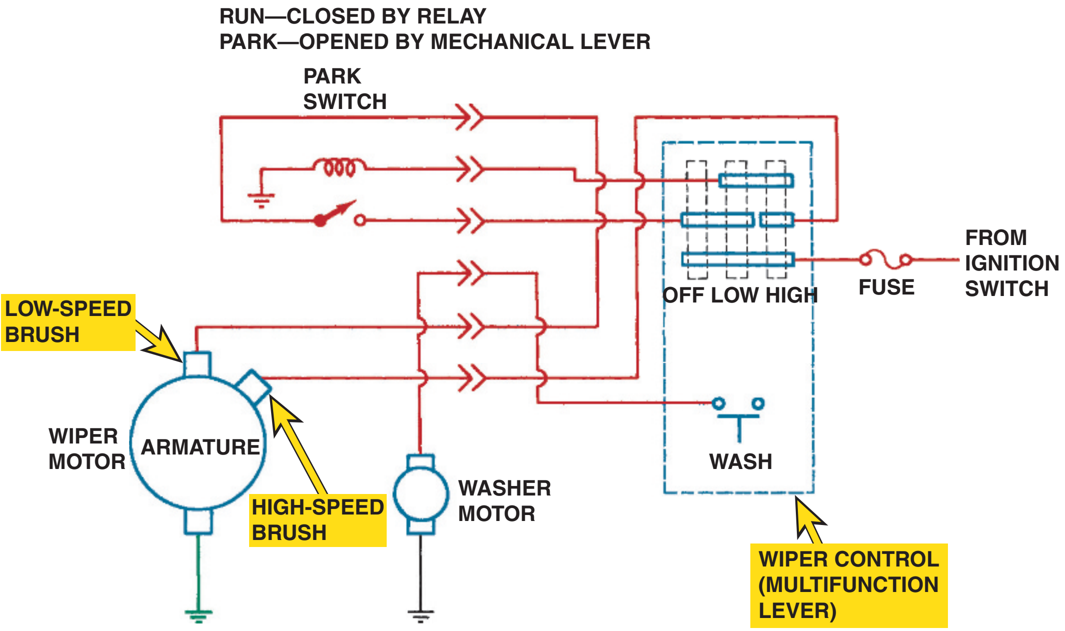


FIGURE 57–6 A wiring diagram of a two-speed windshield wiper circuit using a three-brush, two-speed motor. The dashed line for the multifunction lever indicates that the circuit shown is only part of the total function of the steering column lever.

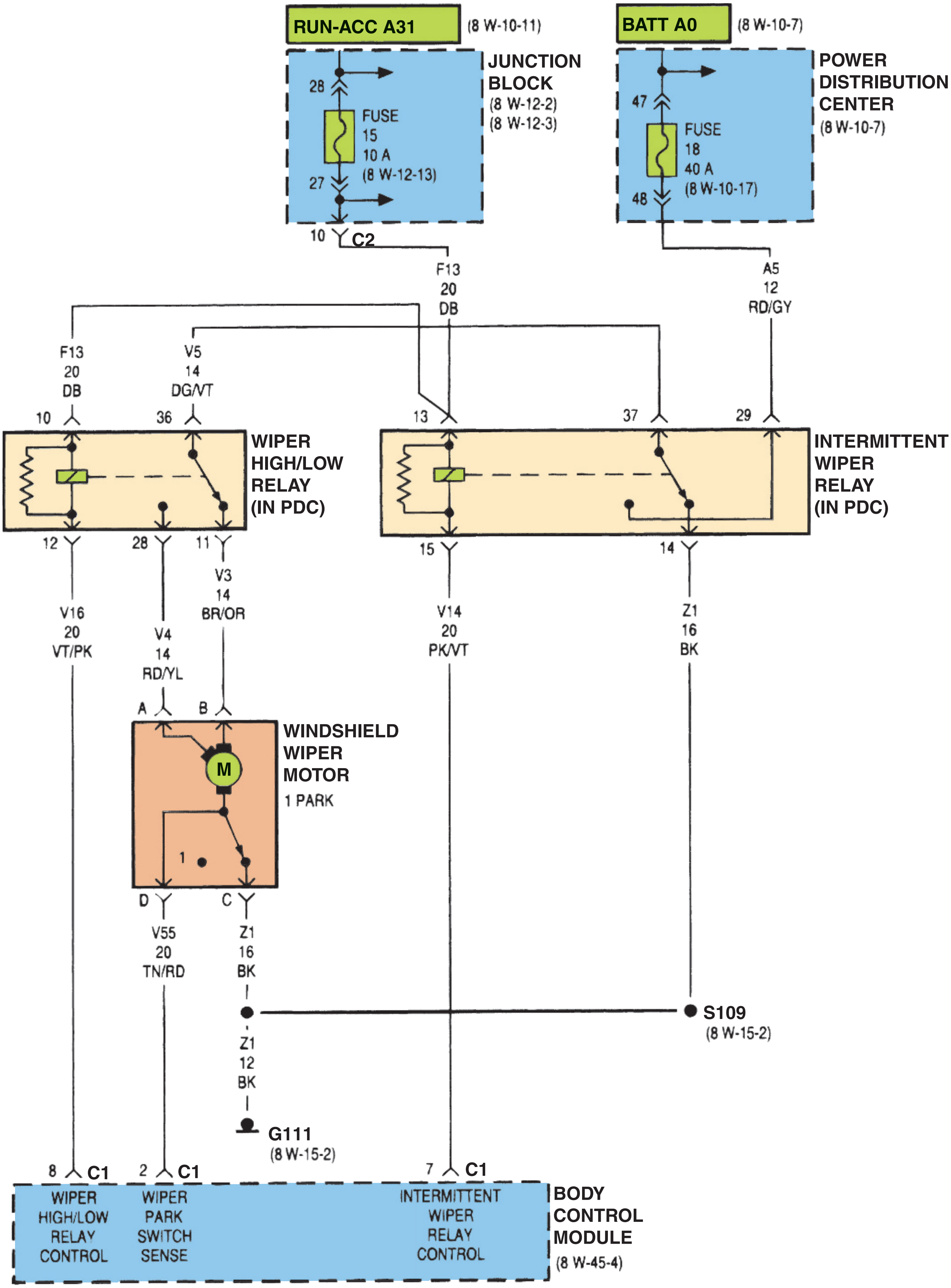

RUN-ACC A31
(8 W-10-11)
BATT A0
(8 W-10-7)
JUNCTION BLOCK
(8 W-12-2)
(8 W-12-3)
28
FUSE 15 10 A (8 W-12-13)
27
POWER DISTRIBUTION CENTER
(8 W-10-7)
47
FUSE 18 40 A (8 W-10-17)
48
10
C2
F13 20 DB
A5 12 RD/GY
F13 20 DB
V5 14 DG/VT
10
36
13
37
29
WIPER HIGH/LOW RELAY (IN PDC)
INTERMITTENT WIPER RELAY (IN PDC)
12
28
11
15
14
V3 14 BR/OR
V16 20 VT/PK
V4 14 RD/YL
V14 20 PK/VT
Z1 16 BK
A
B
WINDSHIELD WIPER MOTOR
M
1 PARK
1
D
C
V55 20 TN/RD
Z1 16 BK
S109
(8 W-15-2)
Z1 12 BK
G111
(8 W-15-2)
8
C1
2
C1
7
C1
WIPER HIGH/LOW RELAY CONTROL
WIPER PARK SWITCH SENSE
INTERMITTENT WIPER RELAY CONTROL
BODY CONTROL MODULE
(8 W-45-4)

FIGURE 57–7 A circuit diagram is necessary to troubleshoot a windshield wiper problem.

CASE STUDY

Wipers Would Stop Working

The owner of a Ford Focus stated that the wipers would stop working randomly in the middle of a sweep. The technician saw that the wiper blades were aftermarket multiple blade type. The wiper motors have a fail-safe over load protection built in. If the body control module (BCM) detects too much current, it will shut the motors down to protect them. The motors communicate over a LIN network between the two motors.

The technician replaced the wiper blades with factor original equipment (OE) blades. This corrected the customer concern.

Summary:

Complaint—The wipers would stop working randomly in the middle of a sweep.
Cause—The aftermarket wiper blades created too much of a drag on the wiper motor and caused it to stop working.
Correction—The wiper blades were replaced with the factory original type.

from the motor and gearbox. If the motor operates, but the wipers do not, check for the following:

- Stripped gears in the gearbox or stripped linkage connection
- Loose or separated motor-to-gearbox connection
- Loose linkage to the motor connection

If the motor does not shut off, check for the following:

- Defective park switch inside the motor
- Defective wiper switch
- Poor ground connection at the wiper switch

WIPER MOTOR REPLACEMENT Wiper motors are replaced if defective. The motor usually mounts on the bulkhead (firewall). Bulkhead-mounted units are accessible from under the hood, while the cowl panel needs to be removed to service a motor mounted in the cowl. ● **SEE FIGURE 57–8**.

REAR WIPERS Rear window wiper motors are generally located inside the rear hatch panel on vehicles with a hatchback or lift gate. After removing the trim panel covering the motor, replacement is essentially the same as replacing the front wiper motor.

WINDSHIELD WASHERS

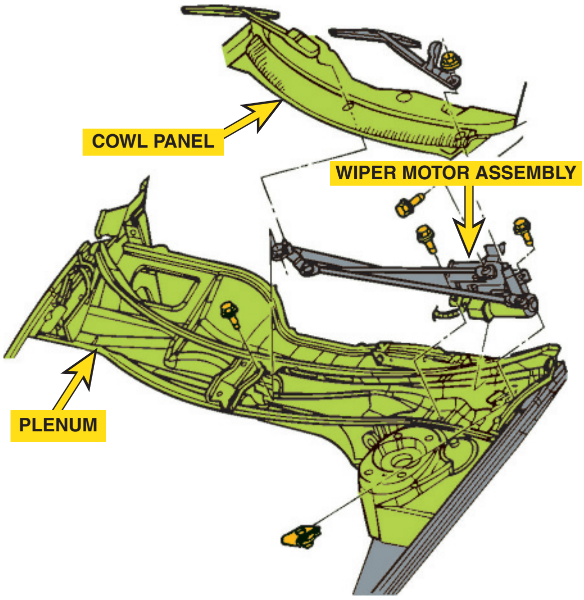


FIGURE 57–8 The wiper motor and linkage mount under the cowl panel on many vehicles.

OPERATION Windshield washers are used to squirt washer fluid onto the surface of the windshield where it can help dissolve debris and clean the viewing area of the windshield when the wipers are used. Most vehicle windshield washers use a positive-displacement or centrifugal-type washer pump located in the washer reservoir. A momentary contact switch, which is often part of a steering column–mounted combination switch assembly, energizes the washer pump. Washer pump switches are installed either on the steering column or on the instrument panel. The nozzles can be located on the bulkhead, in the hood, or mounted as part of the wiper arms, depending on the vehicle.

REAR WASHERS Vehicles equipped with a rear wiper are also equipped with a rear washer. The rear washer may share a fluid reservoir with the front wipers, or it may have its own reservoir.

TECH TIP

Scan Tool Bidirectional Control

Most vehicles built since 2000 can have the lighting and accessory circuits checked using a scan tool. A technician can use the following:

Factory scan tool, such as:

- GDS II (General Motors vehicles)
- DRB III, Star Scan, Star Mobile, WiTech, or MicroPOD II (Chrysler-Jeep vehicles)
- New Generation Star or IDS (Ford)
- Honda Diagnostic System (HDS)
- TIS Tech Stream (Toyota/Lexus)

An enhanced aftermarket scan tool has body bidirectional control capability, including

- Snap-on Modis, Solus, or Verus
- OTC Genisys
- AutoEnginuity

Using a bidirectional scan tool allows the technician to command the operation of electrical accessories, such as horns, windows, lights, door locks, and wipers. ● **SEE FIGURE 57–9**.

If the circuit operates correctly when commanded by the scan tool and does not function using the switch(s), follow service information instructions for the exact tests and testing procedures to follow for the vehicle being tested.

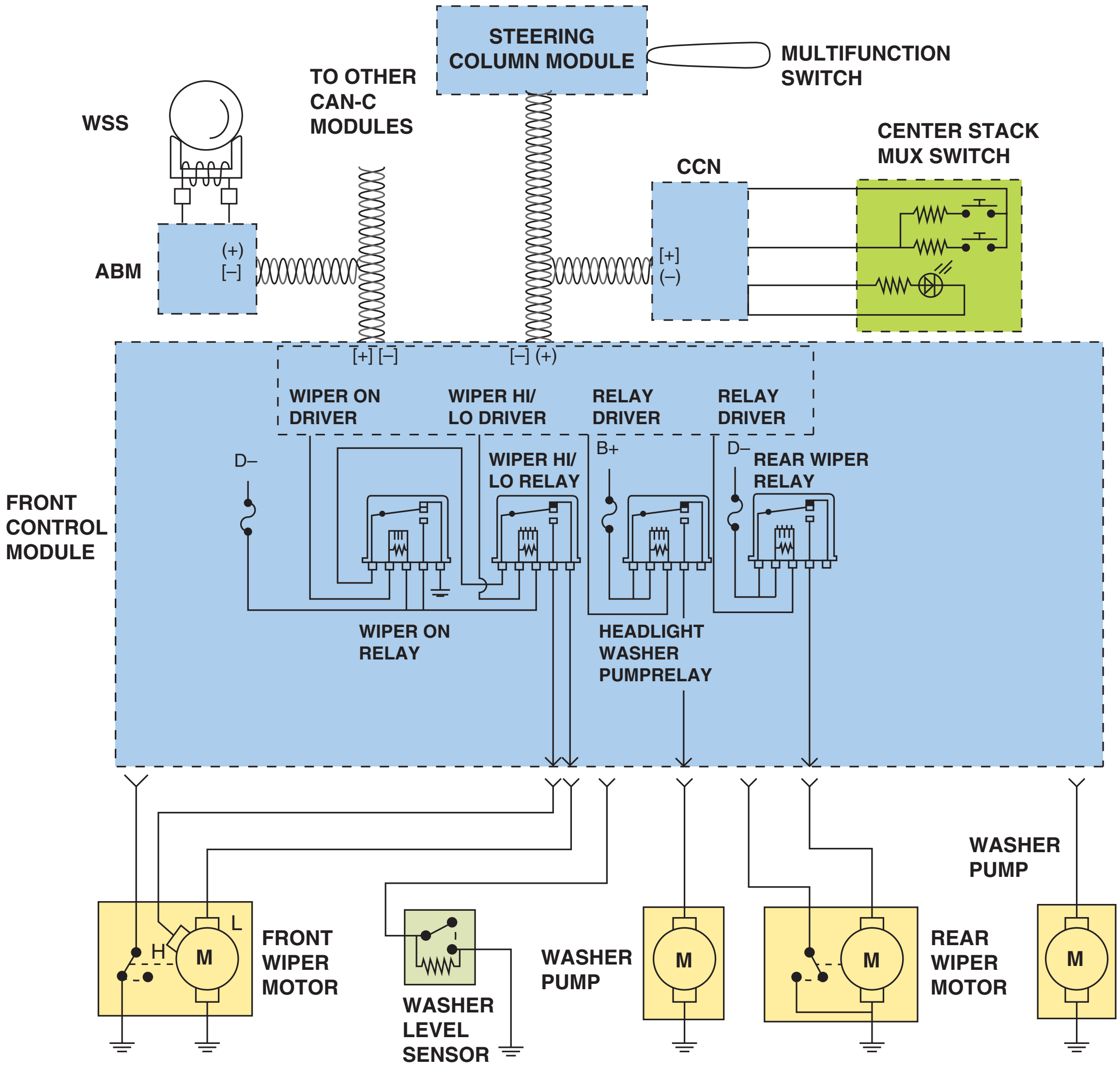

STEERING COLUMN MODULE
MULTIFUNCTION SWITCH
TO OTHER CAN-C MODULES
WSS
CCN
CENTER STACK MUX SWITCH
ABM
(+)
[–]
[+]
(–)
FRONT CONTROL MODULE
[+] [–]
[–] (+)
WIPER ON DRIVER
WIPER HI/ LO DRIVER
RELAY DRIVER
RELAY DRIVER
D–
WIPER HI/ LO RELAY
B+
D–
REAR WIPER RELAY
WIPER ON RELAY
HEADLIGHT WASHER PUMPRELAY
H
L
M
FRONT WIPER MOTOR
WASHER LEVEL SENSOR
WASHER PUMP
M
M
REAR WIPER MOTOR
WASHER PUMP
M

FIGURE 57–9 A typical schematic showing how relays inside the front control module are all tied to other modules on the BUSS.

The rear washer switch is located on either the steering column or on the instrument panel.

HEADLIGHT WASHERS Many vehicles are equipped with headlight washers that spray washer fluid into the surface of the headlights when actuated. Some systems even include small wiper blades. Headlight washers are usually operated from the main headlight control switch, if equipped. Most headlight washers use the same windshield washer reservoir as is used for the front windshield washers.

WINDSHIELD WASHER DIAGNOSIS To diagnose the washer system, follow service information procedures that usually include the following steps:

STEP 1 To quick check any washer system, make sure the reservoir has fluid and is not frozen. Then, disconnect the pump hose and operate the washer switch.

NOTE: Always use good-quality windshield washer fluid from a closed container to prevent contaminated fluid from damaging the washer pump. Radiator antifreeze (ethylene glycol) should never be used in any windshield wiper system.

● **SEE FIGURE 57–10.**

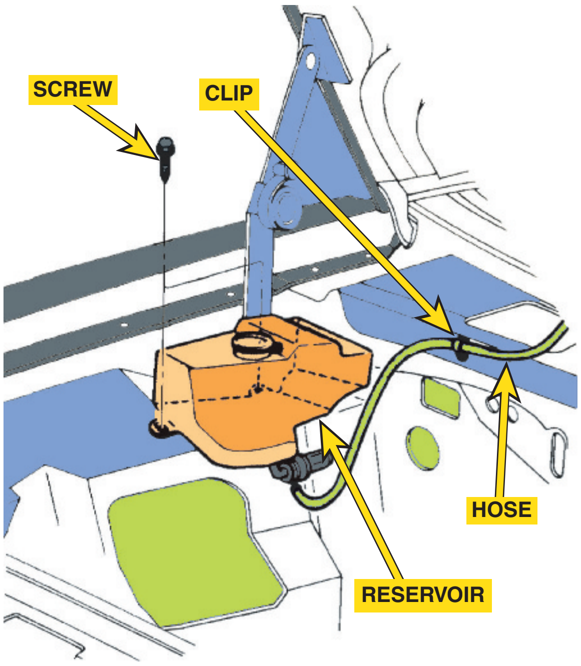

SCREW
CLIP
HOSE
RESERVOIR

FIGURE 57–10 A typical windshield washer reservoir and pump assembly.

STEP 2 If fluid squirts from the pump, the delivery system is at fault, not the motor, switch, or the electrical circuits (switch input, BCM, etc.).

STEP 3 If no fluid squirts from the pump, the problem is most likely a circuit failure, defective pump, or faulty switch.

STEP 4 A clogged reservoir screen also may be preventing fluid from entering the pump.

WINDSHIELD WASHER SERVICE

When a fluid delivery problem is indicated, check for:

- Blocked, pinched, broken, or disconnected hoses
- Clogged nozzles
- Blocked washer pump outlet

If the pump motor does not operate, check for battery voltage available at the pump while operating the washer switch.

- If voltage is available and the pump does not run, check for continuity on the pump ground circuit.
- If there is no voltage drop on the ground circuit, replace the pump motor. If battery voltage is not available at the motor, check for power through the washer switch.
- If voltage is available at and through the switch, there is a problem in the wiring between the switch and pump. Perform voltage drop tests to locate the fault. Repair the wiring as needed and retest.

Washer motors are not repairable and are replaced if defective. Centrifugal or positive-displacement pumps are located on or inside the washer reservoir tank or cover. ● **SEE FIGURE 57–11**.

RAIN-SENSE WIPERS

PARTS AND OPERATION

Rain-sense wiper systems use a sensor located on the inside and at the top of the windshield to detect rain droplets. This sensor is often called the *rain-sense module (RSM)*. It determines and adjusts the time delay of the wiper based on how much moisture it detects on the windshield. The wiper switch can be left on the sense position all the time, and if no rain is sensed, the wipers do not swipe. ● **SEE FIGURE 57–12**.

The control knob is rotated to the desired wiper sensibility level. The microprocessor in the RSM sends a command to the body control module. The rain-sense module is a triangle- or rectangle-shaped black plastic housing. Fine openings on the windshield side of the housing are fitted with eight convex clear plastic lenses. The unit contains four infrared (IR) diodes, two photocells, and a microprocessor.

The IR diodes generate IR beams that are aimed by four of the convex optical lenses near the base of the module through the windshield glass. Four additional convex lenses near the top of the RSM are focused on the IR light beam on the outside of the windshield glass and allow the two photocells to sense changes in the intensity of the IR light beam. When sufficient moisture accumulates, the RSM detects a change in the monitored IR light beam intensity. The RSM processes the rain intensity signal and sends it over the data BUS to the BCM, which then commands a swipe of the wiper. ● **SEE FIGURE 57–13**.

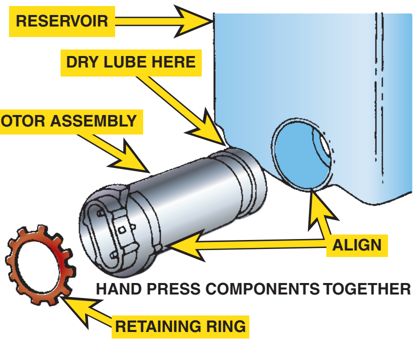


FIGURE 57–11 Washer pumps usually install into the reservoir and are held in place with a retaining ring.

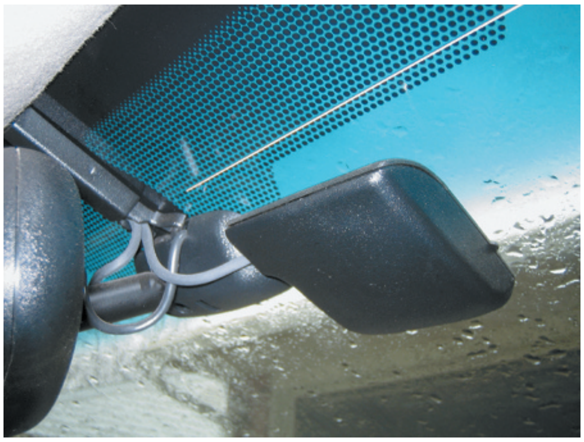


FIGURE 57–12 A typical rain-sensing module located on the inside of the windshield near the inside rearview mirror.

CASE STUDY

Intermittent Wipers Inoperative

The owner of a Chevrolet Tahoe LTZ complained the intermittent wipers did not work. On the initial selection of the wiper switch to one of the pulse positions, the wipers made one swipe and stopped working after that. The wipers would just sit in the park position. The low speed, high speed, and park positions worked fine.

This vehicle was equipped with rain-sense wipers. The wipers are not supposed to work in the pulse mode unless there is water on the windshield. In this case, the rain sensor at the top of the windshield was defective. The wipers would not come on because the body control module (BCM) was not being notified that there was a wipe pulse required. The rain sensor was replaced. After replacement of the sensor, with wipers in pulse mode, the windshield was sprayed with a spray bottle and the wipers operated correctly.

Summary:

Complaint—Intermittent wipers inoperative.
Cause—The rain senor on the inside of the windshield was defective.
Correction—The rain sensor was replaced and normal operation of the windshield wipers was restored.

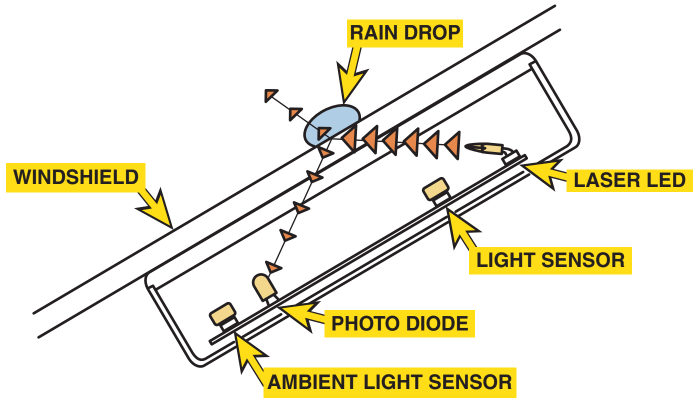


FIGURE 57–13 The electronics in the rain-sense wiper module can detect the presence of rain drops under various lighting conditions.

TECH TIP

Rain Sense and Cruise Control

The rain-sense wiper module communicates with the BCM over the data links and, if the rain is heavy, a signal is sent to deactivate the cruise control. A message is then displayed on the instrument panel warning that the cruise control is not available. This is normal operation and is used to help prevent the vehicle from hydroplaning during heavy rain. Normal cruise control operation resumes when the rain intensity is reduced. This is normal operation and not a fault with the cruise control system.

DIAGNOSIS AND SERVICE If there is a complaint about the rain-sense wipers not functioning correctly, check the owner's manual to be sure that they are properly set. Also, verify that the windshield wipers are functioning correctly on all speeds before diagnosing the rain-sensor circuits. Most rain-sensing wiper systems can be tested by misting water on the windshield in the area of the sensor. Always follow the vehicle manufacturer's recommended diagnosis and testing procedures.

BLOWER MOTOR

PURPOSE AND FUNCTION The same blower motor moves air inside the vehicle for:

1. Air conditioning
2. Heat
3. Defrosting
4. Defogging
5. Venting of the passenger compartment.

The motor turns a squirrel cage-type fan. A squirrel cage-type fan is able to move air without creating a lot of noise. The fan switch controls the path that the current follows to the blower motor. ● **SEE FIGURE 57–14.**

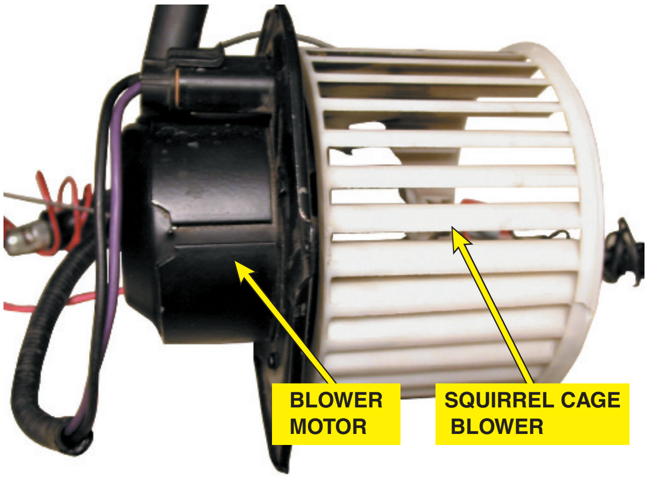


FIGURE 57–14 A squirrel cage blower motor. A replacement blower motor usually does not come equipped with the squirrel cage blower, so it has to be switched from the old motor.

PARTS AND OPERATION The motor is usually a permanent magnet, one-speed motor that operates at its maximum speed with full battery voltage. The switch gets current from the fuse panel with the ignition switch on, and then directs full battery voltage to the blower motor for high speed and to the blower motor through resistors for lower speeds.

VARIABLE SPEED CONTROL The fan switch controls the path of current through a resistor pack to obtain different fan speeds of the blower motor. The electrical path can be:

- Full battery voltage for high-speed operation
- Through one or more resistors to reduce the voltage and the current to the blower motor, which then rotates at a slower speed.

The resistors are located near the blower motor and mounted in the duct where the airflow from the blower can cool the resistors. The current flow through the resistor is controlled by the switch and often uses a relay to carry the heavy current (10 to 12 amperes) needed to power the fan. Normal operation includes

- Low speed. Current flows through three resistors in series to drop the voltage to about 4 volts and 4 amperes
- Medium-low speed. Current is directed through two resistors in series to lower the voltage to about 6 volts and 6 amperes
- Medium-high speed. Current is directed through one resistor resulting in a voltage of about 9 volts and 9 amperes
- High speed. Full battery voltage, usually through a relay, is applied to the blower motor resulting in a current of about 12 amperes. ● **SEE FIGURES 57–15 AND 57–16.**

Some blower motors are electronically controlled by the body control module and include electronic circuits to achieve a variable speed. ● **SEE FIGURE 57–17.**

BLOWER MOTOR DIAGNOSIS If the blower motor does not operate at any speed, the problem could be any of the following:

1. Defective ground wire or ground wire connection.
2. Defective blower motor (not repairable; must be replaced).
3. Open circuit in the power-side circuit, including fuse, wiring, or fan switch. If the blower works on lower speeds, but

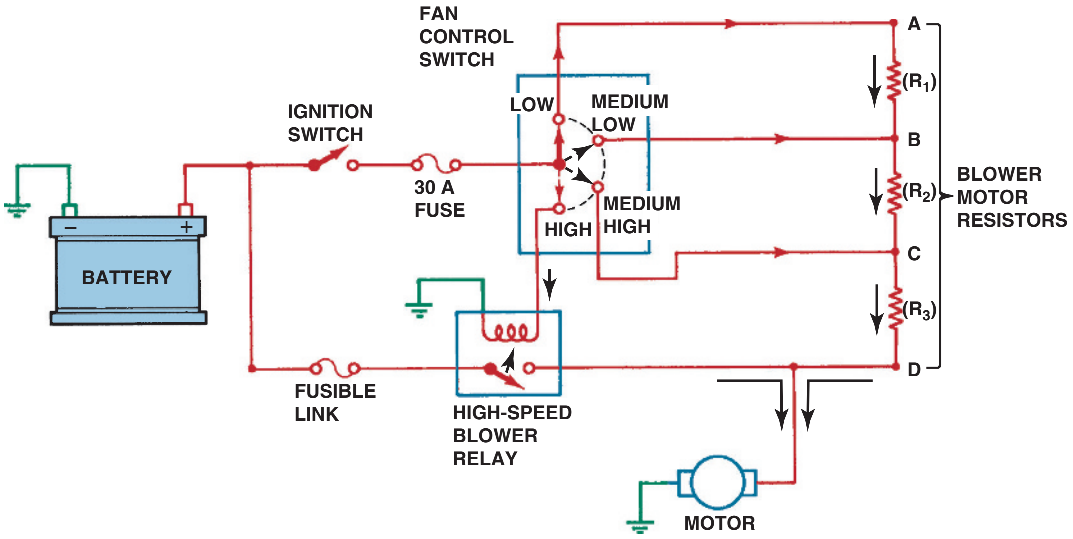


FIGURE 57–15 A blower motor circuit with four speeds controlled by resistors. The three lowest fan speeds (low, medium-low, and medium-high) use the blower motor resistors to drop the voltage to the motor and reduce current to the motor. On high, the resistors are bypassed. The "high" position on the fan switch energizes a relay, which supplies the current for the blower on high through a fusible link or maxi fuse.

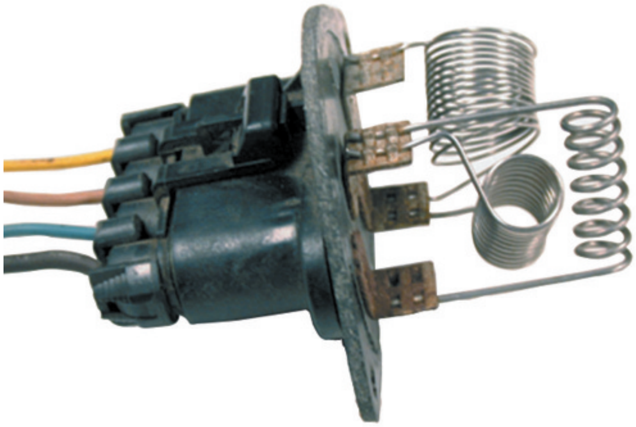


FIGURE 57–16 A blower motor resistor pack used to control blower motor speed. Some blower motor resistors are flat and look like a credit card and are called credit card resistors.

not on high speed, the problem is usually an in-line fuse or high-speed relay that controls the heavy current flow for high-speed operation.

The high-speed fuse or relay usually fails as a result of internal blower motor bushing wear, which causes excessive resistance to motor rotation. At slow blower speeds, the resistance is not as noticeable and the blower operates normally. The blower motor is a sealed unit and, if defective, must be replaced as a unit. The squirrel-cage fan usually needs to be removed from the old motor and attached to the replacement motor. If the blower motor operates normally at high speed, but not at any of the lower speeds, the problem could be melted wire resistors or a defective switch.

The blower motor can be tested using a clamp-on DC ammeter. ● **SEE FIGURE 57–18**.

Most blower motors do not draw more than 15 amperes on high speed. A worn or defective motor usually draws more current than normal and could damage the blower motor resistors or blow a fuse if not replaced.

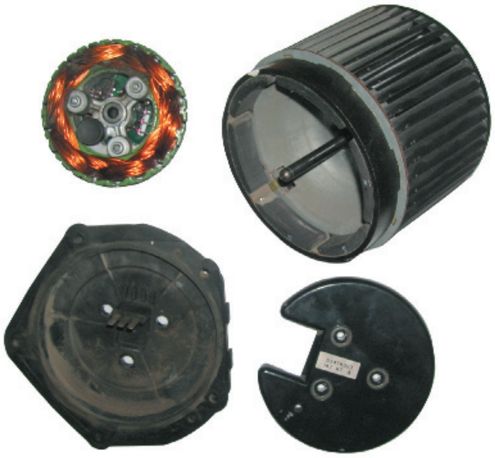


FIGURE 57–17 A brushless DC motor that uses the body computer to control the speed.

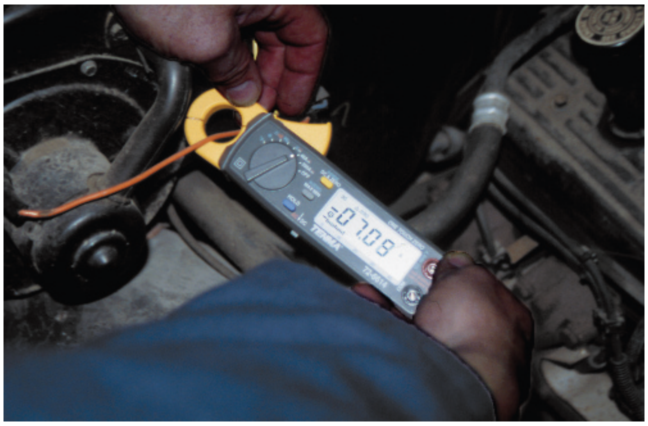


FIGURE 57–18 Using a mini AC/DC clamp-on multimeter to measure the current drawn by a blower motor.

CRUISE CONTROL

PURPOSE AND FUNCTION **Cruise control**, also called vehicle *speed control*, is used to maintain a preset vehicle speed, even up gentle grades. Some vehicles are programmed to downshift the transmission to maintain the vehicle speed when descending grades if the speed increases more than 5 MPH (7 km/h) faster than the preset speed. Using cruise control avoids the tendency to drive at varying speeds, helps to reduce driver fatigue, and allows for driver position changes when driving for a long period of time. Cruise control should be avoided if driving on curving roads or when it is raining.

CRUISE CONTROL OPERATION A typical cruise control system can be set only if the vehicle speed is 25 MPH (40 km/h) or more. Computer-controlled cruise control systems use the vehicle's speed sensor input to the powertrain control module (PCM) for speed reference. Older systems use a throttle actuator to control the throttle opening, control switches for driver control of cruise control functions, and electrical brake and clutch (if equipped) pedal-release switches. The typical actuator uses a stepper motor or vacuum to move the throttle linkage based on commands from the cruise control module, which is often inside the cruise control assembly. ● **SEE FIGURE 57–19**.

ELECTRONIC THROTTLE CRUISE CONTROL Many vehicles are equipped with an electronic throttle control (ETC) system. Vehicles equipped with such a system do not use throttle actuators for the cruise control, but instead use the electronic throttle to control vehicle speed. ● **SEE FIGURE 57–20**.

The cruise control on a vehicle equipped with an electronic throttle control system consists of a switch to set the desired

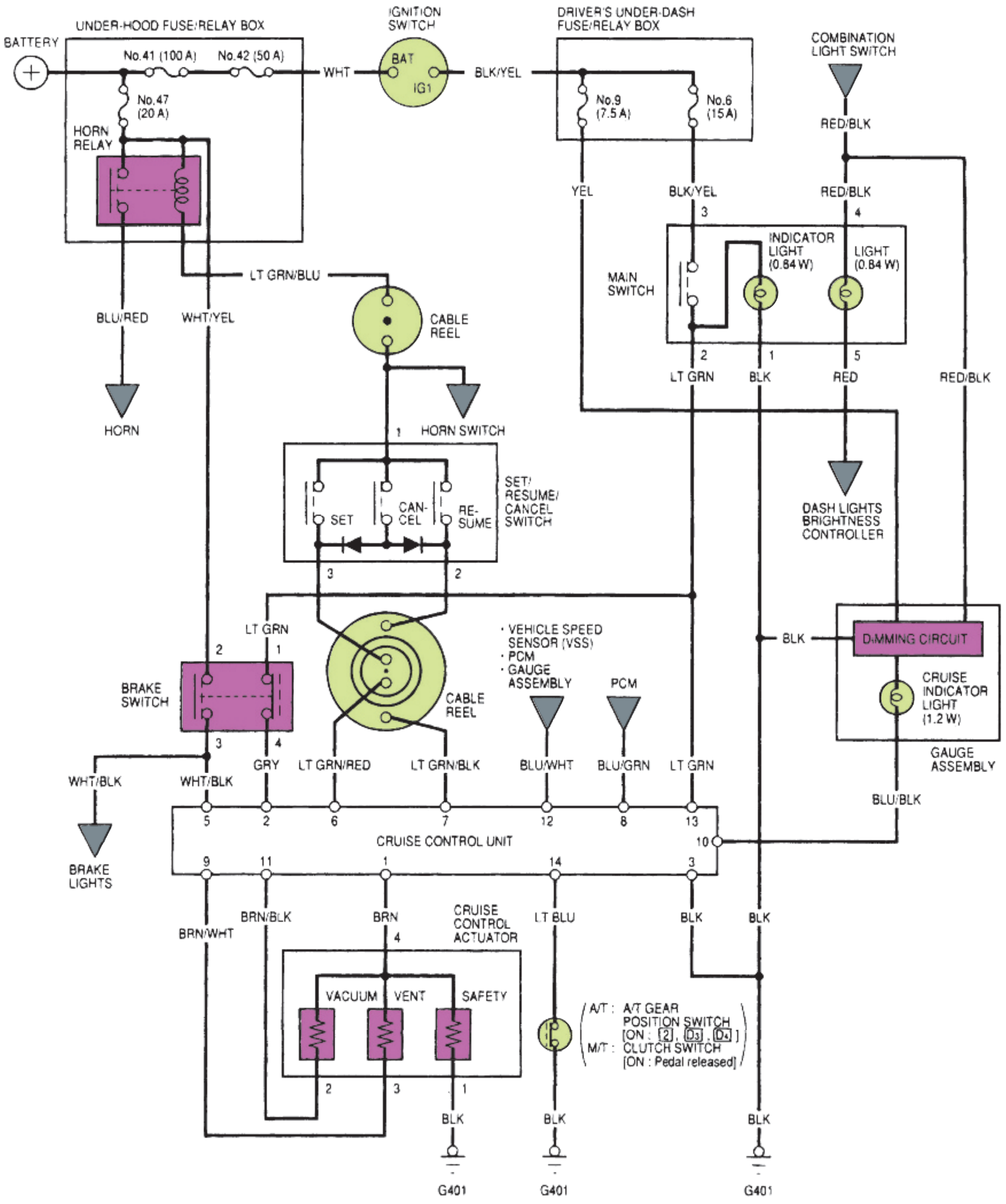

UNDER-HOOD FUSE/RELAY BOX
BATTERY
No.41 (100 A)
No.42 (50 A)
No.47 (20 A)
HORN RELAY
WHT
IGNITION SWITCH
BAT
IG1
BLK/YEL
DRIVER'S UNDER-DASH FUSE/RELAY BOX
No.9 (7.5 A)
No.6 (15A)
COMBINATION LIGHT SWITCH
RED/BLK
YEL
BLK/YEL
RED/BLK
3
4
INDICATOR LIGHT (0.84 W)
LIGHT (0.84 W)
MAIN SWITCH
2
1
5
LT GRN
BLK
RED
RED/BLK
LT GRN/BLU
CABLE REEL
BLU/RED
WHT/YEL
HORN
1
HORN SWITCH
SET/ RESUME/ CANCEL SWITCH
SET
CAN-CEL
RE-SUME
3
2
DASH LIGHTS BRIGHTNESS CONTROLLER
BLK
DIMMING CIRCUIT
CRUISE INDICATOR LIGHT (1.2 W)
GAUGE ASSEMBLY
LT GRN
2
1
BRAKE SWITCH
3
4
CABLE REEL
· VEHICLE SPEED SENSOR (VSS)
· PCM
· GAUGE ASSEMBLY
PCM
WHT/BLK
WHT/BLK
GRY
LT GRN/RED
LT GRN/BLK
BLU/WHT
BLU/GRN
LT GRN
BLU/BLK
BRAKE LIGHTS
5
2
6
7
12
8
13
10
CRUISE CONTROL UNIT
9
11
1
14
3
BRN/BLK
BRN
4
CRUISE CONTROL ACTUATOR
LT BLU
BLK
BLK
BRN/WHT
VACUUM
VENT
SAFETY
2
3
1
A/T : A/T GEAR POSITION SWITCH [ON : 2, D3, D4]
M/T : CLUTCH SWITCH [ON : Pedal released]
BLK
BLK
BLK
G401
G401
G401

FIGURE 57–19 Circuit diagram of a typical electronic cruise control system.

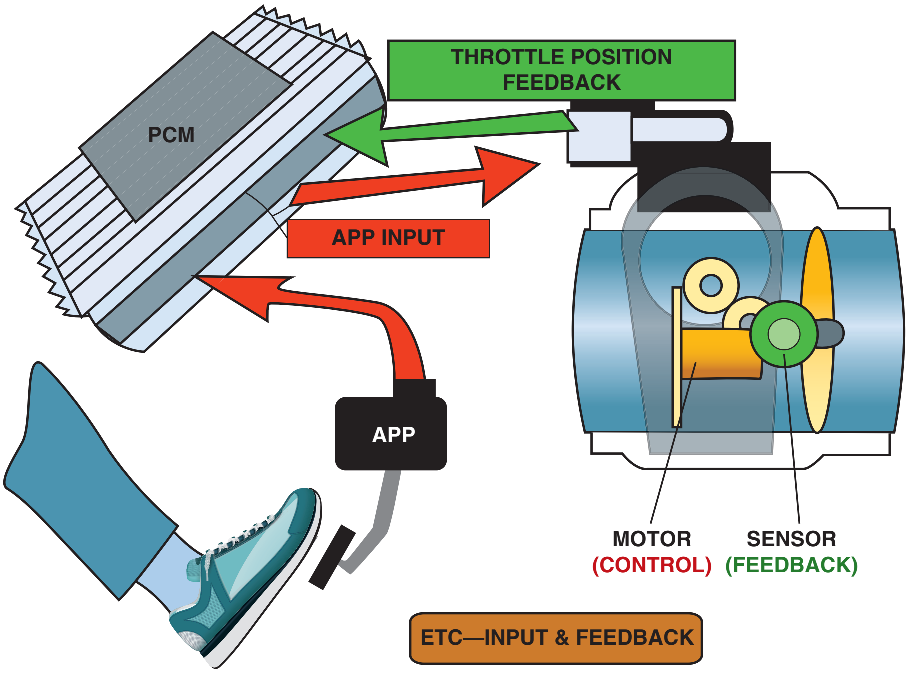


FIGURE 57–20 The electronic throttle control (ETC) system uses a sensor that measures the position and the speed of the driver's foot on the accelerator pedal. A throttle position sensor measures the throttle angle. An electric motor operates the movement of the throttle plate using commands from the PCM.

speed. The PCM receives the vehicle speed information from the vehicle speed (VS) sensor. The PCM then commands the ETC throttle to open or close the throttle valve as needed to maintain desired vehicle speed.

DIAGNOSIS AND SERVICE Any fault in the accelerator pedal position (APP) sensor, brake switch, or ETC system disables the cruise control function. Always follow the specified troubleshooting procedures, which usually include the use of a scan tool to properly diagnose the ETC system.

HEATED REAR WINDOW DEFOGGERS

PARTS AND OPERATION An electrically **heated rear window defogger** system uses an electrical grid baked on the glass that warms the glass to about 85°F (29°C) and clears it of fog or frost. The rear window is also called a *backlight*. The rear window defogger system is controlled by a driver-operated switch and a timer relay. ● **SEE FIGURE 57–21**.

The timer relay is necessary because the window grid can draw up to 30 amperes, and continued operation puts a strain on the battery and the charging system. Generally, the timer relay permits current to flow through the rear window grid for only 10 minutes. If the window is still not clear of fog after 10 minutes, the driver can turn the defogger on again, but after the first 10 minutes, any additional defogger operation is limited to 5 minutes.

The electrical current through the grids depends, in part, on the temperature of the conductor grids. As the temperature decreases, the resistance of the grids decreases and the current flow increases, helping to warm the rear glass. As the temperature of the glass increases, the resistance of the conductor grids increases and the current flow decreases. Therefore, the defogger system tends to self-regulate the electrical current requirements to match the need for defogging.

NOTE: Some vehicles use the wire grid of the rear window defogger as the radio antenna. Therefore, if the grid is damaged, radio reception can also be affected.

TECH TIP

Bump Problems

Cruise control problem diagnosis can involve a complex series of checks and tests. The troubleshooting procedures vary among manufacturers (and year), so a technician should always check service information for the exact vehicle being serviced. However, every cruise control system uses a brake safety switch and, if the vehicle has manual transmission, a clutch safety switch. The purpose of these safety switches is to ensure that the cruise control system is disabled if the brakes or the clutch are applied. Some systems use a redundant brake pedal safety switch. If the cruise control "cuts out" or disengages itself while traveling over bumpy roads, the most common cause is a misadjusted brake (and/or clutch) safety switch(es). Often, a simple readjustment of these safety switches cures the intermittent cruise control disengagement problems.

CAUTION: Always follow the manufacturer's recommended safety switch adjustment procedures. If the brake safety switch(es) is misadjusted, it could keep pressure applied to the master brake cylinder, resulting in severe damage to the braking system.

TECH TIP

Check the Brake Lights

On many vehicles, the cruise control does not work if the brake lights are not working. This includes the third brake light, commonly called the center high-mounted stop light (CHMSL). Always check for the proper operation of the brake lights first if the cruise control does not work.

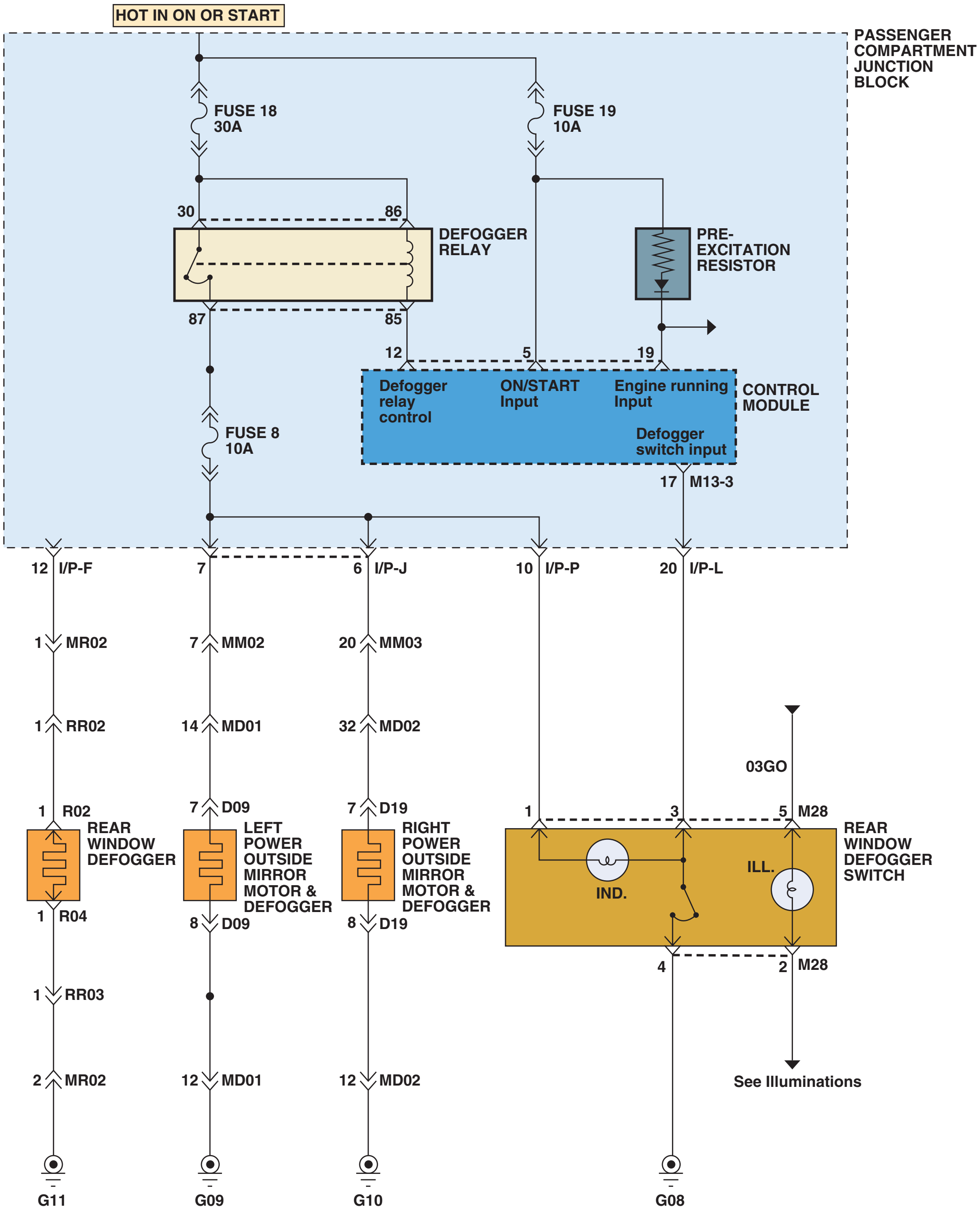

HOT IN ON OR START
PASSENGER COMPARTMENT JUNCTION BLOCK
FUSE 18 30A
FUSE 19 10A
30
86
DEFOGGER RELAY
PRE-EXCITATION RESISTOR
87
85
12
5
19
Defogger relay control
ON/START Input
Engine running Input
Defogger switch input
CONTROL MODULE
FUSE 8 10A
17
M13-3
12
I/P-F
7
6
I/P-J
10
I/P-P
20
I/P-L
1
MR02
7
MM02
20
MM03
1
RR02
14
MD01
32
MD02
03GO
1
R02
REAR WINDOW DEFOGGER
7
D09
LEFT POWER OUTSIDE MIRROR MOTOR & DEFOGGER
7
D19
RIGHT POWER OUTSIDE MIRROR MOTOR & DEFOGGER
1
3
5
M28
IND.
ILL.
REAR WINDOW DEFOGGER SWITCH
1
R04
8
D09
8
D19
4
2
M28
1
RR03
2
MR02
12
MD01
12
MD02
See Illuminations
G11
G09
G10
G08

FIGURE 57–21 A schematic showing that the side view mirrors are heated along with the rear window defogger whenever the rear window switch (lower right) is turned to the on position.

TECH TIP

The Infrared Camera Test

It is difficult to test for the proper operation of all grids of a rear window defogger unless the rear window happens to be covered with fog. A common trick that works is to turn on the rear defogger and look at the outside of the rear window glass using an infrared camera. The image shows if all sections of the rear grids are working. ● **SEE FIGURE 57–22**.

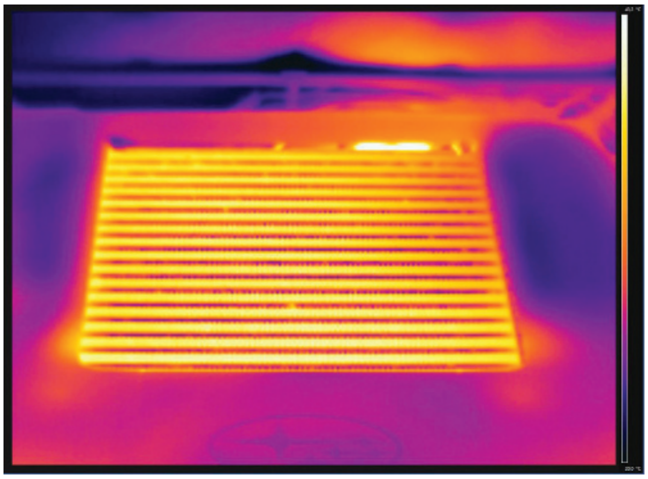


FIGURE 57–22 A typical image captured using an infrared camera of a rear defogger that is working as designed.

HEATED REAR WINDOW DEFOGGER DIAGNOSIS Troubleshooting a nonfunctioning rear window defogger unit involves using a test light or a voltmeter to check for voltage to the grid. If no voltage is present at the rear window, check for voltage at the

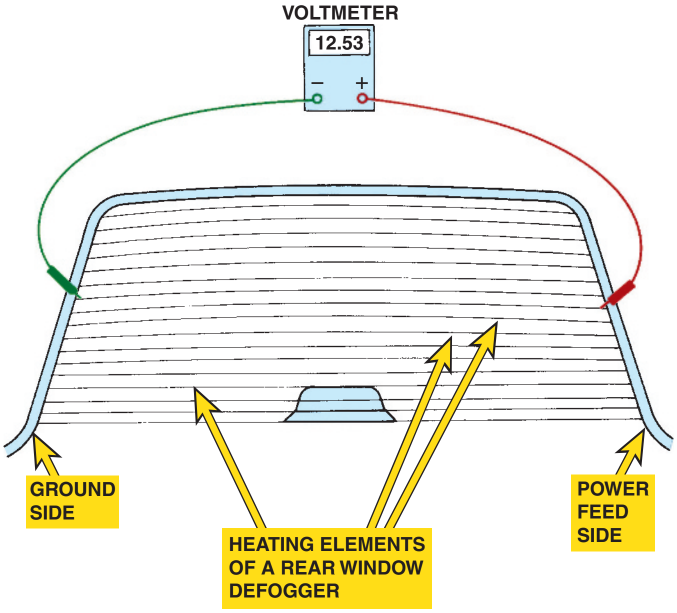


FIGURE 57–23 A rear window defogger electrical grid can be tested using a voltmeter to check for a decreasing voltage as the meter lead is moved from the power side toward the ground side. As the voltmeter positive lead is moved along the grid (on the inside of the vehicle), the voltmeter reading should steadily decrease as the meter approaches the ground side of the grid.

switch and relay timer assembly. A poor ground connection on the opposite side of the grid from the power side can also cause the rear defogger not to operate. Because most defogger circuits use an indicator light switch and a relay timer, it is possible to have the indicator light on, even if the wires are disconnected at the rear window grid. A voltmeter can be used to test the operation of the rear window defogger grid. ● **SEE FIGURE 57–23**.

With the negative meter lead attached to a good body ground, carefully touch the positive meter lead to the grid conductors. There should be a decreasing voltage reading as the meter lead is moved from the power ("hot") side of the grid toward the ground side of the grid.

REPAIR OR REPLACEMENT Electric grid-type rear window defoggers can be damaged easily by careless cleaning or scraping of the inside of the rear window glass. If there is a broken grid wire, it can be repaired using an electrically conductive substance available in a repair kit. Most vehicle manufacturers recommend that grid wire less than 2 inches (5 cm) long be repaired. If a bad section is longer than 2 inches, the entire rear window needs to be replaced.

POWER WINDOWS

SWITCHES AND CONTROLS **Power windows** use electric motors to raise and lower door glass. They can be operated by both a master control switch located beside the driver and additional independent switches located at each electric window. Some power window systems use a lockout/child safety switch located on the driver's controls to prevent operation of the power windows from the independent switches. Power windows are designed to operate only with the ignition switch in the on (run) position, although some manufacturers use a time delay for accessory power after the ignition switch is turned off. This feature permits the driver and passengers an opportunity to close all windows or operate other accessories for about 10 minutes or until a vehicle door is opened after the ignition has been turned off. This feature is often called *retained accessory power (RAP).*

POWER WINDOW MOTORS Most power window systems use permanent magnet (PM) electric motors. It is possible to run a PM motor in the reverse direction by reversing the polarity of the two wires going to the motor. Most power window motors do not require that the motor be grounded to the body (door) of the vehicle. The ground for all the power windows is most often centralized near the driver's master control switch. The up-and-down motion of the individual window motors is controlled by double-pole, double-throw (DPDT) switches. These DPDT switches have five contacts and permit battery voltage to be applied to the power window motor, as well as reverse the polarity and direction of the motor.

Each motor is protected by a positive temperature coefficient (PTC) electronic circuit breaker. These circuit breakers are built into the motor assembly and are not a separate replaceable part. ● **SEE FIGURE 57–24**.

The power window motors rotate a mechanism called a *window regulator*. The window regulator is attached to the door glass and controls opening and closing of the glass. Door glass adjustments, such as glass tilt and upper and lower stops, are usually the same for both power and manual windows. ● **SEE FIGURE 57–25**.

AUTO DOWN/UP FEATURES Many power windows are equipped with an auto down feature that allows windows to be lowered all the way if the control switch is moved to a detent or held down for longer than 0.3 second. The window then moves down all the way to the bottom, and then the motor stops.

Public Law 110-189, also known as the Cameron Gulbransen Kids Transportation Safety Act, mandated the use of power window **automatic reversal systems (ARS)**. The automatic reversal system is designed to prevent windows from causing injury when they are closing, if the vehicle is equipped with power windows. The Department of Transportation (DOT) established a limit of 136 ft-lb (100 N-m) of force be exerted by the window before the window retracts. There are two methods used for controlling ARS and auto up and auto down windows, including

1. An encoder wheel and position sensor are used to monitor the speed and position of the window as it travels up and down.
2. The current (amperes) required is measured by the power window control module.

The window direction reverses if the current draw exceeds a predetermined value. If an object is in the path of the window, the current draw and or slowing of the window causes the control module to reverse. The system is designed to expect increased current flow and slower window movement in cold weather conditions. However, sudden vehicle movement, such as hitting a bump in the road as the window is moving upward or a fault in the window track, can cause the window to reverse.

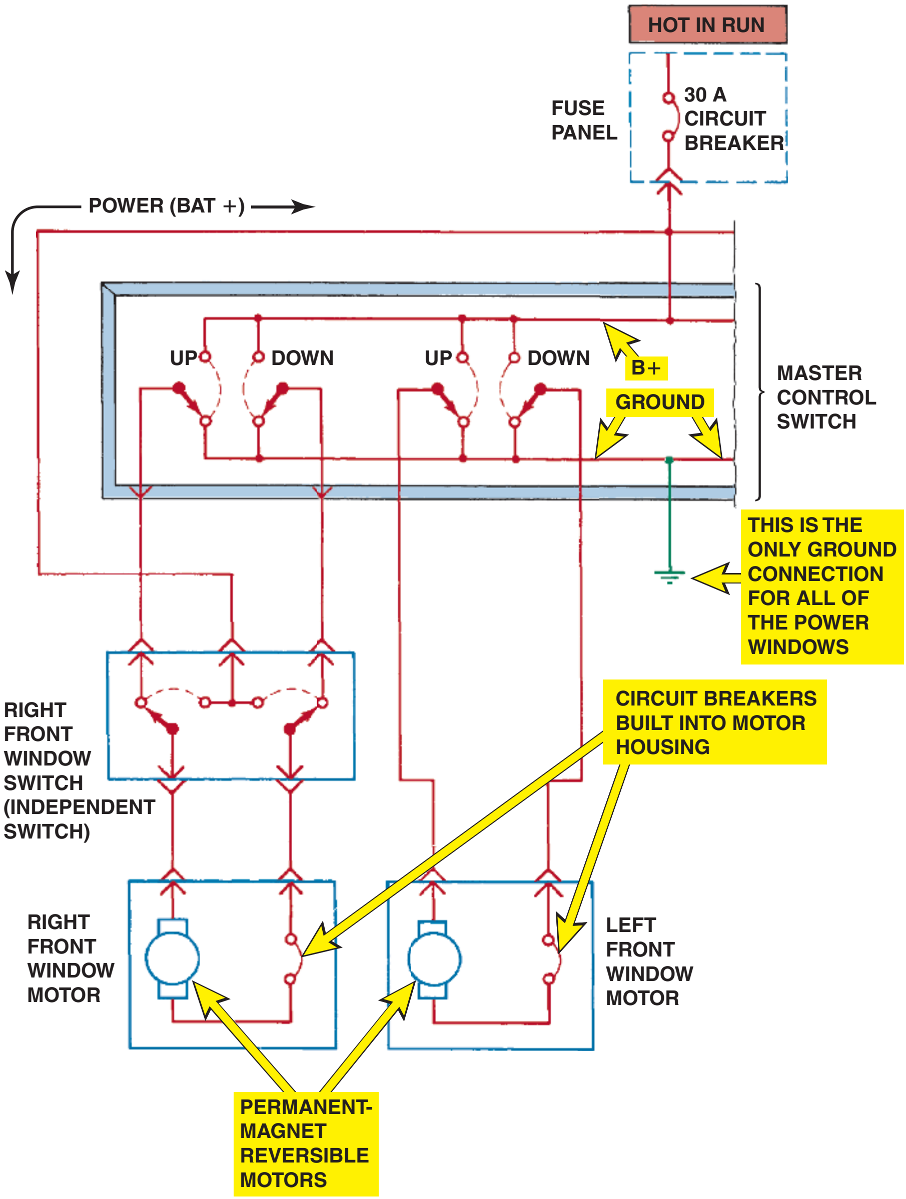

HOT IN RUN
FUSE PANEL
30 A CIRCUIT BREAKER
POWER (BAT +)
UP
DOWN
UP
DOWN
B+
GROUND
MASTER CONTROL SWITCH
THIS IS THE ONLY GROUND CONNECTION FOR ALL OF THE POWER WINDOWS
CIRCUIT BREAKERS BUILT INTO MOTOR HOUSING
RIGHT FRONT WINDOW SWITCH (INDEPENDENT SWITCH)
RIGHT FRONT WINDOW MOTOR
LEFT FRONT WINDOW MOTOR
PERMANENT-MAGNET REVERSIBLE MOTORS

FIGURE 57–24 A typical power window circuit using PM motors. Control of the direction of window operation is achieved by directing the polarity of the current through the non-grounded motors. The only ground for the entire system is located at the master control (driver's side) switch assembly.

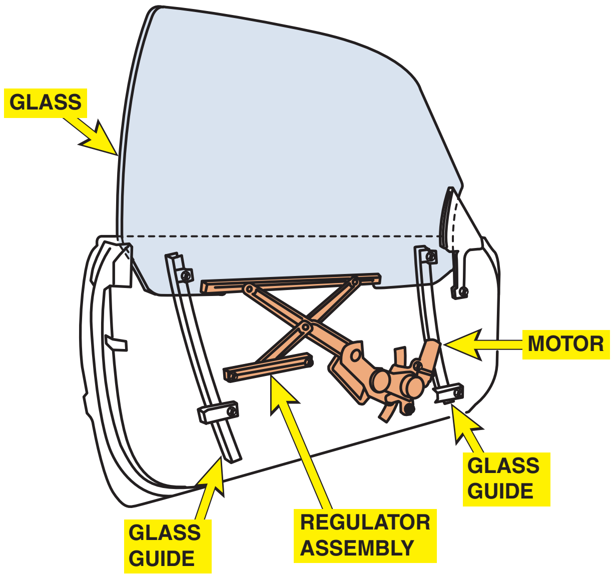

GLASS
MOTOR
GLASS GUIDE
GLASS GUIDE
REGULATOR ASSEMBLY

FIGURE 57–25 An electric motor and a regulator assembly raise and lower the glass on a power window.

A factory or factory-level scan tool is used to diagnosis this system, which can monitor switch operation and can be used to control the operation of the windows using bidirectional controls.

TROUBLESHOOTING POWER WINDOWS Before troubleshooting a power window problem, check for proper operation of all power windows. Also check that the child-proof switch is not in the disable position, which prevents the windows from being operated from any position except the driver's master control. Check service information for the exact procedure to follow. In a newer system, a scan tool can be used to perform the following:

- Check for B (body) or U (network) diagnostic trouble codes (DTCs)
- Operate the power windows using the bidirectional control feature
- Relearn or program the operation of the power windows after a battery disconnect

Always follow the diagnosis and repair procedures as specified in service information.

TECH TIP

Programming Auto Down/Up Power Windows

Many vehicles are equipped with automatic operation that can cause the window to go all the way down (or up) if the switch is depressed beyond a certain point or held for a fraction of a second. Sometimes this feature is lost if the battery in the vehicle has been disconnected. Although this programming procedure can vary depending on the make and model, many times the window(s) can be reprogrammed without using a scan tool by depressing and holding the down button for 10 seconds. If the vehicle is equipped with an auto up feature, repeat the procedure by holding the button up for 10 seconds. Always check exact service information for the vehicle being serviced.

ELECTRIC POWER DOOR LOCKS

PARTS AND OPERATION Electric power door locks use a permanent magnet (PM) reversible motor to lock or unlock all vehicle door locks from a control switch or switches. The electric motor uses a built-in circuit breaker and operates the lock-activating rod. PM reversible motors do not require grounding because, as with power windows, the motor control is determined by the polarity of the current through the two motor wires. ● **SEE FIGURES 57–26 AND 57–27**.

Some two-door vehicles do not use a power door lock relay because the current flow for only two PM motors can be handled through the door lock switches. However, most four-door vehicles and vans with power locks on rear and side doors use a relay to control the current flow necessary to operate four or more power door lock motors. The door lock relay is controlled by the door lock switch and is commonly the location of the one and only ground connection for the entire door lock circuit.

TECH TIP

Check the Glove Box Switch Position

A common customer complaint is that the trunk or lift gate can be opened manually, but it cannot be opened using the remote. Most vehicles are equipped with a lockout switch in the glove compartment (instrument panel compartment) that can be switched off, and the glove box door locked to limit access when the vehicle is parked, and the valet has the key to the ignition. If the switch is in the locked position, the trunk cannot be opened using the remote. Check that first before following the recommended diagnostic procedures found in service information. ● **SEE FIGURE 57–28**.

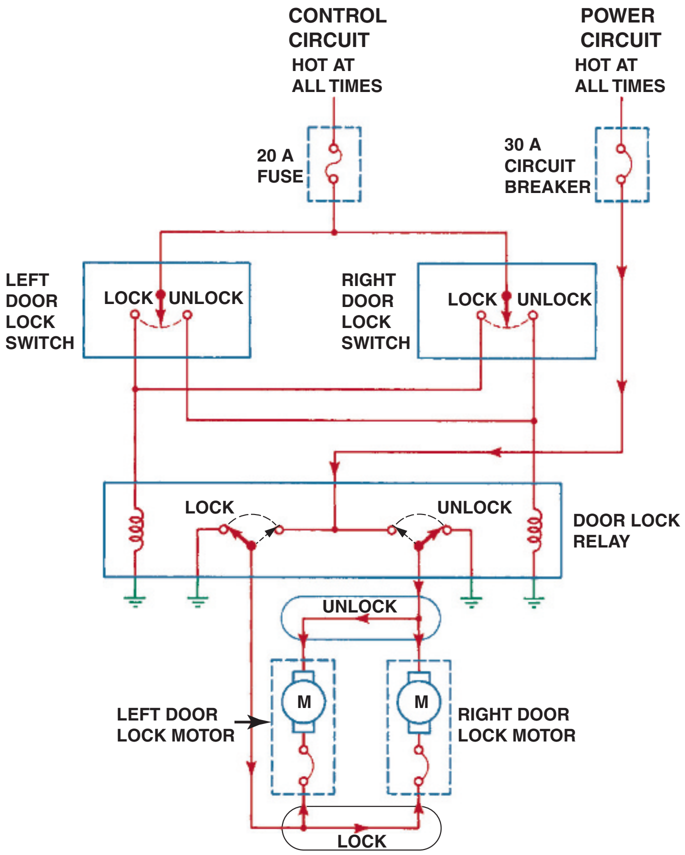


FIGURE 57–26 A typical electric power door lock circuit diagram. Note that the control circuit is protected by a fuse, whereas the power circuit is protected by a circuit breaker. As with the operation of power windows, power door locks typically use reversible permanent magnet (PM) non-grounded electric motors. These motors are geared mechanically to the lock–unlock mechanism.

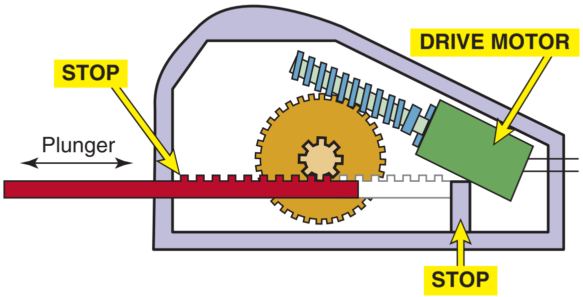


FIGURE 57–27 A typical power door lock mechanism showing a DC drive motor used to move the door lock plunger

TROUBLESHOOTING POWER LOCKS If all power door locks are inoperative, use a factory or factory-level aftermarket scan tool and try operating the locks using the bidirectional control. If the door locks do not operate using a scan tool, refer to service information for the exact procedure to follow.

If only the power door lock is inoperative, check for the power and ground, as well as possible physical binding of the lock mechanism. Repair or replace as needed.

TRUNK/LIFT GATE LOCKS The electric power trunk/lift gate lock uses a permanent magnet (PM) reversible motor to lock or

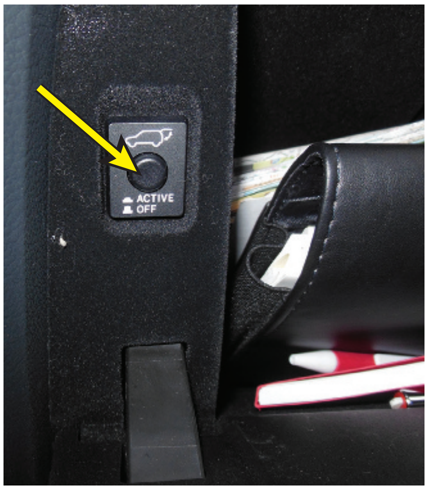


FIGURE 57–28 The switch to disable the outside opening of the trunk/lift gate is often in the glove box.

unlock the trunk/lift gate lock from a control switch or with the remote. The electric motor uses a built-in circuit breaker and operates the lock-activating rod. PM reversible motors do not require grounding because, as with power windows and door locks, the motor control is determined by the polarity of the current through the two motor wires.

POWER SUN ROOF/ MOON ROOF

DEFINITIONS While they are similar in nature and often used interchangeably, there is a difference between a sun roof and a moon roof.

- **Sun roof**—A sun roof is basically any kind of panel on the roof of a car that permits light, air, or both to come into a vehicle, but only if the panel is opened. A sunroof includes two types of panels:
    1. One panel may be made of either metal or the same material as the ceiling of the car and can be retracted to expose the glass panel above.
    2. The other panel is made of glass that can be either tilted open or completely retracted to essentially serve as an open window in the roof.
- **Moon roof**—A moon roof is made of a tinted glass panel that can be either tilted open or completely retracted to operate as an open window in the roof. Most new cars have moon roofs.

OPERATION Most moon or sun roof systems use permanent magnet (PM) electric motors to open and close the moveable glass panel. The open and close, or tilt up or down, motion of the moon roof motors is controlled by double-pole, double-throw (DPDT) switches. These DPDT switches have five contacts and permit battery voltage to be applied to the power moon roof motor, as well as reverse the polarity and direction of the motor. Each motor is protected by an electronic circuit breaker. These circuit breakers are built into the motor assembly and are not a separate replaceable part.

DIAGNOSIS AND SERVICE Always check service information for the exact procedure to use because the moon roofs have many different service items that are likely to need service or repair, including

- **Water leaks**—Engineers refer to water seals around moon roofs as "controlling the flow of water" and not necessarily trying to provide a water-proof seal. Because the roof of a vehicle flexes when the being driven, no seal can prevent water from leaking around the area around the moon roof. Instead, the water is directed to a tray under the outer seal and then tubes are installed at the four corners of the moon roof to drain the water from the tray to the ground. If water is entering the passenger compartment, make sure the drain tubes are not clogged. The tubes are routed though the two front "A" pillars and the two rear "C" pillars. ● **SEE FIGURE 57–29**.
- **Electrical/Mechanical issues—**Electrical or mechanical issues can prevent the moon roof from opening or closing. Most vehicle manufacturers include a crank or a way to close the roof if the roof fails to close due to an electrical fault.

Always follow the vehicle manufacturer's recommended service and repair instructions and procedures.

SUN SHADES **Sun shades** are fabric or screen-like material installed on the inside of the vehicle that can be raised, lowered, or moved to block the rays of the sun from entering the interior of the vehicle. Most of the sun shades used on the side windows are operated manually and either can be pulled down from the top of the inside of the door or up from the inner part of the door panel. Sun shades used to block the sun in the rear backlight or moon roof are often electrically powered and use a reversible PM motor to drive the roll holding the fabric. ● **SEE FIGURE 57–30**.

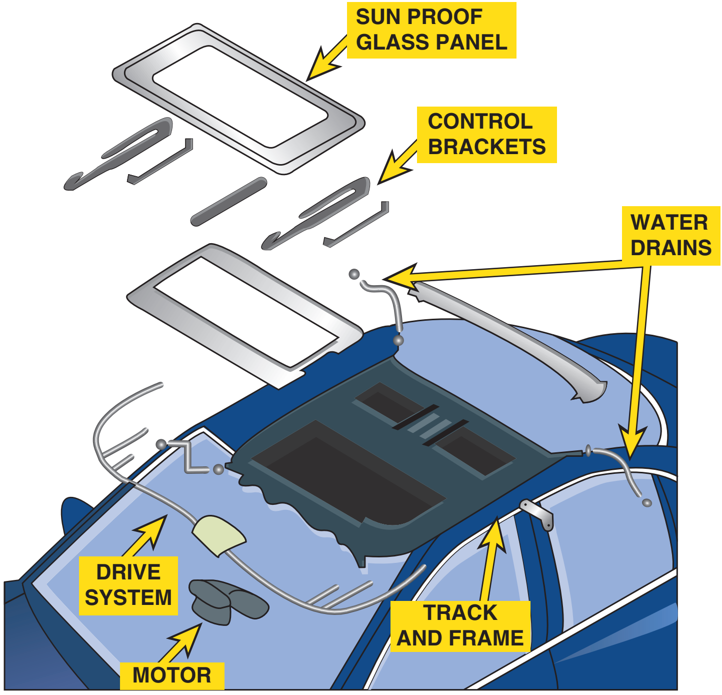


FIGURE 57–29 An exploded view of a typical moveable roof showing the location of the motor and the drain tubes that direct the water to the ground.

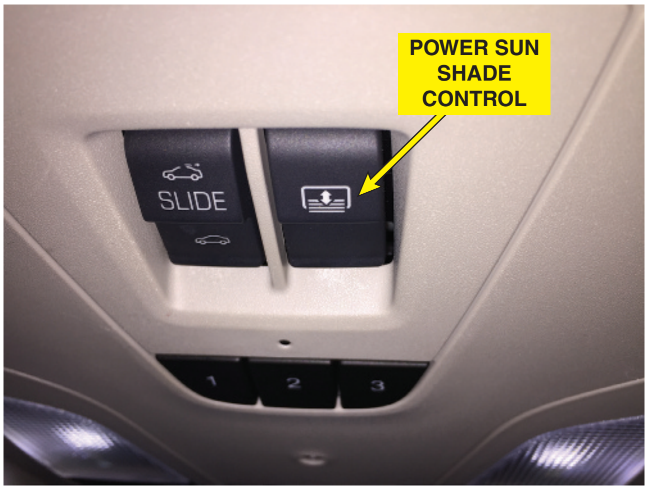

POWER SUN SHADE CONTROL
SLIDE
1
2
3

FIGURE 57–30 The control for the operation of the powered inside sun shade on this Chevrolet Impala is in the overhead control panel.

Sun shades are vehicle-specific, so check service information for the exact procedures to follow when servicing or repairing a sun shade.

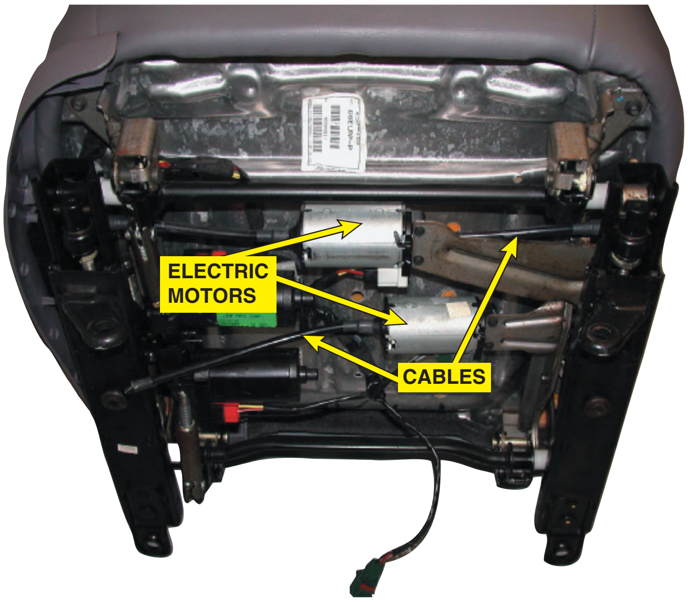

ELECTRIC MOTORS
CABLES

FIGURE 57–31 A power seat uses electric motors under the seat, which drive cables that extend to operate screw jacks (up and down) or gears to move the seat forward and back.

POWER SEATS

PARTS AND OPERATION A typical power-operated seat includes a reversible electric motor and a transmission assembly that may have three solenoids or motors, and six drive cables that turn the six seat adjusters. A six-way power seat offers seat movement forward and backward, plus seat cushion movement up and down at the front and the rear. The drive cables rotate inside a cable housing and connect the power output of the seat transmission to a gear or screw jack assembly that moves the seat. ● **SEE FIGURE 57–31**.

A *screw jack assembly* is often called a *gear nut*. It is used to move the front or back of the seat cushion up and down. A rubber coupling, usually located between the electric motor and the transmission, prevents electric motor damage in the event of a jammed seat. This coupling is designed to prevent motor damage. Most power seats use a permanent magnet motor that can be reversed by reversing the polarity of the current sent to the motor by the seat switch. ● **SEE FIGURE 57–32**.

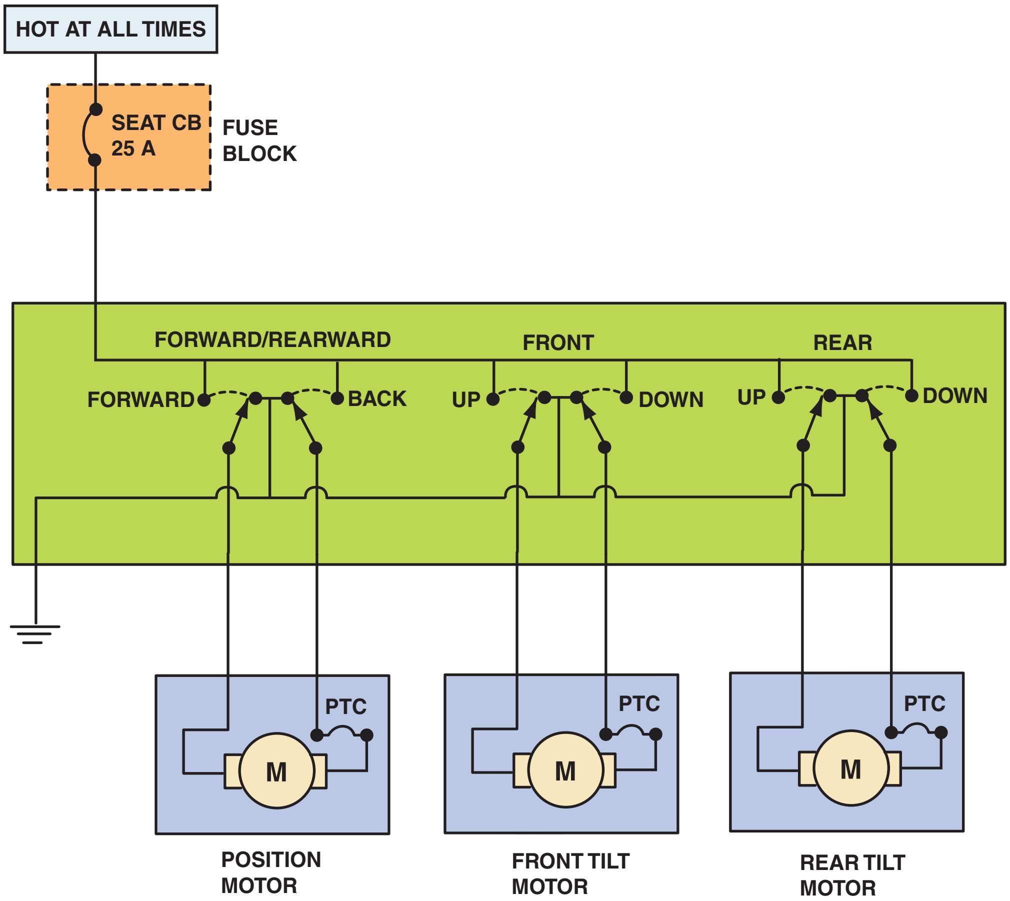

HOT AT ALL TIMES
SEAT CB 25 A
FUSE BLOCK
FORWARD/REARWARD
FRONT
REAR
FORWARD
BACK
UP
DOWN
UP
DOWN
PTC
M
PTC
M
PTC
M
POSITION MOTOR
FRONT TILT MOTOR
REAR TILT MOTOR

FIGURE 57–32 A typical power seat circuit diagram. Notice that each motor has a built-in electronic (solid-state) PTC circuit protector. The seat control switch can change the direction in which the motor(s) runs by reversing the direction in which the current flows through the motor.

POWER SEAT MOTOR(S) Power seats use a PM motor to power the movement of the seat. Most PM motors have a built-in circuit breaker or PTC circuit protector to protect the motor from overheating. Some older Ford power seat motors use three separate armatures inside one large permanent magnet field housing. Some power seats use a series-wound electric motor with two separate field coils, one field coil for each direction of rotation. This type of power seat motor typically uses a relay to control the direction of current from the seat switch to the corresponding field coil of the seat motor. This type of power seat can be identified by the "click" heard when the seat switch is changed from up to down or front to back, or vice versa. The click is the sound of the relay switching the field coil current. Some power seats use as many as eight separate PM motors that operate all functions of the seat, including headrest height, seat length, and side bolsters, in addition to the usual six-way power seat functions.

NOTE: Some power seats use a small air pump to inflate a bag (or bags) in the lower part of the back of the seat, called the lumbar, because it supports the lumbar section of the lower back. The lumbar section of the seat can also be changed, using a lever or knob that the driver can move to change the seat section for the lower back.

MEMORY SEAT Memory seats use a potentiometer to sense the position of the seat. The seat position can be programmed into the BCM or memory seat module, and stored by position number 1, 2, or 3. The driver pushes the desired button and the seat moves to the stored position. On some vehicles, the memory seat position is also programmed into the remote keyless entry (RKE) key fob. ● **SEE FIGURE 57–33.**

Check service information for the exact procedure to follow when diagnosing power seats.

TECH TIP

Easy-Exit Seat Programming

Some vehicles are equipped with memory seats that allow the seat to move rearward when the ignition is turned off to allow easy exit from the vehicle. Vehicles equipped with this feature include an *exit/entry* button that is used to program the desired exit/entry position of the seat for each of two drivers. If the vehicle is not equipped with this feature and only one driver primarily uses the vehicle, the second memory position can be programmed for easy exit and entry. Set position 1 to the desired seat position and position 2 to the entry/exit position. When exiting the vehicle, press memory 2 to allow easy exit and easy entry the next time. Press memory 1 to return the seat memory to the desired driving position.

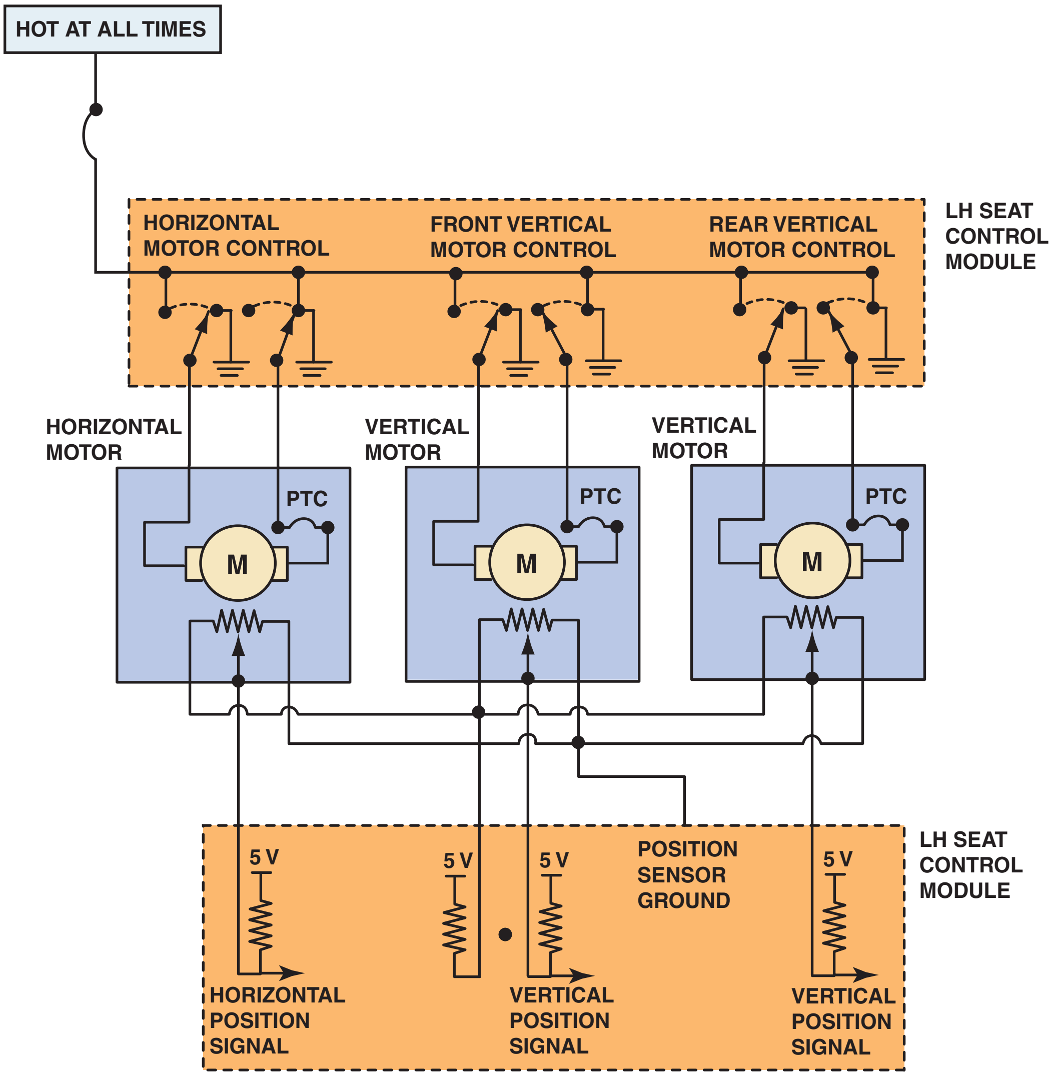

HOT AT ALL TIMES
HORIZONTAL MOTOR CONTROL
FRONT VERTICAL MOTOR CONTROL
REAR VERTICAL MOTOR CONTROL
LH SEAT CONTROL MODULE
HORIZONTAL MOTOR
VERTICAL MOTOR
VERTICAL MOTOR
PTC
PTC
PTC
M
M
M
5 V
5 V
5 V
POSITION SENSOR GROUND
5 V
LH SEAT CONTROL MODULE
HORIZONTAL POSITION SIGNAL
VERTICAL POSITION SIGNAL
VERTICAL POSITION SIGNAL

FIGURE 57–33 A typical memory seat module showing the three-wire potentiometer used to determine seat position.

TECH TIP

What Every Driver Should Know about Power Seats

Power seats use an electric motor or motors to move the position of the seat. These electric motors turn small cables, gears, and/or shafts that operate mechanisms that move the seat. Never place rags, newspapers, or any other object under a power seat. Even ice scrapers can get caught between moving parts of the seat and can often cause serious damage or jamming of the power seat. In many cases, after the object is removed that caused the seat jam, the memory function needs to be relearned for proper operation to resume.

HEATED AND COOLED SEATS

HEATED SEATS **Heated seats** use electric heating elements in the seat bottom, as well as in the seat back, in many vehicles. The heating element is designed to warm the seat and/or back of the seat to about 100°F (38°C) or close to normal body temperature (98.6°F [37°C]). Many heated seats also include a high-position or a variable temperature setting, so the temperature of the seats can, therefore, be as high as 110°F (44°C).

A temperature sensor in the seat cushion is used to regulate the temperature. The sensor is a variable resistor, which changes with temperature and is used as an input signal to a heated seat control module. The heated seat module uses the seat temperature input, as well as the input from the high–low (or variable) temperature control, to turn the current on or off to the heating element in the seat. Some vehicles are equipped with heated seats in both the front and the rear seats.

When diagnosing a heated seat concern, start by verifying that the switch is in the on position and that the temperature of the seat is below normal body temperature. Using service information, check for power and ground at the control module and to the heating element in the seat. Most vehicle manufacturers recommend replacing the entire heating element if it is defective. ● **SEE FIGURE 57–34**.

HEATED AND COOLED SEATS Most electrically heated and cooled seats use a thermoelectric device (TED) located under the seat cushion and seat back. The thermoelectric device consists of positive and negative connections between two ceramic plates. Each ceramic plate has copper fins to allow the transfer of heat to or from air passing over the device and directed into the seat cushion. The thermoelectric device uses the Peltier effect, named after the inventor Jean C. A. Peltier (1785–1845), a French clockmaker. When electrical current flows through the module, one side is heated, and the other side is cooled. Reversing the polarity of the current changes the side to be heated. ● **SEE FIGURE 57–35**.

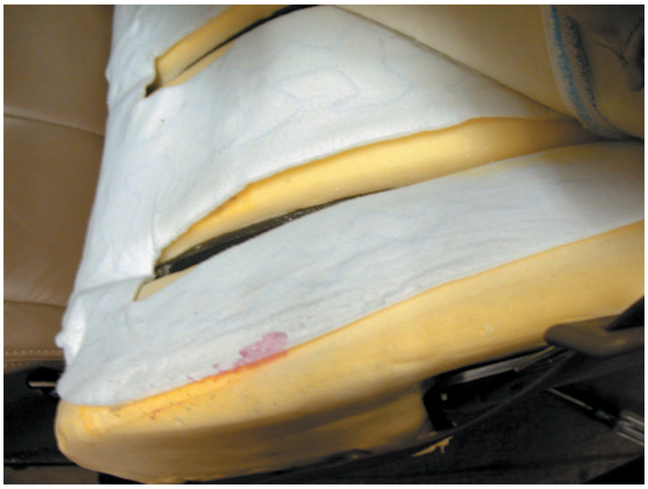


FIGURE 57–34 The heating element of a heated seat is a replaceable part, but service requires that the upholstery be removed. The yellow part is the seat foam material and the entire white cover is the replaceable heating element. This is then covered by the seat material.

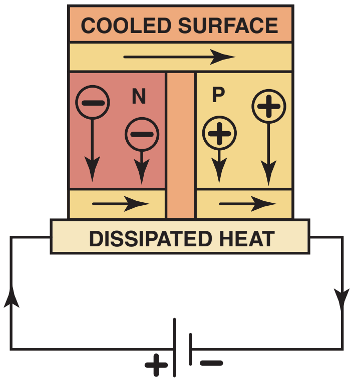


FIGURE 57–35 A Peltier effect device is capable of heating or cooling, depending on the polarity of the applied current.

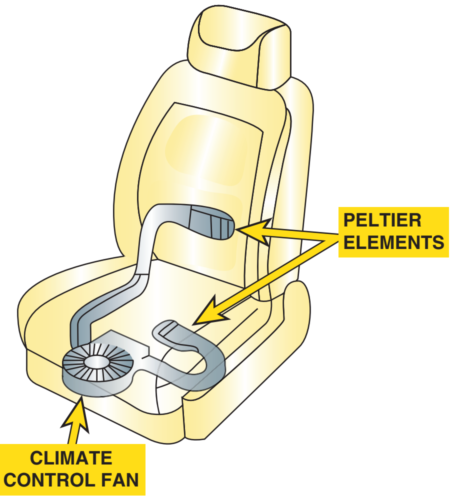


FIGURE 57–36 A fan is used to move the heated or cooled air to heat or cool the bottom or the back of the seat.

Most vehicles equipped with heated and cooled seats use two modules per seat, one for the seat cushion and one for the seat back. When the heated and cooled seats are turned on, air is forced through a filter and then through the thermoelectric modules. The air is then directed through passages in the foam of the seat cushion and seat back. Each thermoelectric device has a temperature sensor called a thermistor. The control module uses sensors to determine the temperature of the fins in the thermoelectric device so the controller can maintain the set temperature. ● **SEE FIGURE 57–36**.

TECH TIP

Check the Seat Filter

Heated and cooled seats often use a filter to trap dirt and debris to help keep the air passages clean. If a customer complains of a slow heating or cooling of the seat, check the air filter and replace or clean as necessary. Check service information for the exact location of the seat filter and for instructions on how to remove and/or replace it.

Always follow the vehicle manufacturer's recommended diagnosis and service procedures for the repair of heated and cooled seat systems.

HEATED STEERING WHEEL

PARTS INVOLVED A **heated steering wheel** usually consists of the following components:

- Steering wheel with a built-in heater in the rim
- Heated steering wheel control switch
- Heated steering wheel control module

OPERATION When the steering wheel heater control switch is turned on, a signal is sent to the control module and electrical current flows through the heating element in the rim of the steering wheel. ● **SEE FIGURE 57–37**.

The system remains on until the ignition switch is turned off or the driver turns off the control switch. The temperature of the steering wheel is usually calibrated to stay at about 90°F (32°C), and it requires three to four minutes to reach that temperature, depending on the outside temperature. Most heated steering wheels only heat a part and often not all the steering wheel. Before trying to repair a condition where just some sections of the steering wheel are being warmed, check service information for what parts are normally heated.

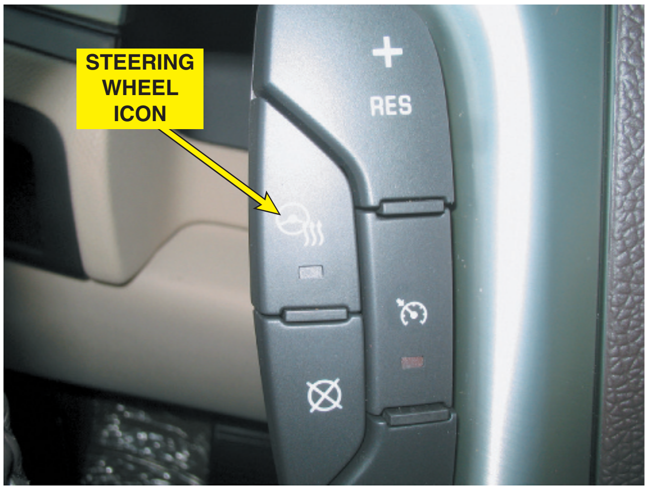


FIGURE 57–37 The heated steering wheel is controlled by a switch on the steering wheel in this vehicle.

Always follow the vehicle manufacturer's recommended diagnosis and testing procedures for heated steering wheel diagnosis and repair.

HEATED MIRRORS

PURPOSE AND FUNCTION The purpose and function of heated outside mirrors is to heat the surface of the mirror, which evaporates moisture on the surface. Heated mirrors may be an option for the left-side outside mirror or both the left- and right-side outside mirrors, depending on the vehicle. The heat helps keep ice and fog off the mirrors to allow for better driver visibility.

PARTS AND OPERATION Heated outside mirrors are often tied into the same electrical circuit as the rear window defogger. Therefore, when the rear defogger is turned on, the heating grid on the backside of the mirror is also turned on. On some vehicles, the heated mirrors are activated when the heating, ventilation, and cooling (HVAC) system is placed in the defrost mode. Some vehicles use a switch for each mirror.

DIAGNOSIS The first step in any diagnosis procedure is to verify the customer concern. Check the owner's manual or service information for the proper method to use to turn on the heated mirrors.

NOTE: Heated mirrors are *not* designed to melt snow or a thick layer of ice.

If a fault has been detected, check service information instructions for the exact procedure to follow. If the mirror itself is found to be defective, it is usually replaced as an assembly, instead of being repaired.

ADJUSTABLE PEDALS

PURPOSE AND FUNCTION Adjustable pedals, also called *pedal height* or **electric adjustable pedals (EAP)**, place the brake pedal and the accelerator pedal on movable brackets that are motor operated. The height of the accelerator pedal and the brake pedal are adjusted together and cannot be adjusted individually. A typical adjustable pedal system includes the following components:

- Adjustable pedal position switch: Allows the driver to position the pedals.
- Adjustable pedal assembly: Includes the motor, threaded adjustment rods, and a pedal position sensor. ● **SEE FIGURE 57–38**.

The position of the pedals, as well as the position of the seat system, is usually included as part of the memory seat function and can be set for two or more drivers.

DIAGNOSIS AND SERVICE The first step when there is a customer concern about the functioning of the adjustable pedals is to verify that the unit is not working as designed. Check the owner's manual or service information for the proper operation. Follow the vehicle manufacturer's recommended troubleshooting procedure. Many diagnostic procedures include the use of a factory scan tool with bidirectional control capabilities to test this system.

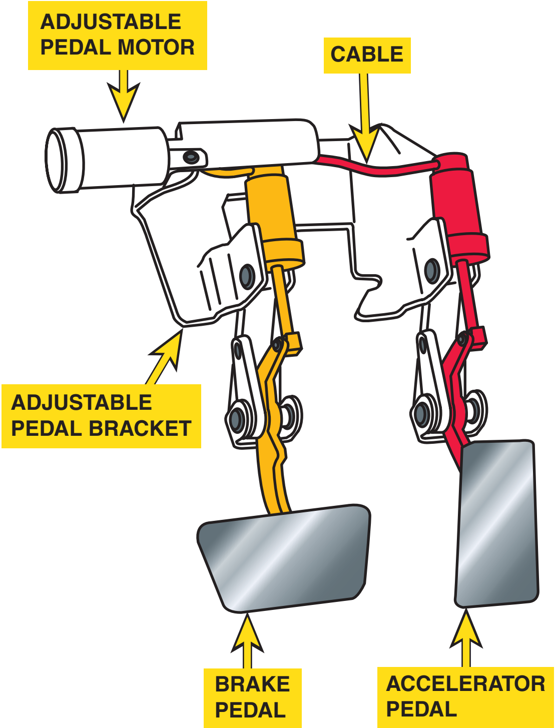


FIGURE 57–38 A typical adjustable pedal assembly. Both the accelerator and the brake pedal can be moved forward and rearward by using the adjustable pedal position switch.

TECH TIP

Check the Remote

The memory function may be programmed to a particular key fob remote, which commands the adjustable pedals to move to the position set in memory. Always check the settings of all remotes before attempting to repair a problem, which may not be a problem.

CASE STUDY

The Case of the Haunted Mirrors

The owner complained that while driving, either one or the other, outside mirror folded in without any button being depressed. Unable to verify the customer concern, the service technician looked at the owner's manual to find out exactly how the mirrors were supposed to work. In the manual, a caution statement said that if the mirror is electrically folded inward and then manually pushed out, the mirror does not lock into position. The power folding mirrors must be electrically cycled outward, using the mirror switches to lock them in position. After cycling both mirrors inward and outward electrically, the problem was solved. ● **SEE FIGURES 57–39 AND 57–40**.

Summary:

Complaint—Customer stated that the outside power folding mirror folded by itself at times.
Cause—The mirrors must be moved electrically, not manually, to work correctly.
Correction—Cycling the mirrors electrically restored proper operation.

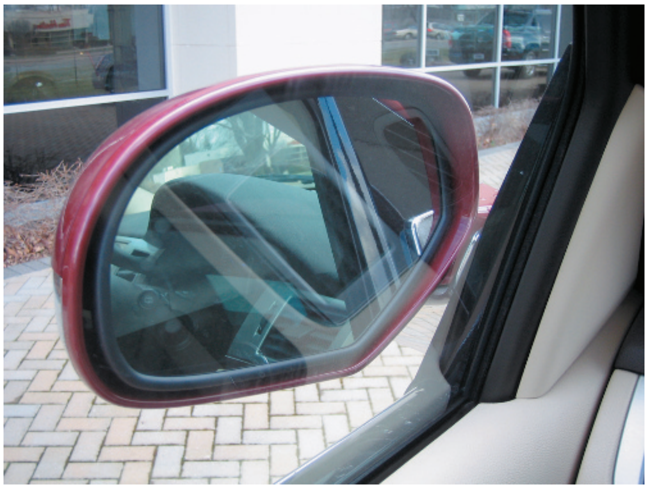


FIGURE 57–39 Electrically folded mirror in the folded position.

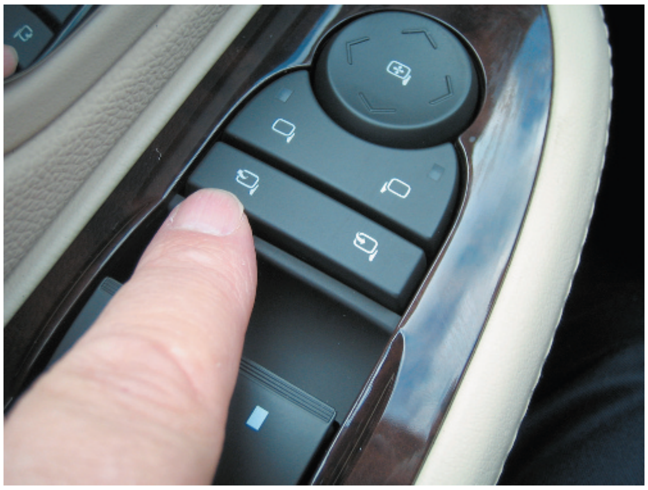


FIGURE 57–40 The electric mirror control is located on the driver's side door panel on this Cadillac Escalade.

FOLDING OUTSIDE MIRRORS Mirrors that can be electrically folded inward are a popular feature, especially on larger sport utility vehicles. A control inside is used to fold both mirrors inward when needed, such as when entering a garage or a tight parking spot. For diagnosis and servicing of outside folding mirrors, check service information for details.

KEYLESS ENTRY

SYSTEM DESCRIPTION Even though some Ford vehicles use a keypad located on the outside of the door, most keyless entry systems use a wireless transmitter built into the key fob or remote. A key fob is a decorative item on a key chain. ● **SEE FIGURE 57–41**.

FIGURE 57–41 A key fob remote.

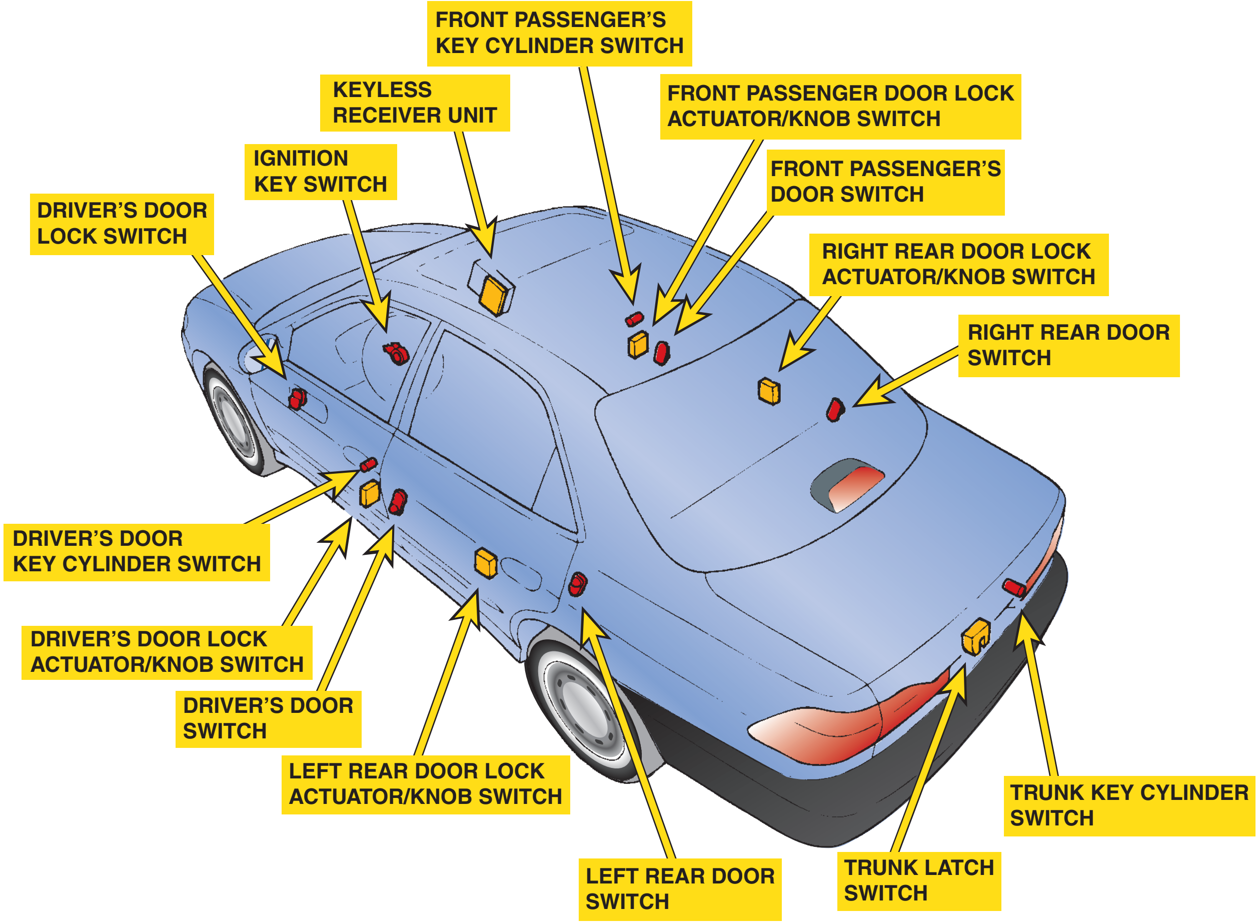

FRONT PASSENGER'S KEY CYLINDER SWITCH
KEYLESS RECEIVER UNIT
FRONT PASSENGER DOOR LOCK ACTUATOR/KNOB SWITCH
IGNITION KEY SWITCH
FRONT PASSENGER'S DOOR SWITCH
DRIVER'S DOOR LOCK SWITCH
RIGHT REAR DOOR LOCK ACTUATOR/KNOB SWITCH
RIGHT REAR DOOR SWITCH
DRIVER'S DOOR KEY CYLINDER SWITCH
DRIVER'S DOOR LOCK ACTUATOR/KNOB SWITCH
DRIVER'S DOOR SWITCH
LEFT REAR DOOR LOCK ACTUATOR/KNOB SWITCH
TRUNK KEY CYLINDER SWITCH
LEFT REAR DOOR SWITCH
TRUNK LATCH SWITCH

FIGURE 57–42 A typical vehicle showing the location of the various components of the remote keyless entry system.

The transmitter broadcasts a signal that is received by the electronic control module, which is generally mounted in the trunk or under the instrument panel. ● **SEE FIGURE 57–42**.

The electronic control unit sends a voltage signal to the door lock actuator(s) located in the doors. Generally, if the transmitter unlock button is depressed once, only the driver's door is unlocked. If the unlock button is depressed twice, then all doors unlock.

ROLLING CODE RESET PROCEDURE Many keyless remote systems use a rolling-code type of transmitter and receiver. In a conventional system, the transmitter emits a certain fixed frequency, which is received by the vehicle control module. This single frequency can be intercepted and rebroadcast to open the vehicle. A rolling-code type of transmitter emits a different frequency every time the transmitter button is depressed and then rolls over to another frequency so that it cannot be intercepted. Both the transmitter and the receiver must be kept in synchronized order so that the remote functions correctly. If the transmitter is depressed when it is out of range from the vehicle, the proper frequency may not be recognized by the receiver, which did not roll over to the new frequency when the transmitter was depressed. If the transmitter does not work, try to resynchronize the transmitter to the receiver by depressing and holding both the lock and the unlock button for 10 seconds when within range of the receiver.

PASSIVE KEYLESS ENTRY SYSTEM A passive system uses the key fob as a transmitter, which communicates with the vehicle as it comes close. The key is identified using one of several antennas around the body of the vehicle and a radio pulse generator in the key housing. Depending on the system, the vehicle is automatically unlocked when a button or sensor on the door handle or trunk release is depressed. ● **SEE FIGURE 57–43**.

A passive system can also be used to unlock and open a rear lift gate on an SUV if a foot is moved under the edge of the vehicle, allowing it to open the slider or the rear hatch. Vehicles with a passive (smart) key system can also have a mechanical backup, usually in the form of a key blade built into the key fob. Vehicles with a smart key system can be started without inserting a key in the ignition, provided the driver has the key fob inside the vehicle. On most vehicles, this is done most often by pressing a start button. When leaving a vehicle equipped with a smart key system, the vehicle is locked, depending on the make, model, and year of manufacture of vehicle, by:

- Pressing a button on one of the door handles
- Touching a capacitive area on a door handle
- Walking away from the vehicle and the door locks when the key fob is further away than 15 feet (5 m).

KEYLESS ENTRY DIAGNOSIS A small battery powers the transmitter, and a weak battery is a common cause of remote power locks failing to operate. If the keyless entry system fails to operate after the transmitter battery has been replaced, check the following items:

- Mechanical binding in the door lock
- Low vehicle battery voltage
- Blown fuse
- Open circuit to the control module

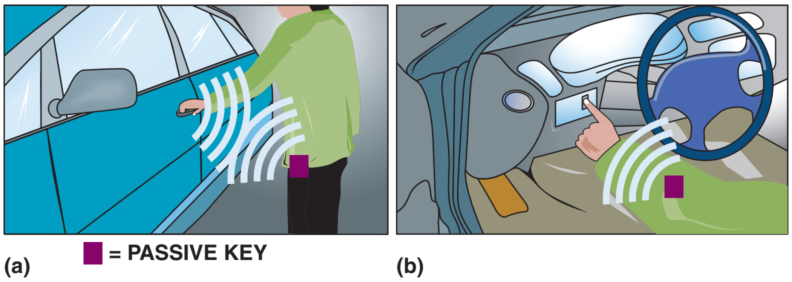


FIGURE 57–43 (a) If the passive key is within about 15 feet (5 m) of the vehicle when the door handle is touched, the door unlocks, allowing access to the interior. (b) The engine starts if the smart key is detected being inside the vehicle. This system is commonly called the **passive entry**, **passive starting (PEPS)** system.

- Defective control module
- Defective transmitter

PROGRAMMING A NEW REMOTE If a new or additional remote transmitter is to be used, it must be programmed to the vehicle. Generally, all remotes previously programmed to the vehicle must be present during the programming or they no longer work. The programming procedure varies and may require the use of a scan tool. Check service information for the exact procedure to follow.

GARAGE DOOR OPENER

OPERATION HomeLink or Car2U is a device installed in many new vehicles that duplicates the radio-frequency code of the original garage door opener. The frequency range is 288 to 418 MHz. The typical vehicle garage door opening system has three buttons that can be used to operate one or more of the following devices:

- Garage doors equipped with a radio transmitter electric opener
- Gates
- Entry door locks
- Lighting or small appliances

The devices include both fixed-frequency devices, usually in older units, and rolling (encrypted) code devices. ● **SEE FIGURE 57–44**.

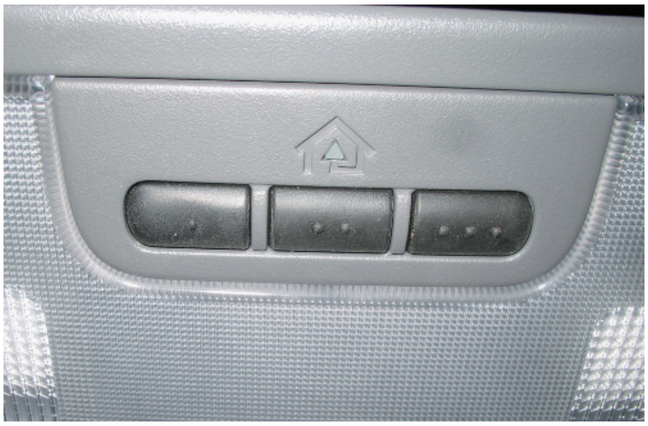


FIGURE 57–44 Typical HomeLink garage door opener buttons. Notice that three different units can be controlled from the vehicle using the HomeLink system.

PROGRAMMING A VEHICLE GARAGE DOOR OPENER When a vehicle is purchased, it must be programmed using the transmitter for the garage door opener or other device.

NOTE: The garage door opening controller can only be programmed by using a transmitter. If an automatic garage door system does not have a remote transmitter, the system cannot be programmed.

Normally, the customer is responsible for programming the garage door opener. However, some customers may find that help is needed from the service department. The steps that are usually involved in programming a garage door opener in the vehicle to the garage door opener are as follows:

STEP 1 Unplug the garage door opener during programming to prevent it from being cycled on and off, which could damage the motor.

STEP 2 Check that the frequency of the handheld transmitter is between 288 to 418 MHz.

STEP 3 Install new batteries in the transmitter to be assured of a strong signal being transmitted to the garage door opener module in the vehicle.

STEP 4 Turn the ignition on, engine off (KOEO).

STEP 5 While holding the transmitter 4 to 6 inches away from the opener button, press and hold the button while pressing and releasing the handheld transmitter every two seconds. Continue pressing and releasing the transmitter until the indicator light near the opener button changes from a slow blink to a rapid flash.

STEP 6 Verify that the vehicle garage door system (HomeLink or Car2U) button has been programmed. Press and hold the garage door button. If the indicator light blinks rapidly for two seconds and then comes on steady, the system has been successfully programmed using a rolling code design. If the indicator light is on steady, then it has been successfully programmed to a fixed frequency device.

DIAGNOSIS AND SERVICE If a fault occurs with the garage door opening system, first verify that the garage door opener is functioning correctly. Also, check if the garage door opener remote control can operate the door. Repair the garage door opener system as needed. If the problem still exists, attempt reprogramming the HomeLink/Car2U vehicle system, being sure that the remote has a newly purchased battery.

WARNING

Never use the remote start to start the engine if the vehicle is located inside a garage or an area without proper ventilation, or if a car cover is covering the body of the vehicle.

REMOTE START

PURPOSE AND FUNCTION A **remote start** is the ability to start the engine of the vehicle from a distance by using a remote control. This a popular option, especially in cold climates, which allows the driver to start the engine when inside the house or office to start the warm-up process before even entering the vehicle. It is also popular in the warm weather areas where the interior can be cooled by the air conditioning before entering the vehicle. Most factory-installed remote start systems use the same key fob that it used to unlock the doors.

PARTS AND OPERATION The remote start system uses a signal from the transmitter (usually the key fob on factory systems) to start the engine. The engine runs for about ten minutes, depending on the system, and then shuts off. The vehicle needs to be setup ahead of time with the HVAC system set to heat or A/C and the transmission gear selector in park, or in neutral on vehicles equipped with a manual transmission. Always check service information for the conditions that allow remote starting, which often includes the following:

- The keyless remote is not inside the vehicle.
- The gearshift lever is in the "P" (Park) position.
- The security warning system is not activated.
- The brake pedal is not depressed.
- The engine hood is closed.
- All the doors are closed and locked.
- The trunk or tailgate is closed.
- The ignition key is removed from the ignition switch.
- The vehicle battery is not low.

Check service information for the exact procedures to follow when diagnosing a fault with the remote engine start system.

BODY ELECTRICAL SYSTEMS DIAGNOSIS

BODY CONTROL MODULE COMMUNICATION The body control module (BCM) and other electronic modules are used to operate the various vehicle systems. The number of these modules and the purpose of them varies among the vehicle manufacturers. All these systems use the different controller area networks (CAN) to connect all these modules together. If there are communication errors on the various networks some or all of these modules may not function. Many communication errors will set a "U" DTC. If this network is active or partially active, a bidirectional factory level scan tool is needed to diagnose the diagnostic trouble code(s). A factory or factory-level aftermarket scan tool is also required to reprogram the current or new BCM with the latest operating software and calibrations.

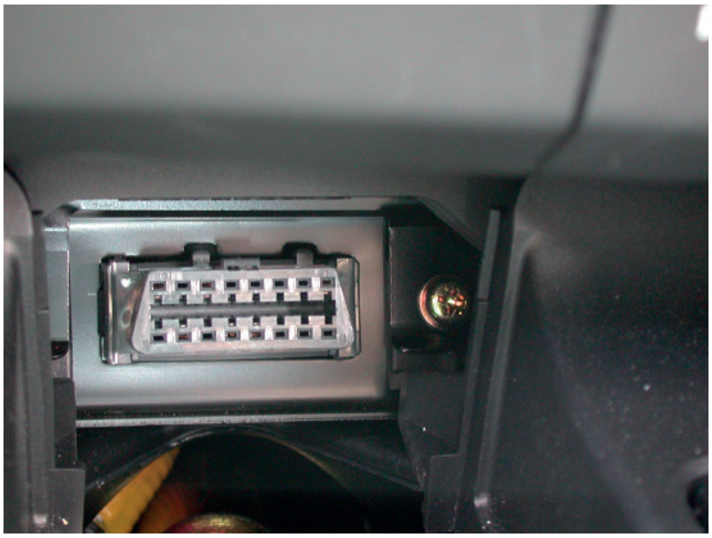


FIGURE 57–45 The data link connector is located under the dash.

STEPS INVOLVED The following steps are needed to be performed to access and determine module communications:

STEP 1 Connect a factory or factory-level scan tool to the DLC. ● **SEE FIGURE 57–45**.

STEP 2 Perform an all-module scan to check for any diagnostic trouble codes that may be stored in all of the modules.

STEP 3 Command the module using the scan tool to take the appropriate action and observe the response. If the component operates correctly, this means that there is nothing wrong on the output side of the circuit. If an incorrect response is shown, then refer to the service information for the specific diagnostic procedure.

SOFTWARE UPDATES TRANSFERS/FLASH PROGRAMMING When diagnosing and repairing many of these vehicles that use multiple electronic modules, it may be required to do a software transfer, update or flash reprogramming or relearning of the modules with the latest OEM update information. OEMs will periodically update the software for these modules to enhance vehicle operation or correct a fault. In many cases there will be a technical service bulletin (TSB) on these updates. Flash reprogramming tools are available to connect to the DLC to update the software. OEMs will make updates available over the Internet, generally using one of their subscription services like AC Delco.

REPROGRAMMING STEPS Before a data transfer is performed, connect a battery charger specifically designed to provide a clean direct current output to the battery. Using a conventional battery charger should be avoided because they often supply some alternating current (AC) that can disrupt the data transfer.

STEP 1 Download the latest vehicle software program updates from the OEM or a subscription website and load these updates onto the flash programmer or your factory level scan tool.

STEP 2 Locate the datalink connector and power on the flash programming tool, then turn on the ignition (KOEO).

STEP 3 Establish flash programming tool communication with the vehicle.

STEP 4 Identify the vehicle modules that will need to be updated, and use the flash programming tool (J2934) or the scan tool to perform software transfers updates or flash reprogramming. ● **SEE FIGURE 57–46**.

FIGURE 57–46 A laptop computer being used to download the latest software from the Internet, which needs to be transferred to a factory or factory-level scan tool that is connected to the vehicle at the DLC to perform the file transfer.

STEP 5 Disconnect the flash programmer or scan tool and then check the vehicle to see that the system is now functioning or functioning properly.

FREQUENTLY ASKED QUESTION

How Do Over the Air (OTA) Module Updates Work?

Electronic modules can be updated using **over the air (OTA)** on many vehicles. Tesla was the first to use OTA to update some of the electronic modules in 2012 on their Model S. Since then, many vehicle manufacturers are able to update the software of many electronic modules using OTA communication. Some use Wi-Fi whereas others use cellular systems to communicate with the vehicle.

REVIEW QUESTIONS

1. What are the advantages of using the BCM to able to operate the horns?
2. How do rain-sense wipers work?
3. How do power door locks work?
4. How can an infrared camera be used to test a rear window defogger?
5. What is meant by a “rolling code”?

CHAPTER QUIZ

1. In most recent-model vehicles, the horn button is an input to the _________, which then activates the horn circuit.
   a. horn relay
   b. instrument cluster
   c. BCM
   d. garage door opener
2. Technician A says that the cruise control on a vehicle that uses an electronic throttle control (ETC) system uses a servo to move the throttle. Technician B says that a blower motor speed can be controlled using resistors. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Most vehicles use _________ to control the actual operation of the wipers.
   a. variable resistors
   b. changing the voltage to the brushes
   c. the BCM
   d. changing the position of the brushes
4. Technician A says that the automatic reversal system operates by detecting the force needed to close the window. Technician B says that rain sensing wipers use a water detection module attached to the inside of the windshield. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. What should be used during module reprogramming to maintain the vehicle voltage level?
   a. A 24-volt battery
   b. A charger that outputs clean DC voltage
   c. A memory saver
   d. Any of the above

6. When checking the operation of a rear window defogger, heated and cooled seats, heated steering wheel or heated mirrors, what can be used to check their operation?
   - **a.** A voltmeter
   - **b.** A scan tool
   - **c.** Infrared camera
   - **d.** Some or all may be used
7. PM motors used in power windows, mirrors, and seats can be reversed by __________.
   - **a.** sending current to a reversed field coil
   - **b.** reversing the polarity of the current to the motor
   - **c.** using a reverse relay circuit
   - **d.** using a relay and a two-way clutch
8. How is the panel of a sun roof opened and closed?
   - **a.** With a reversible PM motor
   - **b.** By way of vacuum actuators
   - **c.** With a handle and cables
   - **d.** None of these
9. A keyless remote start is not working. Technician A says the trunk of the vehicle may be open. Technician B says that the key fob may be too far away from the vehicle. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. Technician A says that adjustable pedals move both the accelerator pedal and the brake pedal. Technician B says that only the brake pedal moves when adjusting the pedals. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both technicians are correct
    - **d.** Neither technician is correct

Chapter

58

ADVANCED DRIVER ASSIST SYSTEMS (ADAS)

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the purpose and function of advanced driver assist systems.
- Discuss blind spot monitors.
- Discuss parking assist as well as self-parking systems.
- Explain lane departure warning systems.
- Explain lane keep assist systems.
- Describe how adaptive cruise control systems work.
- Discuss rear cross-traffic warning system operation.
- Explain automatic emergency braking.
- Explain pre-collision systems.
- Describe the operation of hill start assist.
- Describe the diagnostic procedures for advanced driver assist systems.
- Describe camera and radar sensor calibration.

KEY TERMS:

Adaptive cruise control (ACC) 695 • Automatic emergency braking (AEB) 697 • Blind spot monitor (BSM) 692 • Cross-traffic alert 694 • Electromagnetic parking sensors (EPS) 693 • Human–machine interface (HMI) 693 • Intelligent Speed Advice (ISA) 697 • Lane departure warning system (LDWS) 694 • Lane keep assist (LKA) 695 • Rear cross-traffic warning (RCTW) 697 • Self-parking 694 • Ultrasonic object sensors 693

ADVANCED DRIVER ASSIST SYSTEMS

PURPOSE The purpose of advanced driver assist systems (ADAS) is to provide the driver with systems that help the driver by doing the following:

- Alert the driver of a potential issue, such as getting too close to the center line or too far to the right of the roadway.
- Take the responsibility off the driver, such as maintaining an ensured clear distance from the vehicle in front while at the same time handling the accelerator pedal to maintain a set speed.
- Help the driver avoid a collision if a vehicle in front of the driver stops quickly.
- Make the parking safer through parking assist systems that use ultrasonic sensors to detect when the front or rear bumper is getting close to an object.

CAUTION: The advanced driver assist systems are designed as a driver aid and are not intended to replace the driver. It is the responsibility of the driver to be aware of the surroundings and be able to take control of the vehicle at all times.

BLIND SPOT MONITOR

FUNCTION AND TERMINOLOGY The **blind spot monitor (BSM)** is a vehicle-based sensor device that detects other vehicles located to the side and rear of the vehicle. Warnings can be any of the following:

- Visual—Usually a warning light in the outside rearview mirrors. ● **SEE FIGURE 58–1**.
- Audible—Usually a beep or buzzer sound.
- Vibrating (tactile)—A vibration is often created in the steering wheel or the driver's seat.

The term used varies with vehicle manufacturers and includes the following:

Acura—Blind Spot Information (BSI)
Audi—Side Assist
BMW—Active Blind Spot Detection
Buick—Side Blind Zone Alert
Cadillac—Side Blind Zone Alert
Chevrolet—Side Blind Zone Alert
Dodge—Blind Spot Monitoring
Fiat—Blind Spot Monitoring

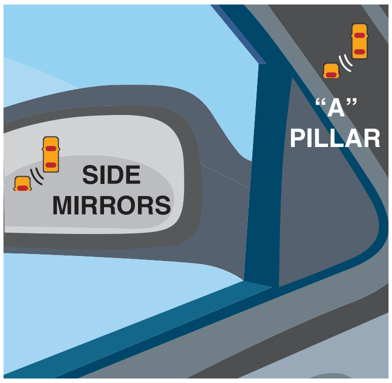


FIGURE 58–1 Blind spot monitoring systems usually use a warning system in the side-view mirror or in the "A" pillar near the side-view mirror to warn the driver that there is a vehicle in the potential blind spot.

FREQUENTLY ASKED QUESTION

What Is Meant by Human–Machine Interface (HMI)?

Human–machine interface (HMI) was very basic in the past because the vehicles were equipped with most of the following to let the driver know what the vehicle (the machine) was doing:

- Speedometers
- Fuel level gauge
- Engine coolant temperature
- Oil pressure (some vehicles)

Vehicles with advanced technology need to communicate to the driver or occupants using the following:

1. Visual displays
2. Sounds
3. Tactile (called "haptic" feedback vibrations of the seat or the steering wheel, which are created using a DC motor turning an offset weight to create the vibrations)

The hardware involved includes the following:

1. A display
2. Speakers
3. Input devices, such as a mouse or joystick
4. Microphone for voice commands

Behind the scenes, software is used to sort out the vast amount of information and reduce it to the levels where the driver can understand and react to situations as needed.

Ford—Blind Spot Information System (BLIS)
GMC—Side Blind Zone Alert
Honda—Lane Watch System
Hyundai—Blind Spot Detection
Infiniti—Blind Spot Intervention System
Jeep—Blind Spot Monitoring
Land Rover—Blind Spot Monitor
Lexus—Blind Spot Monitor
Mazda—Blind Spot Monitoring (BSM)
Mercedes-Benz—Active Blind Spot Assist
Mitsubishi—Blind Spot Warning (BSW)
Nissan—Blind Spot Warning
Porsche—Lane Change Assist
Subaru—Blind Spot Detection
Toyota—Blind Spot Monitor
Volvo—Blind Spot Information System (BSIS)

PARTS AND OPERATION When the vehicle is first started, the outside mirror displays will come on briefly indicating that the system is turned on and operating. The typical detection zone includes the following:

- Most systems are designed to detect objects that are as small as a motorcycle with rider.
- The detection zone extends out from the sides and behind the vehicle about 10 feet (3 m).
- It is capable of detecting objects that are about 2 to 6 feet (0.6 to 1.8 m) tall (above the ground).

NOTE: The blind spot monitoring system does not detect objects that are not moving, such as walls, curbs, bridges, or parked vehicles.

If the blind spot monitoring system fails to work as designed, check service information for the specified troubleshooting and repair procedure to follow.

PARKING-ASSIST SYSTEMS

FUNCTION AND COMPONENTS The parking-assist system is used to help drivers avoid contact with another object while moving slowly. When backing up at speed of less than 5 MPH (8 km/h), the system constantly monitors for objects located around the vehicle. The parking-assist system can usually detect objects that are greater than 3 inches (8 cm) wide and 10 inches (25 cm) tall, but the system cannot detect objects below the bumper or underneath the vehicle. As the vehicle gets closer to an object, there is an audible beep out of the speakers, and the time between the beeps becomes shorter, the closer to the object. The parking-assist system usually includes the following components:

- **Ultrasonic object sensors** are used to measure the distances to nearby objects and are built into the fender, and front and rear bumper assembly. The sensors send out acoustic pulses, and a control unit measures the return interval of each reflected signal, calculating object distances. ● **SEE FIGURE 58–2**.

  The system warns the driver with warning tones with the frequency indicating object distance. The faster the tone sounds, the closer is the vehicle to the object. A continuous tone indicates a minimal predefined distance. Systems may also include visual aids, such as LED or LCD readouts, to indicate object distance. A vehicle may include a vehicle pictogram on the infotainment screen. ● **SEE FIGURE 58–3**.
- **Electromagnetic parking sensors (EPS)** detect when a vehicle is moving slowly and toward an object. Once detected, the sensor continues to give signal of presence of the obstacle. If the vehicle then continues

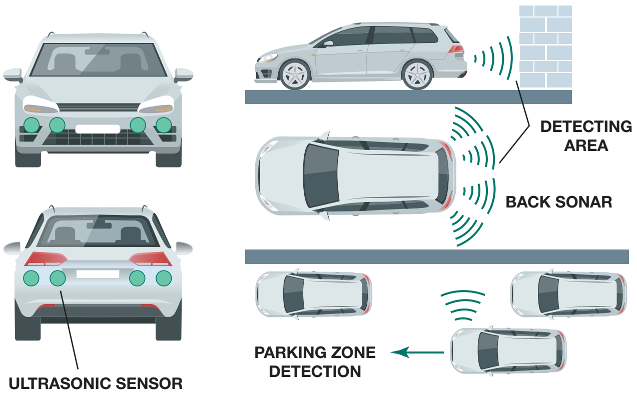


FIGURE 58–2 The small round buttons in the rear bumper are ultrasonic sensors used to sense distance to an object.

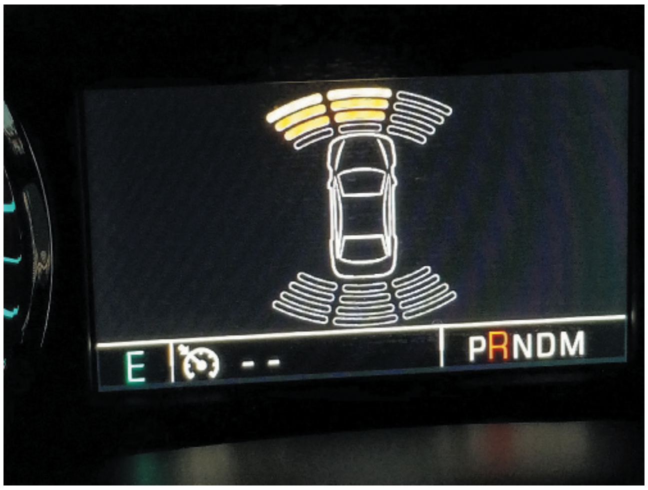


FIGURE 58–3 The dash display on a Chevrolet showing that an object is being detected at the front and left-front of the vehicle.

to move toward the object, the alarm signal becomes more and more impressive as the obstacle approaches. Electromagnetic parking sensors do not require any holes in the bumper and cannot be seen from the outside of the vehicle. A BSM is an option that may include more than monitoring the front, rear, and sides of the vehicle. It can include **cross-traffic alert**, which can sound an alarm when backing out of a parking space and traffic is approaching from either side.

TECH TIP

Check for Repainted Bumpers

The ultrasonic sensors embedded in the bumper are sensitive to paint thickness because the paint covers the sensors. If the system does not seem to be responding to objects, and if the bumper has been repainted, measure the paint thickness using a nonferrous paint thickness gauge. The maximum allowable paint thickness is 6 mils (0.006 inch or 0.15 millimeter).

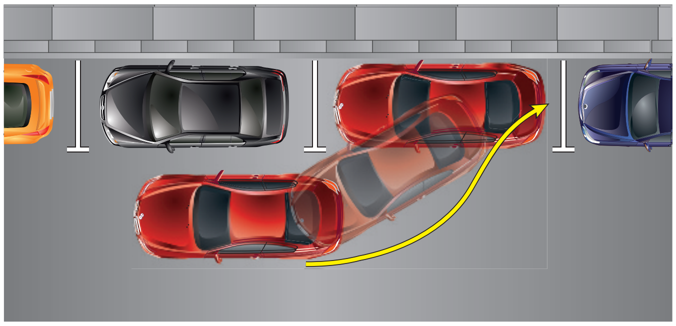


FIGURE 58–4 A self-parking-capable vehicle is able to parallel park or enter into a parking spot with little, or no input from the driver.

OPERATION The system is activated automatically when the vehicle is started. The indicator light on the dash or driver information center indicates the system is on. The parking-assist system is active from the time the engine is started until the vehicle exceeds a speed of approximately 6 MPH (10 km/h). It is also active when the vehicle is backing up. The parking-assist system is automatically reactivated the next time the engine is started, even if the system was turned off by the driver the last time the vehicle was driven.

DIAGNOSIS The parking-assist control module can detect faults and store diagnostic trouble codes. If a fault has been detected by the control module, the red lamp flashes and the system is disabled. Follow service information diagnostic procedures because the parking-assist module cannot usually be accessed using a scan tool.

SELF-PARKING **Self-parking** vehicles, also called *automatic parking vehicles*, use the camera(s) and control the electric power steering to guide the vehicle into a parking space. The driver may or may not have to add anything in many advanced systems, whereas the driver must control the throttle and the brakes in early systems. ● **SEE FIGURE 58–4**.

LANE DEPARTURE WARNING

PARTS AND OPERATION The **lane departure warning system (LDWS)** uses cameras to detect if the vehicle is crossing over lane marking lines on the pavement. Some systems use two cameras, one mounted on each outside rearview mirror. Some systems use infrared sensors located under the front bumper to monitor the lane markings on the road surface. The system names also vary according to vehicle manufacturers, including the following:

Honda/Acura: Lane Keep Assist System (LKAS)
Toyota/Lexus: Lane Monitoring System (LMS)
General Motors: Lane Departure Warning (LDW)
Ford: Lane Departure Warning (LDW)
Nissan/Infiniti: Lane Departure Prevention (LDP) System

If the cameras detect that the vehicle is starting to cross over a lane dividing line, a warning chime sounds or a vibrating mechanism mounted in the driver's seat cushion is triggered on the side where the departure is being detected. This warning does not

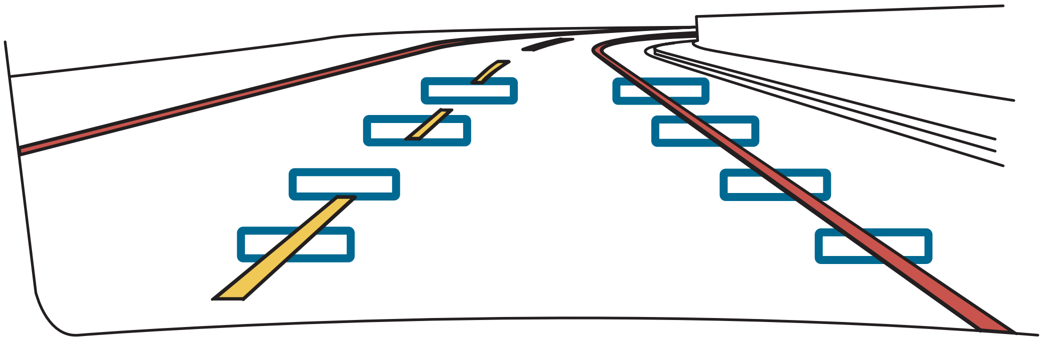


FIGURE 58–5 A lane departure warning system often uses cameras to sense the road lines and warns the driver if the vehicle is not staying within the lane, unless the turn signal is on.

occur if the turn signal is on in the same direction as detected. ● **SEE FIGURE 58–5**.

DIAGNOSIS AND SERVICE Before attempting to service or repair an LDWS fault, check service information for an explanation on how the system is supposed to work. If the system is not working as designed, perform a visual inspection of the sensors or cameras, checking for damage from road debris or evidence of body damage, which could affect the sensors. After a visual inspection, follow the vehicle manufacturer's recommended diagnosis procedures to locate and repair the fault in the system.

LANE KEEP ASSIST

PURPOSE AND FUNCTION The purpose of **lane keep assist (LKA)**, also called *lane keep assist system (LKAS)*, is not only to warn the driver if the vehicle is moving out of the lane of traffic, but when no response, it uses the electric power steering system to steer the vehicle back into the lane. ● **SEE FIGURE 58–6**.

PARTS AND OPERATION Most lane keep assist systems use a camera mounted in front of the inside rearview mirror with a clear view of the road ahead. A typical LKAS is able to monitor the road about 160 feet (50 m) ahead, and at vehicle speeds above 40 MPH (60 km/h) with the camera observing a 40-degree view ahead of the vehicle. The camera can detect the lane marking, which includes the center line and the right-side painted line, often called the fog line because it helps drivers see the right side of the road under poor or in foggy visibility.

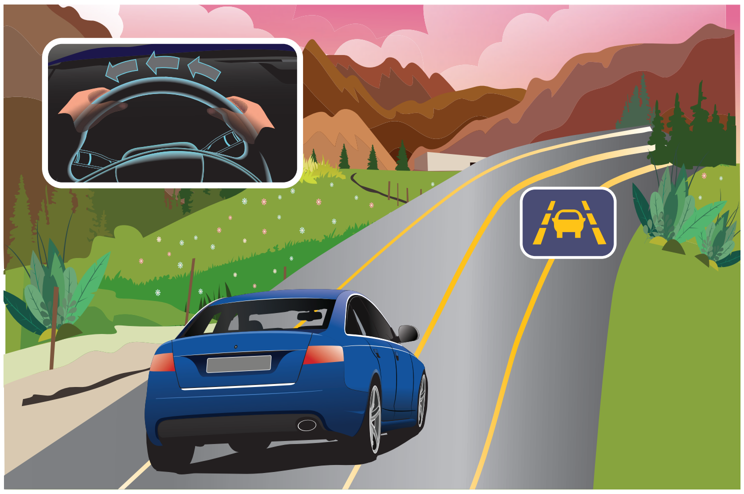
When the camera detects that the vehicle is starting to get close to either lane marking, the vehicle performs the following functions:

1. It warns the driver by a warning sound, and/or lights the LKA symbol on the dash. In some vehicles, the warning includes vibrating the steering wheel in an attempt to get the driver's attention.
2. If the warnings do not result in corrective action by the driver, the LKAS uses the electric power steering to steer the vehicle back into the lane between the two lane markings.

ADAPTIVE CRUISE CONTROL

PURPOSE AND FUNCTION **Adaptive cruise control (ACC)**, also called *radar cruise control*, gives the driver more control over the vehicle by keeping an assured clear distance behind the vehicle in front. If the vehicle in front slows, the ACC detects the slowing vehicle and automatically reduces the speed of the vehicle to keep a safe distance. Then, if the vehicle speeds up, the ACC also allows the vehicle to increase to the preset speed. This makes driving in congested areas easier and less tiring.

FIGURE 58–6 Lane keep assist systems not only warns the driver that the vehicle is not staying within the lane of traffic, but will also uses the electric power steering to actually move the steering wheel to bring the vehicle back into the lane. This action can startle a driver if the driver has never experienced the vehicle taking control of the steering before.



TERMINOLOGY Depending on the manufacturer, adaptive cruise control is also referred to as the following:

- **Adaptive cruise control** (Audi, Ford, General Motors, and Hyundai)
- **Dynamic cruise control** (BMW, Toyota/Lexus)
- **Active cruise control** (Mini Cooper, BMW)
- **Autonomous cruise control** (Mercedes)

It uses forward-looking radar to sense the distance to the vehicle in front and maintains an assured clear distance. This type of cruise control system works within the following conditions:

- Speeds from 20 to 100 MPH (30 to 161 km/h)
- Designed to detect objects as far away as 500 feet (150 m)

The cruise control system is able to sense both distance and relative speed. ● **SEE FIGURE 58–7**.

PARTS AND OPERATION Radar cruise control systems use long-range radar (LRR) to detect faraway objects in front of the moving vehicle. Some systems use a short-range radar (SRR) and/or infrared (IR) or optical cameras to detect when the distance between the moving vehicle and another vehicle in front is reduced. ● **SEE FIGURE 58–8**.

The radar frequencies include the following:

- 76 to 77 GHz (long-range radar)
- 24 GHz (short-range radar)

DIAGNOSIS AND SERVICE If the radar cruise control is not working properly, begin by making sure the sensor, which is usually behind the grille on most vehicles, is not covered. The system does not operate if the system is covered by heavy mud, ice, or snow. Additionally, some aftermarket vehicle front covers obstruct the sensor view. If the sensor is replaced, some systems require a re-alignment using special tools. Always refer to the manufacturer's service information for specific instructions.

CASE STUDY

The Case of The Inoperative Radar Cruise Control

The driver of a Lexus NX experienced a situation where the radar cruise control stopped working due to ice on the sensor after driving through light snow showers. When the front was checked, it was discovered that ice had accumulated on the front grille. Using an ice scraper brush, the grille was cleaned, which restored the proper operation of the radar cruise control. ● **SEE FIGURE 58–9**.

In automated vehicles, the sensors need to be heated, and maybe cleaned, so that they can operate under all driving conditions.

Summary:

Complaint—Radar cruise stopped working and a message appeared to clean the sensor.

Cause—Ice buildup on the grille.

Correction—Cleaning the front of the grille, using a brush restored the proper operation of the radar cruise control.

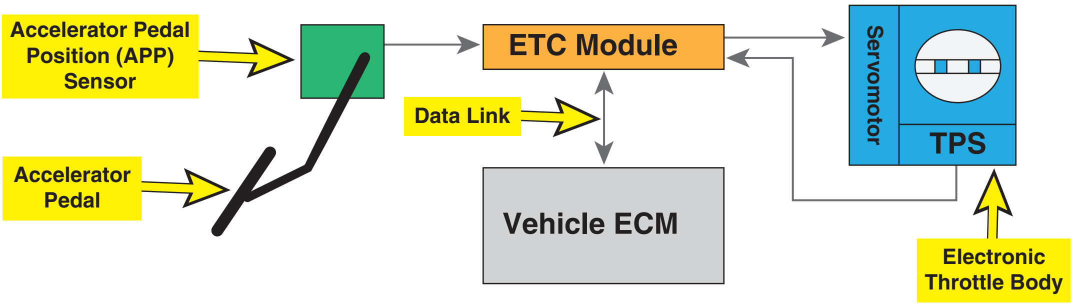


FIGURE 58–7 Adaptive cruise control can use radar to determine the distance of another vehicle in front. The control unit checks the driver's selected speed and sets the distance between the vehicles to determine what action is needed. The PCM then can operate the throttle or the brakes through the antilock brake/electronic stability control system to slow the vehicle, if needed, to maintain the set distance.

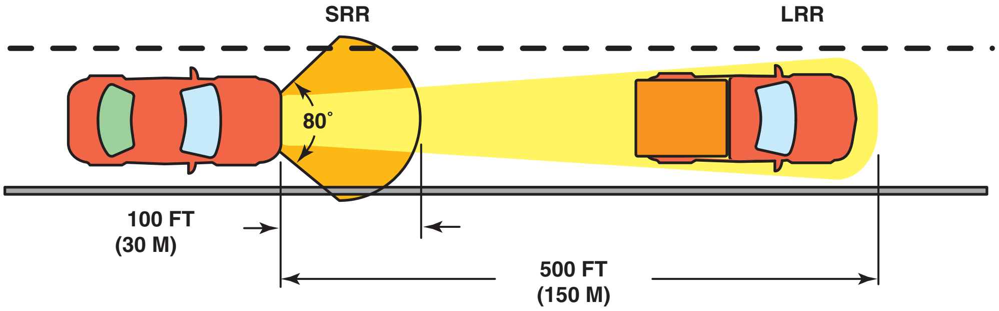
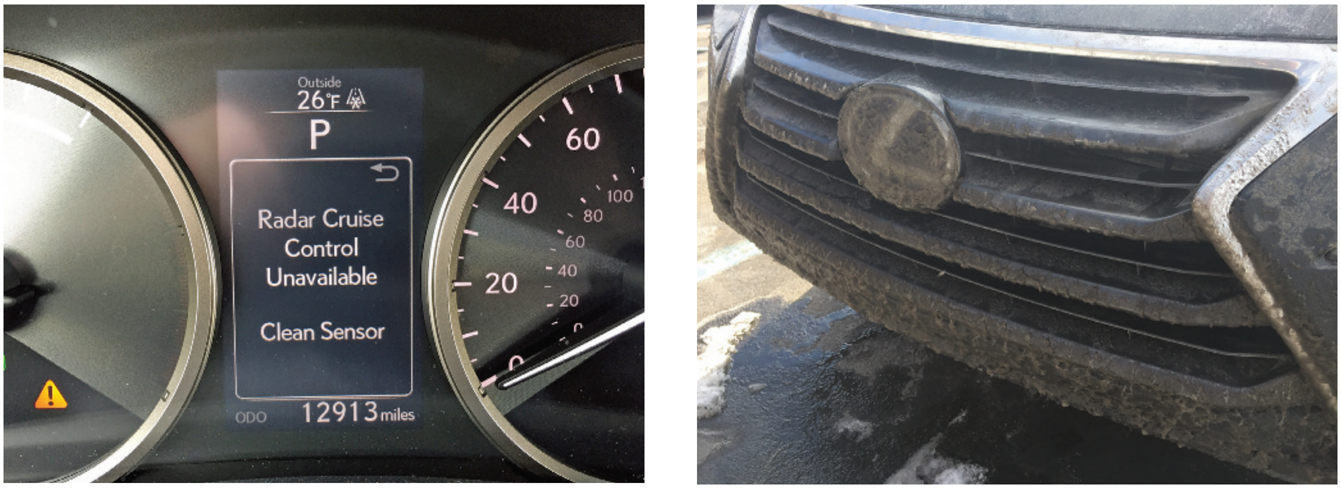


FIGURE 58–8 Most radar cruise control systems use radar, both long and short range. Some systems use optical or infrared cameras to detect objects.



(a)

(b)

FIGURE 58–9 (a) This dash warning message appeared when the cruise control stopped working. (b) The front of a Lexus shows some ice buildup that was enough to block the radar signals needed for the radar cruise control to work.

FREQUENTLY ASKED QUESTION

What Is Intelligent Speed Advice (ISA)?

Intelligent Speed Advice (ISA) uses a sign recognition camera or a navigation system (GPS) to determine the speed limit, which is used to warn the driver of the posted speed limit. Some ISA systems automatically limit the speed of the vehicle by limiting engine power to prevent the vehicle from accelerating past the current speed limit unless overridden. The European New Car Assessment Program (Euro NCAP) is a European car safety performance assessment program which is awarding vehicle manufacturers if their vehicle is equipped with this system.

REAR CROSS-TRAFFIC WARNING (RCTW)

PURPOSE AND FUNCTION A **rear cross-traffic warning (RCTW)** system sounds an audible warning when a vehicle is crossing at the rear while backing. Some vehicles are capable of automatically braking to avoid a collision.

PARTS AND OPERATION Rear cross-traffic alert is used to warn the driver when backing from a parking space if there is a vehicle approaching from either side. The system uses radar sensors that are installed on both sides of the vehicle near the rear bumper. These sensors are able to detect vehicles approaching from the left or right side of the vehicle. These sensors activate when the vehicle is placed in reverse and can detect vehicles from up to 65 feet (20 m) on either side. The system is usually designed to function under the following conditions:

- When the vehicle is in reverse and your speed is less than 5 MPH (8 km/h)
- The system is designed to detect other vehicles approaching between 5 and 18 MPH (8 to 29 km/h).

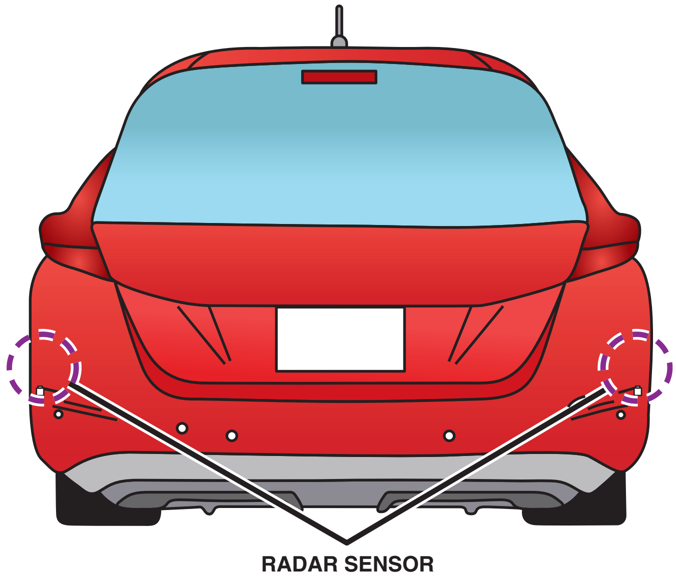


FIGURE 58–10 Rear cross-traffic warning systems use radar sensors at the rear corners of the vehicle which are able to detect a moving vehicle approaching from the sides.

- If a vehicle is detected, the system will sound a warning and often flash the side mirror indicators.
- Rear cross-traffic alert may not work if one of the rear sensors is blocked or during heavy rain or snow.

● **SEE FIGURES 58–10 AND 58–11**.

AUTOMATIC EMERGENCY BRAKING

PURPOSE AND FUNCTION An **automatic emergency braking (AEB)** system intervenes and automatically applies the brakes if needed. Automatic braking is often part of a safety package that includes radar cruise control, and will apply the brakes in the event of a possible collision. Sensors such as radar, sonar, and/or cameras are used depending on the system to

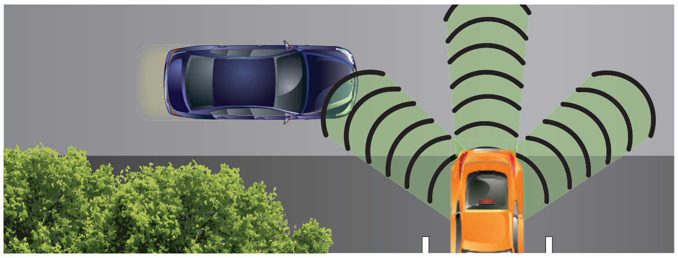


FIGURE 58–11 If a vehicle is approaching from the side when the gear selector is in reverse, a warning is sounded.

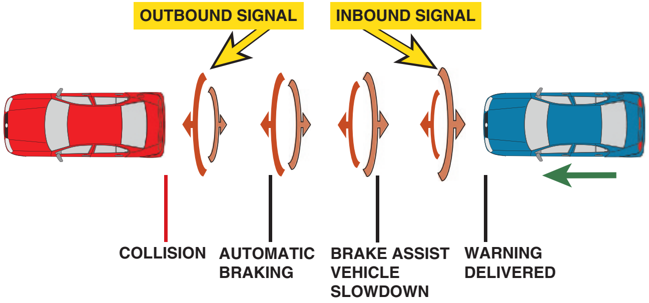


FIGURE 58–12 Sensors are used to detect when the distance is closing fast enough that a collision may be possible, and the system intervenes to automatically apply the brakes if needed.

detect the distance to another object. The controller, usually an antilock braking system (ABS) controller, then issues a warning if a collision is possible.

This warning can include one or more of the following:

1. A buzzer
2. A warning light flashing on the dash
3. A vibration of the driver's seat

If the warnings are ignored, the automatic braking system will intervene and either provide brake assist or apply the brakes autonomously (by itself) to achieve maximum braking in an effort to avoid a collision. ● **SEE FIGURE 58–12**.

PRE-COLLISION SYSTEM

PURPOSE AND FUNCTION The purpose and function of a pre-collision system is to monitor the road ahead and prepare to avoid a collision, and to protect the driver and passengers.

A pre-collision or a collision avoidance system uses the following systems:

1. The long-range and short-range radar or detection systems used by a radar cruise control system to detect objects in front of the vehicle
2. Antilock brake system (ABS)
3. Adaptive (radar) cruise control
4. Brake assist system

TERMINOLOGY Pre-collision systems can be called by various names, depending on the make of the vehicle. Some commonly used names for a pre-collision or pre-crash system include the following:

- **Ford/Lincoln:** Collision Warning with Brake Support
- **Honda/Acura:** Collision Mitigation Brake System (CMBS)
- **Mercedes-Benz:** Pre-Safe or Attention Assist
- **Toyota/Lexus:** Pre-Collision System (PCS) or Advanced Pre-Collision System (APCS)
- **General Motors:** Pre-Collision System (PCS)
- **Volvo:** Collision Warning with Brake Support or Collision Warning with Brake Assist Operation

The system functions by monitoring objects in front of the vehicle and can act to avoid a collision by the following actions:

- Sounds an alarm
- Flashes a warning lamp
- Applies the brakes and brings the vehicle to a full stop (if needed), if the driver does not react following actions:

1. Applies the brakes in full force to reduce vehicle speed as much as possible.
2. Closes all windows and the sunroof to prevent the occupants from being ejected from the vehicle.
3. Moves the seats to an upright position.
4. Raises the headrest (if electrically powered).
5. Pretensions the seat belts.
6. Airbags and seat belt tensioners function as designed during the collision.

● **SEE FIGURE 58–13**.

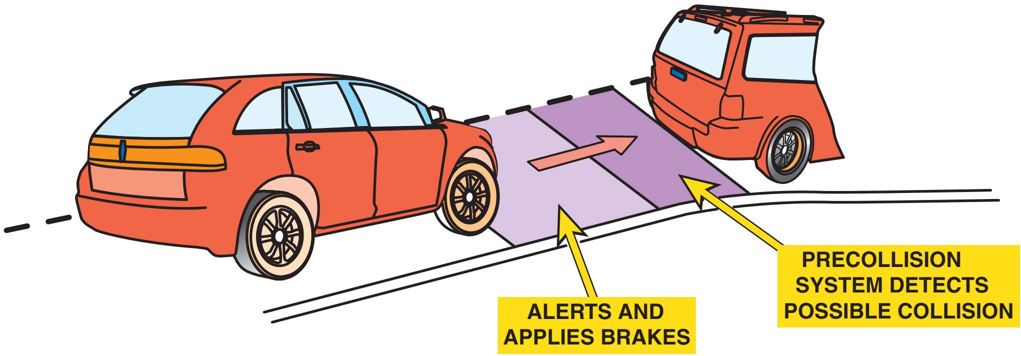

PRECOLLISION SYSTEM DETECTS POSSIBLE COLLISION
ALERTS AND APPLIES BRAKES

FIGURE 58–13 A pre-collision system is designed to prevent a collision first, and interacts to prepare for a collision, if needed.

HILL START ASSIST

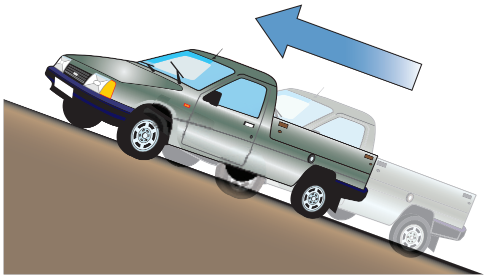
PURPOSE AND FUNCTION The hill start assist feature allows the driver to launch his vehicle without a rollback while moving the foot from the brake pedal to the accelerator pedal. The electronic brake control module calculates the brake pressure that is needed to hold the vehicle on an incline, and locks that pressure for a certain time by commanding the appropriate solenoid valves on and off when the brake pedal is released. Hill start assist is activated when the electronic brake control module determines that the driver wishes to move their vehicle uphill, either backward or forward. ● **SEE FIGURE 58–14**.

The following inputs are used for the hill start assist feature:

- Brake switch
- Brake pressure sensors
- Longitudinal acceleration sensor
- Engine torque
- Reverse gear information
- Clutch switch
- Accelerator pedal position
- Vehicle speed

Drivers of vehicles equipped with hill start assist systems are often not aware that the vehicle is equipped with this system. As a result, it is often a concern of drivers when the brake pedal is released when starting forward after being stopped on a hill (the brakes seem to be slow to release). This is normal and not a fault with the system.

WITH HILL START ASSIST



WITHOUT HILL START ASSIST

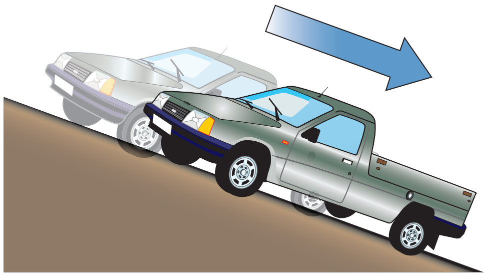


FIGURE 58–14 A hill start assist system applies the brakes when the system detects that the vehicle is stopped on a hill, either down or up. This system keeps the vehicle from rolling down the hill without requiring the driver to keep the brakes applied.

ADAS DIAGNOSIS

VIN DECODER To identify what ADAS a vehicle is equipped with, use the vehicle identification number (VIN), or the regular production order (RPO) for vehicles built by General Motors. There are many online VIN decoders available, including one on the National Highways Traffic Safety Administration (NHTSA) website. Visit https://vpic.nhtsa.dot.gov/decoder/

At this site, enter the VIN and select “decode.” The results will show all of the ADAS used on that specified vehicle.

DIAGNOSTIC STEPS Similar to troubleshooting any other system or fault, the steps in the diagnostic procedure include the following:

STEP 1 Verify the customer concern. Check the customer concern and determine that it is a true fault and not a misunderstanding on how the system is supposed to work.

STEP 2 Perform a visual inspection. Check for any physical faults that could affect the operation of the advanced driver assist system, such as road debris and/or minor collision damage.

STEP 3 Check for any stored or pending diagnostic trouble codes. Check all modules by performing a full module scan to check for faults in all of the modules.

STEP 4 Check service information for the specified procedure to follow to service or repair the verified fault.

STEP 5 Perform the specified procedure and static calibrations of the sensors as needed.

STEP 6 Perform the specified dynamic celebration of the sensors as needed.

STEP 7 Test drive the vehicle under the same operating conditions that were used to verify the fault to verify the repair.

STEP 8 Clear all advanced driver assist system-related diagnostic trouble codes (DTCs) and return the vehicle to the customer.

CAMERA AND RADAR SENSOR CALIBRATION

CAMERA CALIBRATION The operation of the camera can be affected by heavy rain, snow, or an accumulation of ice or mud. Before making any repairs, it is important to verify that the lens of the camera is free of anything that obstructs its view.

Calibration of the camera is required when one or more cameras are replaced on a mounting component, such as a windshield, bumper cover, mirror, or door. The calibration is an in-shop static process. Large patterned mats are placed around the vehicle at specific locations and the scan tool is used to initiate the process. ● **SEE FIGURE 58–15**.

TYPICAL PROCEDURE Some camera systems require a specific target so that the camera can be calibrated. Some vehicles that do not require a special target require a factory or factory-level

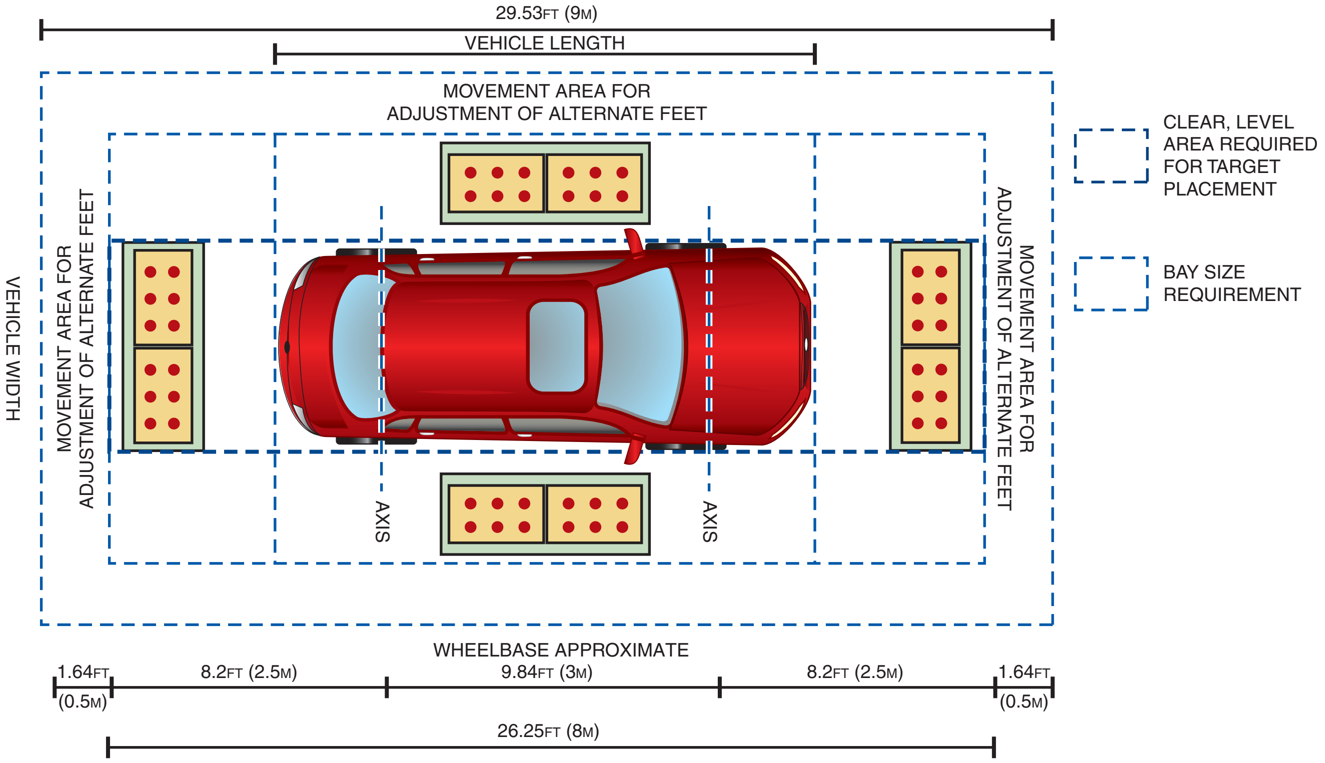

29.53FT (9M)
VEHICLE LENGTH
MOVEMENT AREA FOR ADJUSTMENT OF ALTERNATE FEET
CLEAR, LEVEL AREA REQUIRED FOR TARGET PLACEMENT
BAY SIZE REQUIREMENT
VEHICLE WIDTH
MOVEMENT AREA FOR ADJUSTMENT OF ALTERNATE FEET
MOVEMENT AREA FOR ADJUSTMENT OF ALTERNATE FEET
AXIS
AXIS
WHEELBASE APPROXIMATE
1.64FT (0.5M)
8.2FT (2.5M)
9.84FT (3M)
8.2FT (2.5M)
1.64FT (0.5M)
26.25FT (8M)

FIGURE 58–15 A typical camera calibration shop requirement to be used to calibrate the cameras on a vehicle equipped with advance driver assist systems. The area around the vehicle must be open and free from objects or windows that could affect the camera calibration.

scan tool to imitate the learning process. They will often use lines that are taped to the floor around the vehicle to use as a target. ● **SEE FIGURE 58–16**.

Some systems also require that the vehicle be driven at slow speeds under specific operating conditions to complete the learning. This process is used to do the final accurate calibrations.

Refer to service information for specific diagnostic and calibration information for the vehicle being serviced.

RADAR CALIBRATION Calibration of the radar is required anytime the unit is replaced or reinstalled. In many cases, the calibration procedure must be performed anytime a grille or fascia is removed or replaced. The calibration process may be static (in the shop), or dynamic (on the road), or a combination of the two. The static process involves the use of a scan tool and an aiming procedure. The aiming procedure requires manufacturer-specific targets. ● **SEE FIGURES 58–17 AND 58–18**.

Check service information for specific diagnostic and calibration information for the vehicle being serviced.

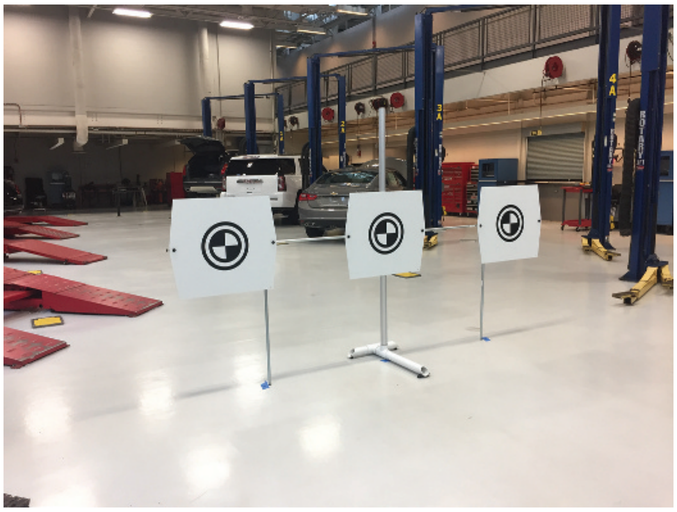


FIGURE 58–16 A typical target setup required to calibrate the camera on a vehicle equipped with an advanced driver assist system. Always follow the specified calibration procedure for the vehicle being serviced.

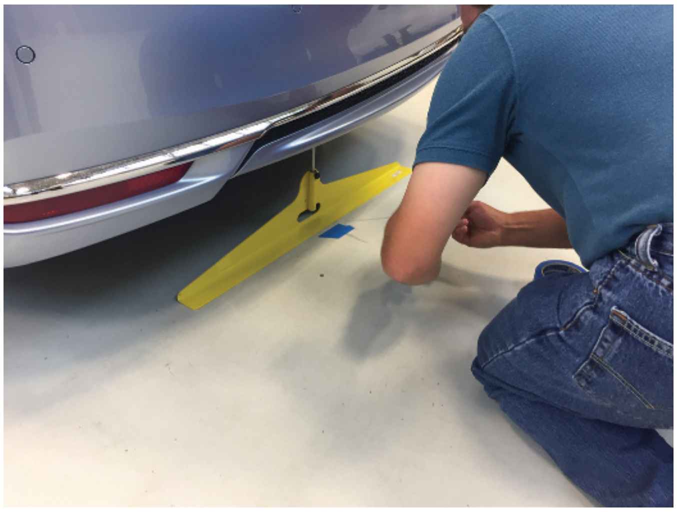


FIGURE 58–17 Before the radar sensor can be calibrated, the target must be installed at a very precise location at the front of the vehicle. The measurements involved include finding the exact center of the vehicle often using a special tool as shown.

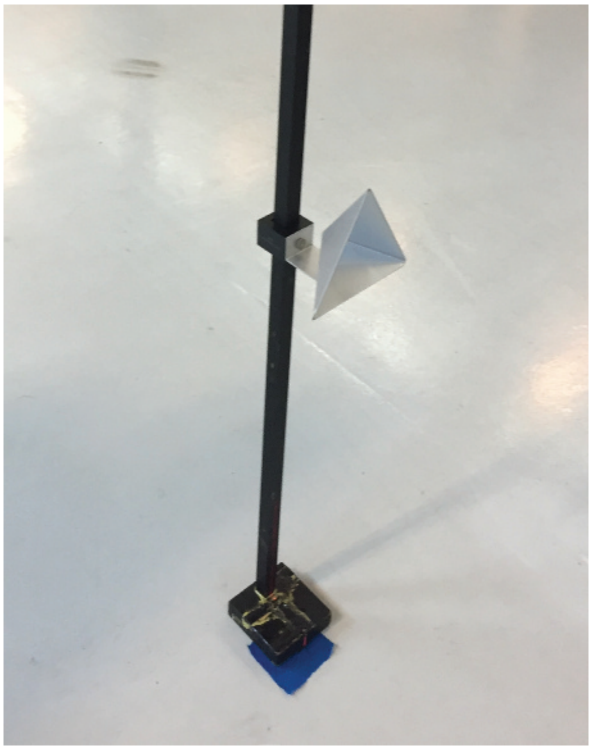


FIGURE 58–18 A typical radar target being placed in the specified position after careful measurements from the centerline of the vehicle and the exact distance from the front and at the specified height.

REVIEW QUESTIONS

1. Parking-assist systems use what type of sensor?
2. What is the difference between a lane departure warning and a lane keep assist?
3. What type of sensors are used in adaptive cruise control systems?
4. What type of sensors are used in automatic emergency braking and pre-collision control systems?
5. What is the purpose and function of advanced driver assist systems?

CHAPTER QUIZ

1. What is *not* a function of advanced driver assist systems?
   - **a.** Self-drive capability
   - **b.** Take the load off the driver
   - **c.** Help the driver avoid a collision if a vehicle in front of them stops quickly
   - **d.** Alert the driver of a potential issue
2. Blind spot monitor (BSM) and lane departure warnings can be __________.
   - **a.** visual
   - **b.** audible
   - **c.** vibrating (tactile)
   - **d.** Any of the above
3. Self-parking vehicles use __________ and control the __________ to control the vehicle into a parking space.
   - **a.** radar; throttle
   - **b.** camera; electric power steering
   - **c.** sonic sensor; brakes
   - **d.** radar; electric power steering
4. The purpose of lane keep assist (LKA) is __________.
   - **a.** to warn the driver if moving out of a lane
   - **b.** used with adaptive cruise control to self-drive the vehicle without driver input or control
   - **c.** to use the electric power steering to keep the vehicle within the lane
   - **d.** Both a and c
5. A driver complains that the brakes seem to release slowly at times, usually when stopped on a hill. This is normal operation of the __________ system.
   - **a.** hill start assist
   - **b.** adaptive cruise control
   - **c.** pre-collision
   - **d.** automatic emergency braking
6. Adaptive cruise control systems can also be called __________.
   - **a.** dynamic cruise control
   - **b.** active cruise control
   - **c.** radar cruise control
   - **d.** Any of the above
7. Rear cross-traffic alert is used to warn the driver when backing out from a parking space if there is a vehicle approaching from either side. The system uses __________ installed on both sides of the vehicle near the rear bumper.
   - **a.** sonar
   - **b.** ultrasonic sensors
   - **c.** radar
   - **d.** cameras

8. Automatic braking uses a ___________ to warn of a possible collision.
- **a.** buzzer
- **b.** flashing light
- **c.** vibrating brake pedal
- **d.** Either a or b

9. A parking-assist system works to warn the driver if the vehicle is getting close to an object. What type of object *cannot* be detected by most systems?
- **a.** Objects larger than 3 inches (8 cm) wide
- **b.** Objects larger than 10 inches (25 cm) high
- **c.** Objects under the vehicle
- **d.** Any of the above

10. Calibrating radar and cameras involves all of the following *except* ___________.
- **a.** factory or factory-level scan tool
- **b.** special targets set at precisely specified location around the vehicle
- **c.** both static (stationary) and dynamic (moving) calibration is required
- **d.** driving the vehicle in a circle 10 times to calibrate the cameras

Chapter 59

AUDIO SYSTEM OPERATION AND DIAGNOSIS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss audio system fundamentals.
- Describe radios and receivers.
- Describe types of antennas and antenna testing.
- Discuss the purpose and function of speakers.
- Describe types of speakers.
- Explain the decibel scale.
- Discuss voice recognition systems.
- Explain how Bluetooth systems work.
- Explain how satellite radio systems work.

KEY TERMS:

AM 704 • Bluetooth 708 • Decibel (dB) 707 • FM 704 • Frequency 703 • Hertz (Hz) 704 • Modulation 704 • Radio frequency (RF) 703 • SDARS 708 • Speakers 705 • Voice recognition 707

AUDIO FUNDAMENTALS

INTRODUCTION The audio system of today's vehicles is a complex combination of antenna system, receiver, amplifier, and speakers, all designed to provide living room–type music reproduction while the vehicle is traveling in city traffic or at highway speed.

Audio systems produce audible sounds and include the following:

- Radio (AM, FM, and satellite)
- Antenna systems that are used to capture electronic energy broadcast to radios
- Speaker systems
- Aftermarket enhancement devices that increase the sound energy output of an audio system
- Diagnosis of audio-related problems

Many audio-related problems can be addressed and repaired by a service technician.

TYPES OF ENERGY There are two types of energy that affect audio systems:

- **Electromagnetic energy or radio waves.** Antennas capture the radio waves, which are then sent to the radio or receiver to be amplified.
- **Acoustical energy, usually called sound.** Radios and receivers amplify the radio wave signals and drive speakers, which reproduce the original sound as transmitted by radio waves.
● **SEE FIGURE 59–1**.

TERMINOLOGY Radio waves travel at approximately the speed of light (186,282,000 miles per second) and are electromagnetic. Radio waves are measured in two ways, wavelength and frequency. A radio wave has a series of high points and low points. A wavelength is the time and distance between two consecutive points, either high or low. Wavelength is measured in meters. **Frequency**, also known as **radio frequency (RF)**, is the number of times a particular waveform repeats itself in a

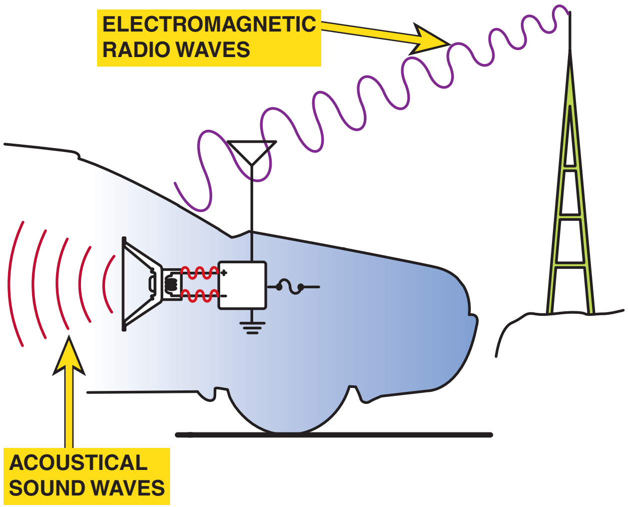


FIGURE 59–1 Audio systems use both electromagnetic radio waves and sound waves to reproduce sound inside the vehicle.

given amount of time and is measured in **hertz (Hz)**. A signal with a frequency of 1 Hz is one radio wavelength per second. Radio frequencies are measured in kilohertz (kHz), thousands of wavelengths per second, and megahertz (MHz), millions of wavelengths per second. ● **SEE FIGURE 59–2**.

- The higher the frequency, the shorter the wavelength.
- The lower the frequency, the longer the wavelength.

A longer wavelength can travel a further distance than a shorter wavelength. Therefore, lower frequencies provide better reception at further distances.

- AM radio frequencies range from 530 to 1,710 kHz.
- FM radio frequencies range from 87.9 to 107.9 MHz.

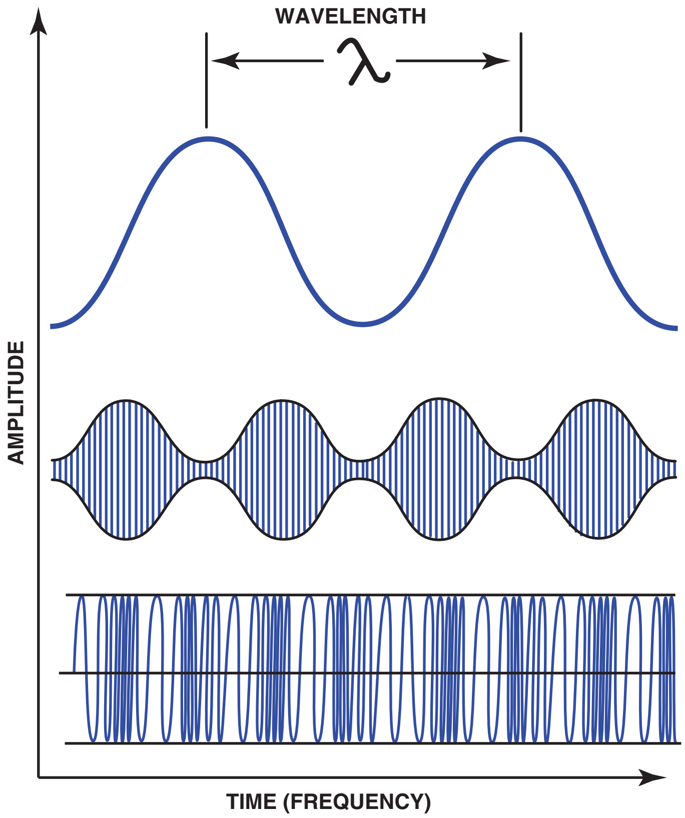


FIGURE 59–2 The relationship among wavelength, frequency, and amplitude.

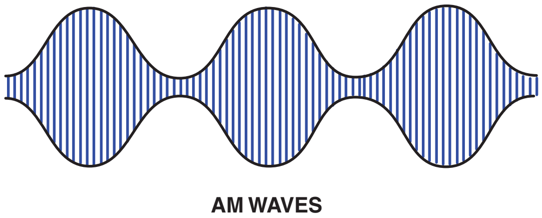


FIGURE 59–3 The amplitude changes in AM broadcasting.

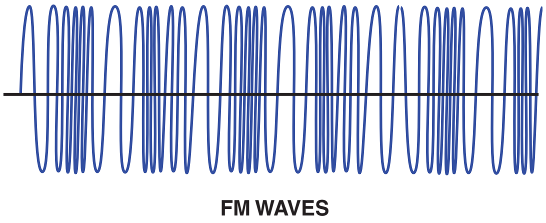


FIGURE 59–4 The frequency changes in FM broadcasting and the amplitude remains constant.

MODULATION **Modulation** is the term used to describe when information is added to a constant frequency. The base radio frequency used for RF is called the *carrier wave.* A carrier is a radio wave that is changed to carry information. The two types of modulation are:

- **Amplitude modulation (AM)**
- **Frequency modulation (FM)**

AM waves are radio waves that have amplitude that can be varied, transmitted, and detected by a receiver. Amplitude is the height of the wave as graphed on an oscilloscope. ● **SEE FIGURE 59–3**.

FM waves are also radio waves that have a frequency that can be varied, transmitted, and detected by a receiver. This type of modulation changes the number of cycles per second, or frequency, to carry the information. ● **SEE FIGURE 59–4**.

RADIO WAVE TRANSMISSION More than one signal can be carried by a radio wave. This process is called *sideband operation.* Sideband frequencies are measured in kilohertz. The amount of the signal above the assigned frequency is referred to as the upper sideband. The amount of the signal below the assigned frequency is called the lower sideband. This capability allows radio signals to carry stereo broadcasts. Stereo broadcasts use the upper sideband to carry one channel of the stereo signal and

FREQUENTLY ASKED QUESTION

What Does a “Capture” Problem Mean?

A capture problem affects only FM reception and means that the receiver is playing more than one station if two stations are broadcasting at the same frequency. Most radios capture the stronger signal and block the weaker signal. However, if the stronger signal is weakened due to being blocked by buildings or mountains, the weaker signal is then used. When this occurs, it sounds as if the radio is changing stations by itself. This is not a fault with the radio, but simply a rare occurrence with FM radio.

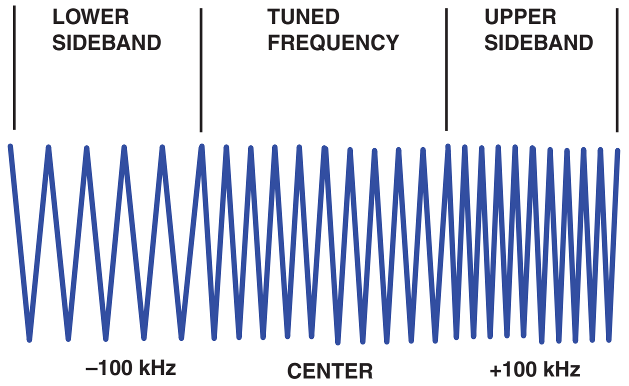


FIGURE 59–5 Using upper and lower sidebands allows stereo to be broadcast. The receiver separates the signals to provide left and right channels.

the lower sideband to carry the other channel. When the signal is decoded by the radio, these two signals become the right and left channels. ● **SEE FIGURE 59–5**.

NOISE Because radio waves are a form of electromagnetic energy, other forms of energy can impact them. For example, a bolt of lightning generates broad radio-frequency bandwidths known as radio-frequency interference (RFI). RFI is one type of electromagnetic interference (EMI) and is the frequency that interferes with radio transmission.

AM CHARACTERISTICS AM radio reception can be achieved over long distances from the transmitter because the waves can bounce off the ionosphere, usually at night. Even during the day, the AM signals can be picked up some distance from the transmitter. AM radio reception depends on a good antenna. If there is a fault in the antenna circuit, AM reception is affected the most.

FM CHARACTERISTICS Because FM waves have a high RF and a short wavelength, they travel only a short distance. The waves cannot follow the shape of the earth but instead travel in a straight line from the transmitter to the receiver. FM waves travel through the ionosphere and into space and do not reflect back to earth like AM waves.

MULTIPATH Multipath is caused by reflected, refracted, or line-sight signals reaching an antenna at different times. Multipath results from the radio receiving two signals to process on the same frequency. This causes an echo effect in the speakers. *Flutter,* or *picket fencing* as it is sometimes called, is caused by the blocking of part of the FM signal. This blocking causes a weakening of the signal resulting in only part of the signal getting to the antenna, causing an on-again off-again radio sound. Flutter also occurs when the transmitter and the receiving antenna are far apart.

RADIOS AND RECEIVERS

The antenna receives the radio wave where it is converted into very weak fluctuating electrical current. This current travels along the antenna lead-in to the radio that amplifies the signal and sends the new signal to the speakers where it is converted into acoustical energy.

Most late-model radios and receivers use five input/output circuits:

1. **Power.** Usually a constant 12 volt feed to keep the internal clock alive.
2. **Ground.** This is the lowest voltage in the circuit and connects indirectly to the negative terminal of the battery.
3. **Serial data.** Used to turn the unit on and off and provide other functions, such as steering wheel control operation.
4. **Antenna input.** From one or more antennas.
5. **Speaker outputs.** These wires connect the receiver to the speakers or as an input to an amplifier.

ANTENNAS

TYPES OF ANTENNAS The typical radio electromagnetic energy from the broadcast antenna induces a signal in the antenna that is very small, only about 25 microvolts AC (0.000025 volt AC), in strength. The radio contains amplifier circuits that increase the received signal strength into usable information.

For example, some types of antennas used on vehicles include the following:

- **Rear window defogger grid.** This type of system uses the heating wires to receive the signals and special circuitry to separate the RF from the DC heater circuit.
- **Fixed mast antenna.** The mast is simply a vertical rod. Mast antennas are typically located on the fender or rear quarter panel of the vehicle.
- **Integrated antenna.** This type of antenna is sandwiched in the windshield and an appliqué on the rear window glass. The antenna in the rear window is the primary antenna and receives both AM and FM signals. The secondary antenna is located in the front windshield typically on the passenger side of the vehicle. This antenna receives only FM signals.
- **Shark-fin antenna.** This type of antenna contains multiple antennas, including radio, GPS, and cellular system antennas.

ANTENNA HEIGHT The antenna collects all radio-frequency signals. An AM radio operates best with as long an antenna as possible, but FM reception is best when the antenna height is exactly 31 inches (79 cm). Most fixed-length antennas are, therefore, exactly this height. Even the horizontal section of a windshield antenna is 31 inches (79 cm) long.

A defective antenna:

- Greatly affects AM radio reception
- May affect FM radio reception

ANTENNA TESTING If the antenna or lead-in cable is broken (open), FM reception is heard but may be weak, and there is *no* AM reception. An ohmmeter should read infinity between the center antenna lead and the antenna case. For proper reception and lack of noise, the case of the antenna must be properly grounded to the vehicle body. ● **SEE FIGURE 59–6**.

SPEAKERS

PURPOSE AND FUNCTION The purpose of any **speaker** is to reproduce the original sound as accurately as possible. Speakers are also called *loudspeakers.* The human ear is capable of hearing sounds from a very low frequency of 20 Hz (cycles per seconds)

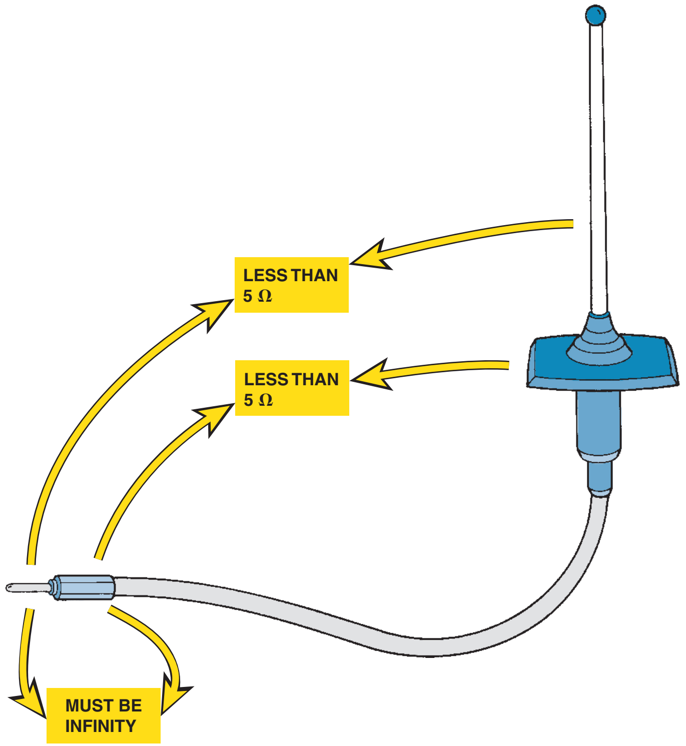


FIGURE 59–6 If all ohmmeter readings are satisfactory, the antenna is good.

to as high as 20,000 Hz. No one speaker is capable of reproducing sound over such a wide frequency range. ● **SEE FIGURE 59–7**.

Good-quality speakers are the key to a proper sounding radio or sound system. Replacement speakers should be securely mounted and wired according to the correct *polarity*. ● **SEE FIGURE 59–8**.

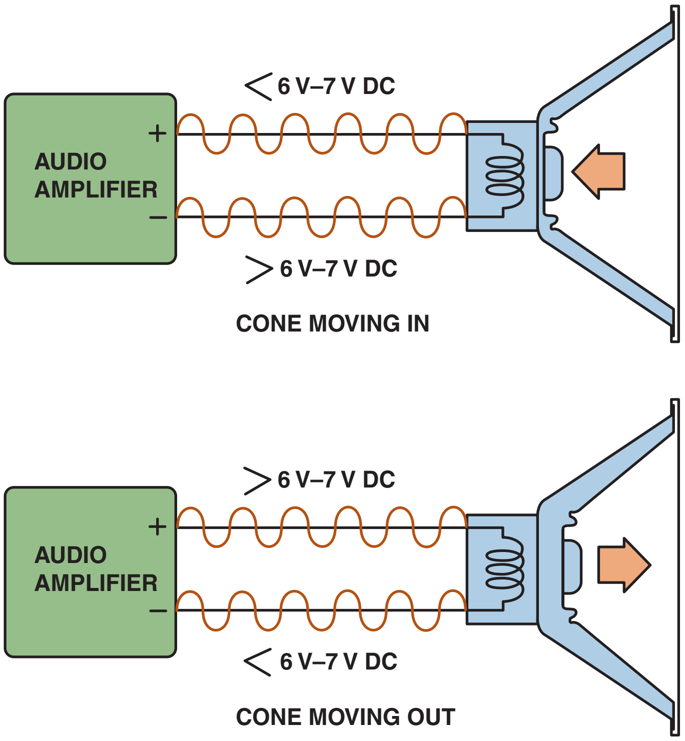


FIGURE 59–7 Between 6 and 7 volts is applied to each speaker terminal, and the audio amplifier then increases the voltage on one terminal and at the same time decreases the voltage on the other terminal, causing the speaker cone to move. The moving cone then moves the air, causing sound.

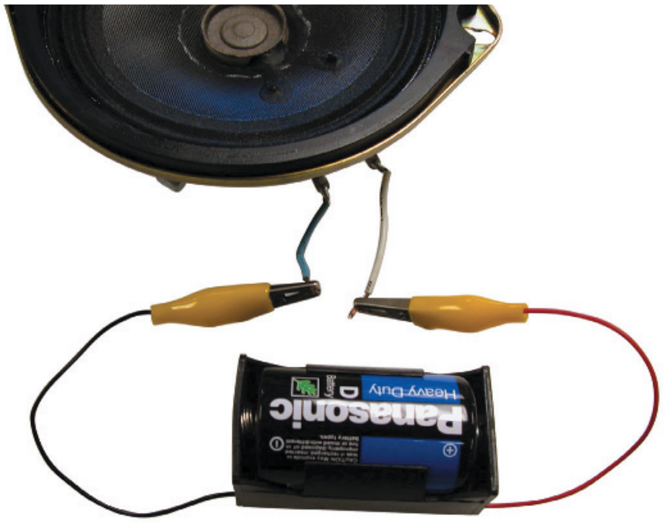


FIGURE 59–8 A typical automotive speaker with two terminals. The polarity of the speakers can be identified by looking at the wiring diagram in the service manual or by using a 1.5 volt battery to check. When the battery positive is applied to the positive terminal of the speaker, the cone moves outward. When the battery leads are reversed, the speaker cone moves inward.

SPEAKER WIRING The wire used for speakers should be as large a wire (as low an AWG number) as is practical in order to be assured that full power is reaching the speakers. Typical "speaker wire" is about 22 gauge (0.35 mm^2), yet tests conducted by audio engineers have concluded that increasing the wire gauge—up to 4 gauge (19 mm^2) or larger—greatly increases sound quality. All wiring connections should be soldered after making certain that all speaker connections have the correct polarity.

CAUTION: Regardless of radio speaker connections used, *never* operate any radio without the speakers connected, or the speaker driver section of the radio may be damaged as a result of the open speaker circuit.

SPEAKER TYPES

INTRODUCTION No one speaker is capable of reproducing sound over such a wide frequency range. Therefore, speakers are available in three basic types:

1. Tweeters are for high-frequency ranges.
2. Midrange are for mid-frequency ranges.
3. Woofers and subwoofers are for low-frequency ranges.

TWEETER A tweeter is a speaker designed to reproduce high-frequency sounds, usually between 4,000 and 20,000 Hz (4 and 20 kHz). Tweeters are very directional. This means that the human ear is most likely to be able to detect the location of the speaker while listening to music. This also means that a tweeter should be mounted in the vehicle where the sound can be directed in line of sight to the listener. Tweeters are usually mounted on the inside door near the top, windshield "A" pillar or similar locations.

MIDRANGE A midrange speaker is designed and manufactured to be able to best reproduce sounds in the middle of the

WARNING

Hearing loss is possible if exposed to loud sounds. According to noise experts (audiologists), hearing protection should be used whenever the following occurs:

1. You must raise your voice to be heard by others next to you.
2. You cannot hear someone else speaking who is less than 3 feet (1 m) away.
3. You are operating power equipment, such as a lawnmower.

human hearing range, from 400 to 5,000 Hz. Most people are sensitive to the sound produced by these midrange speakers. These speakers are also directional in that the listener can usually locate the source of the sound.

SUBWOOFER A subwoofer, sometimes called a *woofer,* produces the lowest frequency of sounds, usually 125 Hz and lower. A *midbass* speaker may also be used to reproduce those frequencies between 100 and 500 Hz. Low-frequency sounds from these speakers are *not* directional. This means that the listener usually cannot detect the source of the sound from these speakers. The low-frequency sounds seem to be everywhere in the vehicle, so the location of the speakers is not as critical as with the higher frequency speakers.

The subwoofer can be placed almost anywhere in the vehicle. Most subwoofers are mounted in the rear of the vehicle where there is more room for the larger subwoofer speakers.

SOUND LEVELS

DECIBEL SCALE A **decibel (dB)** is a measure of sound power, and it is the faintest sound a human can hear in the midband frequencies. The dB scale is not linear (straight line) but logarithmic, meaning that a small change in the dB reading results in a large change in volume of noise. An increase of 10 dB in sound pressure is equal to doubling the perceived volume. Therefore, a small difference in dB rating means a big difference in the sound volume of the speaker.

EXAMPLES Some examples of decibel sound levels include the following:

■ Quiet, faint	30 dB: whisper, quiet library
	40 dB: quiet room
■ Moderate	50 dB: moderate-range sound
	60 dB: normal conversation
■ Loud	70 dB: vacuum cleaner, city traffic
	80 dB: busy noisy traffic, vacuum cleaner
■ Extremely loud	90 dB: lawnmower, shop tools
	100 dB: chain saw, air drill
■ Hearing loss possible	110 dB: loud rock music

VOICE RECOGNITION

PARTS AND OPERATION **Voice recognition** is an expanding technology. It allows the driver of a vehicle to perform tasks, such as locate an address in a navigation system by using voice commands rather than buttons. In the past, users had to say the exact words to make it work such as the following examples listed from an owner's manual for a vehicle equipped with a voice-actuated navigation system:

"Go home"

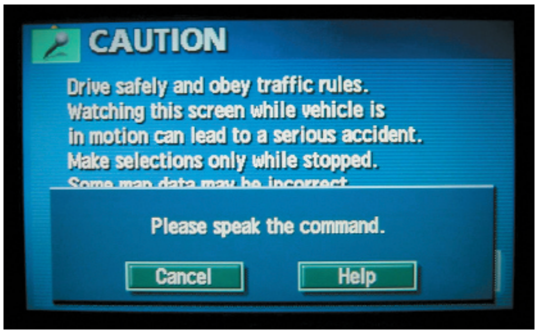
"Repeat guidance"

"Nearest ATM"

The problem with these simple voice commands was that the exact wording had to be spoken. The voice recognition software compares the voice command to a specific list of words or phrases stored in the system in order for a match to occur. Newer systems recognize speech patterns and take action based on learned patterns. Voice recognition can be used for the following functions:

1. Navigation system operation (● **SEE FIGURE 59–9**.)
2. Sound system operation
3. Climate control system operation
4. Telephone dialing and other related functions (● **SEE FIGURE 59–10**.)

A microphone is usually placed in the driver's side sun visor or in the overhead console in the center top portion of the windshield area.



CAUTION

Drive safely and obey traffic rules.
Watching this screen while vehicle is
in motion can lead to a serious accident.
Make selections only while stopped.
Some map data may be incorrect.

Please speak the command.

FIGURE 59–9 Voice commands can be used to control many functions, including navigation systems, climate control, telephone, and radio.

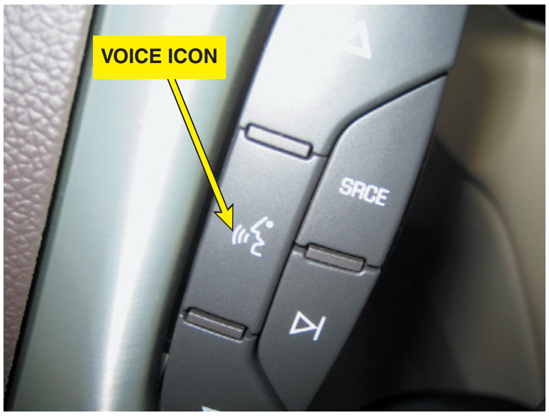


FIGURE 59–10 The voice command icon on the steering wheel of a Cadillac.

DIAGNOSIS AND SERVICE Voice recognition is usually incorporated into many functions of the vehicle. If a problem occurs with the system, perform the following steps:

1. Verify the customer complaint (concern). Check the owner's manual or service information for the proper voice commands and verify that the system is not functioning correctly.
2. Check for any aftermarket accessories that may interfere or were converted to components used by the voice recognition system, such as remote start units, MP3 players, or any other electrical component.
3. Check for stored diagnostic trouble codes (DTCs) using a scan tool.
4. Follow the recommended troubleshooting procedures as stated in service information.

BLUETOOTH

OPERATION **Bluetooth** is a (radio frequency) standard for short-range communications. The range of a typical Bluetooth device is 33 feet (10 m) and it operates in the ISM (industrial, scientific, and medical) band between 2.4000 and 2.4835 MHz.

Bluetooth is a wireless standard that works on two levels:

- It provides physical communication using low power, requiring only about 1 milliwatt (1/1,000 of a watt) of electrical power, making it suitable for use with small handheld or portable devices, such as an ear-mounted speaker/microphone.
- It provides a standard protocol for how bits of data are sent and received.

The Bluetooth standard is an advantage because it is wireless, low cost, and automatic. The automotive use of Bluetooth technology is in the operation of a cellular telephone being tied into the vehicle. The vehicle allows the use of hands-free telephone usage. A vehicle that is Bluetooth telephone equipped has the following components:

- A Bluetooth receiver can be built into the navigation or existing sound system.
- A microphone allows the driver to use voice commands as well as telephone conversations from the vehicle to the cell via Bluetooth wireless connections.

Many cell phones are equipped with Bluetooth, which may allow the caller to use an ear-mounted microphone and speaker. ● **SEE FIGURE 59–11**.

If the vehicle and the cell phone are equipped with Bluetooth, the speaker and microphone can be used as a hands-free telephone when the phone is in the vehicle. The cell phone can be activated in the vehicle by using voice commands.

FIGURE 59–11 Bluetooth earpiece that contains a microphone and speaker unit that is paired to a cellular phone. The telephone has to be within 33 feet (10 m) of the earpiece.

FREQUENTLY ASKED QUESTION

Where Did Bluetooth Get Its Name?

The early adopters of the standard used the term "Bluetooth," and they named it for Harold Bluetooth, the king of Denmark in the late 900s. The king was able to unite Denmark and part of Norway into a single kingdom.

FREQUENTLY ASKED QUESTION

Can Two Bluetooth Telephones Be Used in a Vehicle?

Usually, in order to use two telephones, the second phone needs to be given a name. When both telephones enter the vehicle, check which one is recognized. Say "phone status" and the system tells you to which telephone the system is responding. If it is not the one you want, simply say, "next phone" and it moves to the other one.

SATELLITE RADIO

PARTS AND OPERATION Satellite radio, also called **Satellite Digital Audio Radio Services** or **SDARS**, is a fee-based system that uses satellites to broadcast high-quality radio. SDARS broadcasts on the S-band of 2.1320 to 2.345 GHz.

SIRIUS/XM RADIO Sirius/XM radio is standard equipment but is optional in most vehicles. XM radio uses two satellites launched in 2001 called Rock (XM-2) and Roll (XM-1) in a geosynchronous orbit above North America. Two replacement satellites, Rhythm (XM-3) and Blues (XM-4), were launched in 2006. Sirius and XM radio combined in 2008 and now share some programming. The two types of satellite radios use different protocols and, therefore, require separate radios, unless a combination unit is purchased.

RECEPTION Reception from satellites can be affected by tall buildings and mountains. To help ensure consistent reception, both SDARS providers do the following:

- Include in the radio itself a buffer circuit that can store several seconds of broadcasts to provide service when traveling out of a service area
- Provide land-based repeater stations in most cities (● **SEE FIGURE 59–12**.)

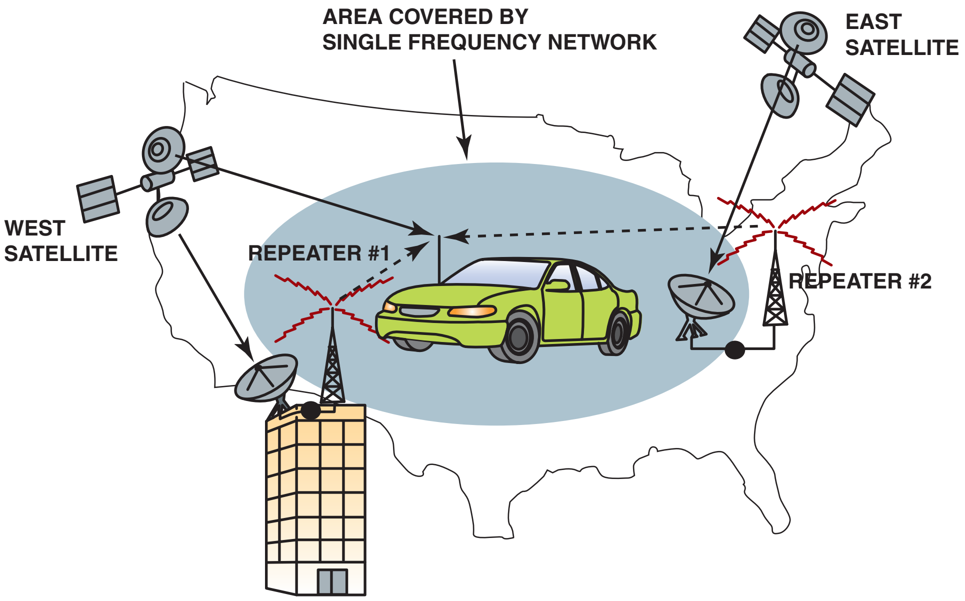


FIGURE 59–12 SDARS uses satellites and repeater stations to broadcast radio.

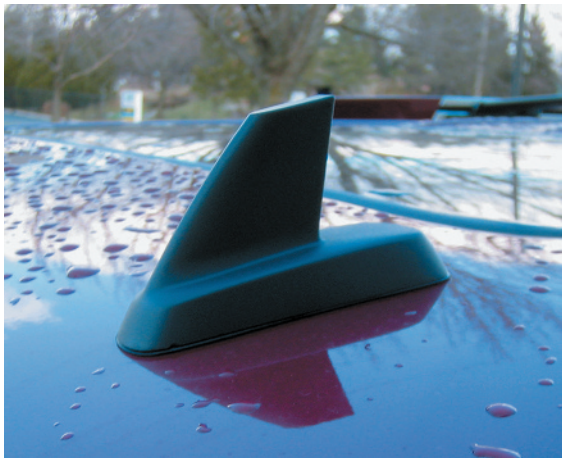


FIGURE 59–13 A shark-fin-type factory antenna used for both XM and OnStar.

ANTENNA To be able to receive satellite radio, the antenna needs to be able to receive signals from both the satellite and the repeater stations located in many large cities. There are various types and shapes of the antennas, ● **FIGURE 59–13**.

DIAGNOSIS AND SERVICE The first step in any diagnosis is to verify the customer complaint (concern). If no satellite service is being received, first check with the customer to verify that the monthly service fee has been paid and the account is up to date. If poor reception is the cause, carefully check the antenna for damage or faults with the lead-in wire. The antennas must be installed on a metal surface to provide the proper ground plane.

For all other satellite radio fault problems, check service information for the exact tests and procedures. Always follow the factory recommended procedures. Check the following websites for additional information:

- **www.xmradio.com**
- **www.sirius.com**
- **www.siriusxm.com**

FREQUENTLY ASKED QUESTION

What Does ESN Mean?

ESN means electronic serial number. This is necessary information to know when reviewing satellite radio subscriptions. Each radio has its own unique ESN, often found on a label at the back or bottom of the unit. It is also often shown on scan tools or test equipment designed to help diagnose faults in the units.

CASE STUDY

Lightning Damage

A radio failed to work in a vehicle that was outside during a thunderstorm. The technician checked the fuses and verified that power was reaching the radio. Then the technician noticed the antenna. It had been struck by lightning. Obviously, the high voltage from the lightning strike traveled to the radio receiver and damaged the circuits. Both the radio and the antenna were replaced to correct the problem. ● **SEE FIGURE 59–14**.

Summary:

Complaint—Customer stated that the radio did not work.
Cause—Visual inspection showed an antenna that had been stuck by lightning.
Correction—Replacing the radio and the antenna restored proper operation.

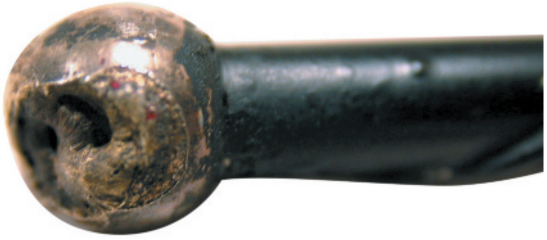


FIGURE 59–14 The tip of this antenna was struck by lightning.

REVIEW QUESTIONS

1. Why do AM signals travel farther than FM signals?
2. What is meant by the term modulation?
3. What is the typical range of Bluetooth?
4. What type of antenna is usually used for satellite radio reception?
5. What can affect the reception of a satellite radio signal?

CHAPTER QUIZ

1. Technician A says that a radio can receive AM signals, but not FM signals, if the antenna is defective. Technician B says that a good antenna should give a reading of about 500 ohms when tested with an ohmmeter between the center antenna wire and ground. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. An antenna lead-in wire should have how many ohms of resistance between the center terminal and the grounded outer covering?
   - **a.** Less than 5 ohms
   - **b.** 5 to 50 ohms
   - **c.** 300 to 500 ohms
   - **d.** Infinity (OL)
3. __________ is the term used to describe when information is added to a constant frequency.
   - **a.** Frequency
   - **b.** Modulation
   - **c.** Radio wave transmission
   - **d.** Any of the above
4. The number of times a particular waveform repeats itself in a given amount of time is measured in __________.
   - **a.** Hertz
   - **b.** AM
   - **c.** FM
   - **d.** RF
5. Receivers have what inputs/outputs?
   - **a.** Power and ground
   - **b.** Serial data
   - **c.** Antenna input
   - **d.** All of the above
6. Radio frequencies are measured in __________.
   - **a.** kHz
   - **b.** MHz
   - **c.** volts
   - **d.** Either a or b
7. What is a measure of sound power?
   - **a.** Amperes
   - **b.** Volts
   - **c.** Decibel (dB)
   - **d.** Any of the above
8. Bluetooth is a __________.
   - **a.** type of radio receiver
   - **b.** radio frequency standard for short-range communications
   - **c.** type of headphones
   - **d.** type of earpiece
9. Sirius/XM radio service uses __________ to transmit the audio signal.
   - **a.** satellites
   - **b.** repeater towers
   - **c.** Both a and b
   - **d.** Neither a nor b
10. Voice recognition can be used for __________.
    - **a.** navigation system operation
    - **b.** sound and climatic control system operation
    - **c.** telephone dialing and other related functions
    - **d.** Any of the above

SECTION VIII

HVAC (A7)

CHAPTERS

60 Heating and Air-Conditioning Principles
61 A/C System Components, Operation, and Service
62 Air Management System
63 Automatic Air-Conditioning and Heat Pump Systems
64 Refrigerants and Refrigerant Oils
65 Refrigerant Recovery, Recycling, and Recharging
66 Air-Conditioning System Diagnosis and Service

Chapter 60

HEATING AND AIR-CONDITIONING PRINCIPLES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss automotive heating, ventilation, and air-conditioning systems, including changes of state, the effects of heat on matter, and humidity.
- Explain heating and cooling load.
- Explain the three ways in which heat flows.
- Describe the air-conditioning process.
- Explain the purpose of an HVAC system.

KEY TERMS:

Absolute humidity 713 • British thermal unit (BTU) 712 • Cabin filter 718 • Calorie 712 • Cooling load 715 • Comfort zone 713 • Evaporative cooling 715 • Heat 712 • Heater core 714 • Heating load 714 • Heating, ventilation, and air conditioning (HVAC) 711 • Latent heat 712 • Mechanical refrigeration 715 • Relative humidity (RH) 714 • Temperature 712

HVAC

PURPOSE AND FUNCTION The **heating, ventilation, and air-conditioning (HVAC)** system of an automobile is designed to provide comfort for the driver and passengers. It is intended to maintain in-vehicle temperature and humidity within a range that is comfortable for the people inside and provide fresh, clean air. The air-conditioning system transfers the heat from inside the vehicle and moves it to the outside of the vehicle. The heater is needed in cold climates to prevent freezing or death.

PRINCIPLES INVOLVED On earth, matter is found in one of three different phases or states:

1. Solid
2. Liquid
3. Vapor (gas)

The state depends upon the nature of the substance, the temperature, and the pressure or force exerted on it. Water occurs naturally in all three states: solid ice, liquid water, and water vapor, depending upon the temperature and pressure. ● **SEE FIGURE 60–1**.

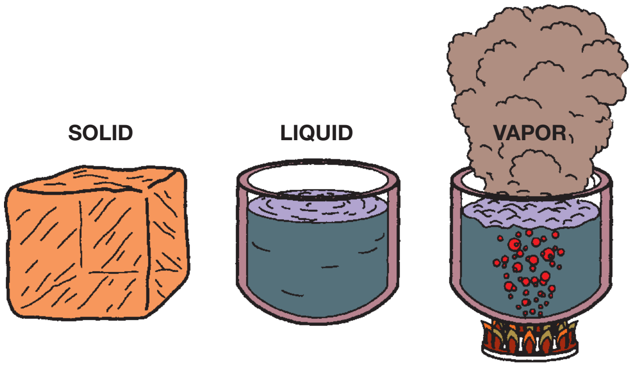


FIGURE 60–1 Water is a substance that can be found naturally in solid, liquid, and vapor states.

CHANGES OF STATE A solid is a substance that cannot be compressed and has strong resistance to flow. The molecules of a solid attract each other strongly, and resist changes in volume and shape.

- A substance is solid at any temperature below its melting point. Melting point is a characteristic of the substance, and is related to the temperature at which a solid turns

FREQUENTLY ASKED QUESTION

Why Is Liquid Sprayed from a Can Cold?

If a pressurized can of liquid is sprayed continuously, the can becomes cold, and so does the liquid being sprayed. The can becomes cold because the pressure in the can is reduced while spraying, allowing the liquid propellant inside the can to boil and absorb heat. The propellant vapor is further cooled as it decompresses when it hits the open air. Rapid decompression results in a rapid temperature drop.

to liquid. For water, the melting point is 32°F (0°C), which means that changes can be observed between liquid water and ice under normal weather conditions.

- A liquid is a substance that cannot be compressed. A substance in a liquid state has a fixed volume, but no definite shape.
- The boiling point is the temperature at which a liquid substance turns to vapor. For water at normal sea level conditions, the boiling point is 212°F (100°C). A vapor is a substance that can be easily compressed, has no resistance to flow, and no fixed volume. Since a vapor flows, it is considered a fluid just like liquids are.

A vapor condenses to liquid if the temperature falls below the vaporizing temperature. Again, the difference is simply whether heat is being added or taken away. Boiling point and condensation point temperatures are not fixed because they vary with pressure.

HEAT AND TEMPERATURE Molecules in a substance tend to vibrate rapidly in all directions, and this disorganized energy is called heat. The intensity of vibration depends on how much kinetic energy, or energy of motion, the atom or molecule contains. Heat and temperature are not the same:

- **Temperature** is the measure of the level of energy. Temperature is measured in degrees.
- **Heat** is measured in the metric unit called **calorie** and expresses the amount of heat needed to raise the temperature of one gram of water one degree Celsius. Heat is also measured in **British Thermal Units (BTU)**. One BTU is the heat required to raise the temperature of one pound of water 1°F at sea level. One BTU equals 252 calories.

SENSIBLE HEAT Sensible heat makes sense because it can be felt and measured on a thermometer. If there is 1 lb. of water at 40°F and 1 BTU of heat is added to it, the temperature will increase to 41°F. Adding another BTU of heat will increase the temperature to 42°F and adding another 170 BTU (212 – 42) will increase the temperature to 212°F, the boiling point.

LATENT HEAT **Latent heat** is the "extra" heat that is needed to transform a substance from one state to another. Imagine that water is being heated on a stove. When water reaches its boiling point, the temperature stops rising. The water begins to boil. This occurs without any sensible change in temperature, even though heat is still being applied from the burner.

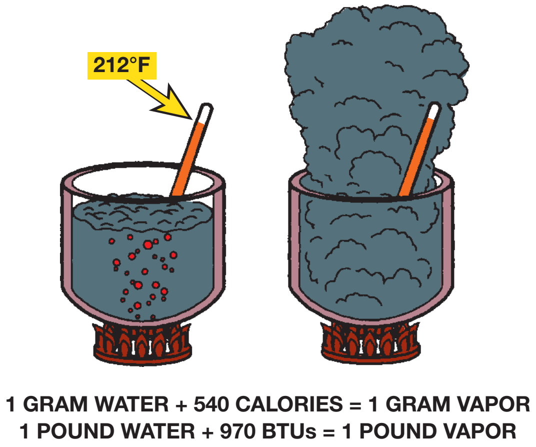

212°F
1 GRAM WATER + 540 CALORIES = 1 GRAM VAPOR
1 POUND WATER + 970 BTUs = 1 POUND VAPOR

FIGURE 60–2 The extra heat required to change a standard amount of water at its boiling point to vapor is called latent heat of vaporization.

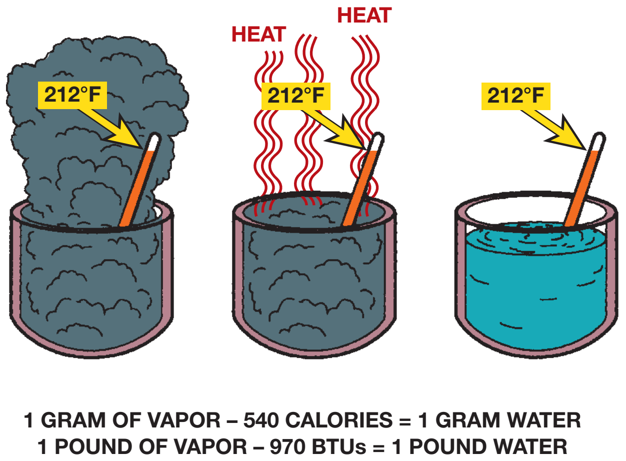

HEAT
HEAT
212°F
212°F
212°F
1 GRAM OF VAPOR – 540 CALORIES = 1 GRAM WATER
1 POUND OF VAPOR – 970 BTUs = 1 POUND WATER

FIGURE 60–3 The latent heat of vaporization that water vapor stores is released when the vapor condenses to a liquid. The temperature stays the same.

The water in the container on the stove boils at a temperature of 212°F (100°C) at sea level, for as long as any liquid water remains. As heat is further added to the water, heat will be used in changing the state of the liquid to a vapor. This extra, hidden amount of energy necessary to change the state of a substance is called latent heat. ● **SEE FIGURES 60–2 AND 60–3**.

Latent heat is important in the operation of an air-conditioning system because the cooling effect is derived from changing the state of liquid refrigerant to vapor. The liquid refrigerant absorbs the latent heat of vaporization, making the air cooler. The cooler air is then blown into the passenger compartment.

TEMPERATURE, VOLUME, AND PRESSURE OF A VAPOR Unlike a solid, vapor has no fixed volume. Increasing the temperature of a vapor, while keeping the volume confined in the same space, increases the pressure. This happens as the vibrating vapor molecules collide more and more energetically with the walls of the container. Conversely, decreasing the temperature decreases the pressure. This relationship between temperature and pressure in vapor is why a can of nonflammable refrigerant can explode when heated by a flame—the pressure buildup inside the can will eventually exceed the ability of the can to contain the pressure. Increasing the pressure by compressing vapor increases the temperature. Decreasing the pressure by permitting the vapor to expand decreases the temperature.

HEAT INTENSITY Intensity of heat is important to us because if it is too cold, humans feel uncomfortable and is measured in degrees. Extremely cold temperatures can cause frostbite and hypothermia. The other end of the scale can also be uncomfortable and may cause heat stress and dehydration. Humans have a temperature **comfort zone** somewhere between 68°F and 78°F (20°C and 26°C). This comfort zone varies among individuals. ● **SEE FIGURE 60–4**.

RULES OF HEAT TRANSFER Heating and air conditioning must follow the basic rules of heat transfer. An understanding of these rules helps greatly in understanding the systems:

- Heat always flows from hot to cold. (From higher level of energy to lower level of energy.) ● **SEE FIGURE 60–5**.
- To warm a person or item, heat must be added.
- To cool a person or item, heat must be removed.
- A large amount of heat is absorbed when a liquid changes state to vapor.
- A large amount of heat is released when a vapor changes state to a liquid.
- Compressing a gas concentrates the heat and increases the temperature.

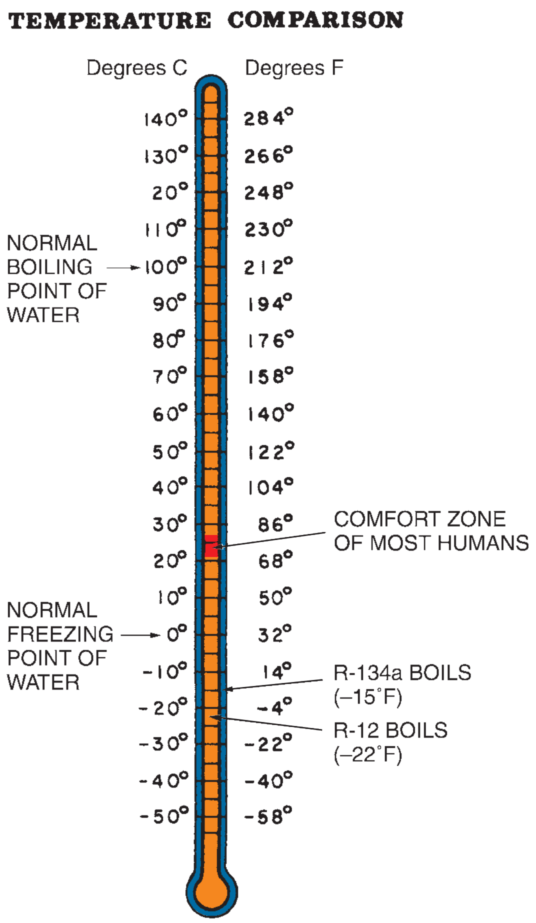

TEMPERATURE COMPARISON
Degrees C
Degrees F
140°
130°
20°
110°
100°
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
-10°
-20°
-30°
-40°
-50°
284°
266°
248°
230°
212°
194°
176°
158°
140°
122°
104°
86°
68°
50°
32°
14°
-4°
-22°
-40°
-58°
NORMAL BOILING POINT OF WATER
NORMAL FREEZING POINT OF WATER
COMFORT ZONE OF MOST HUMANS
R-134a BOILS (–15˚F)
R-12 BOILS (–22˚F)

FIGURE 60–4 Heat intensity is measured using a thermometer. The two common measuring scales, Celsius and Fahrenheit, are shown here. This thermometer is also marked with water freezing and boiling and refrigerant boiling temperatures.

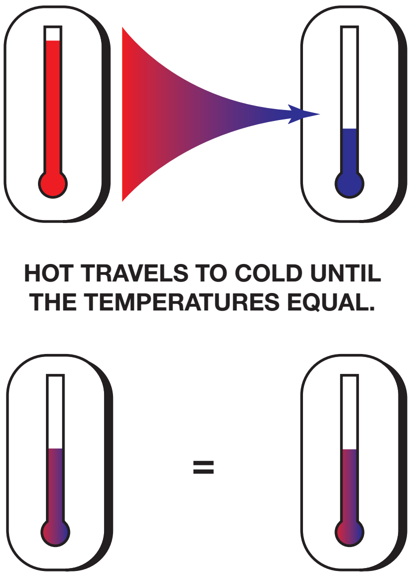

HOT TRAVELS TO COLD UNTIL THE TEMPERATURES EQUAL.
=

FIGURE 60–5 Heat travels from higher temperature (higher energy level), to lower temperature (lower energy level).

TECH TIP

Quick and Easy Temperature Conversion

Temperature in service information and on scan tools is often expressed in degrees Celsius, which is often confusing to those used to temperature expressed in Fahrenheit degrees. A quick and easy way to get an *approximate* conversion is to take the degrees in Celsius, double it, and add 25.

For example,

Celsius × 2 + 25 = approximate Fahrenheit degrees:

0°C × 2 = 0 + 25 = 25°F (actual = 32°F)

10°C × 2 = 20 + 25 = 45°F (actual = 50°F)

15°C × 2 = 30 + 25 = 55°F (actual = 59°F)

20°C × 2 = 40 + 25 = 65°F (actual = 68°F)

25°C × 2 = 50 + 25 = 75°F (actual = 77°F)

30°C × 2 = 60 + 25 = 85°F (actual = 86°F)

35°C × 2 = 70 + 25 = 95°F (actual = 95°F)

40°C × 2 = 80 + 25 = 105°F (actual = 104°F)

45°C × 2 = 90 + 25 = 115°F (actual = 113°F)

50°C × 2 = 100 + 25 = 125°F (actual = 122°F)

The simplest way to convert between the Fahrenheit and Celsius scales accurately is to use a conversion chart or use an app on a smartphone.

HUMIDITY Humidity refers to water vapor present in the air. The level of humidity depends upon the amount of water vapor present and the temperature of the air. The amount of water vapor in the air tends to be higher near lakes or the ocean, because more water is available to evaporate from their surfaces. In desert areas with little open water, the amount of water vapor in the air tends to be low.

- **Absolute humidity** is the measure of the amount of moisture (water vapor) in the air regardless of the temperature.

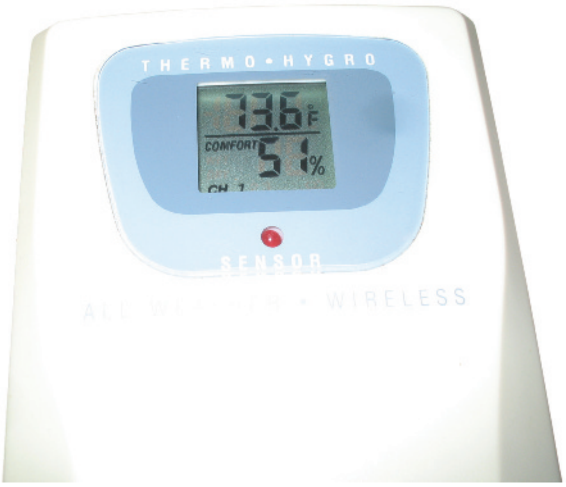


FIGURE 60–6 A combination meter that measures and displays both the temperature and the humidity is useful to use when working on air-conditioning systems.

- **Relative humidity (RH)** is the percentage of how much moisture is present in the air compared to how much moisture the air is capable of holding at that temperature.

Relative humidity is commonly measured with a *hygrometer* or a *psychrometer*. A hygrometer depends on a sensitive element that expands and contracts, based on the humidity. Hygrometers typically resemble a clock, with the scale reading from 0% to 100% relative humidity. ● **SEE FIGURE 60–6**.

FREQUENTLY ASKED QUESTION

What Is a Sling Pyschrometer?

A psychrometer is a measuring instrument used to measure relative humidity. It uses two thermometers, one of which has the bulb covered in a cotton wick soaked in distilled water from a built-in reservoir. The wick keeps the bulb of the "wet thermometer" wet so that it can be cooled by evaporation. Sling psychrometers are spun round in the air a certain number of times. Water evaporates from the cotton wick at a rate inversely proportional to the relative humidity of the air:

- Faster if the humidity is low.
- Slower if the humidity is high.

The "dry thermometer" measures the air temperature:

- The higher the relative humidity, the closer the readings of the two thermometers.
- The lower the humidity, the greater the difference in temperature of the two thermometers.

The different temperatures indicated by the wet and dry thermometers are compared to values given in a chart, which gives the relative humidity. While a sling psychrometer is still used, most technicians use an electronic instrument to measure relative humidity. ● **SEE FIGURE 60–7**.

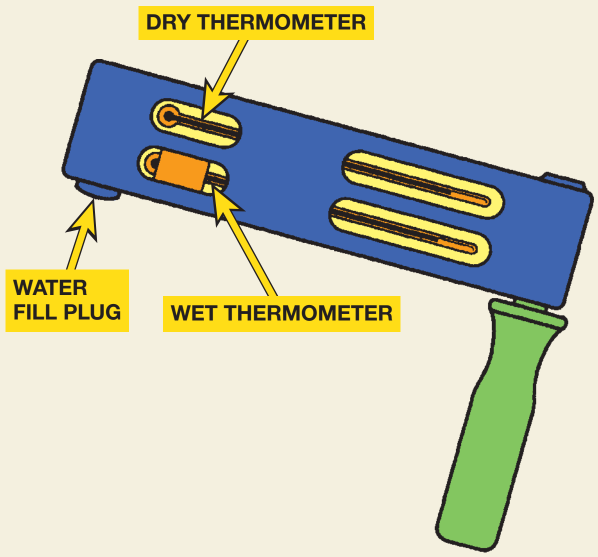


FIGURE 60–7 A sling psychrometer is used to measure relative humidity.

HEATING AND COOLING LOAD

HEATING LOAD **Heating load** is the term used when additional heat is needed. The actual load is the number of BTUs or calories of heat energy that must be added. In a home or office, burning fuel is the usual way to generate heat using coal, gas, or oil as a fuel. In most vehicles, the heat is provided by the heated coolant from the engine cooling system. This coolant is typically at a temperature of 190°F to 205°F (88°C to 98°C) when the engine reaches its normal operating temperature. ● **SEE FIGURE 60–8**.

In most vehicles, heated coolant is circulated through a heat exchanger, called a **heater core**. Air is circulated through the heater core, where it absorbs heat. Then it is blown into the passenger compartment, where the heat travels on to warm the car interior and occupants. The air from the blower motor moves the heat from the heater core to the passengers.

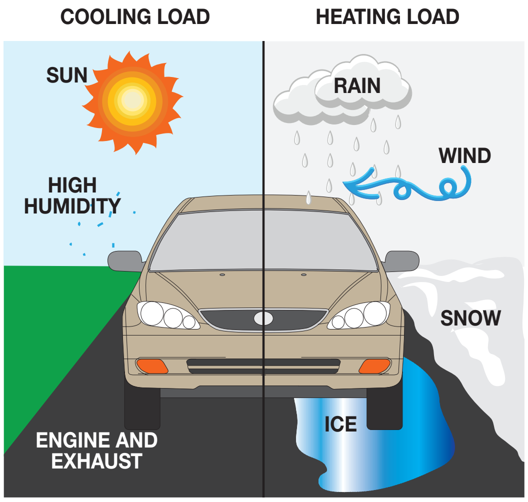


FIGURE 60–8 Cold temperatures present a heat load where heat must be added for comfort (right). Warm temperatures presents a cooling load.

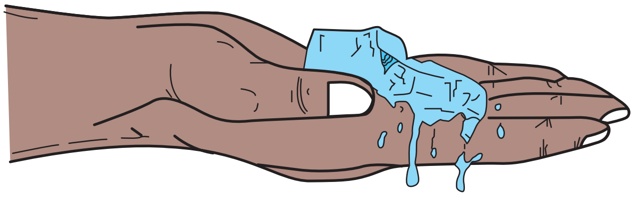


FIGURE 60–9 Ice has a cooling effect because of latent heat of fusion which means that it absorbs heat as it melts.

COOLING WITH ICE One way to move heat, called **cooling load**, is with a block of ice. A substantial amount of latent heat is required to change the state of the solid ice into a liquid:

- 144 BTU per lb. (80 calories per gram).
- A 50-lb. block of ice represents, or 7,200 BTU, of cooling power when it changes from 50 lb. of solid at 32°F to 50 lb. of liquid at 32°F.

In the early days of air conditioning, the term *ton* was commonly used. A ton of air conditioning was the amount of heat it took to melt a ton of ice, or 288,000 BTU. ● **SEE FIGURE 60–9**.

EVAPORATIVE COOLING A method of cooling that works well in areas of low humidity is evaporation of water, commonly called **evaporative cooling**. If water is spread thinly over the extremely large area of a meshed cooler pad and air is blown across it, the water evaporates. For every pound of water that evaporates, 970 BTU (540 calories per gram) of heat is absorbed. This is the latent heat of evaporation, just as when it is boiled. This is a natural process and uses only the energy required by the blower to circulate the air through the cooler pads and on to the space to be cooled. Disadvantages of evaporative coolers, often called "swamp coolers" include:

- increases the relative humidly
- not effective in areas of high humidity because the water does not evaporate rapidly enough to be efficient.

At one time, window-mounted evaporative coolers were used in cars. They were not very popular because they were unattractive and worked well only in dry areas. ● **SEE FIGURE 60–10**.

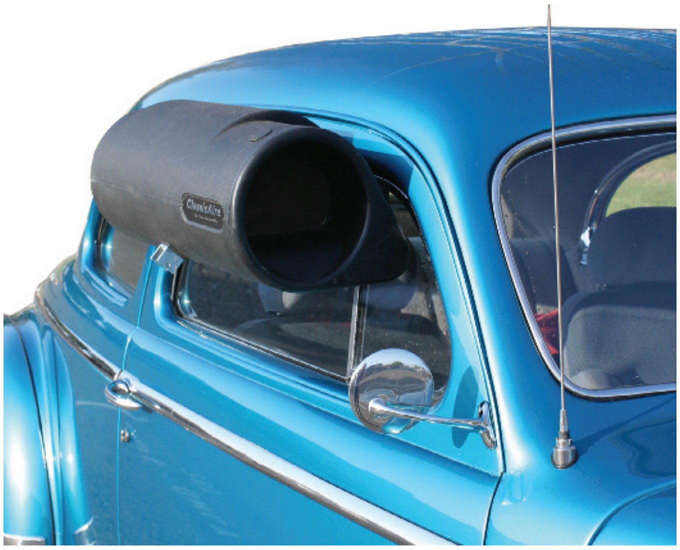


FIGURE 60–10 At one time, evaporative coolers were used to cool car interiors. Air forced through a water-wetted mesh produces evaporation and a cooling effect.

MECHANICAL COOLING A third way to handle a cooling load is by the use of **mechanical refrigeration**, which is called air conditioning. This system also uses evaporation of a liquid and the large amount of heat required for evaporation. The refrigerant boils so that it changes from liquid to gas, but it is condensed back to gas using an engine or electrically powered compressor to move the refrigerant and to increase its pressure in the system. ● **SEE FIGURE 60–11**.

HEAT MOVEMENT

Heat can travel through one or more of three paths as it moves from hot to cold:

1. conduction
2. convection
3. radiation ● **SEE FIGURE 60–12**.

CONDUCTION The simplest heat movement method is conduction, by which heat travels through a medium such as a solid or liquid, moving from one molecule of the material to the next. For example, if one end of wire is heated, the heat will travel through the material itself and will be transferred through to the other end of the wire. Some materials (most of the metals) are good heat conductors. Copper and aluminum are among the best of the commonly used metals, so most heat exchangers (radiators, evaporators, and condensers) use copper or aluminum.

- Some materials, such as wood, are poor heat conductors.
- Some materials, such as Styrofoam, conduct heat so poorly that they are called insulators. Most good insulators incorporate a lot of air or gaseous material in their structure because air is a poor conductor of heat.

CONVECTION Convection is a process of transferring heat by moving the heated medium, usually air or a liquid. An example of convection is the engine cooling system. Coolant is heated in the water jackets next to the cylinders and combustion chambers. Then the coolant is pumped to the radiator, where the heat is transferred to the air traveling through the radiator. Convection also occurs in the interior of the vehicle when air is circulated past the driver and passengers to pick up heat and moved to the evaporator, where the heat is transferred to the evaporator fins. The evaporator fins are cooler, so heat is transferred easily.

RADIATION Heat can travel through heat rays and pass from one location to another without warming the air through which it passes. The best example of this is the heat from the sun, which passes through cold space and warms our planet and everything it shines on. Radiant heat can pass from any warmer object through air to any cooler object. It is affected by the color and texture of the heat emitter, where the heat leaves, and the collector, where the heat is absorbed. Dark, rough surfaces make better heat emitters and collectors than light-colored, smooth surfaces.

NOTE: At one time, California Highway Patrol cars were painted all black. Painting the tops white benefited the patrol officers by lowering the in-vehicle temperature significantly.

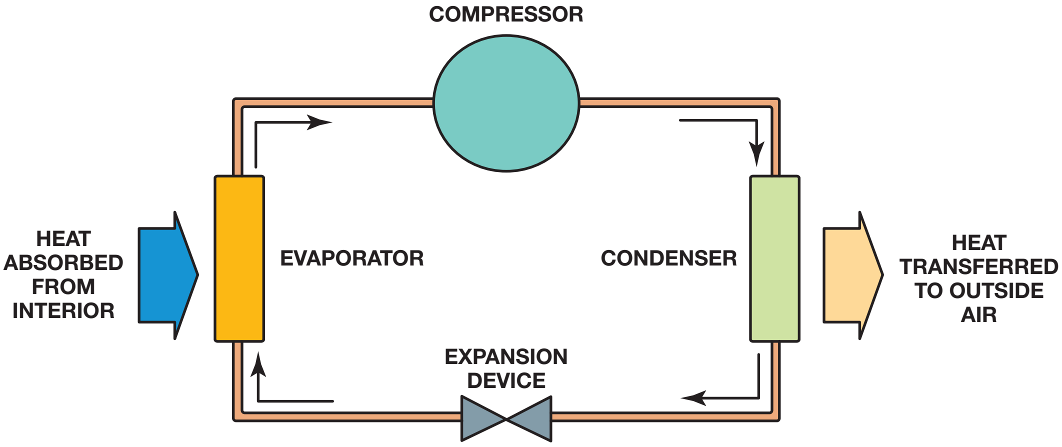


FIGURE 60–11 Heat, from in-vehicle cabin air, causes the refrigerant to boil in the evaporator (left). The compressor increases the pressure and moves refrigerant vapor to the condenser, where the heat is transferred to ambient air. This also causes the vapor to return to liquid form.

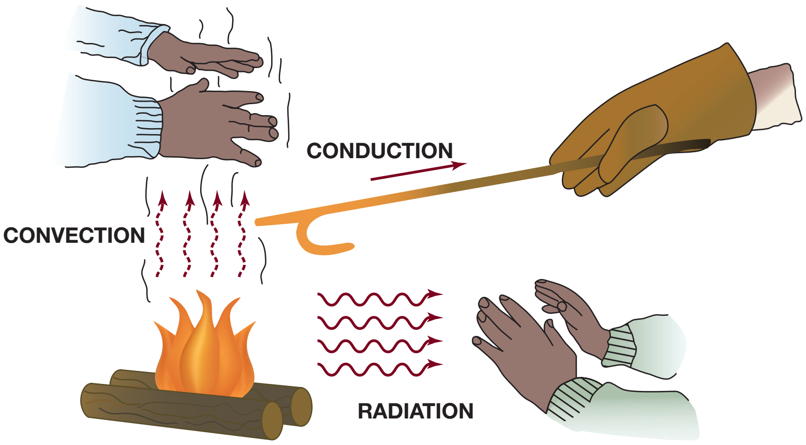


FIGURE 60–12 Heat can be moved from the source by convection, conduction, or radiation.

AIR-CONDITIONING PROCESS

CHANGING THE STATE OF THE REFRIGERANT The air-conditioning process works using a fluid, called *refrigerant,* which continuously changes state from liquid to gas and back to liquid.

Most states of matter can be changed from one state to another by adding or removing heat. ● **SEE FIGURE 60–13**.

Molecules are the building blocks for all things that can be seen or felt. Molecules are combinations of atoms, which are in turn made up of electrons, neutrons, and protons. The protons are in the center, or nucleus, of the atom and the electrons travel in an orbit around them. There are about 100 basic elements or atoms, each having a different atomic number, that combine with other elements to make the many, varied molecules. The atomic number of an element is based on the number of electrons and protons in that element. The periodic table of elements seen in most chemistry laboratories shows the relationship of these elements.

Water molecules, for example, are called H_2O. This is a combination of a single oxygen atom and two hydrogen atoms. Hydrogen has an atomic number of 1 (1 proton and 1 electron), and oxygen has an atomic number of 8 (8 electrons and 8 protons). ● **SEE FIGURE 60–14**. The three states of water are well known and include:

1. Solid ice
2. Liquid water
3. Vapor (gaseous)

SOLID Solid matter has a definite shape and substance. Solids exert pressure in only one direction, and that is downward because of gravity. For example, ice is the solid form of water, and will hold its shape, and is cold. Water is normally a solid at temperatures below 32°F (0°C), which is the normal freezing point. The electrons in the molecule's atoms are still orbiting around the protons, but the movement has been slowed because much of the heat energy has been removed. ● **SEE FIGURE 60–15**.

LIQUID Adding heat to most solids causes them to reach their melting point. It is the same material, but heat energy has broken the molecular bond and the matter becomes fluid. Fluid has no shape and it takes the shape of its container. Liquids can flow through a pipe or hose and can be pumped such as by the air-conditioning compressor.

Water is normally a liquid between 32°F and 212°F (0°C and 100°C). The molecules are same as ice, but heat energy has increased the movement of the electrons. ● **SEE FIGURE 60–16**.

GAS When heat is added to most liquids, it produces gas as the liquids boil. It is the same material, but the heat energy has broken the molecular bonds still further so that the molecules have no shape at all and have expanded so much that they have very little weight. A gas molecule exerts pressure in every direction. Gases can also be pumped through hoses and pipes, making them easy to move through the air-conditioning (A/C) system.

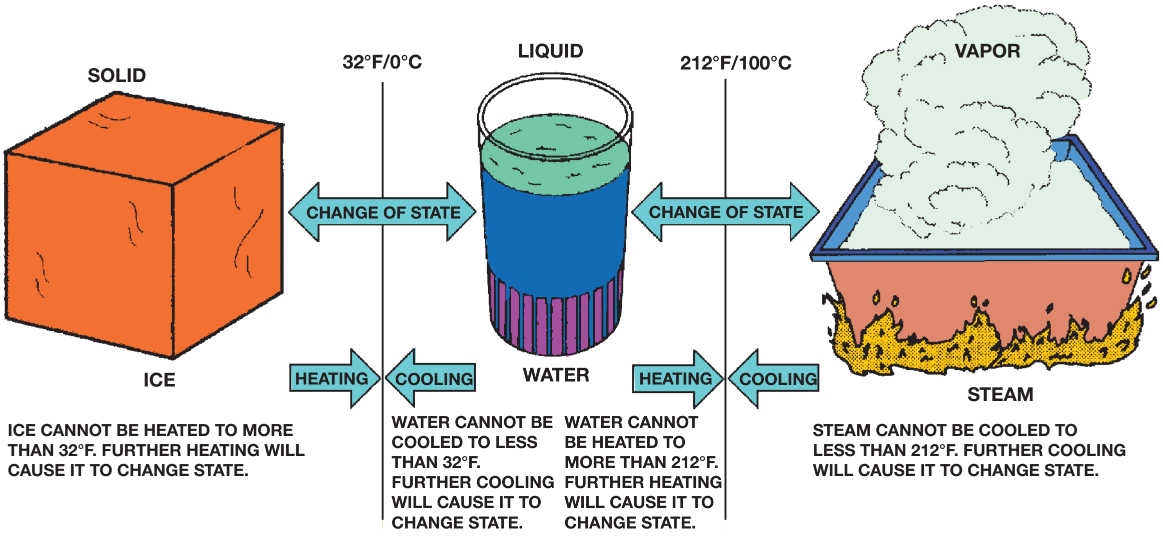

SOLID
32°F/0°C
LIQUID
212°F/100°C
VAPOR
CHANGE OF STATE
CHANGE OF STATE
ICE
HEATING
COOLING
WATER
HEATING
COOLING
STEAM
ICE CANNOT BE HEATED TO MORE THAN 32°F. FURTHER HEATING WILL CAUSE IT TO CHANGE STATE.
WATER CANNOT BE COOLED TO LESS THAN 32°F. FURTHER COOLING WILL CAUSE IT TO CHANGE STATE.
WATER CANNOT BE HEATED TO MORE THAN 212°F. FURTHER HEATING WILL CAUSE IT TO CHANGE STATE.
STEAM CANNOT BE COOLED TO LESS THAN 212°F. FURTHER COOLING WILL CAUSE IT TO CHANGE STATE.

FIGURE 60–13 Matter can change state by adding or removing heat.

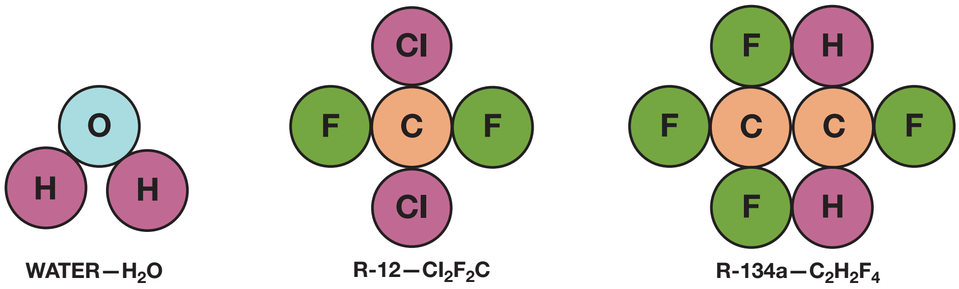

O
H
H
WATER—H_2O
Cl
F
C
F
Cl
R-12—Cl_2F_2C
F
H
F
C
C
F
F
H
R-134a—$C_2H_2F_4$

FIGURE 60–14 A water molecule contains two hydrogen atoms and one oxygen atom. R-12 is a combination of one carbon, two chlorine, and two fluorine atoms. R-134a is a combination of two carbon, four fluorine, and two hydrogen atoms.

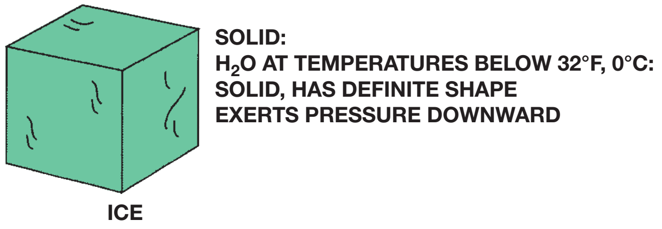

SOLID:
H_2O AT TEMPERATURES BELOW 32°F, 0°C:
SOLID, HAS DEFINITE SHAPE
EXERTS PRESSURE DOWNWARD
ICE

FIGURE 60–15 Ice is a solid form of water with a low temperature and slow molecular action.

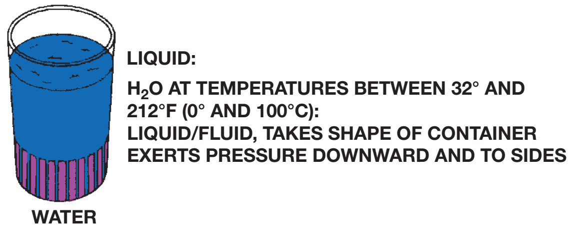

LIQUID:
H_2O AT TEMPERATURES BETWEEN 32° AND 212°F (0° AND 100°C):
LIQUID/FLUID, TAKES SHAPE OF CONTAINER
EXERTS PRESSURE DOWNWARD AND TO SIDES
WATER

FIGURE 60–16 Water is warmer than ice and can flow to take the shape of any container.

At temperatures above 212°F (100°C), water normally boils to become a gas, called *steam*. Again, the molecules are the same as water or ice, but heat energy has greatly increased molecular movement. ● **SEE FIGURE 60–17**.

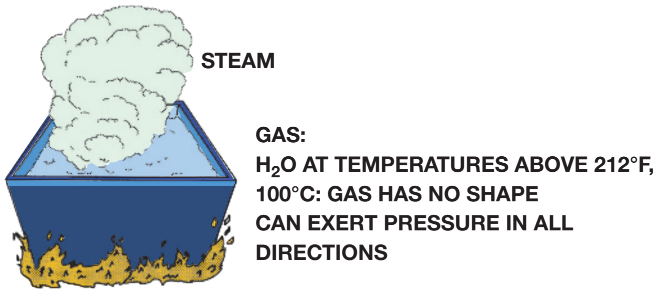

STEAM
GAS:
H_2O AT TEMPERATURES ABOVE 212°F, 100°C: GAS HAS NO SHAPE
CAN EXERT PRESSURE IN ALL DIRECTIONS

FIGURE 60–17 Adding heat to water produces steam, the gas state, with a much freer molecular action.

PURPOSE OF AN HVAC SYSTEM

CONTROL OF TEMPERATURE The goal in heating and air conditioning is to maintain a comfortable in-vehicle temperature and humidity. An air-conditioning system cools the interior of the vehicle by moving the heat from inside the vehicle to outside the vehicle. The internal body temperature of humans is about 98.6°F (37°C), which seems odd when our most comfortable temperature is 68°F to 78°F (20°C to 26°C). This means that in the summer heat must be continually given off to be comfortable, but in the cold weather suitable clothing is needed to maintain warmth. Body comfort is also affected by radiant heat.

The velocity of air past our bodies is another factor in human comfort. Air movement is an important part of heating and air-conditioning systems.

CONTROL OF HUMIDITY Humid cold air feels much colder than dry air at the same temperature.

- Humid hot air slows down our natural body cooling system (evaporation of perspiration), so it can make a day feel much hotter.
- Air that is too dry also tends to make people feel uncomfortable.
- As with temperature, a range of humidity that most people feel comfortable in a relative humidity of about 45% to 55%.

As the air-conditioning system operates, it dehumidifies (removes moisture) from the air. Water vapor condenses on the cold evaporator fins just as it would on a glass holding a cold drink. This condensed water then drops off the evaporator and runs out the drain at the bottom of the evaporator case. In-vehicle humidity is reduced to about 40% to 45% on even the most humid days if the A/C is operated long enough. A good example of this dehumidification process occurs when a vehicle's A/C is operated on cold days when the windows are fogged up. It usually takes only a short time to dry the air and remove the fog from the windows. ● **SEE FIGURE 60–18**.

CLEANLINESS A side effect of air conditioning is the cleaning of the air coming into the vehicle as it passes through the cooling ductwork. The act of cooling and dehumidifying air at the A/C evaporator causes water droplets to form on the evaporator fins. Dust and other contaminants in the air that come into contact with these droplets become trapped and are flushed out of the system as the water drops drain from the evaporator. Most recent vehicles use a **cabin filter** in the A/C and heating systems to clean the air by trapping dust and pollen particles before they enter the passenger compartment. ● **SEE FIGURE 60–19**.

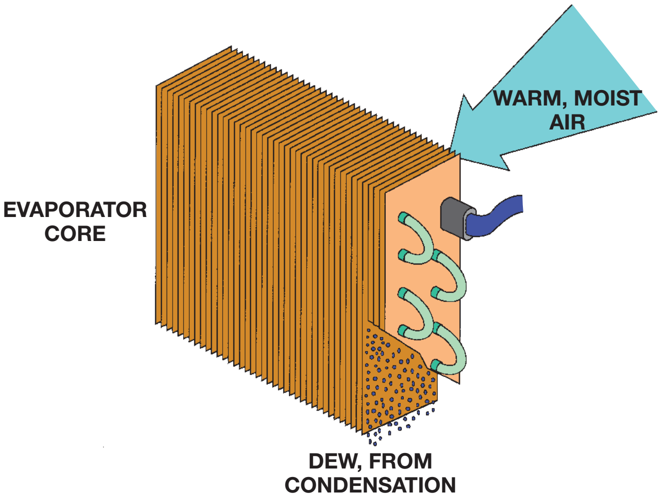


FIGURE 60–18 When air comes into contact with the cold evaporator, excess moisture forms dew. This condensed moisture leaves the car through the evaporator drain.

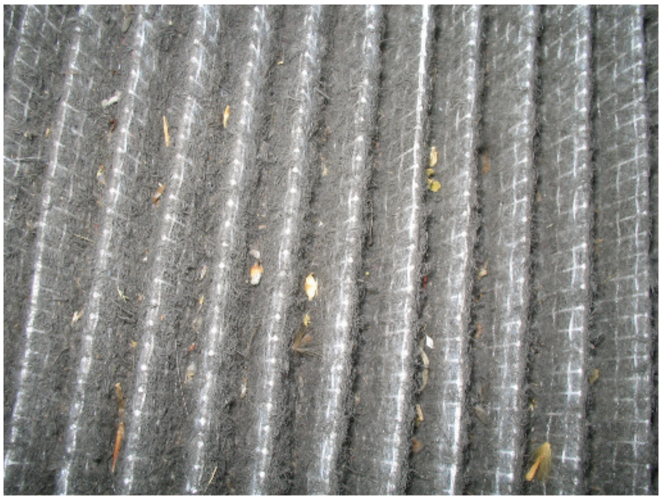


FIGURE 60–19 A cabin filter especially those that are impregnated with charcoal (carbon) are able to filter out dirt, dust, and odors from the outside air before entering the passenger compartment.

REVIEW QUESTIONS

1. Is it possible for heat to be added to water without causing the temperature to increase?
2. What are the three states of matter?
3. What is the difference between heat and temperature?
4. How is relative humidity measured?
5. How does heat move?

CHAPTER QUIZ

1. The three different phases or states of matter include __________.
   - **a.** solid, water, and steam
   - **b.** ice, liquid, and gas
   - **c.** solid, liquid, and gas
   - **d.** liquid, water, and steam
2. An air-conditioning system cools the interior of the vehicle by __________.
   - **a.** moving the heat from inside the vehicle to outside the vehicle
   - **b.** blowing cold air into the interior
   - **c.** moving heat from inside of the vehicle to the engine cooling system
   - **d.** using the engine to move air
3. Twenty degrees Celsius is about how many degrees Fahrenheit?
   - **a.** 25
   - **b.** 45
   - **c.** 65
   - **d.** 85
4. Heat intensity is measured in __________.
   - **a.** BTUs
   - **b.** degrees
   - **c.** RH
   - **d.** calories
5. A psychrometer measures __________.
   - **a.** temperature
   - **b.** relative humidity
   - **c.** amount of heat
   - **d.** radiation
6. A BTU is a measure of __________.
   - **a.** temperature
   - **b.** relative humidity
   - **c.** amount of heat
   - **d.** radiation
7. Heat transferred through the air is called __________.
   - **a.** radiation
   - **b.** insulation
   - **c.** convection
   - **d.** conduction
8. The air conditioning process works through a fluid, called a/an __________ that continuously changes state from liquid to gas and back to liquid.
   - **a.** element
   - **b.** conductor
   - **c.** insulator
   - **d.** refrigerant
9. Humans prefer temperatures that are between __________ and __________.
   - **a.** 55°F; 65°F
   - **b.** 60°F; 70°F
   - **c.** 68°F; 78°F
   - **d.** 76°F; 86°F
10. Humans prefer relative humidity that is between __________ and __________.
    - **a.** 10%; 20%
    - **b.** 20%; 30%
    - **c.** 30%; 40%
    - **d.** 45%; 55%

Chapter

61

A/C SYSTEM COMPONENTS, OPERATION, AND SERVICE

LEARNING OBJECTIVES

After studying this chapter, the reader will be able to:

- Discuss the purpose and function of compressors and condensers.
- Describe the operation of thermal expansion valves.
- Explain the construction and operation of orifice tubes.
- Explain the purpose and function of evaporators.
- Explain the purpose and function of accumulators.
- Discuss the use of lines and hoses in refrigeration.
- Describe electrical switches and evaporator temperature controls used in A/C systems.
- Describe rear A/C systems.
- Explain component replacement procedures.

KEY TERMS

Barrier hoses 728 • Captive O-ring 729 • Discharge line 728 • H-block 722 • Liquid line 728 • Sight glass 726 • Suction line 728 • Thermistor 731 • Transducer 731

COMPRESSORS AND CONDENSERS

COMPRESSORS The compressor is the pump in the system that circulates the refrigerant. The pressure must be increased until the refrigerant temperature is above ambient air temperature so the condenser can get rid of all the heat absorbed in the evaporator.

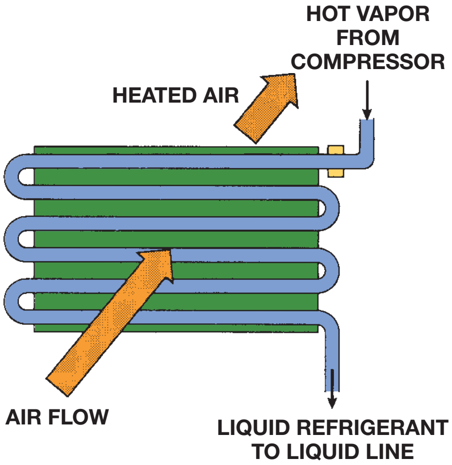


FIGURE 61–1 A condenser is a heat exchanger that transfers heat from the refrigerant to the air flowing through it.

CONDENSERS The condenser is a heat exchanger that is used to get rid of the heat removed from the passenger compartment. The condenser cools the hot refrigerant vapors, which while passing through the condensing tubes condense into high pressure liquid. The condenser of most vehicles is mounted in front of the radiator through which air is forced when the vehicle is moving forward. ● **SEE FIGURE 61–1**.

On most vehicles, the condenser is part of a *cooling module* that can combine the following:

- Condenser
- Radiator
- Automatic transmission fluid cooler
- Power steering pump oil coolers
- An intercooler for engine intake air on turbocharged engines.

Air flow through the condenser is increased by the use of a cooling fan.

- Many rear-wheel-drive (RWD) vehicles use a fan driven by a fan clutch mounted on the water pump. Some RWD vehicles use both an engine-driven fan with a clutch and an electric fan.
- Front-wheel-drive (FWD) vehicles normally use an electric motor to drive the fan(s).

This motor is controlled by relays that are controlled by the powertrain control module (PCM) using temperature information from the engine coolant temperature (ECT) sensor.

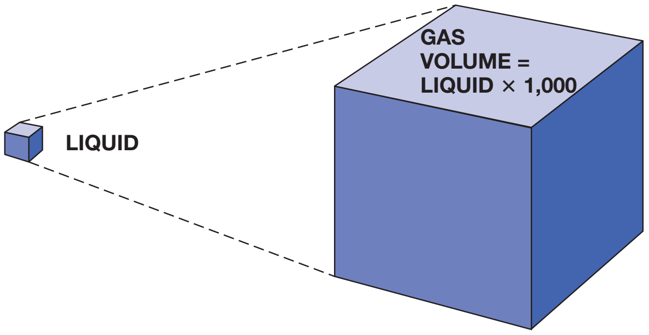

GAS
VOLUME =
LIQUID × 1,000
LIQUID

FIGURE 61–2 The volume of gas that enters a condenser is about 1,000 times the volume of liquid leaving it.

FREQUENTLY ASKED QUESTION

Why Is Sub-Cooling Necessary in Some Condensers?

Condenser sub-cooling makes sure that there is a liquid seal at the bottom of the condenser so the liquid line or receiver will not have any vapors. Some vehicles use a second condenser to make sure that the refrigerant has condensed into liquid before it exits. These secondary condensers can be called:

- *Dual condenser*
- *Secondary condenser*
- *Sub-condenser*
- *Modulator* ● **SEE FIGURE 61–3**.

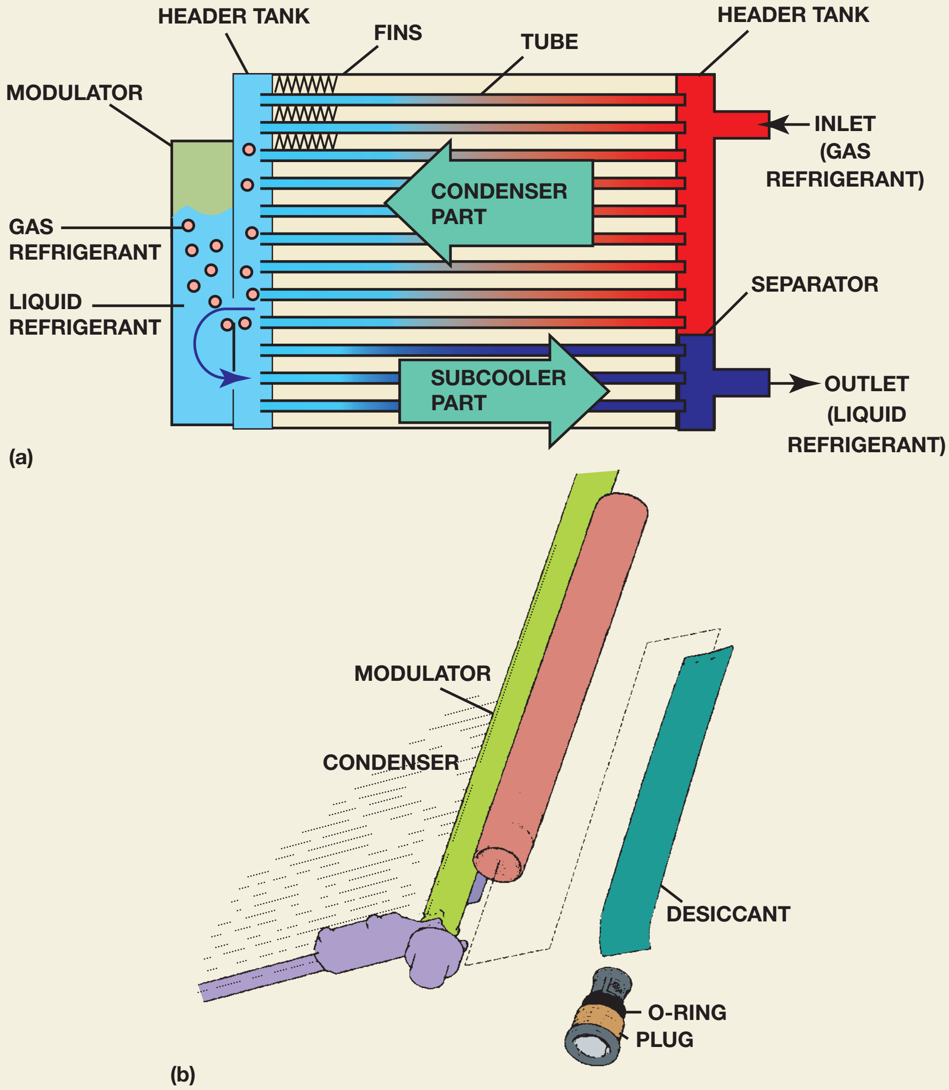

HEADER TANK
FINS
TUBE
HEADER TANK
MODULATOR
INLET
(GAS
REFRIGERANT)
CONDENSER
PART
GAS
REFRIGERANT
SEPARATOR
LIQUID
REFRIGERANT
SUBCOOLER
PART
OUTLET
(LIQUID
REFRIGERANT)
(a)
MODULATOR
CONDENSER
DESICCANT
O-RING
PLUG
(b)

FIGURE 61–3 (a) A dual condenser is a condenser where the refrigerant flows from the condenser portion through the modulator portion and then through the sub-cooling part. (b) The modulator is built as part of the condenser and often includes a removable plug that allows desiccant replacement.

CONDENSER CONSTRUCTION Automotive condensers are heat exchangers that are made in several designs, including the following:

- Older *tube-and-fin* condensers are merely a tube bent back and forth into a *serpentine shape* with fins attached. After the tubes are pressed through the fins, return bends or manifolds are used to connect the tubes to give the desired flow pattern.
- Newer condensers use a *flattened tube* with fins between the tubes. The tubing is formed in either *serpentine* or *parallel-flow* arrangement.
- Many condensers use a flattened, extruded aluminum tube that is divided into small refrigerant passages, 13–16 passages in a tube that is 0.875 inch (24 mm) wide.
- The numerous fins provide the large amount of contact area needed with the airstream. Newer flat-tube, parallel-flow condensers are more efficient and transfer heat much better and therefore allows for a smaller and lighter component.

As the gas condenses to a liquid, the volume is reduced because a gas has about 1,000 times the volume of the same liquid. As the latent heat of condensation is transferred to the airstream, the refrigerant vapor transforms into a liquid state. ● **SEE FIGURE 61–2**.

THERMAL EXPANSION VALVES

PURPOSE AND FUNCTION A thermal expansion valve (TXV) senses both temperature and pressure and controls the flow of refrigerant into the evaporator. ● **SEE FIGURE 61–4**.

CONSTRUCTION AND OPERATION In most TXV systems, the evaporator outlet is connected to the compressor inlet by the suction line with an internal diameter (ID) of about 5/8 inch or 3/4 inch (16 mm or 19 mm). The key to the operation of the expansion valve is the variable orifice. In these systems, the outlet from the high-pressure side to the low-pressure side is a variable-diameter hole. A pintle valve is a ball-and-seat valve used to increase or decrease the size of the opening. The expansion valve uses the pintle valve to control how rapidly refrigerant enters the evaporator. The expansion valve controls the refrigerant flow in response to the temperature of the evaporator outlet, measured by the remotely mounted sensing bulb and capillary tube.

- At room temperature, a TXV is open because the gas pressure in the capillary tube exerts a high pressure, greater than the spring pressure.
- As the system cools, the temperature of the sensing bulb and capillary tube drops, and the pressure on the diaphragm drops with it.
- When the pressure at the diaphragm drops below the spring pressure, the valve closes.
- If an excess amount of refrigerant enters the evaporator, high refrigerant pressure can act through the balance passage to close the TXV. ● **SEE FIGURE 61–5**.

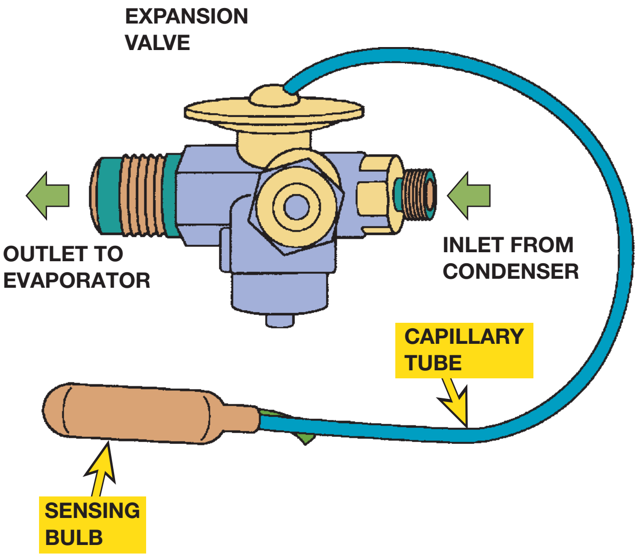


FIGURE 61–4 A typical expansion valve uses an inlet and outlet attachment for the evaporator, and a temperature-sensing bulb that is attached to the evaporator outlet tube.

TYPES OF TXVS Thermal expansion valves come in many types. Most of the early valves were threaded onto the evaporator inlet, and the liquid line threaded onto the valve. The thermal bulb, or end of the capillary tube, was clamped onto the evaporator tailpipe or inserted into a well in it. The thermal bulb has to be clamped tightly and should be well insulated so that it can transmit an accurate temperature signal. If used, the external equalizer line is threaded onto a fitting on the tailpipe. Most TXVs have a small, very fine screen at their inlet. This screen traps debris that can plug the valve, and it can be removed for cleaning or installing a replacement.

H-BLOCKS The thermal expansion block valve is another type of TXV. It is called an **H-block** or an *H-valve.* The H-block design uses four passages and controls the refrigerant flow using opposing pressures. These valves are connected with both the liquid and suction lines and the evaporator inlet and outlet. Some block valves use threaded fittings, and some are bolted between manifolds and are sealed using O-rings. ● **SEE FIGURE 61–6**.

ORIFICE TUBE SYSTEMS

TERMINOLOGY An orifice tube (OT), also called an *expansion tube*, is a fixed-diameter orifice that the refrigerant must flow through. The diameter varies between systems and is about 1/16 inch (0.065 inch or 1.6 mm). ● **SEE FIGURE 61–7**.

CONSTRUCTION AND OPERATION Most orifice tubes are a thin brass tube that is a couple of inches long and has a plastic filter screen around it. This tube is sized to flow the proper amount of refrigerant into the evaporator for maximum cooling loads. Some orifice tubes use a filter made up of many small plastic beads in place of the screen. The orifice tube floods the evaporator during light cooling loads, so a low-side accumulator is always used with an orifice. The flow through an orifice tube is also affected by pressure, and excessive high-side pressure can cause evaporator pressure and temperature to become too high.

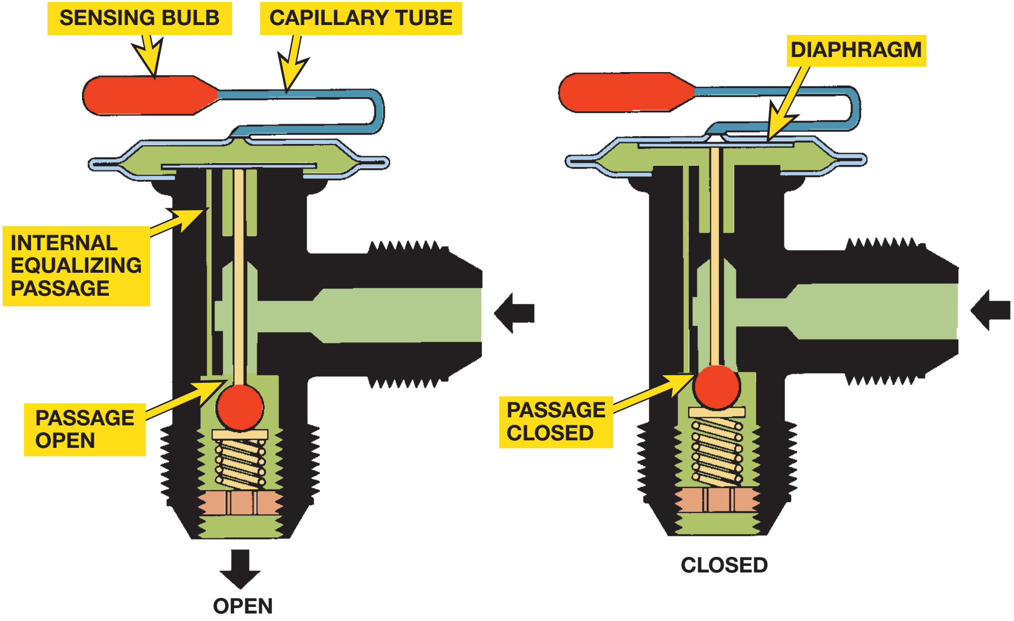

SENSING BULB
CAPILLARY TUBE
DIAPHRAGM
INTERNAL EQUALIZING PASSAGE
PASSAGE OPEN
PASSAGE CLOSED
CLOSED
OPEN

FIGURE 61–5 Pressure from the capillary tube pushes on the spring-loaded diaphragm to open the expansion valve. As the pressure in the capillary tube contracts, the reduced pressure on the diaphragm allows the valve to close.

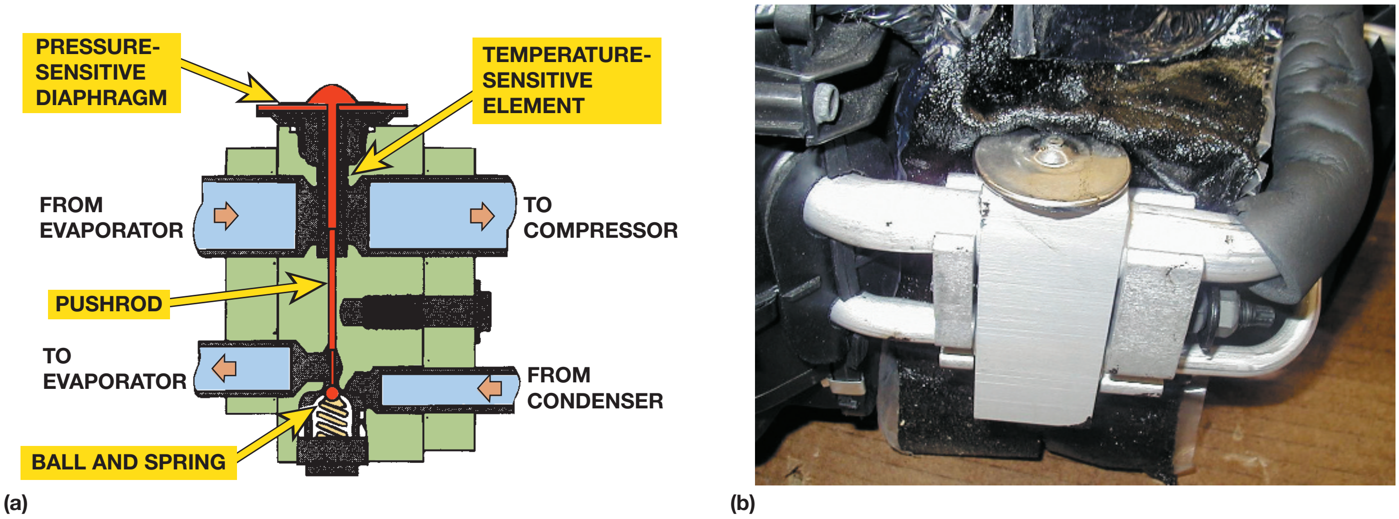

PRESSURE-SENSITIVE DIAPHRAGM
TEMPERATURE-SENSITIVE ELEMENT
FROM EVAPORATOR
TO COMPRESSOR
PUSHROD
TO EVAPORATOR
FROM CONDENSER
BALL AND SPRING
(a)
(b)

FIGURE 61–6 (a) An H-valve (H-block) combines the temperature sensing and pressure-regulating functions into a single assembly. (b) An H-valve as used on a Chrysler minivan.

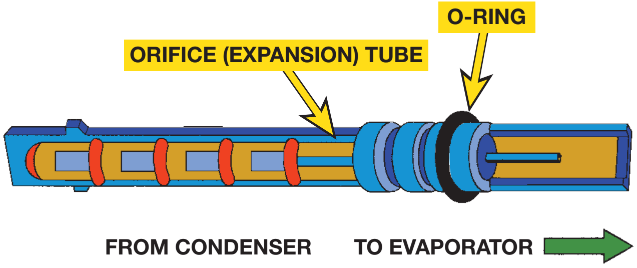

O-RING
ORIFICE (EXPANSION) TUBE
FROM CONDENSER
TO EVAPORATOR

FIGURE 61–7 A typical orifice tube. The refrigerant flow is from the left toward the right.

ORIFICE TUBE SIZES Manufacturers color-code orifice tubes to identify the car make and model for which a tube is made. There are at least eight different sizes of orifice tubes that have similar appearance, but the size ranges from 0.047 inch to 0.072 inch (1.19 mm to 1.8 mm). An R-134a system uses a larger orifice tube than a similar R-12 system.

ORIFICE TUBE LOCATION Some orifice tubes are placed into the evaporator inlet tube. An O-ring was fitted around it to stop refrigerant from flowing past the outside of the orifice tube. Several small indentations, or dimples, were put in the tubing wall to keep the orifice tube from moving too far into the evaporator. ● **SEE FIGURE 61–8**.

TECH TIP

How to Locate the Orifice Tube

In an operating system, the orifice tube position can be located by finding the point where the liquid line changes temperature from hot to cold. If the system is not operating, the dimples in the line show the orifice tube location.

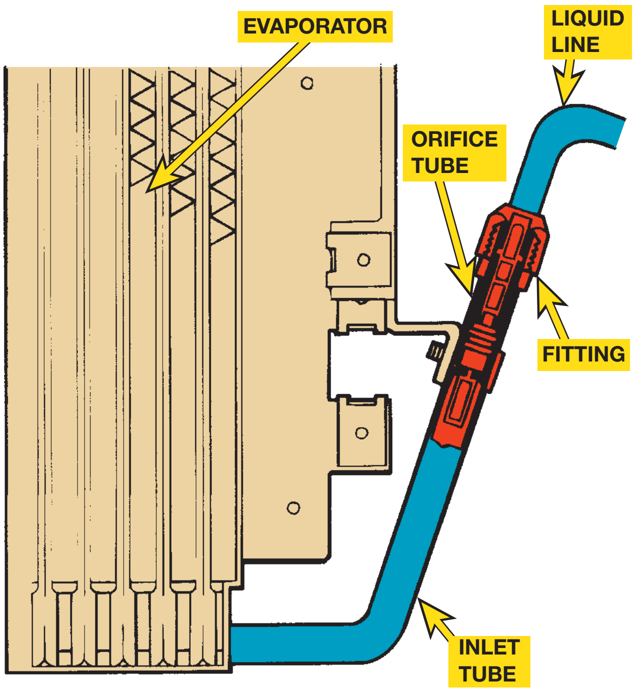

EVAPORATOR
LIQUID LINE
ORIFICE TUBE
FITTING
INLET TUBE

FIGURE 61–8 The orifice tube is usually located at the inlet tube to the evaporator.

Many newer vehicles place the orifice tube in the liquid line farther away from the evaporator, close to the condenser outlet. This is done because of complaints of hissing noises that occur after the vehicle is shut off and high-side pressure bleeds down through the orifice tube.

VARIABLE ORIFICE VALVES (VOVs) One type uses a variable orifice valve (VOV) that senses temperature to change the size of the orifice. A bimetal coil spring senses the temperature of the liquid refrigerant, and when the temperature increases, the spring moves the variable port to a closed position. This increases the restriction at the VOV and reduces the flow to the evaporator. ● **SEE FIGURE 61–9**.

A VOV is similar to a fixed orifice tube but contains an internal valve. Installation of the VOV is simply a matter of removing the orifice tube and installing the VOV. Always follow the instructions for the variable orifice valve if installing it in place of a fixed orifice tube.

EVAPORATORS

PURPOSE AND FUNCTION An evaporator, sometimes called the *evaporator core*, is a heat exchanger. The purpose and function of the evaporator is to remove heat from the air being forced through it to cool the inside of the vehicle. ● **SEE FIGURE 61–10**.

CONSTRUCTION Most evaporators are a series of plates sandwiched together to form both the refrigerant and air passages. ● **SEE FIGURE 61–11**.

Evaporators are normally made from aluminum because it has good thermal properties and is lightweight. Evaporators have at least two line connections:

1. The smaller inlet line (liquid line) connects to the TXV or orifice tube.
2. The larger outlet line connects to the suction line and to the compressor or accumulator on orifice tube systems. ● **SEE FIGURE 61–12**.

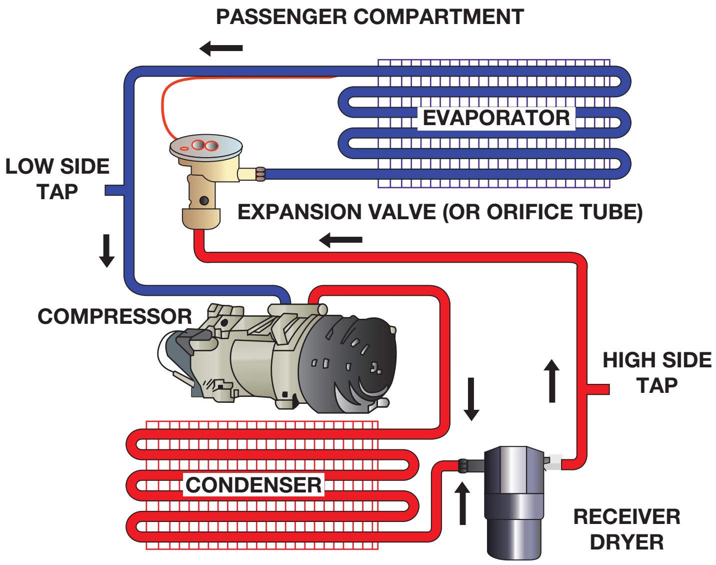

PASSENGER COMPARTMENT
EVAPORATOR
LOW SIDE TAP
EXPANSION VALVE (OR ORIFICE TUBE)
COMPRESSOR
HIGH SIDE TAP
CONDENSER
RECEIVER DRYER

FIGURE 61–10 The evaporator is part of the low pressure side of the refrigeration cycle and is used to transfer the heat from inside the vehicle to the refrigerant flowing through the internal tubes.

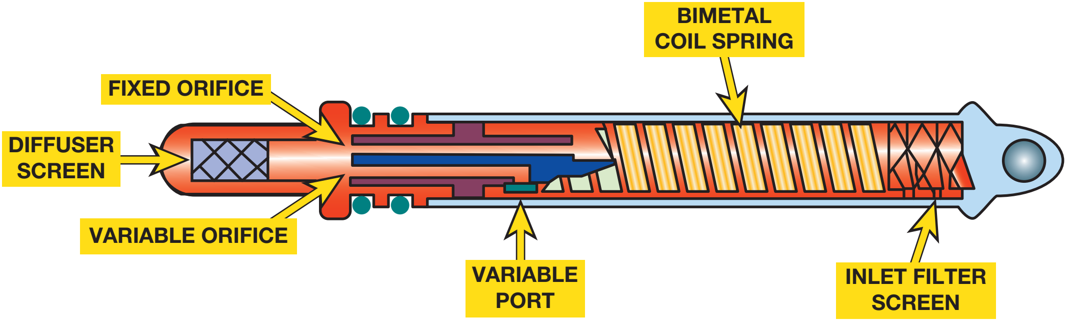

BIMETAL COIL SPRING
FIXED ORIFICE
DIFFUSER SCREEN
VARIABLE ORIFICE
VARIABLE PORT
INLET FILTER SCREEN

FIGURE 61–9 A VOV uses a bimetal coil spring to sense the temperature of the refrigerant. A higher temperature will cause the coil to expand and partially close the variable port to increase the restriction.

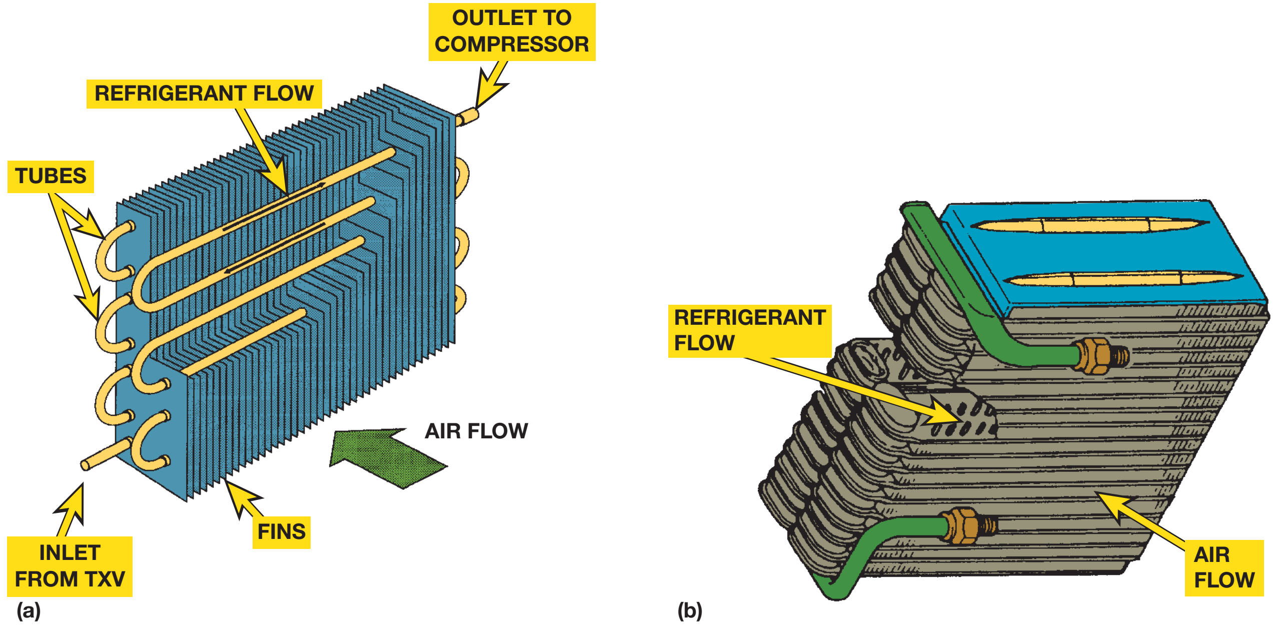


FIGURE 61–11 (a) An older design tube-and-fin evaporator. (b) A plate evaporator. Each type has a large contact area for heat to leave the air and enter the refrigerant.

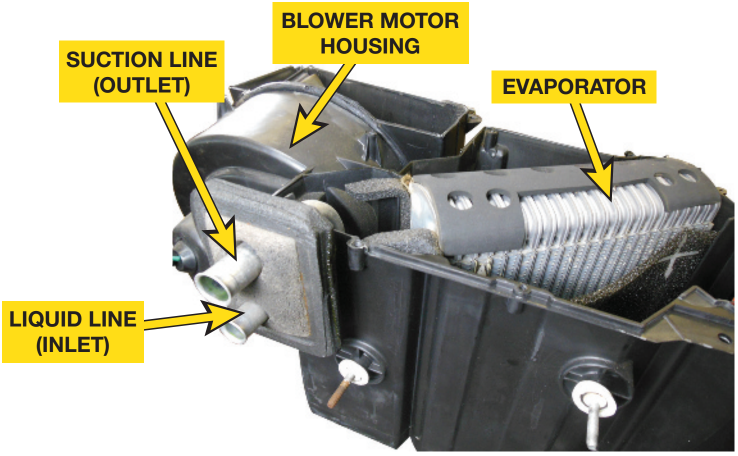


FIGURE 61–12 An evaporator in the HVAC case showing the liquid line inlet tube from the TXV or orifice tube and suction outlet line to the compressor or accumulator.

RECEIVER–DRIERS AND ACCUMULATORS

PURPOSE AND FUNCTION The purpose of refrigerant storage is to compensate for volume changes due to temperature change or refrigerant loss. Desiccant is needed to remove moisture or water, which can cause rusting or corrosion.

DESICCANT The desiccant is a chemical drying agent called "molecular sieve" and its job is to remove all traces of water vapor from a system. Water can mix with refrigerant to form acids, which cause rust and corrosion of metal parts. Water can also freeze and form ice at the TXV or OT, which can block the flow of refrigerant into the evaporator. ● **SEE FIGURE 61–13**.

ACCUMULATORS The accumulator serves three major functions:

1. Prevents liquid refrigerant from passing to the compressor.
2. Holds the desiccant, which helps remove moisture from the system.
3. Holds a reserve of refrigerant.

An accumulator is a container that holds about 1 quart (1 L) or less in volume. The inlet line from the evaporator enters near the top of the accumulator and then drops downward to the bottom, and then exits the accumulator at the top. This routing of the outlet tube separates the refrigerant vapor at the top from the liquid at the bottom so that only vapor will leave the accumulator. A small opening for oil bleed is at the lowermost point and this opening usually has a filter so debris will not block it. A small amount of liquid refrigerant and oil also leaves through the bleed hole. The oil ensures that the compressor is lubricated. ● **SEE FIGURE 61–14**.

The accumulator of some R-134a systems has an insulating jacket to help reduce the heat absorption and lower the air temperature at the discharge ducts. The accumulator or receiver–drier is normally replaced if a system has been opened to the atmosphere for a period of time because the desiccant is probably saturated with moisture. It is also standard practice to replace the accumulator or receiver–drier whenever major service work is done on a system, especially if the compressor is replaced.

The accumulator inlet on many vehicles is connected directly to the evaporator, whereas on other vehicles it is mounted separately with a metal tube or rubber hose to connect it to the evaporator. The outlet of the accumulator is connected to

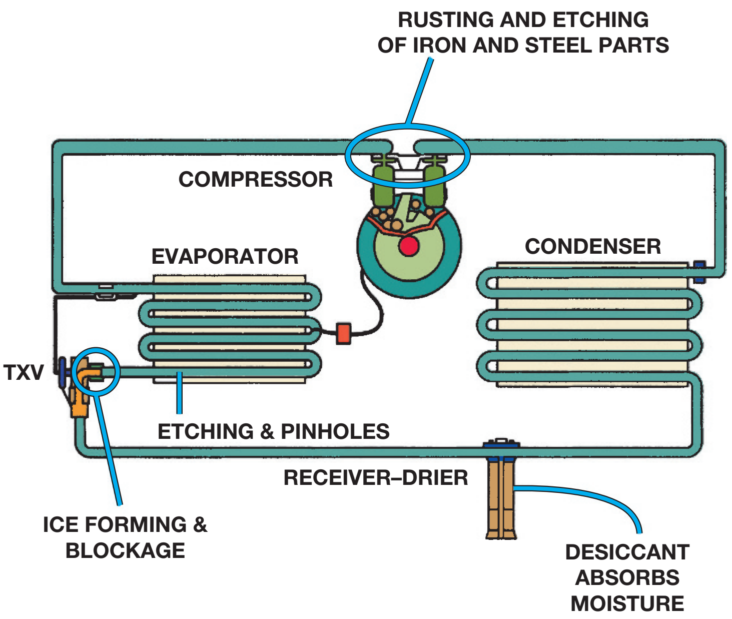

RUSTING AND ETCHING OF IRON AND STEEL PARTS
COMPRESSOR
EVAPORATOR
CONDENSER
TXV
ETCHING & PINHOLES
RECEIVER–DRIER
ICE FORMING & BLOCKAGE
DESICCANT ABSORBS MOISTURE

FIGURE 61–13 Water in an A/C system can combine with the refrigerant to form acid. These acids can etch and dissolve components, causing rusting of metal parts, and ice blockage at the expansion device.

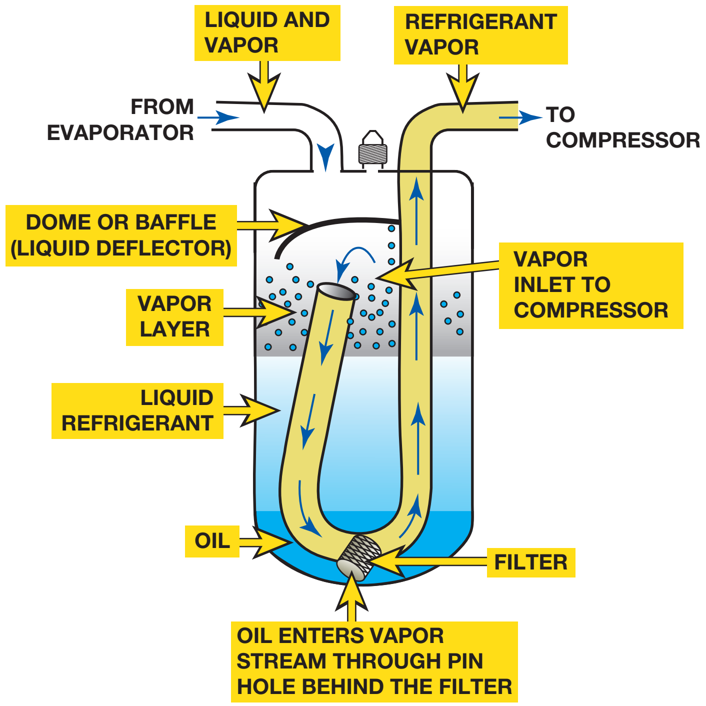

LIQUID AND VAPOR
REFRIGERANT VAPOR
FROM EVAPORATOR
TO COMPRESSOR
DOME OR BAFFLE (LIQUID DEFLECTOR)
VAPOR INLET TO COMPRESSOR
VAPOR LAYER
LIQUID REFRIGERANT
OIL
FILTER
OIL ENTERS VAPOR STREAM THROUGH PIN HOLE BEHIND THE FILTER

FIGURE 61–14 Accumulators are designed so that vapors from the top move to the compressor. They contain desiccant to absorb water from the refrigerant and many include a fitting for low-side pressure and the clutch cycling switch.

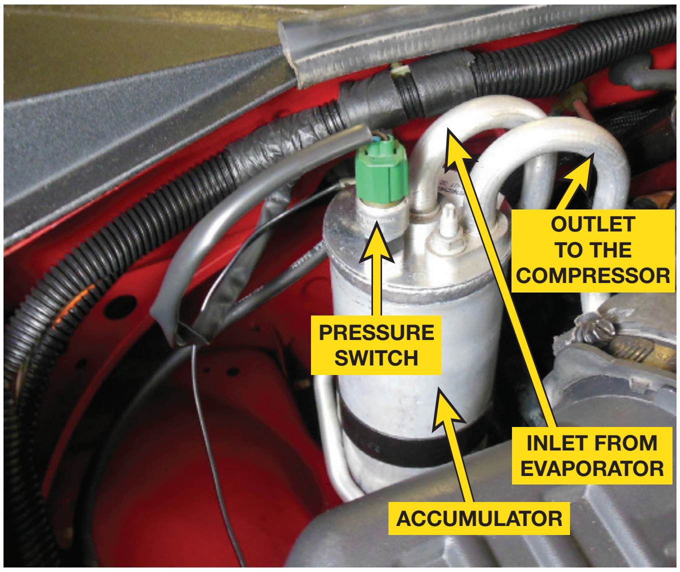

OUTLET TO THE COMPRESSOR
PRESSURE SWITCH
INLET FROM EVAPORATOR
ACCUMULATOR

FIGURE 61–15 This accumulator has an accumulator tube that connects the evaporator outlet and a suction line that connects to the compressor inlet.

the compressor inlet through the flexible suction line. ● **SEE FIGURE 61–15**.

RECEIVER–DRIER The receiver–drier is used with TXV systems and is normally found in the high-side liquid line, somewhere between the condenser and the TXV.

The receiver–drier inlet dumps incoming refrigerant into the container so that the refrigerant passes through a filter pad and the desiccant. The outlet, often called a *pickup tube,* begins near the bottom and usually exits at the top. A fine-mesh filter screen is used at the inner opening to stop debris from passing out of the receiver–drier and on to the TXV. The receiver–drier is usually about half full of liquid refrigerant. ● **SEE FIGURE 61–16**.

SIGHT GLASS A receiver–drier can contain a sight glass, pressure release plug or valve, or switch. The **sight glass** allows observation of the refrigerant flow as it leaves the receiver–drier. The flow of R-12 should be invisible because R-12 is clear, and the oil is dissolved in the liquid refrigerant. Bubbles or foam in the sight glass can indicate abnormal operation. R-134a would appear cloudy in a sight glass, so sight glasses are not commonly used in R-134a systems. The pressure relief switch is used to sense high-side pressure. It can be used to prevent compressor operation if the pressure is either too low or too high.

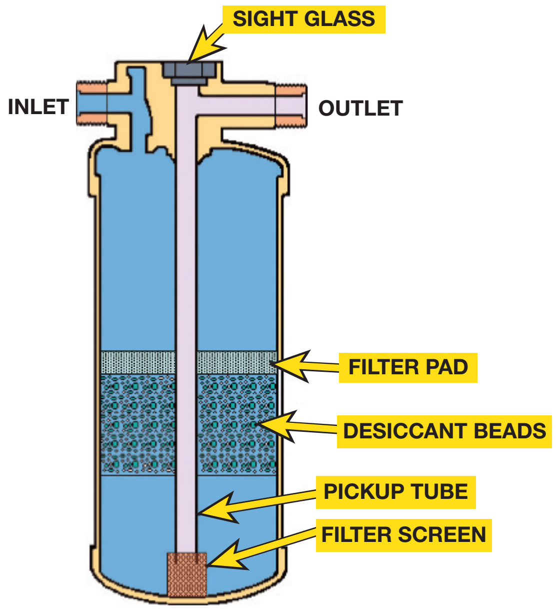

SIGHT GLASS
INLET
OUTLET
FILTER PAD
DESICCANT BEADS
PICKUP TUBE
FILTER SCREEN

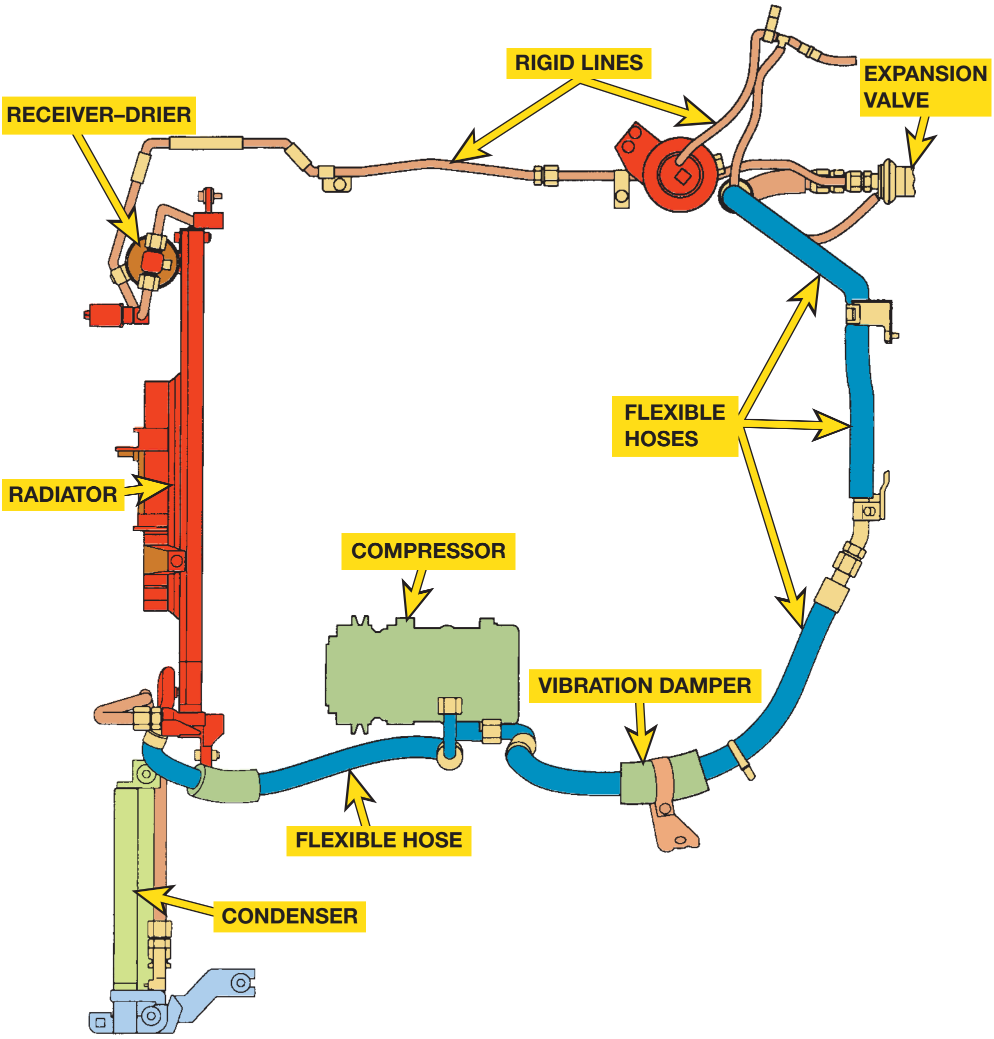
FIGURE 61–16 A cutaway view of a receiver–drier showing the filter pad and desiccant.

LINES AND HOSES

PURPOSE AND FUNCTION The various system components must be interconnected so that refrigerant can circulate through the system. The components are connected using hoses and tubing (also called pipes).

HOSE CONSTRUCTION Both flexible rubber and rigid metal tubing are used to link the components. The connections to the compressor must be flexible to allow for engine and compressor movement. ● **SEE FIGURE 61–17**.

- Early R-12 hoses were made from rubber with one or two layers of braided reinforcing material. Over time refrigerants could permeate most of these flexible hose materials and slowly escape from the system. This design hose worked with R-12, but R-134a (smaller molecule) would permeate (leak through) R-12 hoses.
- Refrigerant hoses designed for R-134a are made with one or two nonpermeable inner layers with internal reinforcement and an outer layer for protection.


RIGID LINES
RECEIVER–DRIER
EXPANSION VALVE
FLEXIBLE HOSES
RADIATOR
COMPRESSOR
VIBRATION DAMPER
FLEXIBLE HOSE
CONDENSER

Parts shown are not in their normal position and some parts are missing, but it does show the locations of the rigid and flexible refrigerant lines.

FIGURE 61–17 Rigid lines and flexible hoses are used throughout the A/C system. The line to and from the compressor must be flexible because it is attached to the engine, which moves on its mounts during normal vehicle operation.

The nonpermeable nylon layer forms a leak-proof barrier commonly called **barrier hoses**. The materials for the various layers are developed to keep refrigerant loss to a minimum.

METAL LINES Metal tubing (usually aluminum) is used in many systems to connect stationary components, such as a condenser, to the receiver–drier or OT.

- Metal tubing is sized by its outside diameter (OD).
- Pipes and hoses are sized by the inside diameter (ID) and these sizes are often nominal (approximate) sizes.

A number sizing is often used for refrigerant hose and fittings, with the most popular sizes being #4, #6, #8, #10, and #12.

- #4 equals 1/4 inch (6 mm)
- #6 equals 3/8 inch (10 mm)
- #8 equals 1/2 inch (13 mm)
- #10 equals 5/8 inch (16 mm)
- #12 equals 3/4 inch (19 mm)

Although metal aluminum tubing does not have permeation problems, corrosion caused by battery spillage or water can create holes in the tubing and produce leakage.

The lines in a system are named for their function or what they contain. Starting at the compressor, the **discharge line**, sometimes called the *hot gas line,* connects the compressor to the condenser inlet. The **liquid line** connects the condenser outlet to the receiver–drier and TXV or OT. A TXV system can have two liquid lines, one on each side of the receiver–drier. The **suction line** connects the evaporator outlet to the accumulator or compressor and has the largest diameter because it transfers a low-pressure vapor. ● **SEE FIGURE 61–18**.

HOSE SIZES

- The suction line has an ID of 1/2 inch or 5/8 inch (12.7 mm to 15.9 mm) (a #10 or #12 hose). The liquid line has the smallest diameter, usually an ID of 5/16 inch (7.9 mm) (#6 hose).

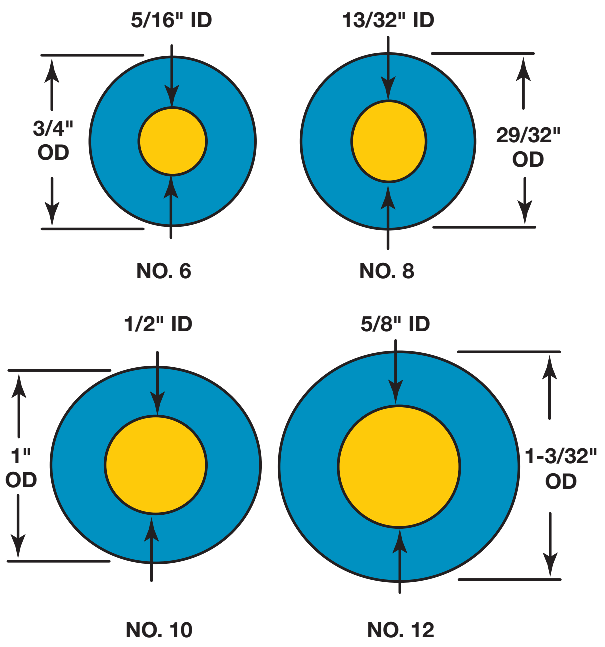


FIGURE 61–19 Most systems use three of these four refrigerant hose sizes. Metal tubing is sized by its outside diameter (OD) and hoses are sized by the inside diameter (ID).

- The discharge line has an ID of 13/32 inch or 1/2 inch (10.3 mm or 12.7 mm) (#8 hose). Metric sizes are also used. ● **SEE FIGURE 61–19**.

CONNECTIONS The lines and hoses are connected to the major components using fittings of several different styles. ● **SEE FIGURE 61–20**.

These fittings allow the lines to be disconnected and are designed to keep refrigerant leakage to a minimum. Most new fittings use an O-ring seal that can be replaced during service. A variety of quick-connect couplers are used to hold two lines together and seal the joint between them. Some of these are held together by one of at least two styles of plastic couplers. One

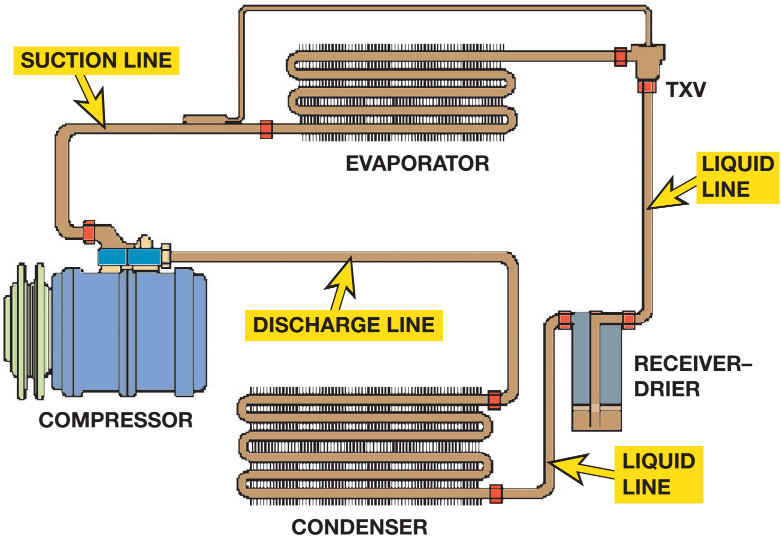


FIGURE 61–18 The three major hoses/lines are the discharge, liquid, and suction lines. A system can have two liquid lines.

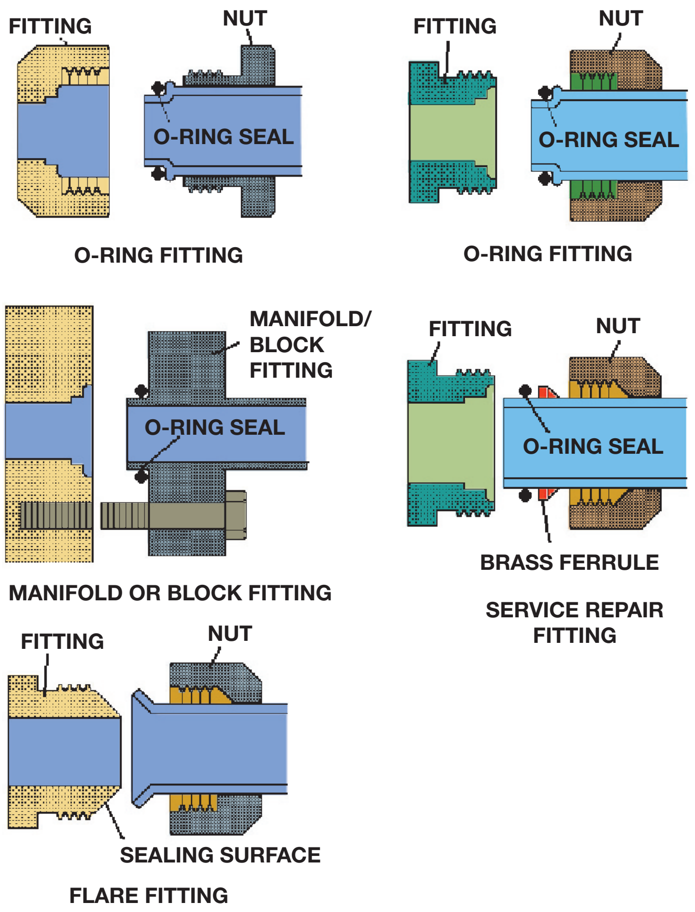

FITTING
NUT
O-RING SEAL
O-RING FITTING
FITTING
NUT
O-RING SEAL
O-RING FITTING
MANIFOLD/
BLOCK
FITTING
O-RING SEAL
MANIFOLD OR BLOCK FITTING
FITTING
NUT
O-RING SEAL
BRASS FERRULE
SERVICE REPAIR
FITTING
FITTING
NUT
SEALING SURFACE
FLARE FITTING

FIGURE 61–20 Various fittings are used to seal the refrigerant line connections. The service fitting is used for metal line repairs or to insert an inline filter.

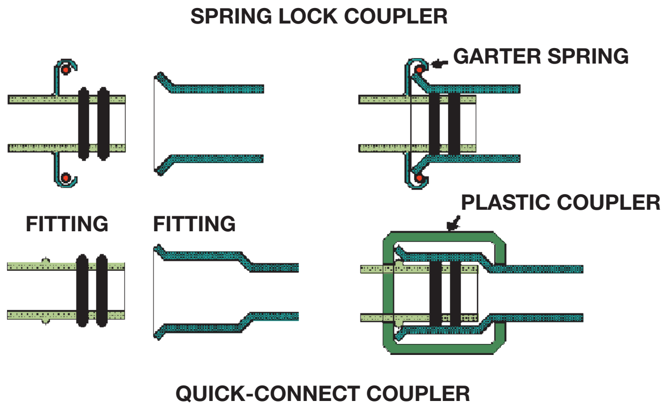

SPRING LOCK COUPLER
GARTER SPRING
FITTING
FITTING
PLASTIC COUPLER
QUICK-CONNECT COUPLER

FIGURE 61–21 Spring-lock and quick-connect couplers are merely pushed together, and a garter spring or plastic cage holds them coupled.

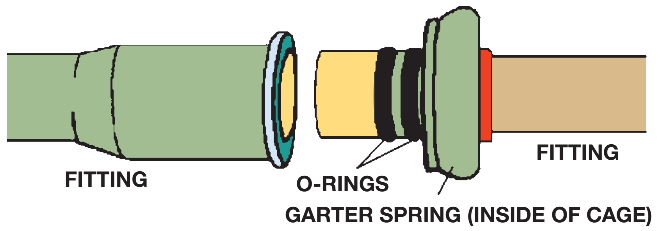

FITTING
FITTING
O-RINGS
GARTER SPRING (INSIDE OF CAGE)

FIGURE 61–22 A spring-lock fitting is a type of quick disconnect fitting that is sealed by two O-rings and held together by a garter spring. A special tool is required to expand the garter spring to release the fitting.

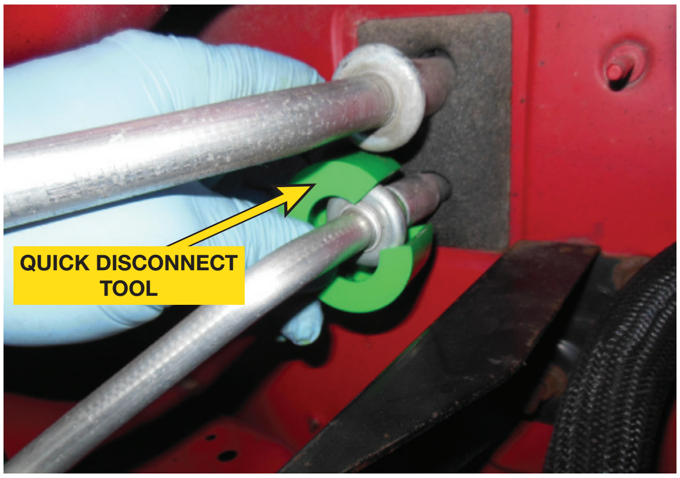

QUICK DISCONNECT
TOOL

FIGURE 61–23 A quick disconnect tool being used to remove the connections at the evaporator.

style was held together using a garter spring and was called a *spring-lock fitting*. ● **SEE FIGURE 61–21**.

Spring-lock fittings are connected by pushing one line over the other until the garter spring moves into position. A special tool is inserted into the fitting to expand the garter spring and release the fitting. ● **SEE FIGURE 61–22**.

A spring-lock fitting is a type of quick-disconnect fitting. One portion of this fitting has a flare-like ridge at the end and is gripped by a garter spring when connected. One or two O-rings form the seal between the two fitting parts. These O-rings must be resilient enough to compensate for slight movement between the two parts. ● **SEE FIGURE 61–23**.

O-RINGS O-ring fittings squeeze a rubber O-ring between the two parts being connected to make the seal. In most cases, the O-ring is slid over the end of the metal tube and is located by a raised metal ring or bead. Some manufacturers use a **captive O-ring**, also called *captured O-ring*, which locates the O-ring more positively in a shallow groove. Captive O-rings use a larger-diameter cross section than standard O-rings. Some designs use two O-rings for a better seal.

O-rings made from Buna or nitrile is commonly used in R-12 systems, but these materials are not compatible with R-134a. High-grade neoprene O-rings (HSN or HNBR), often tinted blue or green, are used in R-134a systems. There is no color standard for O-rings but most manufacturers use the following color designations:

- Black indicates nitrile or neoprene.
- Blue indicates neoprene or nitrile.
- Green indicates HNBR and is generally used in R-134a systems.

ELECTRICAL SWITCHES AND EVAPORATOR TEMPERATURE CONTROLS

CONTROL SWITCHES Various electrical switches are used in A/C systems to prevent evaporator icing, protect the compressor, and control fan motor. Control switches can be located anywhere in the system, such as at the

- compressor discharge
- suction cavities
- receiver–drier
- accumulator

Some recent systems use a variable displacement compressor to prevent icing. A valve that senses evaporator pressure is used in the compressor, and compressor displacement is reduced in response to that pressure.

At one time, the A/C electrical circuit was rather simple:

- A typical circuit connects the evaporator blower motor and compressor clutch at one main switch.
- The power to the compressor clutch passes through a temperature switch that opens the circuit to cycle the clutch when the evaporator gets too cold.
- The power to the blower motor passes through a speed control switch so that the blower speed can be changed. ● **FIGURE 61–24**.

Today various switches, sensors, and relays are used. A sensor is usually an input to an electronic control module (ECM) or body control module (BCM). Many sensors provide a variable signal, so the ECM/BCM will know the actual temperature or pressure at a given point. A relay is essentially a magnetic switch that is controlled by another switch. A relay is used to control a greater amount of current than a switch can handle. Relays also allow computer control modules to control electrical circuits. Any one A/C system will have some of these, but not all of the following, depending on the type of system and manufacturer:

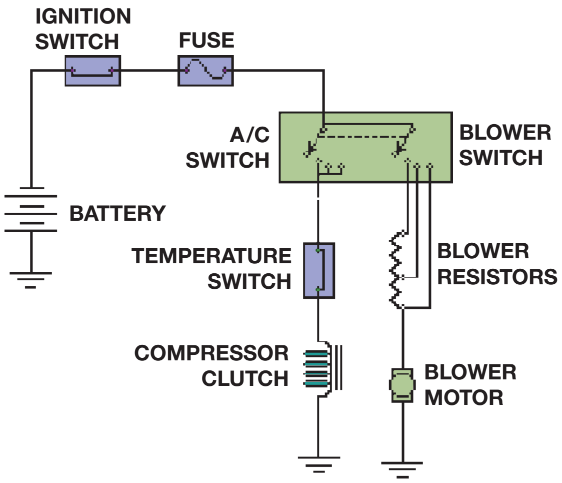


FIGURE 61–24 Many early A/C systems used a simple electrical circuit.

- **A/C clutch relay.** Controls current to compressor clutch and is used to turn the compressor on or off
- **Ambient sensor or switch.** Senses outside temperature and is designed to prevent compressor operation when ambient temperature is below a certain point, about 35°F to 40°F (2°C to 4°C)
- **Compressor high-pressure sensor or switch.** Mounted in compressor discharge cavity and senses high-side pressure and is used to cut out the compressor clutch if pressure is too high or too low, or provides a signal to another device that pressure is too high
- **Compressor low-pressure sensor or switch.** Mounted in compressor suction cavity, this switch or sensor detects low-side pressure and is used to cut out the compressor clutch if pressure is too low
- **Compressor RPM sensor.** Provides input to the ECM/BCM that the compressor is running. The ECM/BCM will cut out compressor if RPM is low (possible belt slippage or impending compressor lockup)
- **Compressor superheat sensor or switch.** Function is similar to compressor low-pressure switch
- **Compressor high-temperature switch.** Mounted on the compressor and shuts off the compressor if the temperature of the compressor gets too hot
- **Power steering compressor cutoff switch.** Mounted at power steering gear, this switch senses pressure in that system and is used to stop the compressor when the pressure in the power steering rises to a high level which increases the load on the engine. The A/C compressor clutch is then disengaged to help remove some of the load from the engine so it does not stall
- **Engine coolant temperature (ECT).** Mounted near the engine thermostat and senses engine temperature for ECM/BCM and is also used to turn on cooling fan(s)
- **Evaporator pressure sensor.** Provides input to the ECM/BCM as to the operating pressure in the evaporator
- **Evaporator temperature sensor.** Mounted at the evaporator, it senses temperature and is used to cycle compressor clutch to prevent icing
- **High-pressure cutout switch.** Mounted at receiver–drier or liquid line, it senses high-side pressure and is used to cut out the compressor clutch if high-side pressure is too high
- **High-temperature cutoff sensor or switch.** Mounted at the condenser outlet, this switch or sensor measures condenser temperature and is used to cut out the compressor clutch if the temperature is too high
- **Low-pressure cutout sensor or switch.** Mounted in receiver–drier or liquid line, it senses low pressure and is used to cut out the compressor clutch with low refrigerant charge
- **Main switch.** Mounted at control head, this switch can be operated by the driver to turn the system on or off

- **Pressure cycling switch.** Mounted at accumulator, it senses low pressure and cycles the compressor clutch to prevent evaporator icing
- **Thermostatic cycling switch.** Mounted at evaporator, it senses air temperature and cycles the compressor clutch to prevent evaporator icing
- **Trinary pressure switch.** Mounted at receiver–drier, this switch senses high-side pressure and cuts out compressor clutch if pressure is too high or too low. It can also be used to control radiator shutters or fan motor
- **Blower relay.** Can be used to turn blower on or off and provide high blower speed
- **Clutch cutoff relay.** Can be used to interrupt compressor clutch
- **Condenser fan relay.** Used to turn condenser fan motor on or off
- **Radiator fan relay.** Used to turn radiator fan motor on or off

THERMOSTATIC CYCLING SWITCH

Evaporator temperature in a cycling clutch system is sometimes controlled by either a thermostatic (thermal) switch or pressure switch. A bellows switch uses a capillary tube inserted into the evaporator fins. As with a TXV, the gas pressure in the capillary tube is exerted on the bellows. In a thermal switch, the bellows acts on a set of contact points:

- A warm evaporator produces a higher bellows pressure, which keeps the points closed.
- A cold evaporator reduces the pressure, which causes the points to open.

A bimetal switch has a contact arm that is laminated from two metals with very different thermal expansion rates:

- When the switch is warm, the metals expand to close the contact points.
- When the switch cools, the metals in the arm contract to open the contacts.

Both of these switch styles are calibrated so they are closed at temperatures above 32°F (0°C) and open at temperatures below 32°F (0°C). When the switch opens, the compressor clutch is turned off. This causes the evaporator to begin warming, and after a few degrees of temperature increase, the switch closes to cycle the compressor in again. Recent systems use thermistors to sense temperature instead of thermostatic cycling switches.

PRESSURE CYCLING SWITCHES

A pressure cycling switch is mounted to sense low-side pressure, usually on the accumulator. Ice begins to form when evaporator pressure drops below 30 PSI in an R-12 system or slightly less in an R-134a system.

- When evaporator pressure is above 30 PSI, the switch contacts close so the compressor will operate.
- When the pressure drops below 30 PSI, the switch opens and cycles the compressor out.
- After the compressor stops, evaporator pressure will increase and after an increase of about 10 PSI to 20 PSI, the pressure switch contacts close to cycle the compressor in again. This switch also prevents the compressor from operating if the pressure is too low from a refrigerant loss. ● **SEE FIGURE 61–25**.

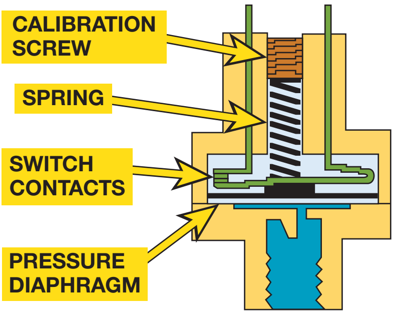


FIGURE 61–25 A pressure switch is either on or off. The contacts are closed by gas pressure on the diaphragm; they are opened by the spring.

LOW-PRESSURE SWITCH

Many systems include a low-pressure switch, located in a low-pressure line or the accumulator to prevent compressor operation if there is loss of refrigerant. Damage will occur if the compressor is operated without the refrigerant or the oil through which the refrigerant circulates.

THERMISTORS AND TRANSDUCERS

Recent systems use solid-state sensors that do not use switch contacts. The most common sensors are thermistors and transducers and these provide a variable output instead of just being on or off like a switch.

- A **thermistor** is commonly used to sense temperatures. It is basically an electrical resistor that changes resistance in inverse relationship to its temperature. Most automotive thermistors are of the negative temperature coefficient (NTC) type. The resistance will increase as the temperature drops and vice versa.
- A **transducer** senses pressure and changes a variable pressure signal into a variable electrical signal. A transducer can let the ECM/BCM know the actual pressure in the low and/or high side of the system. Sensors provide an electrical signal to a control module that, in turn, controls compressor clutch or condenser fan operation.

REAR A/C SYSTEMS

PARTS AND OPERATION

Some larger vehicles (vans and small buses) have dual heat and A/C assemblies, with the rear unit mounted in a rear side panel or in the roof. The rear A/C unit consists of an evaporator and a TXV that operates in parallel flow with the front unit. ● **SEE FIGURE 61–26**.

Tee fittings are placed in the liquid and suction lines so that refrigerant can flow through both units, with the flow through the rear unit dependent on the cooling load. Many dual systems use an orifice tube to control the refrigerant flow into the front

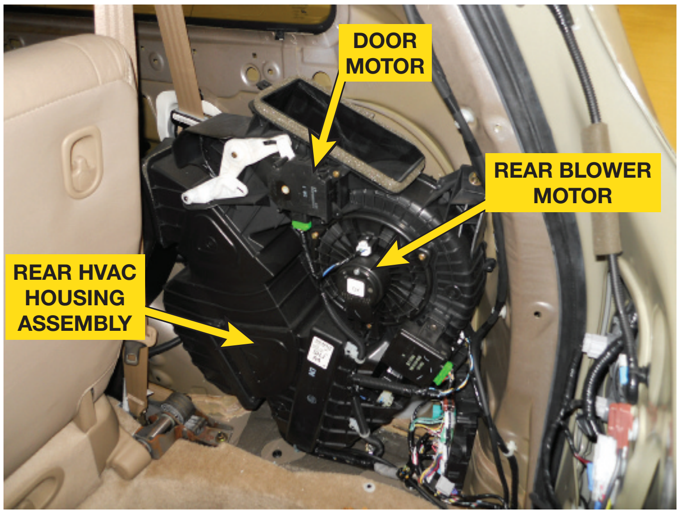


FIGURE 61–26 The rear HVAC module assembly used on a Honda Odyssey minivan.

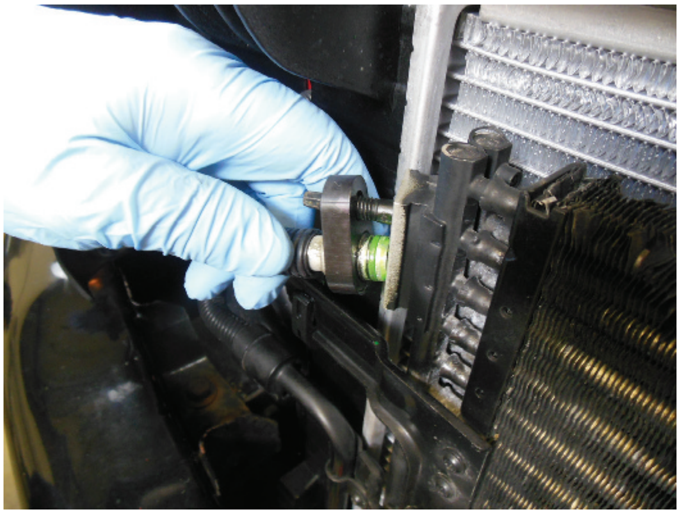


FIGURE 61–27 The line to the condenser from the compressor includes a flange mount with an O-ring. This line is being replaced with a new original equipment line as a result of an accident, which caused the line to be kinked.

evaporator and a TXV with the rear evaporator. The rear evaporator is normally mounted in an assembly that includes a blower, heater core, and doors to control the air temperature and where the air returns to the passenger compartment.

COMPONENT REPLACEMENT PROCEDURES

FITTING REPAIR If the fitting is tight and still leaks, it must be taken apart and inspected for damage and a new O-ring must be installed. Torque specifications for the various line fittings are provided by the vehicle manufacturer. Always use two wrenches when servicing fittings.

LINE REPLACEMENT A faulty hose or metal line is often repaired by replacing it with a new or repaired line. This normally involves disconnecting each end of the line at a fitting. Some hoses, like the suction and discharge, are combined with another line, making a double connection at the compressor, condenser, or evaporator. A manifold-type connector sealed with a pair of O-rings is commonly used at these connections. Some aftermarket suppliers can custom make hoses with fittings. ● **SEE FIGURE 61–27**.

A/C COMPONENT REPLACEMENT Inside-out failure is caused by acids inside of the system, and the accumulator or receiver–drier must be replaced and the refrigerant recycled to remove these acids.

- When the compressor, evaporator, or TXV is replaced, the receiver–drier or accumulator should also be replaced. These failures were possibly caused by system contamination. This contamination will probably have loaded the desiccant capacity with moisture.
- It is good practice to keep the plastic caps in place on the new components until just before installation to keep as much moisture out of the system as possible.
- Removal of an accumulator, condenser, evaporator, or receiver–drier also removes a certain amount of oil from the system, and new oil should be added to the new part. The actual amount is usually specified in service information. ● **SEE CHART 61–1**.

COMPONENT	FLUID OZ.	CC
Accumulator	2	60
Condenser	1	30
Evaporator	2	60
Each hose	0.3	10
Receiver–drier	0.5	15

CHART 61–1

When an A/C component is removed, a certain amount of oil is also removed. These are typical amounts. Check service information for the exact amount to add to each component if it is replaced.

If faulty, a major A/C component (the accumulator, condenser, evaporator, OT, receiver–drier, or TXV) is repaired by replacing it with a new one. At one time, replacement of these components was relatively easy because there was good access, except when working with evaporators. In most cases, getting the evaporator case out of the vehicle is tedious and time consuming, sometimes requiring the vehicle or evaporator case to be cut. Many technicians will not change an evaporator without consulting service information for the exact procedure to follow.

To remove and replace a major A/C component, locate, read, understand, and follow the specified repair procedure found in service information, which usually includes the following steps:

STEP 1 Recover the refrigerant from the system.

STEP 2 Disconnect and cap the refrigerant lines to the component.

STEP 3 Disconnect any mounting brackets and wires connected to the component and remove it.

STEP 4 Install the new part and attach any mounting brackets and wires.

STEP 5 Remove the line caps, pour the proper amount of the correct refrigerant oil into the component or line, and connect the refrigerant lines.

STEP 6 Evacuate and recharge the system and test for leaks.

ORIFICE TUBE REPLACEMENT A special puller that attaches to the orifice tube or needle-nose pliers is normally used to remove it. ● **SEE FIGURE 61–28**.

TXV REPLACEMENT When replacing a TXV (other than a H-block-type TXV), the thermal bulb must be securely attached to the evaporator outlet tube. This area must be clean to ensure good heat transfer. After attaching the thermal bulb, it must be wrapped with insulating refrigerant tape. This thick, pliable tape is used to keep outside heat from reaching the thermal bulb.

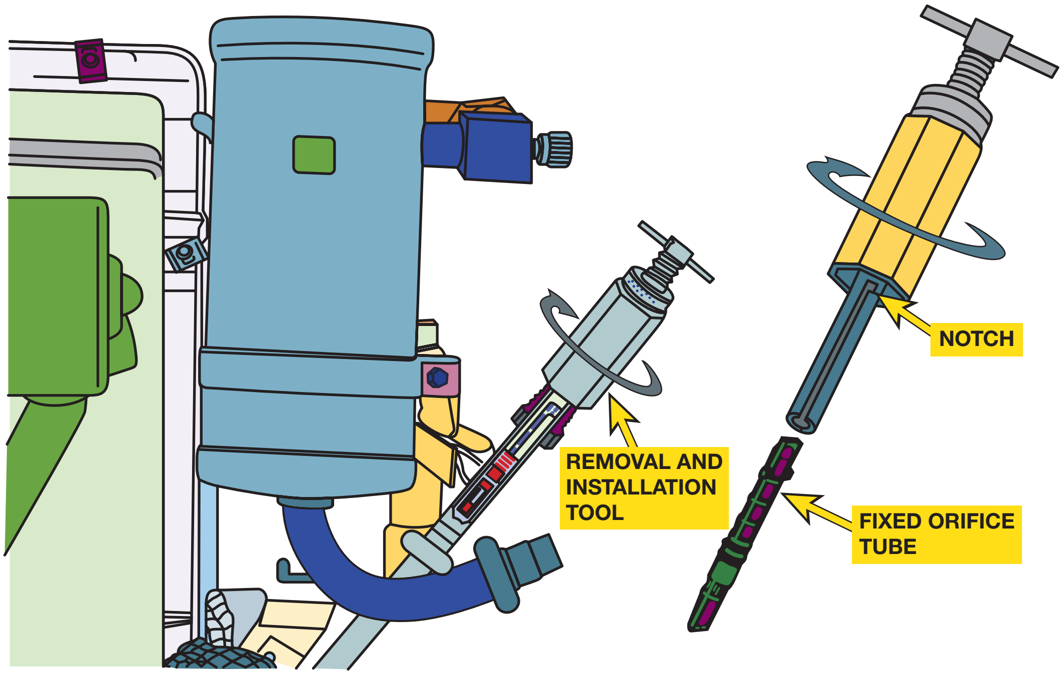


FIGURE 61–28 Needle-nose pliers can sometimes be used to remove an orifice tube, but it requires this special tool in most cases.

REVIEW QUESTIONS

1. Why is sub-cooling necessary in some condensers?
2. Where is the thermal expansion valve located in the refrigeration system?
3. Where is the orifice tube located in the refrigeration system?
4. What is the difference between an accumulator and a receiver–drier?
5. Why does refrigerant oil need to be added to a new component such as a condenser?

CHAPTER QUIZ

1. A cooling module usually includes what components?
   - **a.** Radiator
   - **b.** Automatic transmission fluid cooler
   - **c.** A/C condenser
   - **d.** All of the above
2. As the latent heat of condensation is transferred to the airstream in the condenser, the refrigerant changes into ___________.
   - **a.** liquid
   - **b.** vapor
   - **c.** gas
   - **d.** solid
3. Newer condensers use a ___________ tube design, with fins between the tubes.
   - **a.** copper
   - **b.** flattened
   - **c.** rubber
   - **d.** None of the above
4. What is the purpose of the compressor in a refrigeration system?
   - **a.** Circulates the refrigerant
   - **b.** Raises the pressure of the refrigerant
   - **c.** Raises the temperature of the refrigerant
   - **d.** All of the above

5. The orifice tube is usually located at the inlet tube to the ____________.
    - **a.** condenser
    - **b.** compressor
    - **c.** evaporator
    - **d.** receiver–drier
6. Two technicians are discussing A/C systems. Technician A says that the TXV system uses a receiver–drier mounted in the suction line. Technician B says that the orifice tube system uses an accumulator in the suction line. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B
7. The liquid line ____________.
    - **a.** connects the condenser to the receiver–drier and TXV or OT
    - **b.** is smaller than the suction line
    - **c.** is larger in diameter than the suction line
    - **d.** Both a and b
8. O-rings used in R-134a systems are usually ____________.
    - **a.** green
    - **b.** black
    - **c.** red
    - **d.** orange
9. Various electrical switches used in A/C systems ____________.
    - **a.** prevent evaporator icing
    - **b.** protect the compressor
    - **c.** control fan motors
    - **d.** All of the above
10. Rear A/C systems use ____________.
    - **a.** an orifice tube to control the refrigerant flow into the front evaporator and a TXV with the rear evaporator
    - **b.** an orifice tube to control the refrigerant flow into the front evaporator and the rear evaporator
    - **c.** a TXV to control the refrigerant flow into the front evaporator and an orifice tube with the rear evaporator
    - **d.** a TXV to control the refrigerant flow into the front evaporator and the rear evaporator

Chapter 62

AIR MANAGEMENT SYSTEM

LEARNING OBJECTIVES

After studying this chapter, the reader should be able to:

- Discuss the different components of an air management system.
- Explain airflow control in an A/C system.
- Explain air temperature control in an A/C system.
- Describe air filtration in an A/C system.
- Describe housing and ducts in an A/C system.
- Discuss plenum and control doors.
- Explain nonelectrical and electronic HVAC controls.
- Describe the blower motor.

KEY TERMS

Air doors 735 • Air inlet door 736 • Air management system 735 • Cabin filter 738 • Dual-zone 741 • Inside air 735 • Mode door 736 • Outside air 735 • Plenum 739 • Recirculation 735 • Temperature-blend door 736

TERMINOLOGY

AIR MANAGEMENT A system that contains the HVAC plenum, ducts, and **air doors** is called the **air management system**, or *air distribution system,* and controls the airflow to the passenger compartment. ● **SEE FIGURE 62–1**.

Air flows into the case that contains the evaporator and heater core from two possible inlets:

1. **Outside air**, often called *fresh air*
2. **Inside air**, usually called **recirculation**.

Proper temperature control to enhance passenger comfort during heating should maintain an air temperature in the

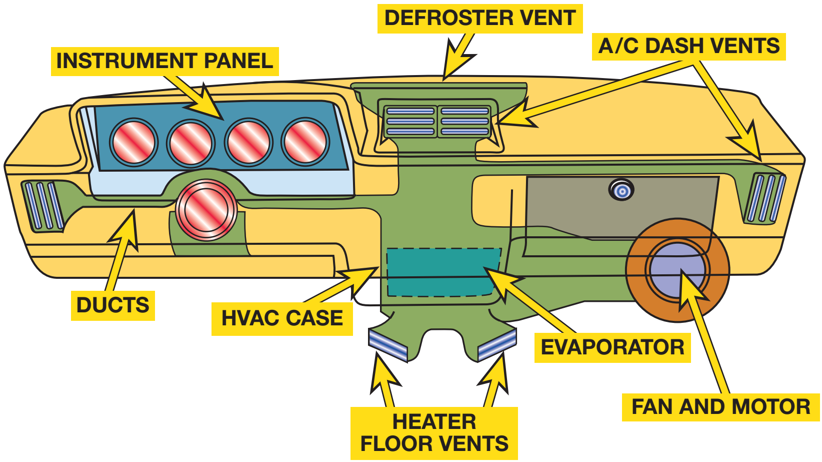


FIGURE 62–1 The HVAC airflow is directed toward the windshield, dash or floor vents, or combinations depending on the system settings.

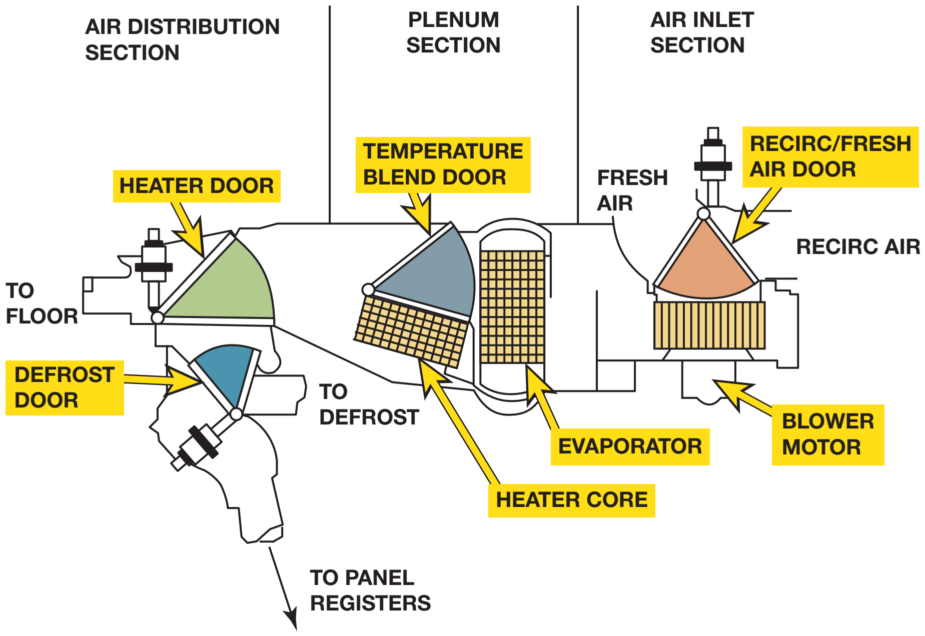


FIGURE 62–2 The three major portions of the A/C and heat system are air inlet, plenum, and air distribution. The shaded portions show the paths of the four control doors.

footwell about 7°F to 14°F (4°C to 8°C) above the temperature around the upper body. This is done by directing the heated airflow to the floor. During A/C operation, the upper body should be cooler, so the airflow is directed to the instrument panel registers. Airflow is usually controlled by three or more doors, which are called *flap doors* or valves by some manufacturers. The three doors include the following:

- **Air inlet door** is used to select outside or inside air inlet.
- **Temperature-blend door** is used to adjust air temperature.
- **Mode door** is used to select air discharge location. ● **SEE FIGURE 62–2**.

The use of these components allows the system to provide airflow under the following conditions:

1. Fresh outside air or recirculated air
2. Air conditioning
3. Defrost
4. Heat

HEAT For heat position, the following can be done:

- Temperature set to the desired setting
- Air intake—select outside air for faster heating
- Air conditioning set to off
- Set airflow to floor
- Fan speed set to desired speed

AIR CONDITIONING For air conditioning position, the following can be done:

- Temperature set to the desired setting
- Air intake—set to outside air or recirculation under high humidity conditions
- Airflow—set to dash vents (also called panel vents)
- Air conditioning set to on
- Fan speed set to desired speed

VENTILATION For ventilation position, the following can be done:

- Temperature set to desired temperature
- Air intake—select outside air
- Airflow—set to dash (panel) vents
- Air conditioning set to off
- Fan speed set to desired speed

DEFOGGING OR DEFROSTING THE INSIDE OF THE WINDSHIELD For defogging or defrosting position, the following can be done:

- Temperature set to high temperature
- Air intake set to outside air
- Airflow set to windshield (defrost)
- Fan speed set to desired speed. ● **SEE FIGURE 62–3**.

HVAC CONTROL HEAD The HVAC control head or panel is mounted in the instrument panel cluster or console. The control head includes the following controls:

- System on and off
- Outside or recirculated air
- Mode position (floor, vent, or defrost)
- Temperature desired
- Blower speed

The control head is connected to various parts through electrical connections, vacuum connections, mechanical cables, or a combination of these. ● **SEE FIGURE 62–4**.

AIRFLOW CONTROL

OPERATION The amount or volume of HVAC air is controlled by blower speed. A multispeed blower is used to force air through the ductwork when the vehicle is moving at low speeds or to increase

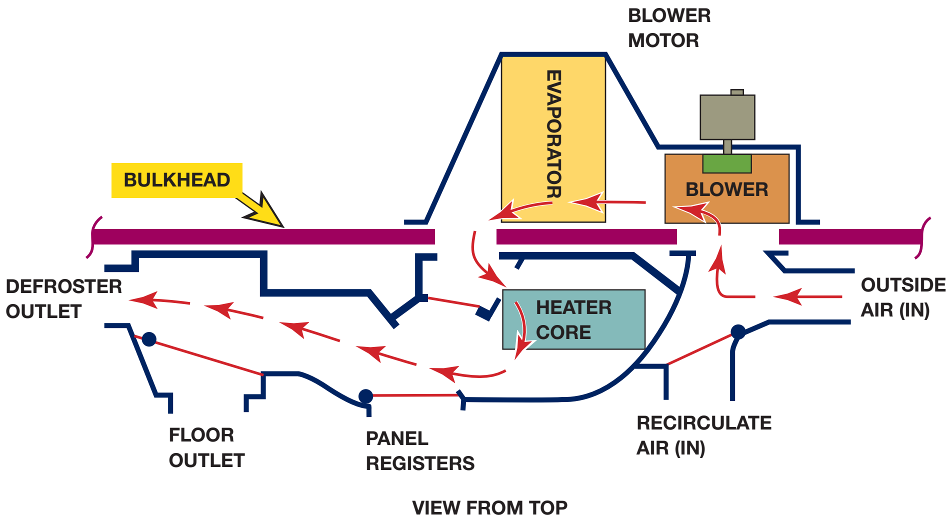

BLOWER
MOTOR
EVAPORATOR
BULKHEAD
BLOWER
DEFROSTER
OUTLET
HEATER
CORE
OUTSIDE
AIR (IN)
FLOOR
OUTLET
PANEL
REGISTERS
RECIRCULATE
AIR (IN)
VIEW FROM TOP

FIGURE 62–3 In the defog or defrost mode position, the air is directed through the evaporator to remove the moisture from the air before being sent through the heater core to warm the air.

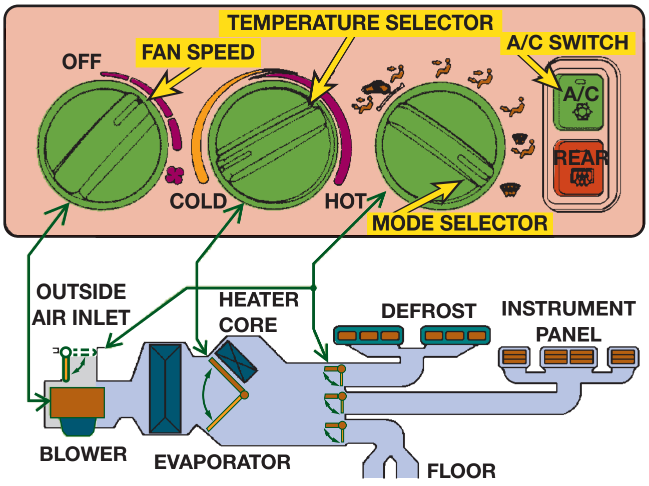

TEMPERATURE SELECTOR
OFF
FAN SPEED
A/C SWITCH
A/C
REAR
COLD
HOT
MODE SELECTOR
OUTSIDE
AIR INLET
HEATER
CORE
DEFROST
INSTRUMENT
PANEL
BLOWER
EVAPORATOR
FLOOR

FIGURE 62–4 Most HVAC control heads include a control for turning units on and setting the mode of operation, a control for adjusting the temperature, and a control for the fan speed.

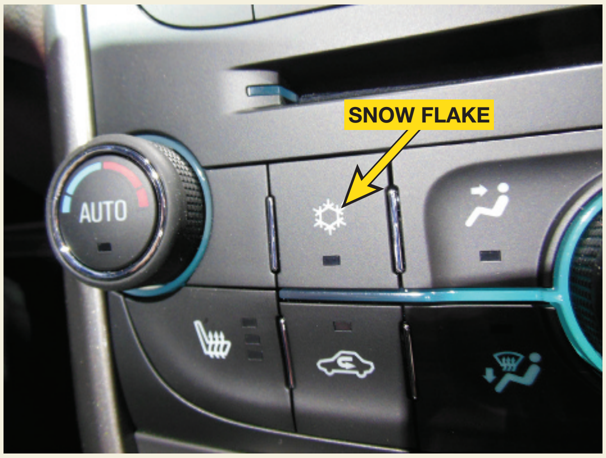

SNOW FLAKE
AUTO

FIGURE 62–5 The A/C compressor is turned on or off by depressing the “snow flake” button on the dash.

the airflow at any speed. At highway speeds, most systems have a natural airflow from ram air pressure created by the forward movement of the vehicle. This is the pressure generated at the base of the windshield by the speed of the vehicle. This airflow is improved in some vehicles by outlet registers placed in low-pressure areas toward the rear of the vehicle. Higher speeds move more air. The inlet and outlet directions of the airflow and the discharge air temperature are controlled by swinging, sliding, or rotating doors.

FREQUENTLY ASKED QUESTION

What Does the Snowflake Button on the Dash Do?

Some people, such as those who drive vehicles that are equipped with automatic climate control systems, sometimes find it hard to figure out how to engage the A/C compressor on a rental car or a vehicle that they have not driven before. Often the driver will turn the fan to high and the mode selector to the dash vent position, but no cool air is being delivered. For the compressor to function, the button that looks like a snowflake has to be pushed. The snowflake button is actually the air conditioning on/off button. ● **SEE FIGURE 62–5**.

TYPES OF DOORS Most systems use a flap door that swings about 45 degrees to 90 degrees. Swinging doors are very simple and require little maintenance. ● **SEE FIGURE 62–6**.

Another design uses a *rotary door*. This pan-shaped door has openings at the side and edge, and the door rotates about 100 degrees to one of four different positions. Each position directs airflow to the desired outlet(s).

The space under the instrument panel is very crowded, and some vehicles use a smaller HVAC case using a *sliding mode door* also called a *rolling door*. Some of these door designs roll up, similar to a window shade, and unroll to block a passage. ● **SEE FIGURE 62–7**.

AIR TEMPERATURE CONTROL

TEMPERATURE CONTROL USING AIRFLOW Most HVAC systems are considered *reheat* systems in that the incoming air is chilled as it passes through the evaporator. The air is then heated

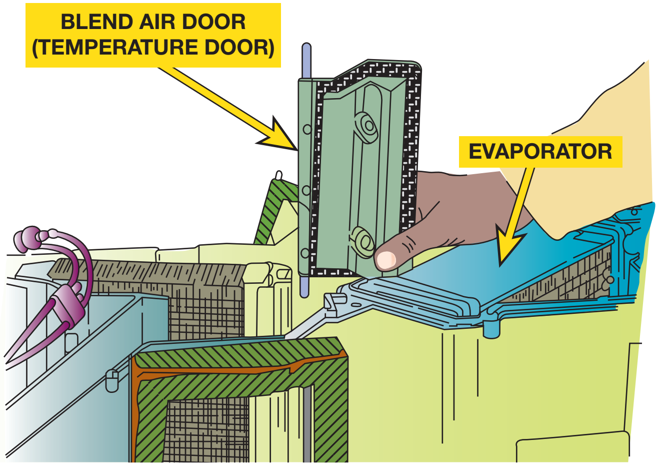


FIGURE 62–6 Many air control doors swing on their upper and lower pivots.

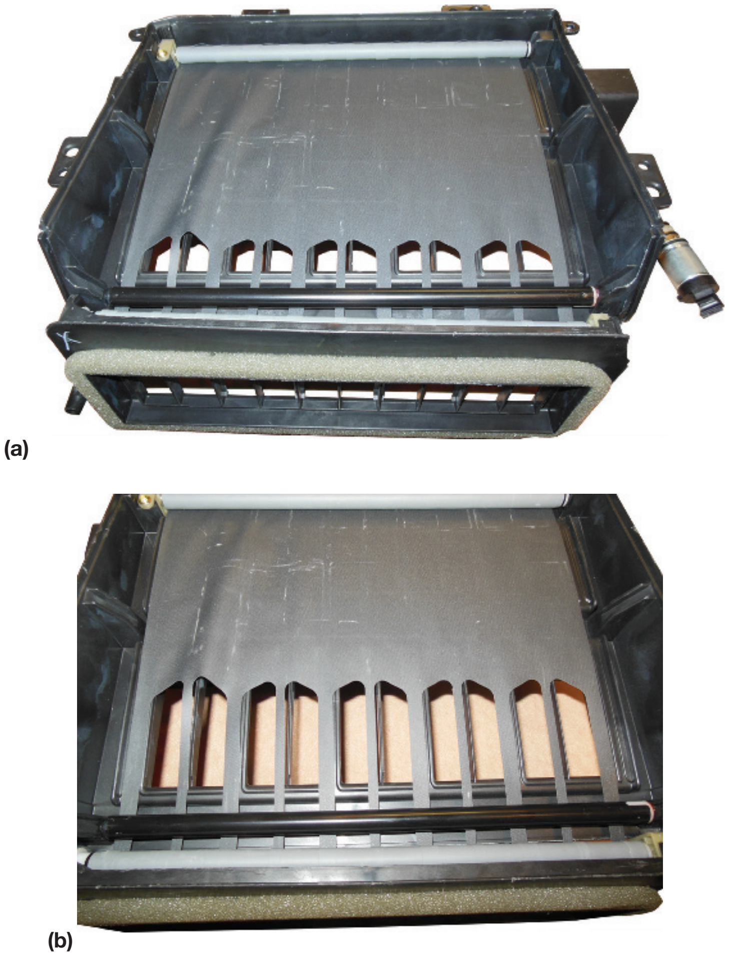


FIGURE 62–7 (a) A typical rolling-door type HVAC door that is shown almost fully closed. (b) The same door is shown about half open.

as part or all of the flow passes through the heater core so it reaches the desired in-vehicle temperature. ● **SEE FIGURE 62–8**.

TEMPERATURE CONTROL USING A VARIABLE COMPRESSOR There is an increasing trend to use an electronically controlled variable displacement compressor with an air temperature sensor after the evaporator. Compressor displacement is adjusted to cool the evaporator just enough to cool the air to the desired temperature. Cooling the incoming air no more than necessary will reduce compressor load on the engine and should improve fuel economy.

AIR FILTRATION

PURPOSE AND FUNCTION Many newer systems include an HVAC air filter, usually called a **cabin filter**, in the air distribution system. Cabin filters are located outside the air inlet and are serviced under the hood, or between blower and evaporator which are serviced from under the dash. ● **SEE FIGURE 62–9**.

This filter can also be referred to as a(n)

- interior filter
- ventilation filter
- micron filter
- particulate filter
- pollen filter

The cabin filter removes small dust or pollen particles from the incoming air stream. These filters require periodic replacement and if they are not serviced properly, they can cause an airflow reduction when they become plugged.

TYPES OF CABIN FILTERS There are two types of filter media:

1. Particle filters. Particle filters remove solid particles such as dust, soot, spores, and pollen using a special paper or nonwoven fleece material; they can trap particles that are about three microns or larger.
2. Adsorption filters. Adsorption filters remove noxious gases and odors using an activated charcoal media with the charcoal layer between layers of filter media. These two filter types can be combined into a combination or two-stage filter. The filter media can have an electrostatic charge to make it more efficient.

CASE STUDY

Cabin Filter Fault

The owner of a Ford Escape complained that the air-conditioning system was not cooling the inside of the vehicle and there seemed to be no airflow from the dash vents yet the blower motor could be heard running. A quick visual inspection of the cabin air filter with access under the hood showed that the cabin filter was almost completely blocked with paper, leaves, and debris. The vehicle had almost 80,000 miles on the odometer and the way it looked, the air filter had never been replaced. Most vehicle manufacturers recommend replacement of the cabin air filter about every three years or every 36,000 miles. Replacing the cabin air filter restored proper operation of the A/C system.

Summary:

Complaint—Customer complained of a lack of airflow from the dash vents.

Cause—A partially clogged cabin filter.

Correction—Replacement of the cabin filter restored proper airflow from the dash vents.

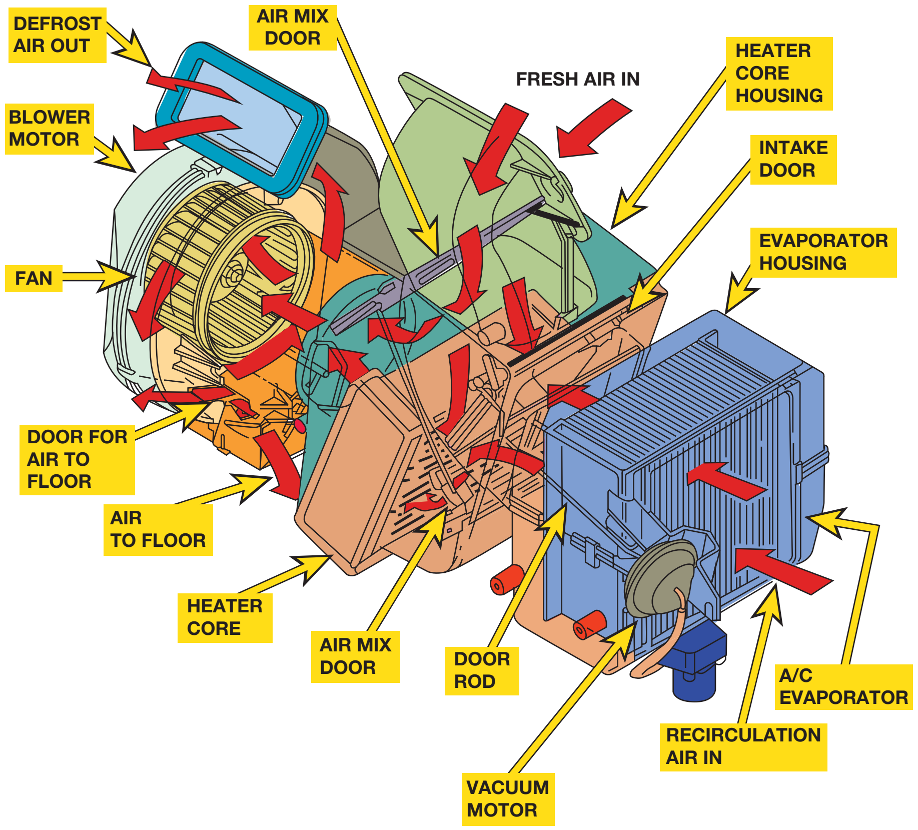

DEFROST AIR OUT
AIR MIX DOOR
FRESH AIR IN
HEATER CORE HOUSING
BLOWER MOTOR
INTAKE DOOR
EVAPORATOR HOUSING
FAN
DOOR FOR AIR TO FLOOR
AIR TO FLOOR
HEATER CORE
AIR MIX DOOR
DOOR ROD
A/C EVAPORATOR
RECIRCULATION AIR IN
VACUUM MOTOR

FIGURE 62–8 The blower motor forces air to flow through the A/C evaporator to remove moisture from the air before it is sent through the heater core where the air is heated before being directed to the defrost and floor vents.

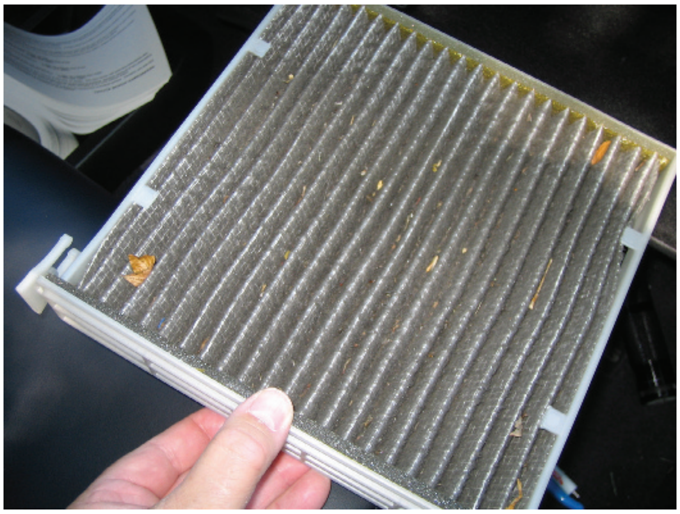


FIGURE 62–9 A cabin filter being removed from behind the glove compartment. The dark color is part of the filter and is activated charcoal used to help remove odors.

HOUSING AND DUCTS

CONSTRUCTION The evaporator and heater housing is molded from reinforced plastic and contains the following components:

- Evaporator
- Heater core
- Blower motor
- Most of the air control doors

The housing, called a **plenum**, is connected to the air inlets and outlets using formed plastic. These parts are required to contain and direct airflow, reduce noise, keep outside water and debris from entering, and isolate engine fumes and noises. ● **SEE FIGURE 62–10**.

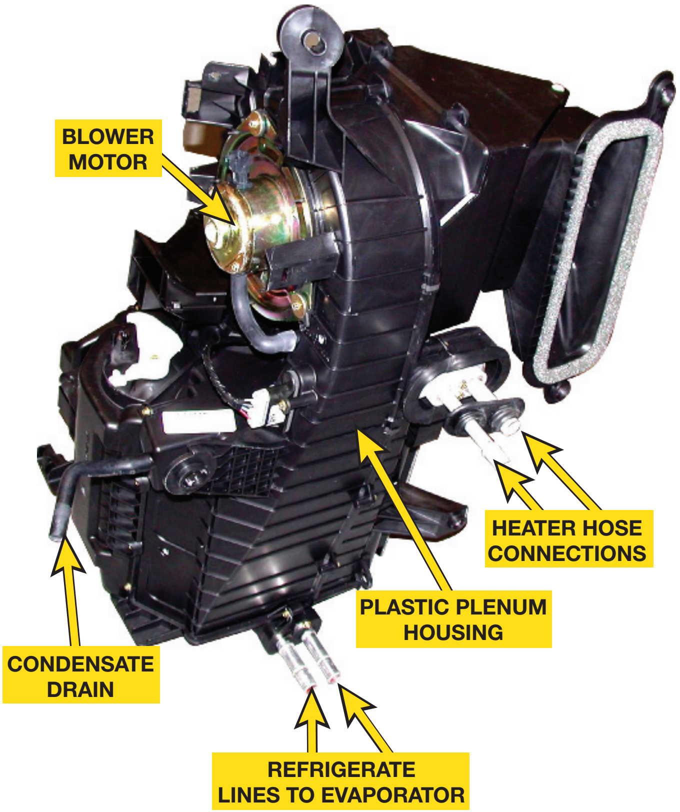

BLOWER MOTOR
HEATER HOSE CONNECTIONS
PLASTIC PLENUM HOUSING
CONDENSATE DRAIN
REFRIGERATE LINES TO EVAPORATOR

FIGURE 62–10 A typical HVAC housing that often has to be removed from the vehicle as an assembly to get access to the heater core and evaporator.

Air can enter the duct system from either the plenum chamber in front of the vehicle's windshield (outside air) or from the *recirc* (short for *recirculation*) or return register (inside air). The return register is often positioned below the right end of the instrument panel. (The right and left sides of the vehicle are always described as seen by the driver.) The outside air

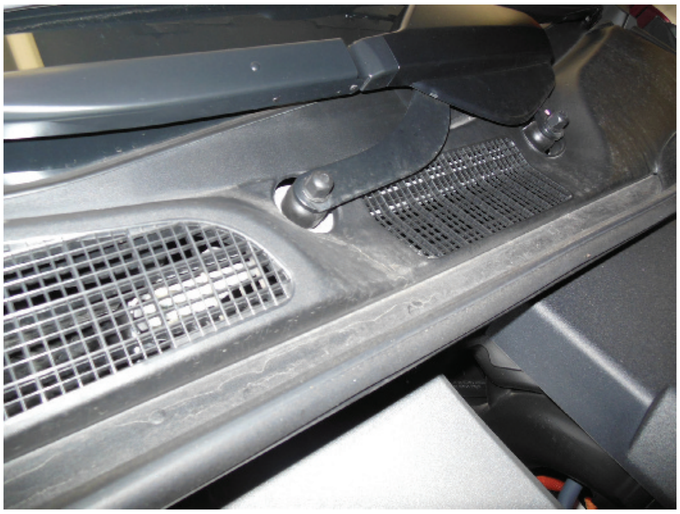


FIGURE 62–11 The air inlet to the HVAC system is usually at the base of the windshield and covered with a plastic screen (grille) to help keep debris such as leaves from entering the system.

plenum often includes a screen to keep leaves and other large debris from entering with the air. ● **SEE FIGURE 62–11**.

PLENUM AND CONTROL DOORS

AIR INLET CONTROL DOOR The air inlet control door is also called

- *Fresh air door*
- *Recirculation door*
- *Outside air door*

This door is normally positioned so it allows airflow from one source while it shuts off the other. It can be positioned to allow:

- Fresh air to enter while shutting off the recirculation opening
- Air to return or recirculate from inside the vehicle while shutting off fresh air
- A mix of fresh air and return air

In many newer vehicles, the door is set to the fresh air position in all function lever positions except off, max heat, and max A/C. Max A/C and max heat settings position the door to recirculate in-vehicle air.

TECH TIP

Keep the Air Screen Clean

The outside air inlet screen must be kept in good condition to prevent debris and small animals from entering the HVAC case. Leaves and pine needles can enter, decay, and mold. Mice have been known to enter and build nests and/or die. Any of these conditions can create a bad smell and are very difficult to clean.

NOTE: In some vehicles, the recirculation door blocks most of the outside air and allows 80% of the air to be recirculated from the passenger compartment. About 20% of the air entering the passenger compartment is outside air to help keep the air in the passenger compartment fresh and keep the CO_2 levels low.

TEMPERATURE-BLEND DOOR Most systems position the evaporator so all air must pass through it. This allows removal of moisture by the evaporator's cold temperature. Many systems operate the A/C when defrost is selected to dry the air. The heater core is placed downstream so that air can be routed either through or around it using one or two doors to control this airflow. The door used to control interior temperature is called the temperature-blend door. Some other names for this door include

- *Air-mix door*
- *Temperature door*
- *Blend door*
- *Diverter door*
- *Bypass door.* ● **SEE FIGURE 62–12**.

The temperature-blend door is connected to the temperature knob or lever at the control head using a mechanical cable or an electric actuator. When the temperature lever is set to the coldest setting, the temperature-blend door routes all air so it bypasses the heater core. This causes the air entering the passenger compartment to be the coldest, coming straight from the evaporator. When the temperature lever is set to the hottest setting, the temperature-blend door routes all air through the heater core, and heated air goes to the passenger compartment.

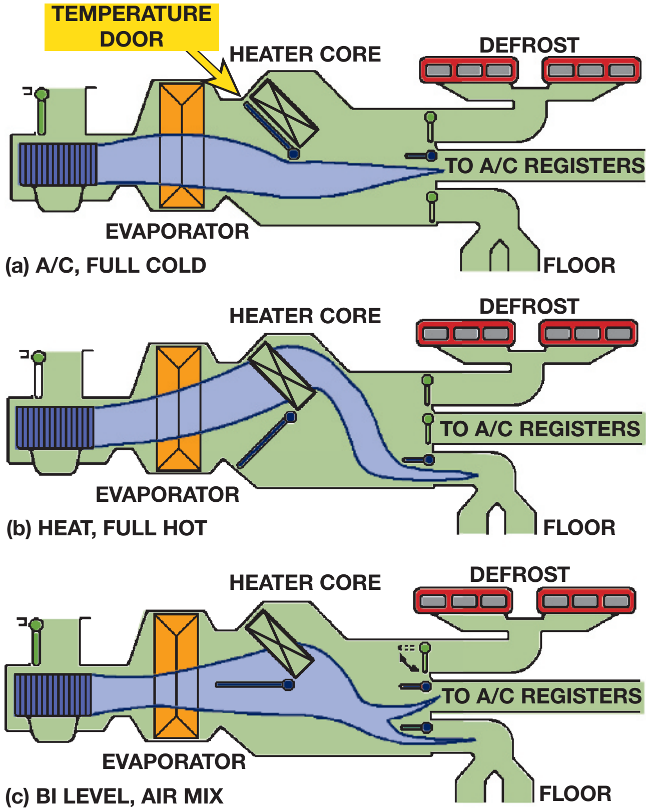


FIGURE 62–12 (a) The temperature and mode doors swing to direct all of the cool air past the heater core, (b) through the core to become hot, (c) or to blend hot and cool air.

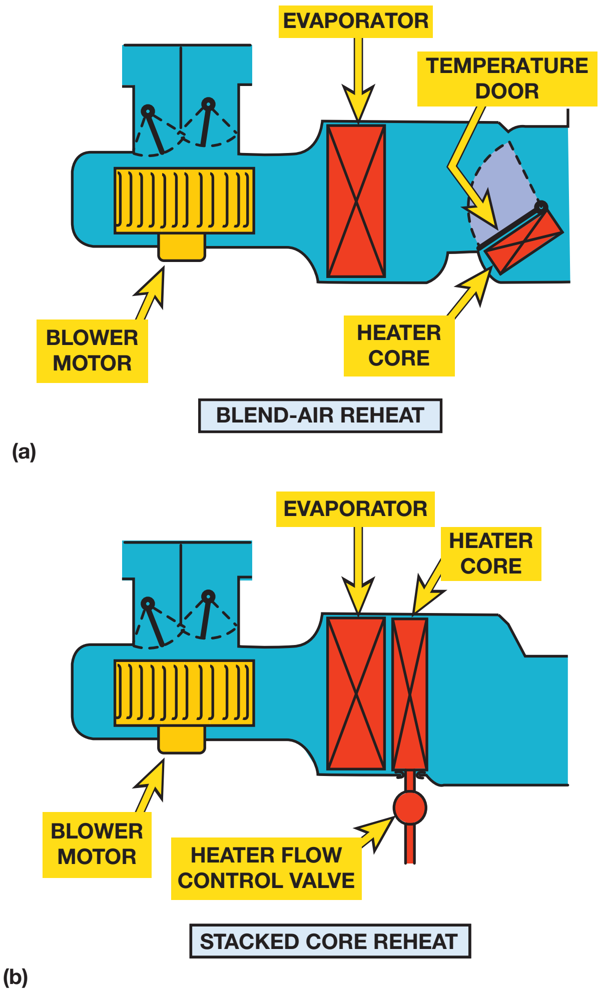

EVAPORATOR
TEMPERATURE DOOR
BLOWER MOTOR
HEATER CORE
BLEND-AIR REHEAT
(a)
EVAPORATOR
HEATER CORE
BLOWER MOTOR
HEATER FLOW CONTROL VALVE
STACKED CORE REHEAT
(b)

FIGURE 62–13 (a) In a blend-air system, all of the air is cooled. Then some of it is reheated and blended with the cool air to get the right temperature. (b) In a reheat system, all of the air is cooled and then reheated to the correct temperature.

Setting the control lever to somewhere between cold and hot will mix or *temper* cold and hot air, allowing the driver to adjust the temperature to whatever is desired.

In the past in some vehicles, the evaporator was placed or stacked right next to the heater core. These systems controlled the air temperature by regulating the amount of reheat at the heater core. ● **SEE FIGURE 62–13**.

AIR DISTRIBUTION AND OUTLETS Air from the plenum can flow into one or two of three outlet paths:

1. The A/C registers (vents) in the face of the instrument panel
2. The defroster registers at the base of the windshield
3. The heater outlets at the floor under the instrument panel

Most vehicles include two ducts under the front seats or in the center console to transfer air to the rear seat area. Most vehicles also direct airflow to the side windows to defog the side windows. ● **SEE FIGURE 62–14**.

Airflow to these ducts is controlled by one or more mode doors controlled by the function lever or buttons. Mode doors are also called *function*, *floor-defrost*, and *panel-defrost* doors. Mode/function control sets the doors as follows:

- **A/C:** in-dash registers with outside air inlet
- **Max A/C:** in-dash registers with recirculation
- **Heat:** floor level with outside air inlet
- **Max Heat:** floor level with recirculation
- **Bi-level:** both in-dash and floor discharge
- **Defrost:** windshield registers

In many systems, a small amount of air is directed to the defroster ducts when in the heat mode, and while in defrost mode, a small amount of air goes to the floor level.

DUAL-ZONE AIR DISTRIBUTION **Dual-zone** air distribution allows the driver and passenger to select different temperature settings. The temperature choices can be as much as 30°F (16°C) different. Dual-zone systems split the duct and airflow past the heater core and use two air mix valves or doors with each air mix valve/temperature door controlled by a separate actuator.

HVAC CONTROLS

CABLE-OPERATED SYSTEMS Mechanical systems are the least expensive. Most early control heads used purely mechanical operation for the doors, and one or more cables connected the function lever to the air inlet and mode doors. The temperature lever was also connected to the temperature-blend door by another cable. These mechanical levers were rather simple and usually trouble free, but they had some disadvantages. They tended to bind and could require a good deal of effort to operate.

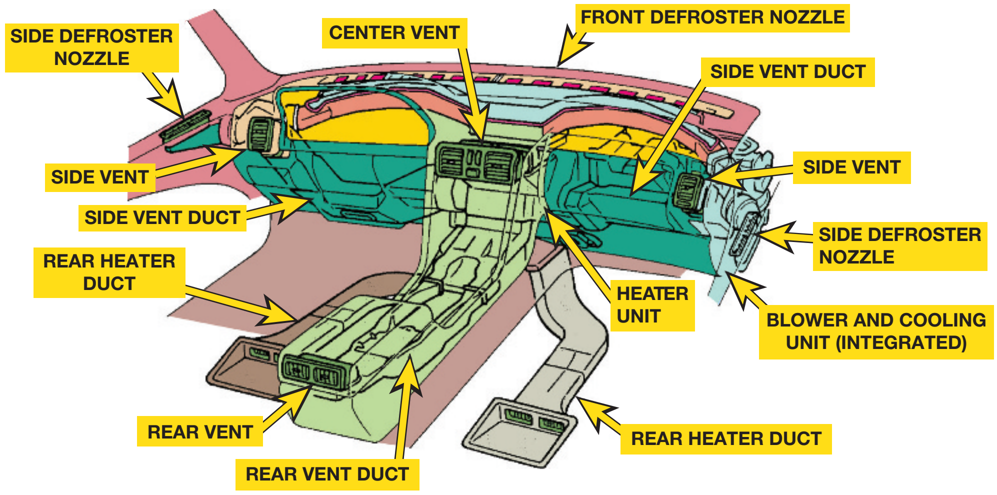

SIDE DEFROSTER NOZZLE
CENTER VENT
FRONT DEFROSTER NOZZLE
SIDE VENT DUCT
SIDE VENT
SIDE VENT
SIDE VENT DUCT
REAR HEATER DUCT
SIDE DEFROSTER NOZZLE
HEATER UNIT
BLOWER AND COOLING UNIT (INTEGRATED)
REAR VENT
REAR VENT DUCT
REAR HEATER DUCT

FIGURE 62–14 Ducts are placed in the center console or on the floor under the front seats to provide heated and cooled air to the rear seat passengers.

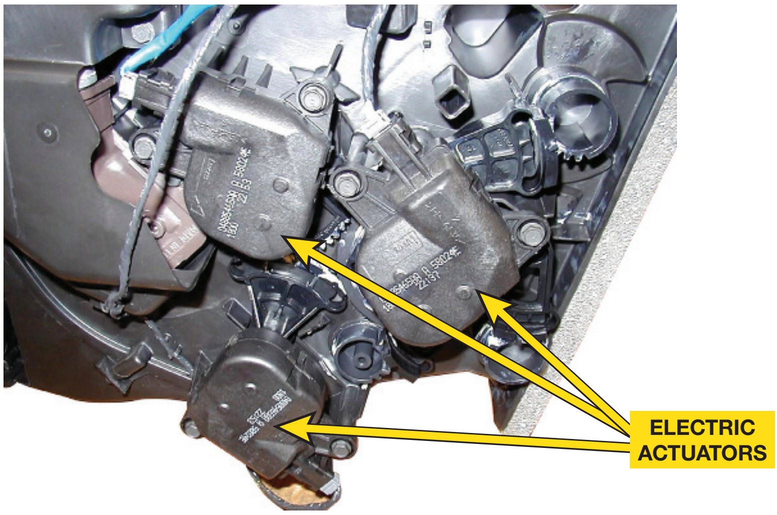


FIGURE 62–15 Three compact, electric actuators/servomotors operate the doors in this part of the HVAC case.

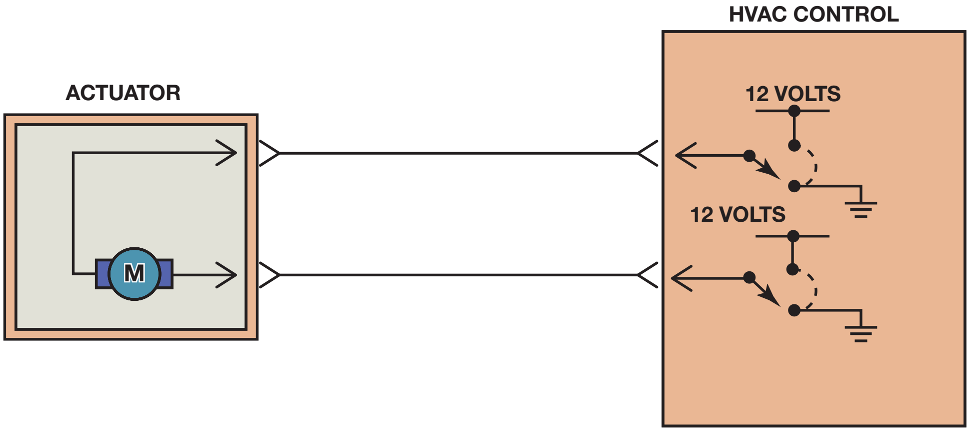


FIGURE 62–16 A two-wire HVAC electronic actuator where the direction of rotation is controlled by the HVAC control head or module, which changes the direction of rotation by changing the polarity of the power and ground connection at the motor.

ELECTRONIC HVAC CONTROLS Most recent vehicles use electrical function switches at the HVAC control head. These are often called *electromechanical controls.* These switches operate electric actuators (motors) to control the air distribution and temperature-blend doors. ● **SEE FIGURE 62–15**.

TWO-WIRE ACTUATORS A typical two-wire actuator rotates when electric impulses are sent to the brushes by the HVAC control head. The direction of rotation, and therefore the movement of the HVAC door position, is changed by changing the wire that is pulsed with power and the other brush is then connected to ground. ● **SEE FIGURE 62–16**.

THREE-WIRE ACTUATORS A typical three-wire actuator uses a power, ground, and an input signal wire from the HVAC control module. There is a module (logic chip) inside the motor assembly that receives a 0–5 volt signal from the HVAC control module. When the actuator gets a 0-volt signal from the control module, it rotates in one direction and when it receives a 5-volt signal, it rotates in the opposite direction. If the motor receives a 2.5 volt signal, the motor stops rotating. ● **SEE FIGURE 62–17**.

FIVE-WIRE ACTUATORS A five-wire actuator uses two wires to power the motor (power and ground) and three wires for a potentiometer that is used to signal the HVAC control module of the position of the motor. The potentiometer may be a separate gear-driven part attached to the motor or a part of the printed circuit board where a slider moves across resistive paint to create the potentiometer signal voltage. ● **SEE FIGURE 62–18**.

Most HVAC control modules convert the potentiometer signal voltage to a binary number ranging from 0 to 255, which is often seen on a scan tool display. The HVAC control module monitors the feedback signal to determine the actual location of the door and to determine if the door is stuck. If the motor position falls outside of the expected range, there can be two things that can occur, depending on the vehicle:

1. The controller, usually the HVAC control module, will drive the motor until it reaches its desired location. This action can result in a ticking sound being heard as the motor attempts to reach the desired position.
2. The controller will move the motor to a default position and then stop working, making the HVAC controls inoperative.

ACTUATOR CALIBRATION PROCEDURES An HVAC actuator may need to be calibrated after the actuator has been replaced. Check service information for the specified procedure to follow to perform a calibration if needed.

A typical calibration procedure to use when installing a new actuator using a scan tool includes the following steps:

STEP 1 Clear all diagnostic trouble codes (DTCs).

STEP 2 Turn the ignition switch to the off position.

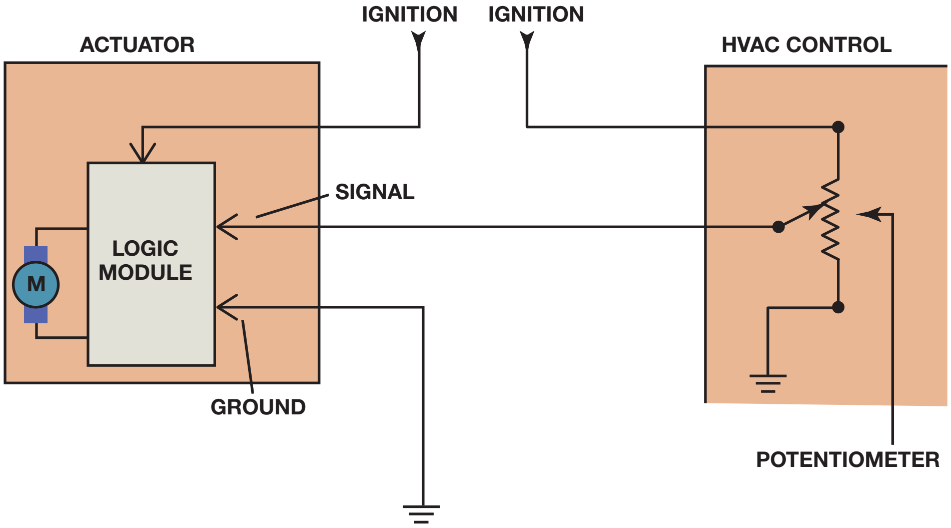

IGNITION
IGNITION
ACTUATOR
HVAC CONTROL
SIGNAL
LOGIC MODULE
M
GROUND
POTENTIOMETER

FIGURE 62–17 Three-wire actuators include a logic chip inside the motor assembly. The HVAC control module then sends a 0 to 5 volt signal to the motor assembly to control the direction of rotation.

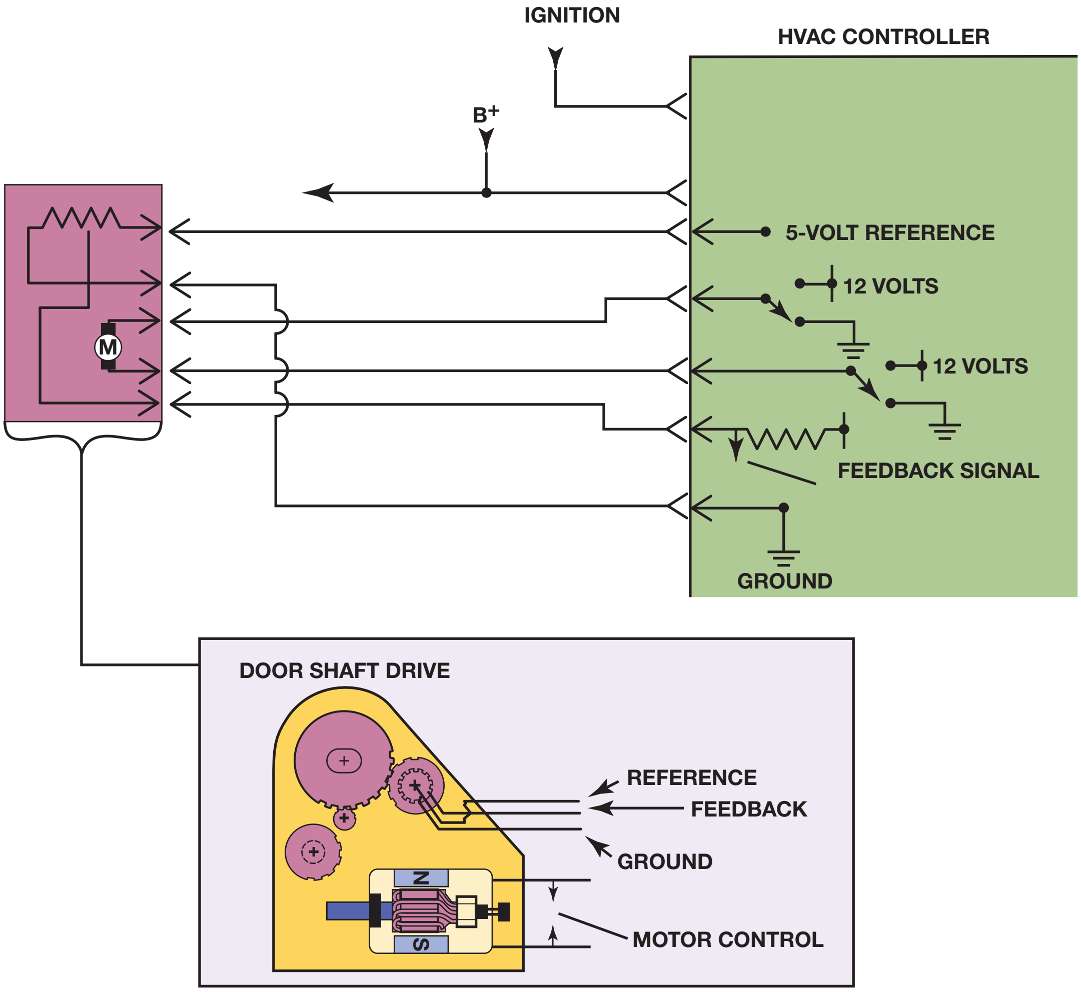

IGNITION
HVAC CONTROLLER
B+
5-VOLT REFERENCE
12 VOLTS
M
12 VOLTS
FEEDBACK SIGNAL
GROUND
DOOR SHAFT DRIVE
REFERENCE
FEEDBACK
GROUND
N
S
MOTOR CONTROL

FIGURE 62–18 A typical five-wire HVAC actuator showing the two wires used to power the motor and the three wires used for the motor position potentiometer.

STEP 3 Install the replacement actuator and reconnect all mechanical and electrical connections.

STEP 4 Start the engine and select motor recalibration program on the scan tool under the functions menu.

STEP 5 Verify that no diagnostic trouble codes have been set.

CAUTION: Do not operate an actuator prior to installation to "test it" because many actuators operate until they are stopped mechanically by the door being fully open or fully closed. If operated using a battery and jumper wires without being installed, the actuator can be moved beyond its normal range of motion and will not operate correctly, if at all, when placed into the HVAC housing.

BLOWER MOTOR

PURPOSE AND FUNCTION The same blower motor moves air inside the vehicle for:

1. Air conditioning
2. Heat
3. Defrosting
4. Defogging
5. Venting of the passenger compartment

The motor turns a squirrel cage-type fan. A squirrel cage-type fan is able to move air without creating a lot of noise. The fan switch controls the path in which the current flows to the blower motor.

PARTS AND OPERATION The motor is usually a permanent magnet, one-speed motor that operates at its maximum speed with full battery voltage. The switch gets current from the fuse panel with the ignition switch on, and then directs full battery voltage to the blower motor for high speed and to the blower motor through resistors for lower speeds.

VARIABLE SPEED CONTROL The fan switch controls the path of current through a resistor pack to obtain different fan speeds of the blower motor. The electrical path can be:

- Full battery voltage for high-speed operation
- Through one or more resistors to reduce the voltage and the current to the blower motor which then rotates at a slower speed

The resistors are located near the blower motor and mounted in the duct where the airflow from the blower can cool the resistors. The current flow through the resistor is controlled by the switch and often uses a relay to carry the heavy current (10 to 12 amperes) needed to power the fan. Normal operation includes the following:

- Low speed. Current flows through three resistors in series to drop the voltage to about 4 volts and 4 amperes.
- Medium-low speed. Current is directed through two resistors in series to lower the voltage to about 6 volts and 6 amperes.
- Medium-high speed. Current is directed through one resistor resulting in a voltage of about 9 volts and 9 amperes.
- High speed. Full battery voltage, usually through a relay, is applied to the blower motor resulting in a current of about 12 amperes.

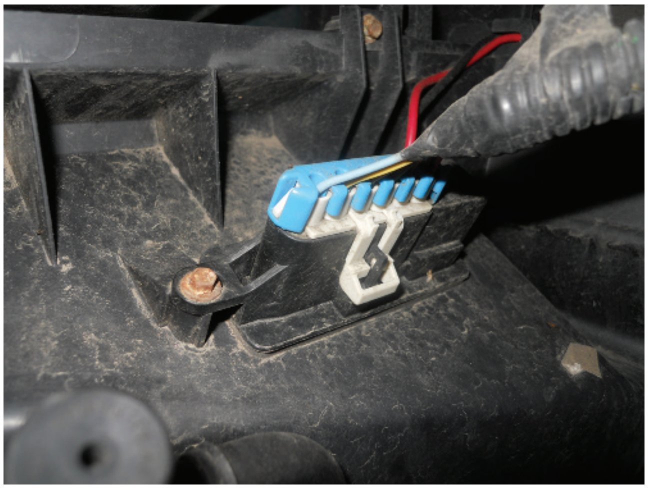
● **SEE FIGURE 62–19**.

Some blower motors are electronically controlled by the body control module and include electronic circuits to achieve variable speeds. ● **SEE FIGURE 62–20**.

BLOWER MOTOR DIAGNOSIS If the blower motor does not operate at any speed, the problem could be any of the following:

1. Defective ground wire or ground wire connection
2. Defective blower motor (not repairable; must be replaced)
3. Open circuit in the power-side circuit, including fuse, wiring, or fan switch

If the blower works on lower speeds but not on high speed, the problem is usually an in-line fuse or high-speed relay that controls the heavy current flow for high-speed operation. The high-speed fuse or relay usually fails as a result of internal blower motor bushing wear, which causes excessive resistance to motor rotation. At slow blower speeds, the resistance is not as noticeable and the blower operates normally. The blower motor is a sealed unit, and if defective, must be replaced as a unit. The squirrel cage fan usually needs to be removed from the old motor and attached to the replacement motor. If the blower motor operates normally at high speed but not at any of the lower speeds, the problem could be melted wire resistors or a defective switch. The blower motor can be tested using a clamp-on DC ammeter. ● **SEE FIGURE 62–21**.



FIGURES 62–19 A blower motor resistor pack used to control blower motor speed. The blower motor resistors are installed in the blower housing and the the wiring is the only part that is visible.

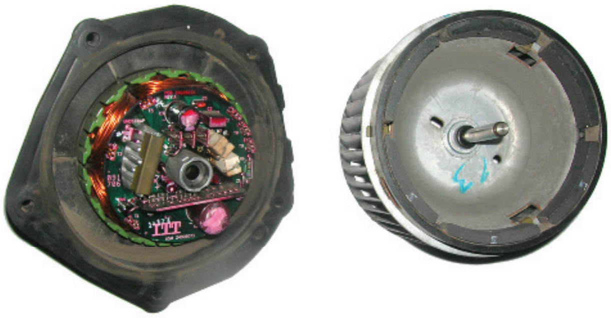


FIGURE 62–20 A brushless DC motor that uses the body computer to control the speed.

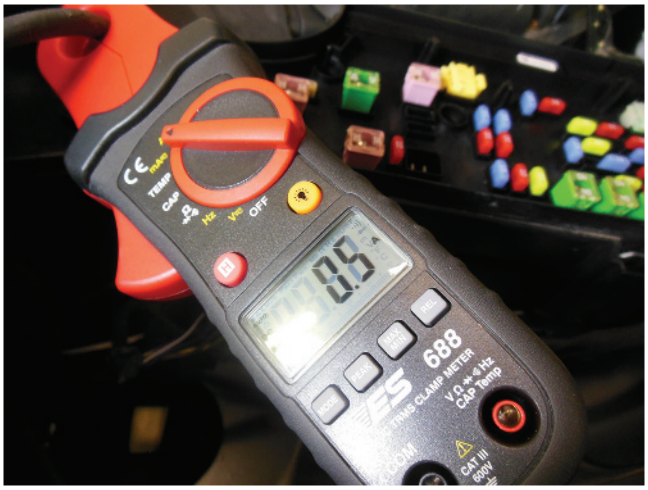


FIGURE 62–21 Using a mini AC/DC clamp-on multimeter to measure the current drawn by a blower motor.

Most blower motors do not draw more than 15 amperes on high speed. A worn or defective motor usually draws more current than normal and could damage the blower motor resistors or blow a fuse if not replaced.

REVIEW QUESTIONS

1. What do the three main HVAC doors do?
2. In the heating mode, why is heat directed toward the floor?
3. Where is the air directed when the control panel is set to defog/defrost position?
4. How does a "reheat" system work?
5. Where does the air enter the vehicle when outside air is selected?

CHAPTER QUIZ

1. "Outside air" is also called ___________ air.
   - **a.** recirculation
   - **b.** fresh
   - **c.** plenum
   - **d.** mode
2. The ___________ door is used to select air discharge location such as floor, vent, or defrost.
   - **a.** mode
   - **b.** recirculation
   - **c.** fresh air
   - **d.** Any of the above
3. What does the snowflake button on the dash do?
   - **a.** Selects defrost
   - **b.** Selects defog
   - **c.** Turns on the A/C compressor
   - **d.** Selects fresh outside air
4. The ram air that enters the vehicle from the outside enters the HVAC system from ___________.
   - **a.** beside the headlight
   - **b.** behind the grille
   - **c.** the side vents
   - **d.** the base of the windshield
5. Most systems use a flap door that swings about ___________ degrees.
   - **a.** 10 to 25
   - **b.** 25 to 40
   - **c.** 45 to 90
   - **d.** 90 to 120
6. The air inlet control door is also called ___________.
   - **a.** fresh air door
   - **b.** recirculation door
   - **c.** outside air door
   - **d.** Any of the above
7. The door used to control interior temperature is called the ___________ door.
   - **a.** temperature-blend
   - **b.** recirculation
   - **c.** outside (fresh) air
   - **d.** mode
8. A five-wire actuator uses two wires to power the motor (power and ground) and three wires for ___________.
   - **a.** direction control
   - **b.** a feedback potentiometer
   - **c.** static electricity protection
   - **d.** redundant control
9. What type of blower motor uses the body computer to control the speed?
   - **a.** An AC brush-type motor
   - **b.** Brush-type DC motor
   - **c.** Brush-less DC motor
   - **d.** Any of the above
10. The cabin filter can be accessed ___________.
    - **a.** behind the glove compartment
    - **b.** under the hood toward the front of the vehicle
    - **c.** under the hood near the windshield
    - **d.** Either a or c

Chapter

63

AUTOMATIC AIR-CONDITIONING AND HEAT PUMP SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the purpose and function of automatic temperature control (ATC) systems.
- Discuss the sensors used in ATC systems.
- Describe airflow control.
- Describe actuators.
- Discuss the purpose of automatic HVAC controls.
- Explain the automatic climatic control diagnostic procedure.
- Discuss heat pump systems.

KEY TERMS:

Ambient temperature sensor 747 • Air management system 749 • Automatic air-conditioning system 746 • Automatic climatic control system 746 • Automatic temperature control (ATC) system 746 • Compressor speed sensor 748 • Discharge air temperature (DAT) sensor 747 • Dual-position actuator 750 • Engine coolant temperature (ECT) sensor 748 • Evaporator temperature (EVT) sensor 747 • Heating ventilation and air conditioning (HVAC) 746 • Infrared (IR) sensors 748 • In-vehicle temperature sensor 747 • Negative temperature coefficient (NTC) 747 • Outside air temperature (OAT) sensor 747 • Pressure transducer 748 • Relative humidity (RH) sensor 749 • Smart motor 751 • Smart control head 751 • Sun load sensor 747 • Three-position actuator 750 • Variable-position actuator 750

AUTOMATIC TEMPERATURE CONTROL SYSTEM

PURPOSE AND FUNCTION The purpose and function of the **heating, ventilation, and air-conditioning (HVAC)** system is to provide comfortable temperature and humidity levels inside the passenger compartment. Proper temperature control to enhance passenger comfort during heating should maintain air temperature at the foot level about 7°F to 14°F (−13°C to −10°C) above the temperature around the upper body. This is accomplished by directing the heated airflow to the floor. During A/C operation, the upper body should be cooler, so the airflow is directed to the instrument panel registers. Most new HVAC systems use an electronic control head and some use electronic blower speed control, radiator fan, and control of compressor displacement.

OPERATION **Automatic temperature control (ATC) system** is also called **automatic climate control system** or **automatic air-conditioning system**. With an ATC system, the driver can turn the automatic controls on or off and select the desired temperature. The ATC will adjust the following parameters:

- Blower speed
- Temperature door
- Air inlet door
- Mode door to achieve the proper temperature
- Control the air-conditioning compressor operation. ● **SEE FIGURE 63–1**.

SENSORS

PURPOSE AND FUNCTION The purpose of using sensors is to provide information to the HVAC controller regarding the conditions outside as well as inside the vehicle. Sensors provide data about the following conditions:

- Different conditions that can affect temperature conditions within the vehicle.
- Temperature setting at the control head.
- Operation of the A/C system.
- Operation of the engine.

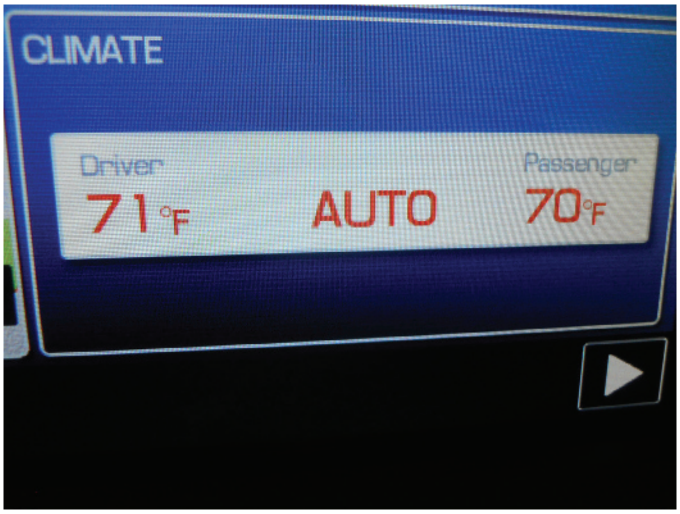


FIGURE 63–1 The automatic climate control display is part of the navigation screen on this vehicle.

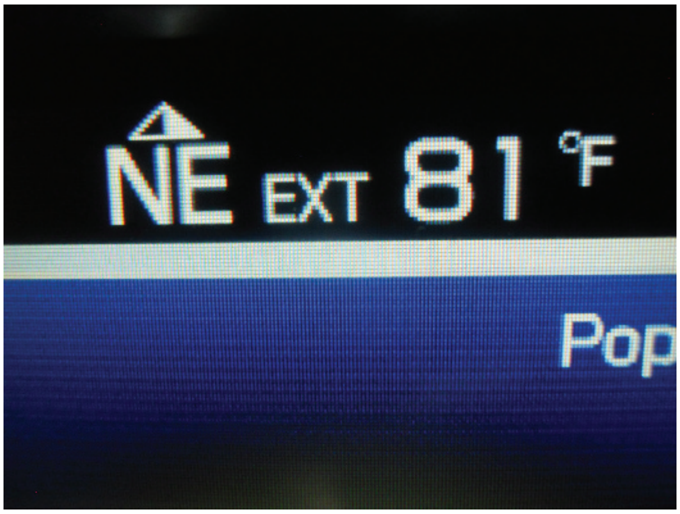


FIGURE 63–3 The outside air temperature is displayed on the navigation screen on this vehicle and uses the information from the outside air temperature sensor.

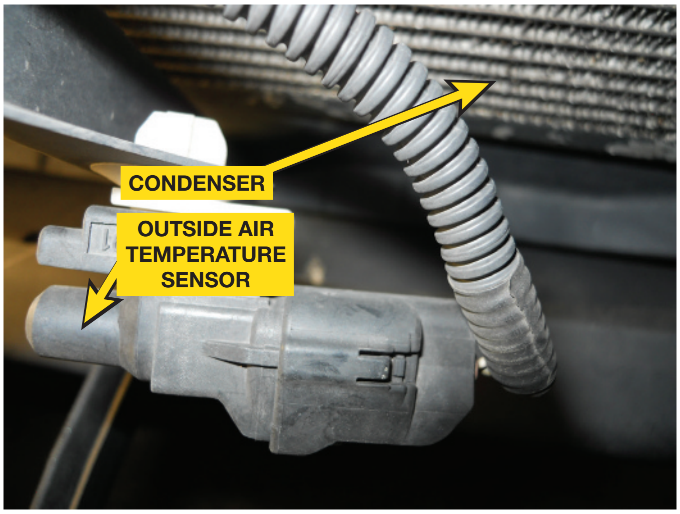


FIGURE 63–2 The outside air temperature sensor is mounted on the radiator core support in front of the A/C condenser on this vehicle.

Pressure and temperature sensors are used to determine the condition in the air-conditioning system so that the controller can do the following functions:

- Provide the most efficient use of energy.
- Provide a comfortable interior environment for the driver and passengers.
- Reduce the load on the engine and electrical system as much as possible to improve fuel economy.

OUTSIDE AIR TEMPERATURE SENSOR The **outside air temperature (OAT) sensor**, also called the **ambient temperature sensor**, measures outside air temperature and is often mounted at the radiator shroud or in the area behind the front grill. ● **SEE FIGURE 63–2**.

- Most automotive thermistors are of the **negative temperature coefficient (NTC)** type; the resistance changes in an inverse or negative relationship with temperature.
- The resistance is low when the temperature is high.
- This sensor is used to determine the outside air temperature that is displayed on the dash. ● **SEE FIGURE 63–3**.

IN-VEHICLE TEMPERATURE SENSOR The **in-vehicle temperature sensor** is often mounted behind the instrument panel, and a set of holes or a small grill allows air to pass by it. Air from the blower motor passes through the venturi of the aspirator and pulls in-vehicle air past the thermistor. This tube is called an aspirator tube and is connected to the blower housing. Blower operation produces airflow through the aspirator and past the sensor. ● **SEE FIGURE 63–4**.

DISCHARGE AIR TEMPERATURE SENSOR The **discharge air temperature (DAT)** sensor is used to measure the temperature of the air leaving the dash vents.

- This discharge air temperature can be used to determine the proper temperature position or control compressor output.
- This sensor reading is used by the controller, which compares the discharge temperature reading with the temperature set by the driver. The control module calculates the temperature difference and automatically adjusts the HVAC system to minimize this temperature difference.

EVAPORATOR TEMPERATURE SENSOR The **evaporator temperature (EVT) sensor** is used to measure the temperature of the air leaving the evaporator. Evaporator air temperature can be used to determine the proper temperature position or control compressor output. The long probe of this sensor passes between the evaporator fins. It provides an evaporator temperature input to the HVAC controller.

SUN LOAD SENSOR The **sun load sensor** (also called a *solar sensor*) is normally mounted on top of the instrument panel and is used to measure radiant heat load that might cause an increase of the in-vehicle temperature. Bright sunshine provides a signal to the electronic control module (ECM) that things are

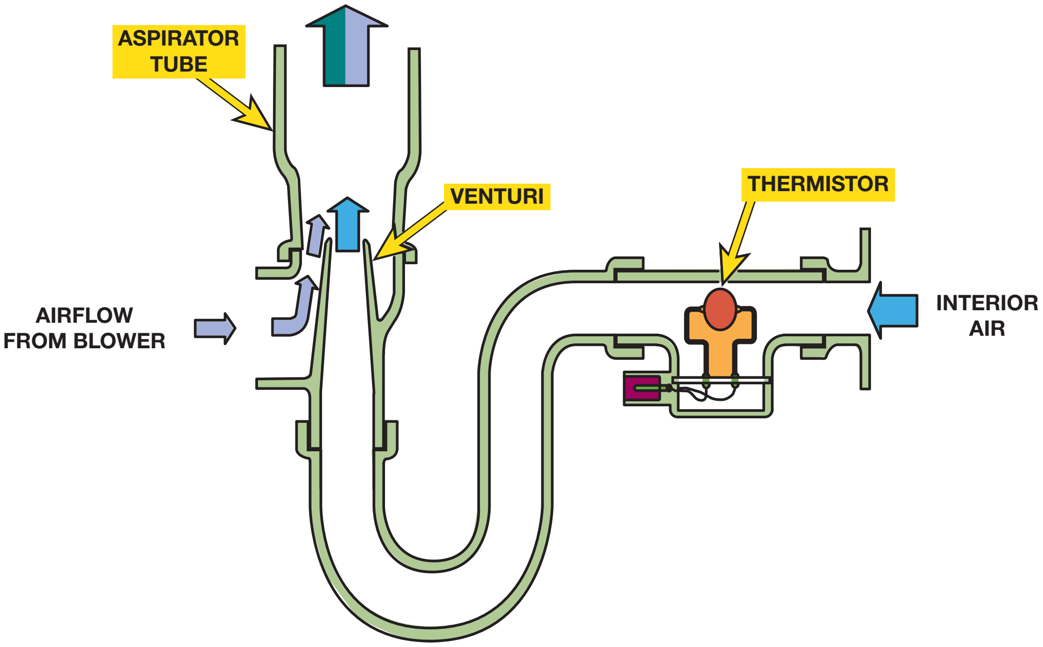


FIGURE 63–4 The airflow from the blower causes airflow to flow past the in-vehicle temperature sensor.

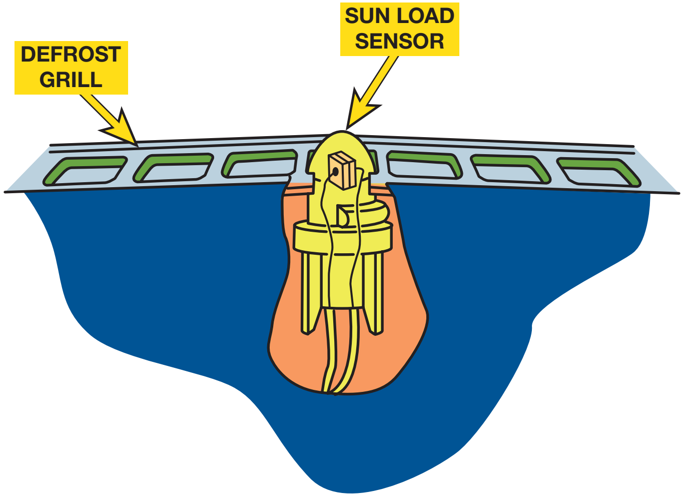


FIGURE 63–5 Sun load sensors are usually located at the top of the instrument panel.

going to get hotter. Sun load sensors are photodiodes that change their electrical conductivity based on the level of sunlight striking the sensor.

A typical sun load sensor uses a 5-volt operating voltage and produces an output signal voltage based on the intensity of the light.

- Dark = 0.3 volts
- Bright sunshine = 3.0 volts. ● **SEE FIGURE 63–5.**

INFRARED SENSORS **Infrared (IR) sensors** are mounted in the control head or overhead in the headliner. They monitor the surface temperature of the head and chest area of the driver and passenger. The system will adjust the temperature and position of the airflow depending on the temperature they measure and the settings on the control head. The detector does not emit an infrared beam but instead measures the infrared rays that are emitted from the person's body.

COMPRESSOR SPEED SENSOR The air-conditioning (A/C) **compressor speed sensor**, also called a *lock* or *belt lock* sensor, is used so the ECM will know if the compressor is running, and by comparing the compressor and engine speed signals, the ECM can determine if the compressor clutch or drive belt is slipping excessively. It prevents a locked-up compressor from destroying the engine drive belt, which, in turn, can cause engine overheating or loss of power steering. If the ECM detects an excessive speed differential for more than a few seconds, it will turn the compressor off. The sensor can be either a magnetic type or a Hall-effect sensor. Check service information for details about the sensor for the vehicle being serviced.

ENGINE COOLANT TEMPERATURE SENSOR The **engine coolant temperature (ECT) sensor** is a thermistor and measures the temperature of the engine coolant and is usually located near the engine thermostat. The ECT sensor is used to keep the system from turning on the heater before the coolant is warmed up, which is often called *cold engine lockout.* ● **SEE FIGURE 63–6.**

PRESSURE TRANSDUCERS A **pressure transducer** can be used in the low- and/or high-pressure refrigerant line. The transducer converts the system pressure into an electrical signal that allows the ECM to monitor pressure. The pressure signal can be used by the controller to

- cycle the compressor to prevent evaporator freeze-up.
- change orifice tube size.
- change the compressor displacement.
- shut off the compressor or speedup cooling fan operation because of high pressures.
- prevent compressor operation if the refrigerant level is low or empty.

The pressures of the refrigerant systems can be checked by looking at the scan tool scan data of a factory or factory-level scan tool. ● **SEE CHART 63–1** for some sample pressures and what they could indicate.

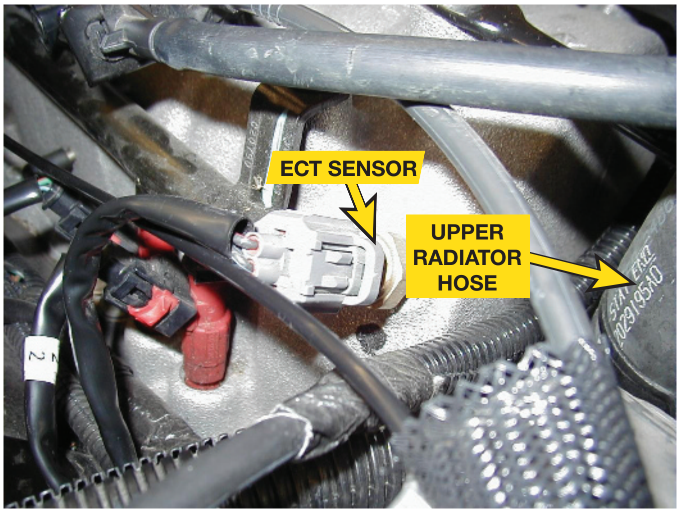


FIGURE 63–6 The engine coolant temperature (ECT) sensor is usually located near the engine thermostat so it can accurately measure the temperature of the coolant.

LOW SIDE PRESSURE	HIGH SIDE PRESSURE	CONDITION
25–35 PSI	170–200 PSI	Normal operation
Low	Low	Low refrigerant charge level
Low	High	Restriction in high-side line
High	High	System is overcharged
High	Low	Restriction in the low-side line

CHART 63–1

Sample refrigerant system pressures and possible causes as shown from the pressure sensors and displayed on a scan tool. Check service information for the exact procedures to follow if the pressures are not correct.

AIR QUALITY SENSORS Some systems use an *air quality sensor*, which detects hydrocarbons (HC) or ozone (O_3). HC can come from vehicle engine exhaust or decaying animal material and often produces offensive odors. Ozone is an irritant to the respiratory system. When the system detects an air quality issue, it automatically switches to using mostly inside air, about 80%, and reduces the amount of outside air entering the system to about 20% from the normal 80% level. This reduces the amount of outside air that is being brought into the passenger compartment until the system detects healthy outside air.

RELATIVE HUMIDITY SENSOR A few vehicles use a **relative humidity (RH) sensor** to determine the level of in-vehicle humidity. High RH increases the cooling load. The sensor responds to the full range from 0% to 100% relative humidity. The output of the sensor is sent to the HVAC controller, which uses the information to control the air inlet door and the air-conditioning compressor operation to achieve the desired level of humidity (20% to 40%) in the passenger compartment.

GPS SENSOR A few vehicles that are equipped with a global positioning system (GPS) for navigation will have a sun position strategy that tracks the angle of the sunlight entering the vehicle. Cooler in-vehicle temperatures are required if the vehicle is positioned so sunlight enters through the windshield or side windows. ● **SEE FIGURE 63–7**.

FIGURE 63–7 Some automatic HVAC system use the information from the factory navigation system to fine tune the interior temperature and airflow needs based on location and the direction of travel.

AIRFLOW CONTROL

NEED FOR AIRFLOW CONTROL The system that controls the airflow to the passenger compartment is called the **air management system** or *air distribution system.* Air flows into the housing (case) that contains the evaporator and heater core from two inlets.

The air management system is the same as a nonautomatic HVAC system. The only difference is that the HVAC controller can adjust the various doors without driver intervention. ● **SEE FIGURE 63–8**.

FREQUENTLY ASKED QUESTION

Why Is an ATC system Slow to Get Airflow?

Some vehicle owners, new to ATC system, complain that it seems to take a long time before the fan starts to move air. There are several reasons that this is done and it is to be considered normal operation: the fan speed is controlled by pulse-width modulating the voltage to the blower motor and it starts slowly, and then ramps up so very little airflow is noticed for the first few seconds.

The control doors are often set to blow first to the floor vents before moving the doors to dash vents. This is done to purge any stale air that may be in the ducts to the floor so that the driver and passengers do not notice the stale air.

As a result, most ATC systems do normally have a delay between the time the engine is started and when airflow is felt. This is perfectly normal operation and no repair or service to the system is needed.

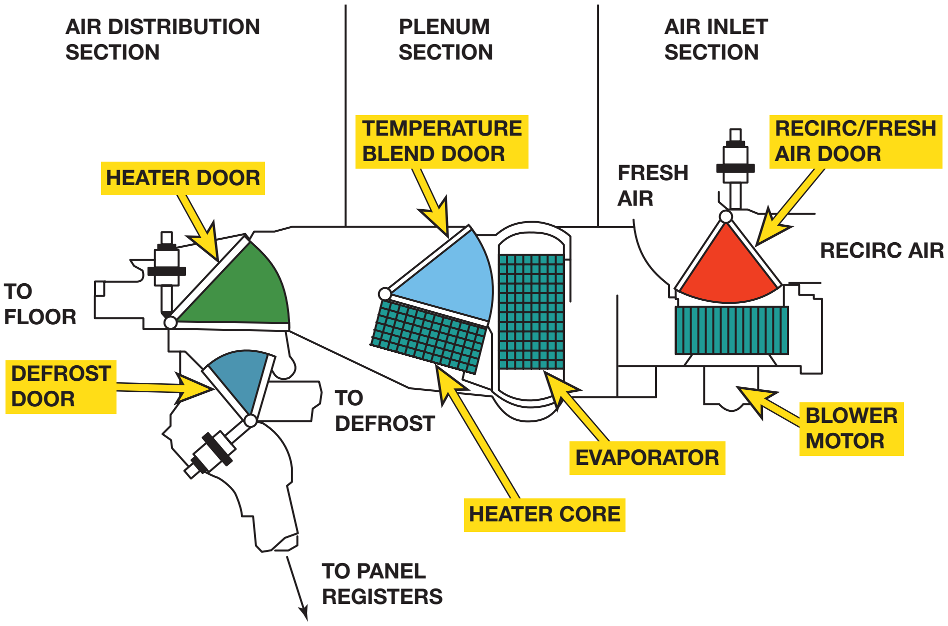


FIGURE 63–8 The three major portions of the A/C and heat system are air inlet, plenum, and air distribution. The shaded portions show the paths of the four control doors.

ACTUATORS

PURPOSE AND FUNCTION HVAC actuators are electric or mechanical devices that move doors to provide the needed airflow at the correct time and location. Actuators include

- Electric motors that operate the air/temperature doors, also called *flaps.*
- Feedback circuits that provide position information to the HVAC controller.

TYPES OF ACTUATORS An actuator is a part that moves the vanes or valves. Actuators used in air-conditioning systems are either electric or vacuum operated and include three different types:

1. **Dual-Position Actuator.** A **dual-position actuator** is able to move either open or closed. An example of this type of actuator is the recirculation door, which can be either open or closed.
2. **Three-Position Actuator.** A **three-position actuator** is able to provide three air door positions, such as the bi-level door, which could allow defrost only, floor only, or a mixture of the two.
3. **Variable-Position Actuator.** A **variable-position actuator** is capable of positioning a valve in any position. All variable position actuators use a *feedback potentiometer*, which is used by the controller to detect the actual position of the door or valve. ● **SEE FIGURE 63–9**.

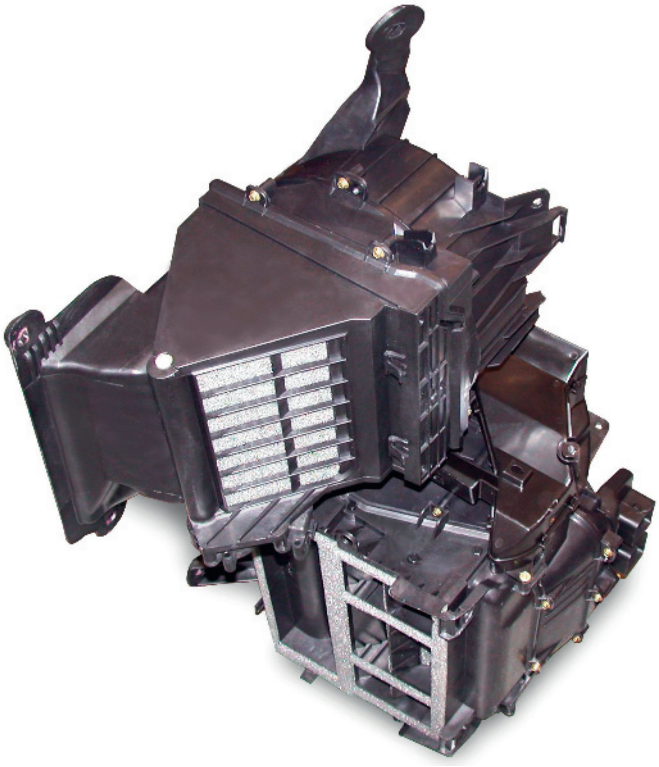


FIGURE 63–9 An entire HVAC module removed from a vehicle.

AUTOMATIC HVAC CONTROLS

OPERATION The HVAC control head or panel is mounted in the instrument cluster. The control head provides the switches and levers needed to control the different aspects of the heating and A/C system, which include the following:

- HVAC system on and off
- A/C on/off
- Outside or recirculated air
- A/C, defrost, or heating mode
- Temperature desired
- Blower speed

COMPRESSOR CONTROLS Most air-conditioning compressors use an electromagnetic clutch. Some systems may connect one or more switches in series with the compressor clutch so that all have to be functioning before the compressor clutch can be engaged. A low- and high-pressure switch or sensor may also be an input to the PCM or HVAC controller for use in controlling the compressor.

- **Low-pressure switch:** This pressure switch is electrically closed only if there is 8 PSI to 24 PSI (55 kPa to 165 kPa) of refrigerant pressure. This amount of pressure means that the system is sufficiently charged to provide lubrication for the compressor.
- **High-pressure switch:** This pressure switch is located in the high-pressure side of the A/C system. If the pressure exceeds a certain level, typically 375 PSI (2,600 kPa), the pressure switch opens, thereby preventing possible damage to the air-conditioning system due to excessively high pressure.
- **A/C relay:** The relay supplies power to the compressor.

CONTROL MODULE The control module used for automatic climatic control systems can be referred by various terms depending on the exact make and model of vehicle. Some commonly used terms include the following:

- ECM (Electronic control module)
- BCM (Body control module)
- HVAC control module (often is built into the smart control head)
- HVAC controller or programmer

The control modules are programmed to open or close circuits to the actuators based on the values of the various sensors. Although it is unable to handle the electric current for devices such as the compressor clutch or blower motor, the control module can operate relays. These relays in turn control the electric devices. Units that use small current flows, such as a light-emitting diode (LED) or digital display, can operate directly from the control module.

An ECM is programmed with various strategies to suit the requirements of the particular vehicle. For example, when A/C is requested by the driver of a vehicle with a relatively small engine, the ECM will probably increase the engine idle RPM. On this same vehicle, the ECM will probably shut off the compressor clutch during wide-open throttle (WOT).

- On other vehicles, the ECM might shut off the compressor clutch at very high speeds to prevent the compressor from spinning too fast.
- In some cases, part of the A/C and heat operating strategy is built into the control head and are called **smart control heads**. In some cases, door operating strategy is built into the door operating motors, and these are called **smart motors**.
- Many control modules are programmed to run a test sequence, called *self-diagnosis*, at start-up (when the ignition key is turned on). If improper electrical values are found, the ECM indicates a failure often by blinking the A/C indicator light at the control head. Some ECMs also monitor the system during operation and indicate a failure or stop the compressor if there is a problem. One system, for example, notes the frequency of clutch cycling that indicates a low refrigerant charge level. If there are too many clutch cycles during a certain time period, the control module will shut off the compressor and set a diagnostic trouble code (DTC). ● **SEE FIGURE 63–10**.

FREQUENTLY ASKED QUESTION

Why Is the Blower Speed So High?

This question is often asked by passengers when riding in a vehicle equipped with automatic climate control. The controller does command a high blower speed if:

- The outside temperature is low and the engine coolant temperature is hot enough to provide heat. The high blower speed is used to warm the passenger compartment as quickly as possible. When the temperature has reached the preset level, the blower speed is reduced to maintain the preset temperature.
- The outside temperature is hot and the air-conditioning compressor is working to provide cooling. The high-speed blower is used to circulate air through the evaporator in an attempt to cool the passenger compartment as quickly as possible. Once the temperature reaches close to the preset temperature, the blower speed is reduced to keep the temperature steady.

AUTOMATIC CLIMATIC CONTROL DIAGNOSIS

DIAGNOSTIC PROCEDURE If a fault occurs in the automatic climatic system, check service information for the specified procedure to follow for the vehicle being checked. Most vehicle service information includes the following steps:

STEP 1 Verify the customer concern. Check that the customer is operating the system correctly. For example, most automatic systems cannot detect when the defrosters are needed so most systems have a control that turns on the defroster(s).

STEP 2 Perform a thorough visual inspection of the heating and cooling system for any obvious faults.

STEP 3 Use a factory scan tool or a factory level aftermarket scan tool and check for diagnostic trouble codes (DTCs).

NOTE: Older systems can be accessed using the buttons on the control panel and then the DTCs and system data are displayed. Check service information for the exact procedures to follow for the vehicle being serviced.

STEP 4 If there are stored DTCs, follow service information instructions for diagnosing the system. ● **SEE CHART 63–2** for sample DTCs.

STEP 5 If there are no stored DTCs, check scan tool data for possible fault areas in the system.

SCAN TOOL BIDIRECTIONAL CONTROL Scan tools are the most important tool for any diagnostic work on all vehicles.

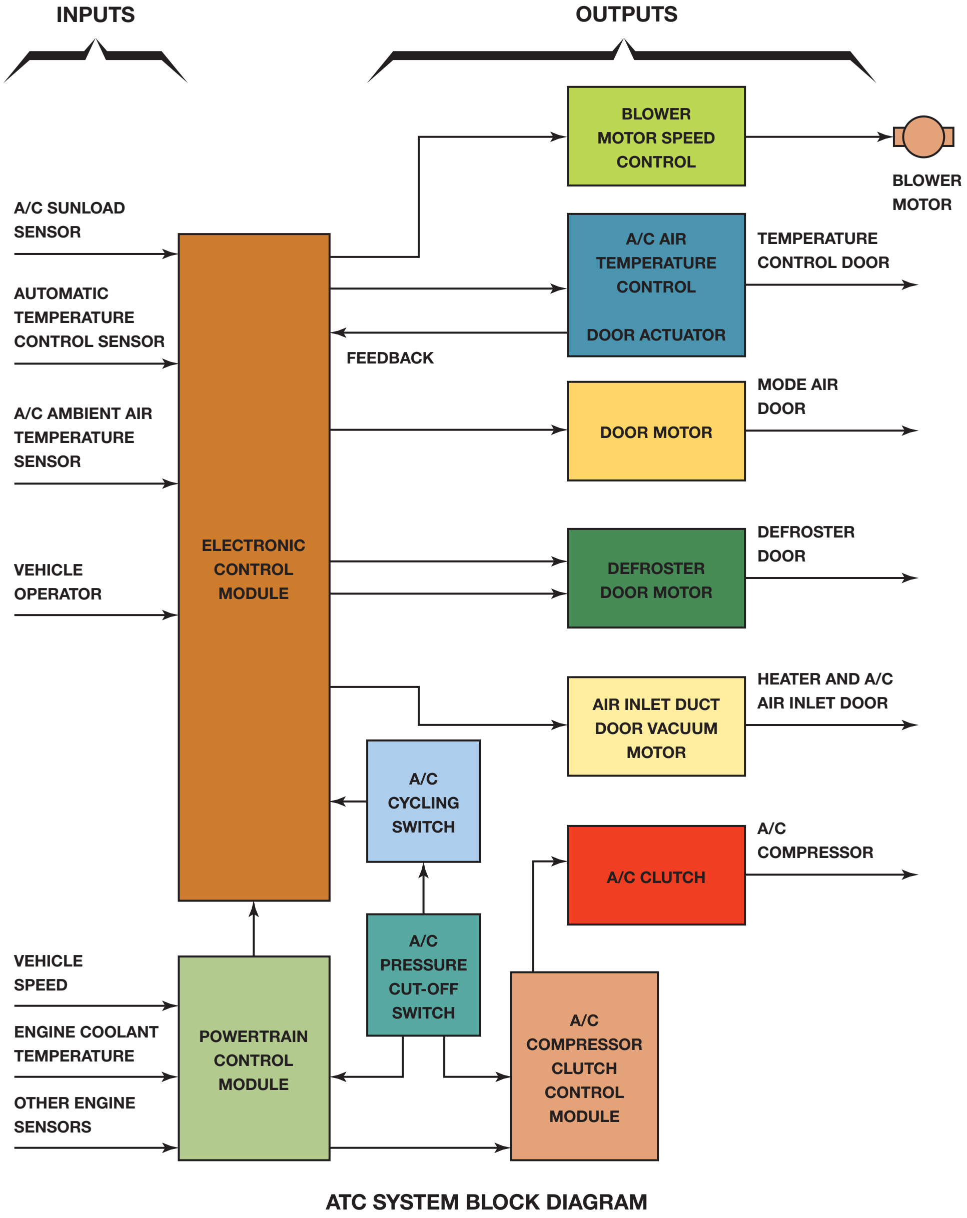

INPUTS
OUTPUTS
A/C SUNLOAD SENSOR
AUTOMATIC TEMPERATURE CONTROL SENSOR
A/C AMBIENT AIR TEMPERATURE SENSOR
VEHICLE OPERATOR
ELECTRONIC CONTROL MODULE
BLOWER MOTOR SPEED CONTROL
BLOWER MOTOR
A/C AIR TEMPERATURE CONTROL
DOOR ACTUATOR
TEMPERATURE CONTROL DOOR
FEEDBACK
DOOR MOTOR
MODE AIR DOOR
DEFROSTER DOOR MOTOR
DEFROSTER DOOR
AIR INLET DUCT DOOR VACUUM MOTOR
HEATER AND A/C AIR INLET DOOR
A/C CYCLING SWITCH
A/C CLUTCH
A/C COMPRESSOR
VEHICLE SPEED
ENGINE COOLANT TEMPERATURE
OTHER ENGINE SENSORS
POWERTRAIN CONTROL MODULE
A/C PRESSURE CUT-OFF SWITCH
A/C COMPRESSOR CLUTCH CONTROL MODULE
ATC SYSTEM BLOCK DIAGRAM

FIGURE 63–10 A block diagram showing the inputs to the electronic control assembly and the outputs; note that some of the outputs have feedback to the ECM.

FREQUENTLY ASKED QUESTION

What Are the Symptoms of a Broken Blend Door?

Blend doors can fail and cause the following symptoms:

- Clicking noise from the actuator motor assembly as it tries to move a broken door.
- Outlet temperature can change from hot to cold or from cold to hot at any time especially when cornering because the broken door is being forced one way or the other due to the movement of the vehicle.
- A change in the temperature when the fan speed is changed. The air movement can move the broken blend door into another position which can change the vent temperature.

If any of these symptoms are occurring, a replacement blend door is required.

ATC-RELATED DIAGNOSTIC TROUBLE CODES

BODY DIAGNOSTIC TROUBLE CODE (DTC)	DESCRIPTION
B0126	Right Panel Discharge Temperature Fault
B0130	Air Temperature/Mode Door Actuator Malfunction
B0131	Right Heater Discharge Temperature Fault
B0145	Auxiliary HAVC Actuator Circuit
B0159	Outside Air Temperature Sensor Circuit Range/Performance
B0160/B0162	Ambient Air Temperature Sensor Circuit
B0164	Passenger Compartment Temperature Sensor #1 (Single Sensor or LH) Circuit Range/Performance
B0169	In-Vehicle Temp Sensor Failure (passenger—not used)
B0174	Output Air Temperature Sensor #1 (Upper Single or LH) Circuit Range/ Performance
B0179	Output Air Temperature Sensor #2 (Lower Single or LH) Circuit Range/ Performance
B0183	Sun Load Sensor Circuit
B0184	Solar Load Sensor #1 Circuit Range (sun load)
B0188	Sun Load Sensor Circuit
B0189	Solar Load Sensor #2 Circuit Range (sun load)
B0229	HVAC Actuator Circuit
B0248	Mode Door Inoperative Error
B0249	Heater/Defrost/AC Door Range Error
B0263	HVAC Actuator Circuit
B0268	Air/Inlet Door Inoperative Error
B0269	Air Inlet Door Range Error
B0408	Temperature Control #1 (Main/Front) Circuit Malfunction
B0409	Air Mix Door #1 Range Error
B0414	Air Temperature/Mode Door Actuator Malfunction
B0418	HVAC Actuator Circuit
B0419	Air Mix Door #2 Range Error
B0423	Air Mix Door #2 Inoperative Error
B0424	Air Temperature/Mode Door Actuator Malfunction
B0428	Air Mix Door #3 Inoperative Error

CHART 63–2

Sample automatic climate control diagnostic trouble codes.

Scan tools can be divided into two basic groups:

1. **Factory scan tools.** These are the scan tools required by all dealers that sell and service a specific brand of vehicle.

   All factory scan tools are designed to provide bidirectional capability, which allows the service technician the opportunity to operate components using the scan tool, thereby confirming that the component is able to work when commanded.

ATC components that may be able to be controlled or checked using a scan tool include

- Blower speed control (faster and slower to check operation)
- Command the position of airflow doors to check for proper operation and to check for proper airflow from the vents and ducts
- Values of all sensors
- Pressures of the refrigerant in the high and low sides of the systems

2. **Aftermarket scan tools.** These scan tools are designed to function on more than one brand of vehicle. Examples of aftermarket scan tools include
   - **Snap-on** (various models, including the Ethos, Modis, and Solus).
   - **OTC** (various models, including Pegasus, Genisys, and Task Master). ● **SEE FIGURE 63–11**.
   - **Autel** (various models).

While many aftermarket scan tools can display most if not all of the parameters of the factory scan tool, there can be a difference when trying to troubleshoot some faults.

SCAN TOOL DATA Scan data related to the automatic climatic control system can be confusing. Typical data and their meaning are shown in ● **CHART 63–3**.

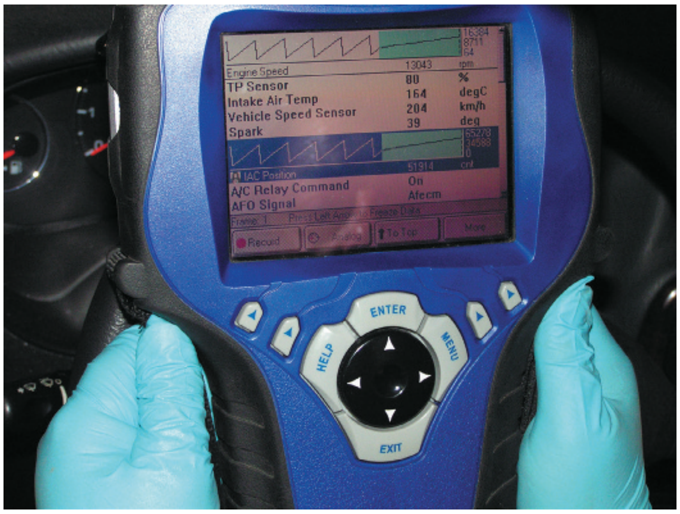


FIGURE 63–11 An OTC Genisys being used to troubleshoot a vehicle. This scan tool can be used on most makes and models of vehicles and is capable of diagnosing other computer systems in the vehicles, such as the automatic temperature control system as well as the antilock braking system (ABS) and airbag systems.

SENSOR	TYPICAL VALUE
Inside air temperature sensor	−40°F to 120°F (−40°C to 49°C)
Ambient air temperature sensor	−40°F to 120°F (−40°C to 49°C)
Engine coolant temperature (ECT) sensor	40°F to 250°F (−40°C to 121°C)
Sun load sensor	0.3 volts (dark) 3.0 volts (bright)
Evaporator temperature (EVT) sensor	Usually 34°F to 44°F (1°C to 7°C)
Relative humidity (RH) sensor	0% to 100%

CHART 63–3

Typical sensors and values that may be displayed on a scan tool. Check service information for the exact specifications for the vehicle being serviced.

HEAT PUMP SYSTEMS

PURPOSE AND FUNCTION Many automakers use a heat pump to maximize the range of an electric vehicle by scavenging waste heat to warm the cabin. A heat pump is more efficient than PTC/electric resistance heating. The 2013 Nissan Leaf was the first mass-produced vehicle in the world to offer a heat pump-based cabin heater, which helped extend driving range during the winter months. Vehicles that use a heat pump include but are not limited to the following:

- BMW i3 EV
- Jaguar I-Pace
- Audi E-tron
- Toyota Prius Prime
- Volkswagen e-Golf
- Kia Niro EV
- Tesla Model Y

NOTE: Most Tesla models don't use a heat pump as part of the climate control system but do use waste heat from the motor and power electronics to help warm the battery. Heat pumps can capture energy by recycling waste heat not only from power electrics (PE) modules, such as drive motors, on-board chargers, and inverters, but also from the battery pack. ● **SEE FIGURE 63–12.**

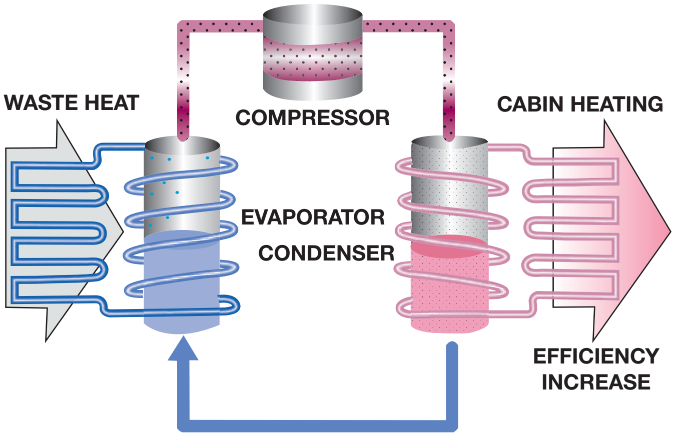


FIGURE 63–12 A heat pump is basically a reversible air-conditioning system that can provide both cabin heating and cabin cooling.

PARTS AND OPERATION A heat pump system is similar to an air-conditioning system where the operation can be reversed to provide both cabin heating and cabin cooling. A heat pump uses one refrigerant circuit that is used for both cooling and heating. ● **SEE FIGURE 63–13.**

- **Heating.** A heat pump system heats the cabin using the temperature difference between a refrigerant and the outside air making it possible to heat the vehicle cabin with less power than heating the air. When the heater is in use, the external condenser absorbs heat from the atmosphere and the compressor is used to compress it into a high-temperature gas. The cabin is heated as the hot air flows into the cabin out of the heating ducts. Heat pumps do not create heat, but instead they move heat. Heat can be moved using less electricity than it takes to heat the air in the cabin using resistive elements.
- **Cooling.** In the summer, heat is absorbed from inside the cabin and released outside by the external condenser, similar to that conventional air-conditioning works. ● **SEE FIGURE 63–14.**

NOTE: Tesla has a feature referred to as "camp mode" where the climate control system can be kept on with the doors locked. Basically, this mode would be used if sleeping in the vehicle.

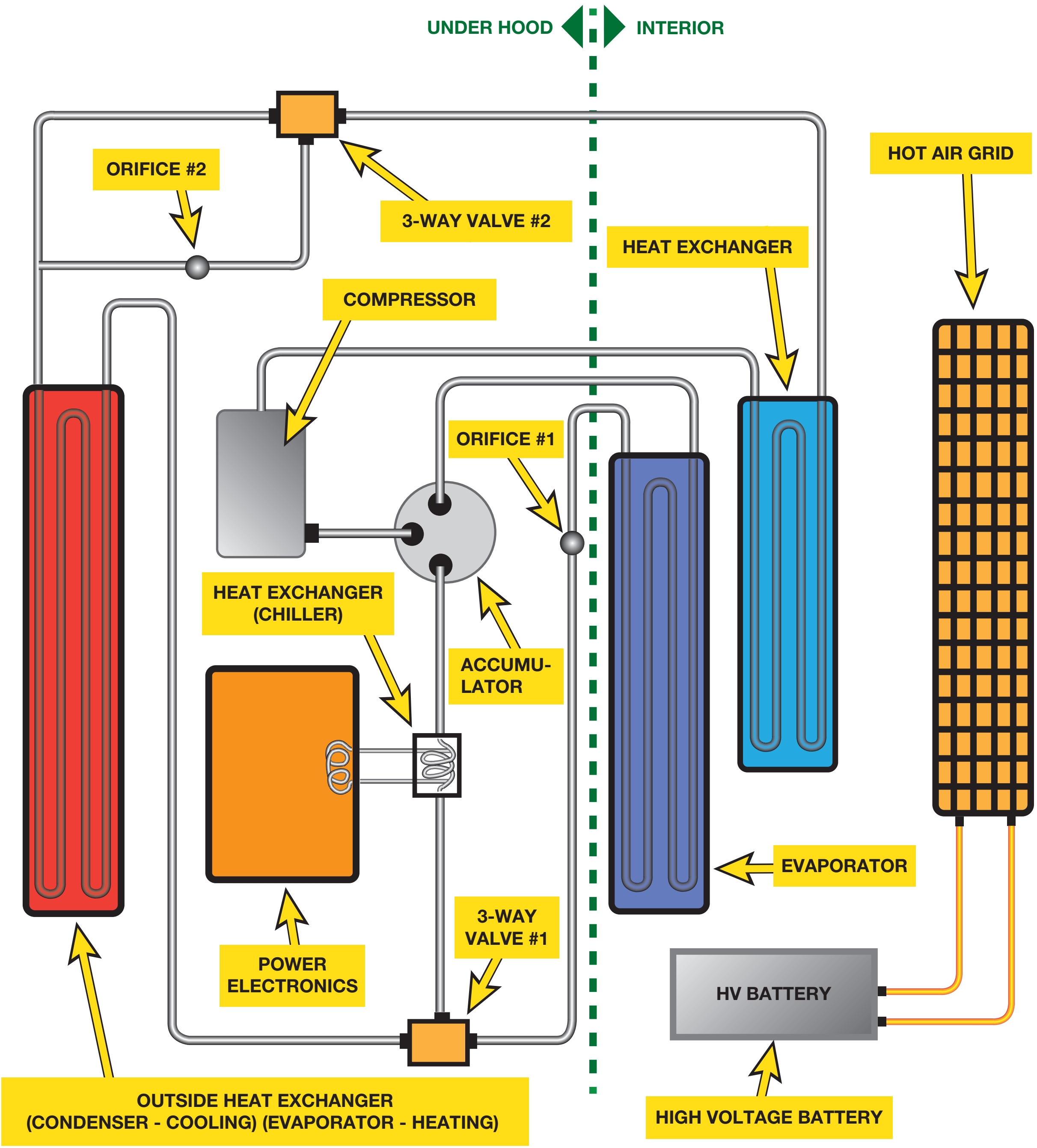

UNDER HOOD
INTERIOR
ORIFICE #2
3-WAY VALVE #2
HOT AIR GRID
HEAT EXCHANGER
COMPRESSOR
ORIFICE #1
HEAT EXCHANGER (CHILLER)
ACCUMU-LATOR
EVAPORATOR
3-WAY VALVE #1
POWER ELECTRONICS
HV BATTERY
OUTSIDE HEAT EXCHANGER (CONDENSER - COOLING) (EVAPORATOR - HEATING)
HIGH VOLTAGE BATTERY

FIGURE 63–13 A heat pump is basically a reversible air-conditioning system that can provide both cabin heating and cabin cooling. It is used to the waste heat from the electronic components to heat the cabin.

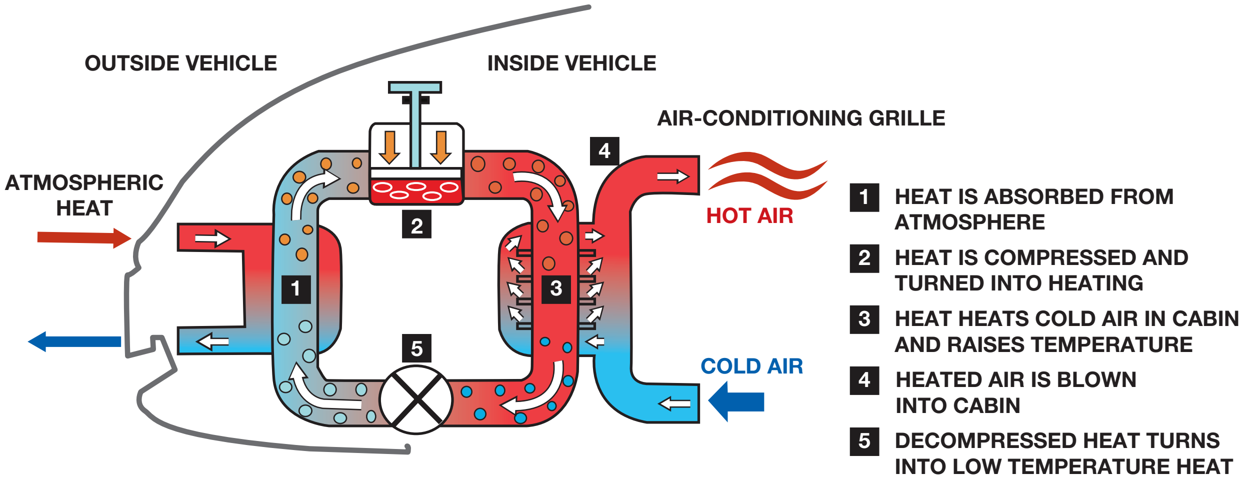

OUTSIDE VEHICLE
INSIDE VEHICLE
AIR-CONDITIONING GRILLE
ATMOSPHERIC HEAT
HOT AIR
COLD AIR
1
2
3
4
5
1 HEAT IS ABSORBED FROM ATMOSPHERE
2 HEAT IS COMPRESSED AND TURNED INTO HEATING
3 HEAT HEATS COLD AIR IN CABIN AND RAISES TEMPERATURE
4 HEATED AIR IS BLOWN INTO CABIN
5 DECOMPRESSED HEAT TURNS INTO LOW TEMPERATURE HEAT

FIGURE 63–14 A typical electric vehicle heat pump system showing the components inside the cabin and outside, under the hood.

FREQUENTLY ASKED QUESTION

What Is “Dog Mode”?

Dog mode (also called pet mode) is a climate control feature in Tesla and some other electric vehicles that leaves the air conditioning or heater on when owners leave their pets in their vehicle. It is accessed through the climate-control settings by selecting “Dog” under the “Keep Climate On” settings. Then, a message is displayed that reads: “My owner will be back soon. Don’t worry! The heater or A/C is on and it’s 72 degrees.” If the owner is gone for long periods of time and the battery goes below 20%, a push notification goes to the owner’s phone to prompt them to get back to their pet. ● **SEE FIGURE 63–15.**

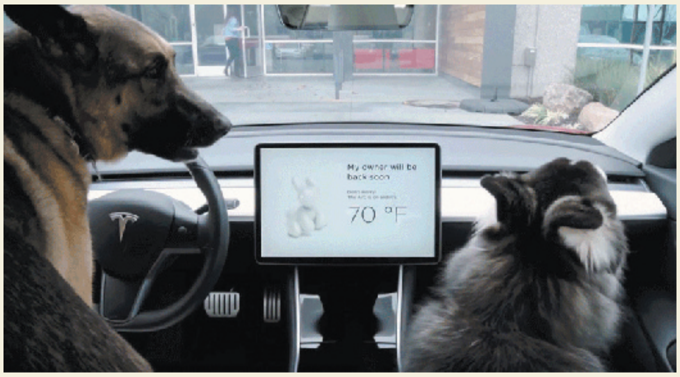


FIGURE 63–15 A message appears on the large center display when the vehicle is placed in dog mode to notify anyone near that the pets are safe being locked in the vehicle.

REVIEW QUESTIONS

1. What sensors are used in a typical automatic temperature control (ATC) system?
2. What is the difference between air conditioning and a heat pump system?
3. Why is a feedback potentiometer used on an electric actuator?
4. What is the purpose of the aspirator tube in the in-vehicle temperature sensor section?
5. What is the difference between an aftermarket scan tool and a factory scan tool?

CHAPTER QUIZ

1. What is the purpose of a compressor speed sensor?
   - **a.** To allow the ECM to control compressor speed
   - **b.** So the ECM can control high-side pressure
   - **c.** So the ECM can control low-side pressure
   - **d.** To let the ECM know if the compressor is turning
2. Which sensor is also called the ambient air temperature sensor?
   - **a.** Outside air temperature (OAT)
   - **b.** In-vehicle temperature
   - **c.** Discharge air temperature
   - **d.** Evaporator outlet temperature
3. What is the most common type of sun load sensor?
   - **a.** Potentiometer
   - **b.** Negative temperature coefficient (NTC) thermistor
   - **c.** Photodiode
   - **d.** Positive temperature coefficient (PTC) thermistor
4. An actuator can be capable of how many position(s)?
   - **a.** Two
   - **b.** Three
   - **c.** Variable
   - **d.** All of the above
5. The ATC will adjust ____________.
   - **a.** blower motor speed
   - **b.** temperature door
   - **c.** air inlet door
   - **d.** All of the above
6. Which sensor might use an aspirator tube?
   - **a.** In-vehicle temperature
   - **b.** Outside air temperature (OAT)
   - **c.** Discharge air temperature
   - **d.** Evaporator outlet temperature
7. A heat pump system is mostly used to heat and cool what type of vehicle?
   - **a.** Hybrid-electric vehicle (HEV)
   - **b.** Plug-in HEV (PHEV)
   - **c.** Electric vehicle (EV)
   - **d.** All of the above
8. Automatic temperature control (ATC) diagnosis includes ____________.
   - **a.** verifying the customer concern
   - **b.** performing a visual inspection
   - **c.** checking for stored DTCs
   - **d.** All of the above
9. The control module used for automatic climatic control systems is called ____________.
   - **a.** ECM
   - **b.** BCM
   - **c.** HVAC control module
   - **d.** Any of the above depending on the make and model of vehicle
10. A feedback potentiometer is used to ____________.
    - **a.** provide feedback to the driver as to where the controls are set
    - **b.** provide feedback to the controller as to the location of a door or valve
    - **c.** give temperature information about the outside air temperature to the dash display
    - **d.** Any of the above depending on the exact make and model of vehicle

Chapter 64

REFRIGERANTS AND REFRIGERANT OILS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- List the different types of refrigerants and refrigerant containers.
- Explain the impact of legislation related to automotive A/C systems.
- Explain the impact of environmental issues related to automotive A/C systems.
- Discuss HFO-1234yf refrigerant.
- Describe carbon dioxide as a refrigerant.
- Describe alternate refrigerants.
- Explain how to check for non-condensable gases.
- Describe refrigerant safety precautions.
- Discuss the different types and viscosities of refrigerant oils.

KEY TERMS:

Carbon dioxide (CO_2) 762 • Clean Air Act 758 • Global warming 760 • Global warming potential (GWP) 760 • Greenhouse effect 760 • Greenhouse gases (GHGs) 760 • Hygroscopic 765 • Mineral oil 765 • Non-condensable gas (NCG) 762 • Ozone depletion potential (ODP) 760 • PAG (polyalkylene glycol) 765 • POE (polyol ester) 765 • R-744 762 • Section 609 758 • Significant new alternatives policy (SNAP) 762 • Stratosphere 759 • Total Environmental Warming Impact (TEWI) 759

REFRIGERANTS

DEFINITION AND TYPES Refrigerants are colorless and odorless compounds that are human-made gases. The R number of a chemical refrigerant is assigned systematically according to molecular structure.

- **CFC-12**—Chemical name is dichlorodifluoromethane and was the first of the refrigerant used in automotive air-conditioning systems. It was commonly referred to as R-12 or by its DuPont trade name of *Freon*. R-12 was used in automotive air-conditioning systems from the early 1950s until the early 1990s.
- **HFC-134a**—Starting in the early 1990s, most vehicle manufacturers used HFC-134a (R-134a)—a refrigerant that is less harmful to the atmosphere.
- **HFO-1234yf**—Starting in the mid-2010s and required by 2021 this refrigerant used in all recent vehicles. It has a lower impact on climate change (global warming).

REFRIGERANT CONTAINERS Refrigerants are commonly available in several sizes of containers including

- Small cans of 12 oz. to 14 oz. (400 g). Small containers of R-12 can be purchased only by certified technicians. There are no national restrictions on purchase of R-134a.

FREQUENTLY ASKED QUESTION

When Was R-12 First Used in Automotive Air-Conditioning Systems?

General Motors created the refrigerant R-12 and marketed it a by the trade name Freon. Freon was first used in refrigerators manufactured by Frigidaire, a division of GM. Packard was the first vehicle manufacturer to install air conditioning in 1939 in their 120, Super-Eight 160 and Custom Super-Eight cars. In 1940, the Cadillac Division of General Motors introduced air conditioning on its 1941 models, installing it on some 300 cars. It was not until the 1953 model year that vehicle manufacturers including General Motors, Chrysler, and Packard introduced a practical system. The early system used an engine-driven compressor with the condenser located in front of the radiator as is done today. However, because the evaporator and blower motor assembly was so large, these components were placed in the trunk of the car. A clear plastic tube on each side of the package shelf directed cool air to registers located in the headliner on both sides of the interior.

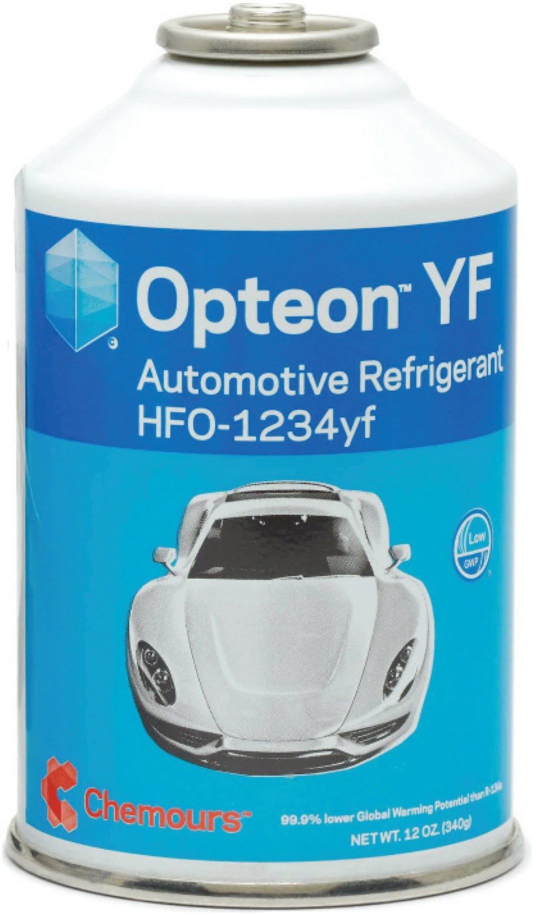


FIGURE 64–1 Because R1234yf is so expensive, many automotive shops purchase this refrigerant in small 12 oz. cans.

- Larger drums or canisters of 15 lb., 20 lb., or 30 lb. (6.8 kg, 9 kg, or 13.6 kg).
- R-1234yf is expensive, and small containers are more affordable for small shops. ● **SEE FIGURE 64–1**.

Refrigerant containers are color coded:

- R-12 containers are white
- R-22 containers are green
- R-134a containers are light blue. ● **SEE FIGURE 64–2**.
- R-1234yf are white with a red stripe

Refrigerant containers are usually disposable. These containers will be evacuated into a recovery unit, marked empty, and properly disposed of when they are emptied. The storage containers for recycled refrigerant must be approved by the DOT and carry the proper marking to show this. ● **SEE FIGURE 64–3**.

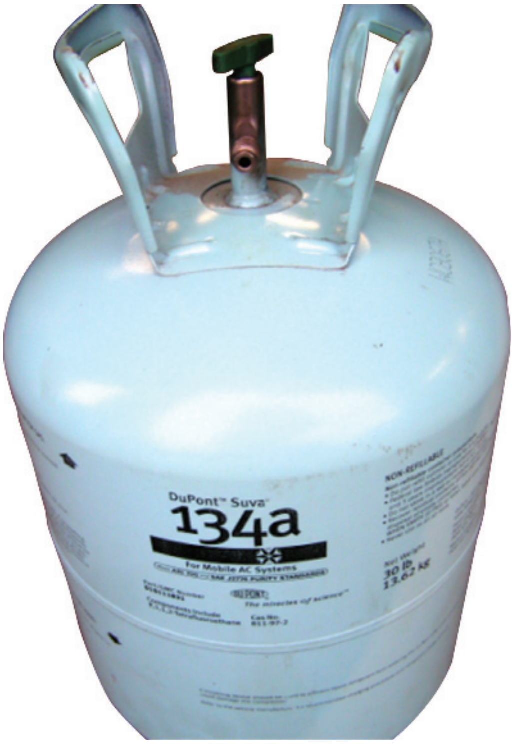


FIGURE 64–2 Large 30 pound containers of R-134a are light blue for easy identification.

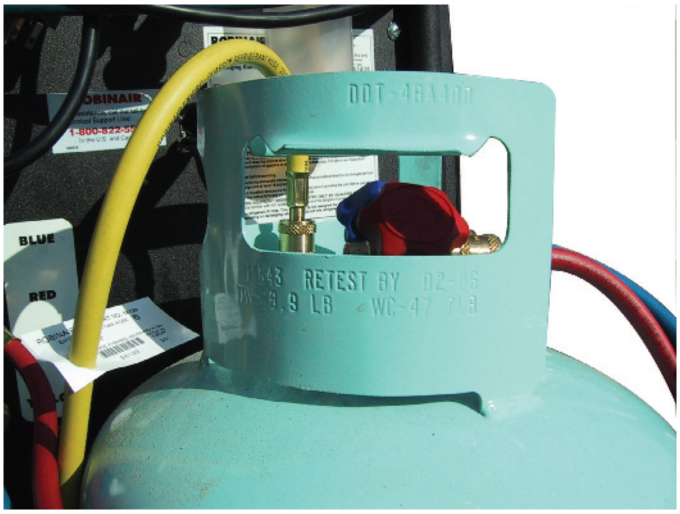


FIGURE 64–3 The stamped text at the top of this container reads "DOT-4BA400."

LEGISLATION

CLEAN AIR ACT At a conference in Montreal, Canada, in 1987, the United States, along with 22 other countries, agreed to limit the production of ozone-depleting chemicals. This agreement is referred to as the Montreal Protocol. In 1990, President Bush (senior) signed the **Clean Air Act**, which phased out the production of CFCs in the United States by the year 2000. R-12 production in the United States ceased at the end of 1995.

SECTION 609 **Section 609** is a portion of the Clean Air Act that places certain requirements on the *mobile vehicle air conditioning (MVAC)* service field. Important portions of this section require the following:

- **Sales Restriction**—Section 609 prohibits the sale of small cans (less than 20 pounds) of CFC-12 to anyone other than an EPA-certified technician.
- **Technician Training and Certification**—Technicians repairing or servicing CFC-12, HFC-134a, and CO_2, HFC-152a, or HFO-1234yf mobile vehicle air-conditioning systems must be trained and certified by an EPA-approved organization. Certification is obtained by passing an EPA-approved examination.
- **Approved Equipment**—Technicians repairing or servicing air-conditioning systems using CFC-12, HFC-134a, HFC-152a, CO_2, or HFO-1234yf must use refrigerant recovery equipment that is approved by EPA.

FREQUENTLY ASKED QUESTION

How Are Refrigerants Named?

The procedure for determining the refrigerant number is rather tedious and is of no value to the refrigerant technician. It is included in this text to reduce some misconceptions and wild stories that have passed through the industry. The system is based on the number of carbons, hydrogen, and fluorine atoms in the refrigerant molecule. Other suffix letters are added for different variations of the molecule. It is a four-character system with the letter "a" added to indicate a nonsymmetrical or asymmetrical molecule. The most common method of numbering system is: C (MINUS 1), H (PLUS 1), and F.

R-12 has 1 C $(1 - 1 = 0)$, O H $(0 + 1 = 1)$, and 2 F (2), to get 012, or 12.

- The R-12 molecule is symmetrical, which means that both sides are the same.
- The R-134a molecule is asymmetrical (the reason for the "a" in the name), which means that the left and right sides are different. The chemical name for CFC-12, dichlorodifluoromethane, indicates that the molecule has two (di) chlorine atoms and two fluorine atoms, and the suffix methane indicates there is one carbon atom. ● **SEE FIGURE 64–4**.

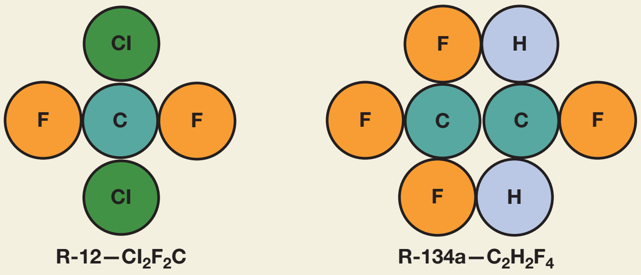


FIGURE 64–4 R-12 is a combination of one carbon, two chlorine, and two fluorine atoms. R-134a is a combination of two carbon and four fluorine atoms.

- **Recordkeeping Requirements**—MVAC service shops must maintain records of the names and addresses of facilities to which the refrigerant they recover is sent. Service shops are also required to maintain records (on-site) showing that all service technicians are properly certified and must certify to EPA that they own approved equipment.
- **Effective January 29, 1998**—Equipment used to recover or recycle R-134a must meet SAE standards. MVAC service technicians must be certified to handle non-ozone-depleting refrigerants (including R-134a).

KYOTO PROTOCOL There is still a major concern about the global warming effect from escaping refrigerants.

Representatives from many nations met in Kyoto, Japan, in 1997 and established the Kyoto Protocol to address these concerns. The **Total Environmental Warming Impact (TEWI)** index was developed, which rates the impact of various refrigerants along with the energy required to perform the cooling operation. In the future, it is hoped that each nation will reduce its negative impact on the environment to zero in order to reduce global change to zero. All factors concerning energy use and emissions will be considered. The United States has not signed the Kyoto Protocol.

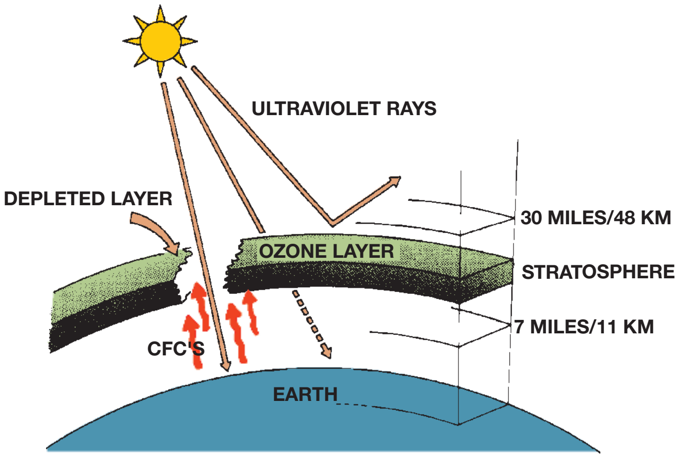


FIGURE 64–5 Depletion of the ozone layer allows more ultraviolet radiation from the sun to reach Earth's surface.

ENVIRONMENTAL ISSUES

OZONE LAYER Planet Earth is unique in many ways. It has an atmosphere that contains a percentage of oxygen high enough to allow mammals, including humans, to live in it. This atmosphere extends outward from Earth for about 31 miles (50 km). The upper layer of the atmosphere is called the **stratosphere**, and it begins about 7 miles to 10 miles (11 km to 16 km) up and extends to the outer limits. A layer of ozone (O_3) extends around the Earth in the stratosphere. ● **SEE FIGURE 64–5**.

The ozone layer is important to us because it blocks the ultraviolet wavelengths of light generated by the sun. Ultraviolet rays can be very harmful to our way of life. In humans, an excess of these rays can cause an increase in skin cancer and cataract of the eyes, as well as damage to our immune system. These same problems can affect many animals. Ultraviolet rays can also damage plants and vegetables. This damage probably also extends to plankton and larvae in the sea, the base of the food chain for sea animals. In the late 1900s, it was determined that the ozone layer is getting much thinner, and large holes are being created in it (mostly near the South Pole). The ozone layer is not providing the same protection from ultraviolet (UV) rays as it once did. It has been determined that

1. The breakup or depletion of the ozone layer is caused by human-made chemical pollution.
2. One of the major ozone-depleting chemicals is chlorine.
3. One of the major sources of chlorine in the atmosphere is R-12.

OZONE DEPLETION A chlorine atom from a *chlorinated fluorocarbon (CFC)* such as R-12 can travel into the stratosphere if it escapes or is released. There, under the effects of ice clouds and sunlight, it can combine with one of the oxygen atoms of an ozone molecule to form chlorine monoxide and an ordinary oxygen molecule, O_2. This destroys that ozone molecule. The chlorine can then break away and attack other ozone molecules.

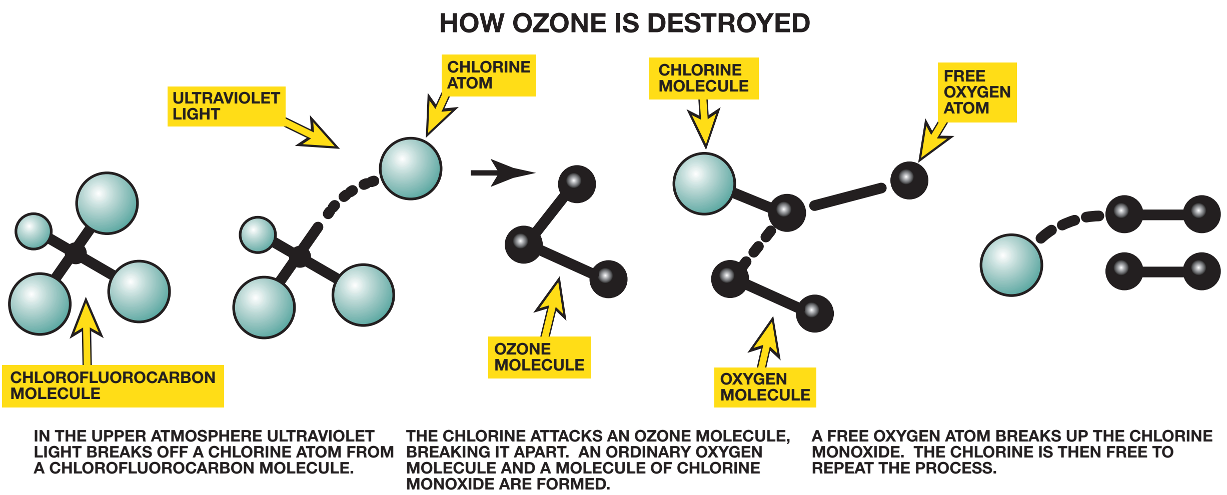

HOW OZONE IS DESTROYED
ULTRAVIOLET LIGHT
CHLORINE ATOM
CHLORINE MOLECULE
FREE OXYGEN ATOM
CHLOROFLUOROCARBON MOLECULE
OZONE MOLECULE
OXYGEN MOLECULE
IN THE UPPER ATMOSPHERE ULTRAVIOLET LIGHT BREAKS OFF A CHLORINE ATOM FROM A CHLOROFLUOROCARBON MOLECULE.
THE CHLORINE ATTACKS AN OZONE MOLECULE, BREAKING IT APART. AN ORDINARY OXYGEN MOLECULE AND A MOLECULE OF CHLORINE MONOXIDE ARE FORMED.
A FREE OXYGEN ATOM BREAKS UP THE CHLORINE MONOXIDE. THE CHLORINE IS THEN FREE TO REPEAT THE PROCESS.

FIGURE 64–6 Chlorofluorocarbon molecules break apart in the atmosphere.

It is believed that 1 chlorine atom can destroy 10,000 to 100,000 ozone molecules. ● **SEE FIGURE 64–6**.

- CFCs do the most damage and have an **ozone depletion potential (ODP)** of 1.
- Hydrochlorofluorocarbon (HCFC), such as R-22, have an ODP around 0.01–0.1, so they have a lesser effect on the ozone layer.
- Since HFCs, such as R-134a, contain no chlorine and have an ODP of 0 (zero), they have no detrimental effect on the ozone layer.

GLOBAL WARMING AND GREENHOUSE GASES Another area of concern is a layer of gases that is causing a **greenhouse effect**. This gas layer traps heat at the Earth's surface and lower atmosphere, and it is increasing the temperature of our living area. This is called **global warming**. CFC and hydrocarbon (HC) gases such as butane and propane are considered **greenhouse gases (GHGs)**. **Global warming potential (GWP)** compares the ability of different gases to trap heat, and this is based on the heat-absorbing ability of each gas. The lower the GWP number, the lower the global warming potential. ● **SEE CHART 64–1**.

HFO-1234yf

DESCRIPTION HFO-1234yf also called R-1234yf is a hydrofluoroolefin with the formula CH2 = CFCF3 and is the refrigerant required to be used in all vehicles by the 2021 model year (MY). It was approved by US EPA in 2011 under the Significant New Alternative Policy (SNAP) for use in new model of vehicles. Since that date, some vehicle manufacturers are producing vehicles equipped with R-1234yf. Refer to the under-hood label to determine what refrigerant is used in the vehicle. ● **SEE FIGURES 64–7 AND 64–8**.

REFRIGERANT	GLOBAL WARMING POTENTIAL (GWP)	OZONE DEPLETION POTENTIAL (ODP)
CFC-12	10,900	1
HFC-134a	1,430	0.055
HFO-1234yf	4	0
R-744 (CO_2)	1	0

CHART 64–1

R-1234yf has zero ozone depletion potential and very low global warming potential compared to R-134a. R-144 is even lower but not by much.

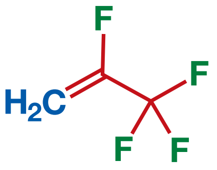


FIGURE 64–7 The chemical symbol for HFO-1234yf.

UNIQUE FITTINGS Each refrigerant is required to have unique fittings to help prevent cross contamination. ● **SEE CHART 64–2**.

MANDATED The United States EPA has banned the use of R-134a after January 1, 2021 and requires all new vehicles sold in the United States to use R-1234yf. R-134a may be used for servicing existing vehicles equipped with R-134a. R-1234yf has operating characteristics similar to R-134a. ● **SEE FIGURE 64–9**.

FLAMMABILITY R-1234yf is mildly flammable. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) have given it an A2L classification. ● **SEE FIGURE 64–10**.

As a result of the possibility of being ignited, the following precautions need to adhered to when servicing an R-1234yf system:

- Do not smoke or have an open flame while working on or servicing a vehicle equipped with R-1234yf.
- Use tools and service equipment designed specifically for R-1234yf.
- If the evaporator is removed for any other service or replaced, it must be replaced with a new part meeting the SAE standard J2842. Using the robustly designed evaporator is one way that the occupants inside the vehicle are protected against the possibility of having the refrigerant escape into the passenger compartment in the event of a collision.

DuPont™ Opteon™ YF
refrigerant (HFO-1234yf)
For Mobile AC Systems
COMPONENTS INCLUDE 2,3,3,3-Tetrafluoropropene
CAS NO. 754-12-1
Net Weight 10 lbs. (4.54 kg)
Dispos-A-Can® Container
NON-REFILLABLE
NON-REFILLABLE CONTAINER PRECAUTIONS

FIGURE 64–8 Due to the cost of R-1234yf, most shops will purchase 10- or 20-pound containers compared to the normal 30 pound container that most shops purchased for R-134a.

REFRIGERANT	LOW SIDE FITTING	HIGH SIDE FITTING
CFC 12 (R-12)	7/16 × 20 Threads	7/16 × 20 Threads (before 1987) 3/8 × 24 (1987 – 1994)
HFC-134a (R-134a)	Quick Coupler unthreaded 13 mm O.D.	Quick Coupler unthreaded 16 mm O.D.
HFO-12343yf (R-1234yf)	Quick Coupler unthreaded 14 mm O.D.	Quick Coupler unthreaded 17 mm O.D.
R-744 (CO_2)	Quick Coupler unthreaded 16.6 mm O.D.	Quick Coupler unthreaded 18.1 mm O.D.

CHART 64–2

Refrigerant fitting sizes must be unique for each type of refrigerant to help prevent cross contamination.

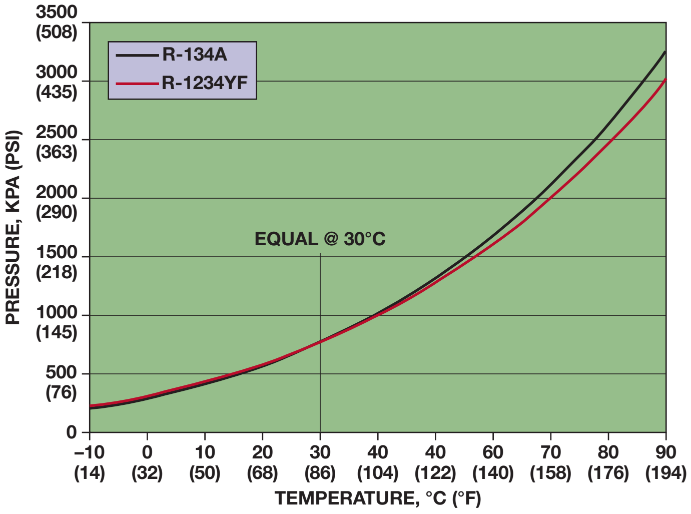


FIGURE 64–9 R-134a and R-1234yf have similar operating pressures.

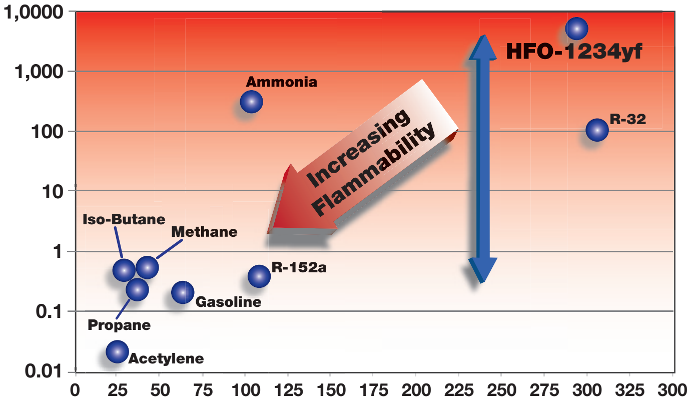


FIGURE 64–10 R-1234yf is just mildly flammable as shown at the top right of the chart.

R-1234yf CONCERNS There is concern about possible cross contamination with either R-134a or an HC:

- As little as 5% of R-134a can increase the pressure in a **recovery** cylinder high enough to cause an "air purge" and this can empty the entire cylinder in the attempt to bleed off air.
- As little as 2% HC with 2% air will increase flammability to greater-than-limits established by the refrigerant manufacturers.

FREQUENTLY ASKED QUESTION

Will R-134a Systems Be Required to Be Retrofitted to R-1234yf?

No. Currently there is no mandate to retrofit existing systems with R-1234yf. If a vehicle came from the factory with R-1234yf, then this refrigerant, of course, will be used when servicing the vehicle and will require a special machine. There is no need or legal requirement to replace it with any other refrigerant at this time.

R1234yf SAFETY PRECAUTIONS Whenever working on a vehicle equipped with R1234yf or servicing the air-conditioning system that uses R1234yf, most experts recommend that the following safety precautions be adhered to:

- Do not smoke or create an open flame in the area where R1234yf may be present.
- Be sure that the area is well ventilated.
- Use the proper torque on all threaded connections and always replace O-rings and seals with a new part and do not reuse the old seals.
- If an evaporator is removed, even if for access to another component, it must be replaced with a new part designed specifically for R1234yf and meets SAE standard J2842.

CARBON DIOXIDE AS A REFRIGERANT

DEFINITION **Carbon dioxide (CO_2)** is a colorless and odorless gas which is a naturally occurring chemical compound. Carbon dioxide is in the atmosphere as a trace gas at a concentration of about 0.04 percent or 400 parts per million (ppm) by volume. Humans breathe in oxygen and breathe out CO_2. As part of the life cycle, plants, algae, and cyanobacteria use light energy to photosynthesize carbohydrate from carbon dioxide and water, with oxygen produced as a waste product.

CO_2 AS A REFRIGERANT A carbon dioxide (CO_2), referred to as **R-744** system, is similar to the present-day systems, but operates at extremely high pressure, 7 to 10 times that of an R-134a system. This pressure puts a large added load on the compressor, heat exchanger, and refrigerant lines. The extremely high pressure requires more power from the engine to operate the compressor and this extra energy causes reduced fuel economy. At this time, a CO_2 system is up to 40% less efficient than an R-134a system and can cost about 30% more to produce. ● **SEE FIGURE 64–11**.

ALTERNATE REFRIGERANTS

SNAP PROGRAM Section 612 of the 1990 Clean Air Act established the **Significant New Alternatives Policy (SNAP)** program to determine acceptable replacements for Class I and Class II chemicals. Class I chemicals include CFCs, and Class II chemicals are HCFCs. SNAP is administered by the EPA and identifies refrigerants that are acceptable from their ozone depleting potential, global warming potential, flammability, and toxicity characteristics. Alternate refrigerants are not tested on their refrigeration quality, but only on their human health and environmental risks.

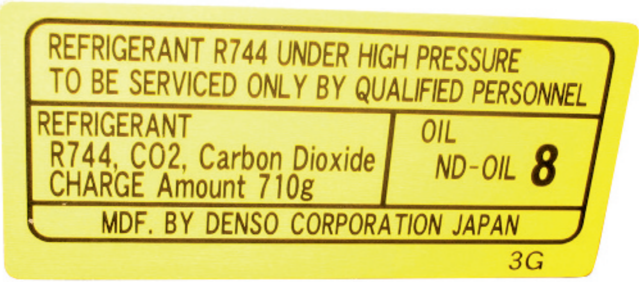

REFRIGERANT R744 UNDER HIGH PRESSURE
TO BE SERVICED ONLY BY QUALIFIED PERSONNEL
REFRIGERANT
R744, CO2, Carbon Dioxide
CHARGE Amount 710g
OIL
ND-OIL 8
MDF. BY DENSO CORPORATION JAPAN
3G

FIGURE 64–11 The label on a Toyota Fuel Cell Hybrid Vehicle (FCHV) showing that CO_2 (R744) is being used as the refrigerant.

R-134a is the only alternate product for an R-12 system that has addressed the SAE retrofit documents (SAE J1657, SAE J1658, SAE J1659, and SAE J1662). These standards are designed to ensure long-term, trouble-free operation of the A/C system. An alternate refrigerant can only be used under the following conditions:

- Each refrigerant must have its own unique set of fittings, and all ports not converted must be permanently disabled.
- Each refrigerant must have a label with a unique color that specifies pertinent information.
- All original refrigerants must be removed before charging with the new refrigerant.
- With blends that contain HCFC-22, hoses must be replaced with less permeable barrier hoses.
- With systems that include a high-pressure release device, a high-pressure shutoff switch must be installed.
- Blends containing HCFC-22 will be phased out in the near future.

COUNTERFEIT AND BOOTLEG REFRIGERANTS With the high cost and limited availability of R-12, a refrigerant buyer has to be careful about where it is purchased from. Refrigerant is being illegally imported, and some of it is contaminated. There are stories of counterfeit refrigerant being sold in containers marked the same as those of a reputable, domestic manufacturer. Other stories tell of containers that contain nothing but water with air pressure. Refrigerant should be purchased only from a known source that handles reputable products.

NON-CONDENSABLE GAS

DEFINITION Any gas that does not condense (change from vapor to liquid) under the normal compression refrigeration conditions is called a **non-condensable gas (NCG)**. Any refrigerant that contains NCG, usually air, is considered contaminated.

CHECKING FOR NCG If there is non-condensable gas in a container of refrigerant, the pressure will be higher than

FREQUENTLY ASKED QUESTION

What Is a Secondary Loop System?

Systems that use potentially hazardous refrigerants will probably use a secondary loop. The CO_2 or HC portion of the system will be entirely under the hood. A heat exchanger will provide a very cold fluid to connect with a liquid-to-air heat exchanger that will replace the evaporator. These systems might also use refrigerant-leak-sensing devices and a method of venting/dumping the refrigerant into one of the fender wells to prevent a buildup of refrigerant in the passenger area. ● **SEE FIGURE 64–12**.

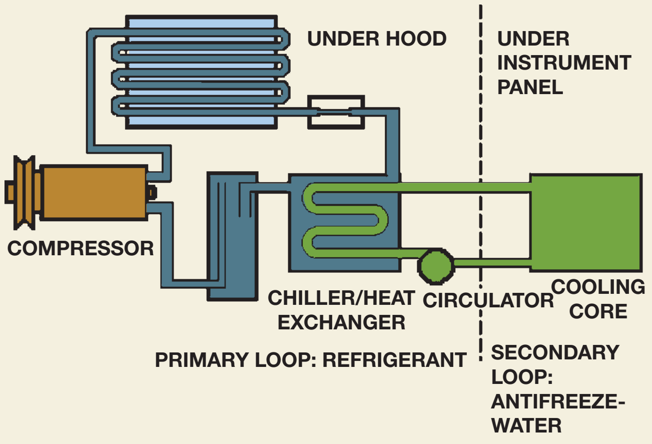


FIGURE 64–12 A secondary loop A/C system keeps the potentially dangerous or flammable refrigerant out of the passenger compartment by using a chiller/heat exchanger to cool an antifreeze and water mixture. This fluid then transfers heat from the cooling core in the air distribution section to the chiller.

normal according to a pressure/temperature chart. To check for non-condensable gas, perform the following steps:

STEP 1 Place the container of refrigerant at a location out of direct sunlight and at a temperature above 65°F (18 °C) for at least 12 hours.

STEP 2 Attach a pressure gauge to the refrigerant container and read the pressure.

STEP 3 Using an accurate infrared thermometer, measure the temperature of the container within 4 inches (10 cm) of the container. Compare the pressure of the refrigerant with the chart. ● **SEE CHART 64–3**.

REFRIGERANT SAFETY

POTENTIAL HAZARDS Refrigerants should be handled only by trained and certified technicians because of potential safety hazards:

- Physiological reaction (get physically sick)
- Asphyxiation (this means that the refrigerant does not contain oxygen, so it cannot sustain life if breathed)

TEMPERATURE F° (C°)	PRESSURE PSI (kPa)	TEMPERATURE F° (C°)	PRESSURE PSI (kPa)
65 (18.3)	69 (476)	88 (31.1)	105 (724)
66 (18.8)	70 (483)	89 (31.7)	107 (738)
67 (19.4)	71 (490)	90 (32.2)	109 (752)
68 (20.0)	73 (503)	91 (32.8)	111 (765)
69 (20.5)	74 (510)	92 (33.3)	113 (779)
70 (21.1)	76 (524)	93 (33.9)	115 (793)
71 (21.6)	77 (531)	94 (34.4)	117 (807)
72 (22.2)	79 (545	95 (35.0)	118 (814)
73 (22.8)	80 (552)	96 (35.6)	120 (827)
74 (23.3)	82 (565)	97 (36.1)	122 (841)
75 (23.9)	83 (572)	98 (36.7)	125 (862)
76 (24.4)	85 (586)	99 (37.2)	127 (876)
77 (25.0)	86 (593)	100 (37.8)	129 (559)
78 (25.6)	88 (607)	101 (38.3)	131 (903)
79 (26.1)	90 (621)	102 (38.9)	133 (917)
80 (26.7)	91 (627)	103 (39.4)	135 (931)
81 (27.2)	93 (641)	104 (40.0)	137 (945)
82 (27.8)	95 (655)	105 (40.6)	139 (958)
83 (28.3)	96 (662)	106 (41.1)	142 (979)
84 (28.9)	98 (676)	107 (41.7)	144 (993)
85 (29.4	100 (689)	108 (42.2)	146 (1007)
86 (30.0)	102 (703)	109 (428)	149 (1027)
87 (30.6)	103 (710)	110 (43.3)	151 (1041)

CHART 64–3

If the pressure is at or below the listed values, the refrigerant is acceptable and does not contain any non-condensable gas (air). If the pressure of the refrigerant is higher than the chart indicates, the vapor should be slowly vented from the top of the container into the recovery/recycling machine until the pressure drops to the limit in the chart.

- Frostbite and blindness
- Poisoning
- Combustion
- Explosion of storage containers

PRECAUTIONS Precautions when working with refrigerants include

- Wear safety goggles or a clear face shield and protective clothing (gloves) when working with refrigerants. If refrigerant splashes into your eyes, blindness can occur. If refrigerant splashes into your eyes or onto your skin, do not rub that body part but instead flush it with cool, clean water to restore the temperature. Place sterile gauze over the eye to keep it clean and get professional medical attention immediately.
- Always be in a well-ventilated shop area when working with refrigerants and avoid small, enclosed areas. Refrigerants do not contain oxygen and are heavier than air. If they are released into a confined area, they fill the lower space, forcing air and its oxygen upward. Any humans or animals that breathe refrigerants can be asphyxiated, and lack of oxygen can cause loss of consciousness or death. In case of accidental release of refrigerant into the atmosphere, move immediately to an area with adequate ventilation.
- If liquid refrigerant is splashed onto the skin or into the eyes of a human or animal, it immediately boils and absorbs heat from the body part it is in direct contact with. The temperature of the area is reduced to the low boiling point of the refrigerant, which is cold enough to freeze that body part.
- If a CFC such as R-12 or R-22 comes into contact with a flame or heated metal, a poisonous gas similar to phosgene is formed. This can occur while using a flame-type leak detector, if refrigerant is drawn into a running engine, or even if it is drawn through burning tobacco. An indication that a poisonous gas is forming is a bitter taste.
- Several flammable refrigerants have been marketed, and even though they have been banned and are illegal, they still show up. A mixture of more than 2% hydrocarbon (butane, isobutane, or propane) is considered flammable and about 4 oz. in a vehicle interior can become an explosive mixture. R-134a can become combustible at higher pressures if mixed with air. Air should not be used to flush an R-134a system because of the remote chance of a fire or explosion.
- When refrigerant containers are filled, room is left for expansion and the container is marked with its critical temperature, the maximum that it will be subjected to. Refrigerant containers are designed to contain the refrigerant under pressures encountered in normal working and storage conditions. Container pressure is about the same as the vapor pressure for that refrigerant up to a certain temperature point, which is where the liquid has expanded to fill the entire container. Beyond this point, any further expansion of the liquid generates very high hydraulic pressures that will rupture the container. The chance of container rupture is generally low unless the container is overfilled or overheated. ● **SEE FIGURE 64–14**.

FREQUENTLY ASKED QUESTION

What Is an HC Refrigerant?

A hydrocarbon (HC) refrigerant is butane/propane blend that is very flammable. It can be used and will function in present-day A/C systems, but it is too dangerous to use. At the present time, the EPA and 19 states have banned flammable refrigerants. A leak or rupture in the evaporator could easily result in a vehicle explosion. Some hydrocarbon refrigerants are sold to do-it-yourselfers (DIY) and while it can work in either an R-12 or an R-134a system, it would contaminate the system and make future repairs of the system much more difficult. ● **SEE FIGURE 64–13**.

HC-12a™
With HC Friction Fighters
OZONE SAFE
Replaces HFC-134a and other CFC-12 substitutes
No retrofit required
WARNING
Flammable
Contents Under Pressure

FIGURE 64–13 A container of refrigerant, which is a replacement for R-12 or R-134a and contains R-134a but also, butane, a flammable gas.

REFRIGERANT OILS

PURPOSE AND FUNCTION Refrigerant oil serves several purposes, the most important being to *lubricate* the moving parts of the compressor to reduce friction and prevent wear. Refrigerant

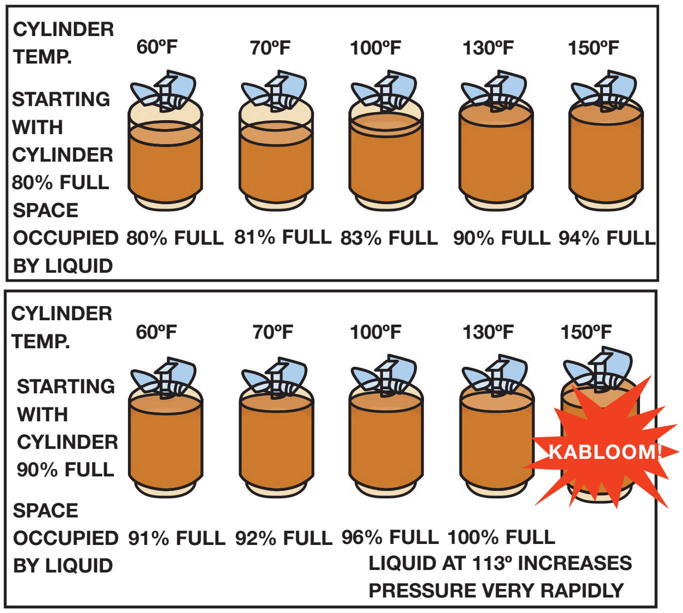

CYLINDER TEMP.
60°F
70°F
100°F
130°F
150°F
STARTING WITH CYLINDER 80% FULL
SPACE OCCUPIED BY LIQUID
80% FULL
81% FULL
83% FULL
90% FULL
94% FULL
CYLINDER TEMP.
60°F
70°F
100°F
130°F
150°F
STARTING WITH CYLINDER 90% FULL
KABLOOM!
SPACE OCCUPIED BY LIQUID
91% FULL
92% FULL
96% FULL
100% FULL
LIQUID AT 113° INCREASES PRESSURE VERY RAPIDLY

FIGURE 64–14 When recovering refrigerant, the container should be filled to a maximum of about 80%.

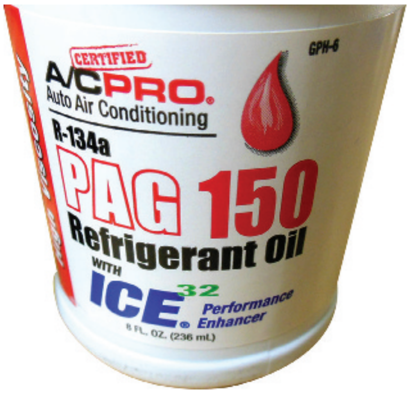


FIGURE 64–15 PAG oil is the type of refrigerant oil specified for use in most R-134a systems and the "150" is the viscosity.

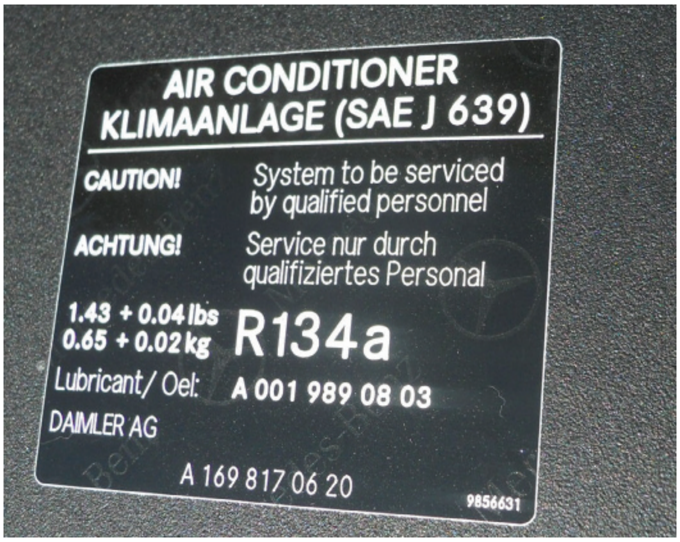


FIGURE 64–16 This under hood decal gives a Mercedes-Benz part number (A 001 989 08 03) instead of the type and viscosity of refrigerant oil. Service information was needed to determine that it was PAG 46.

oil also helps *seal* the compressor shaft seal, the insides of the hoses, and various connections between the parts to reduce refrigerant leakage. In addition, it lubricates the TXV and coats the metal parts inside the system to reduce corrosion. The oil used in a system must be completely compatible with all the materials in the system.

TYPES OF REFRIGERANT OILS

There are three types of refrigerant oils:

1. **Mineral oil** is used in R-12 systems.
2. **PAG (polyalkylene glycol)** oils are used in most R-134a systems. ● **SEE FIGURE 64–15**.
3. **POE (polyol ester)** (ester) oils are used in a few R-134a systems, and either ester or PAG oils are used in R-12 systems that have been retrofitted to R-134a.

PAG and POE are synthetic, manufactured oils. Neither PAG nor POE is soluble in R-134a, but they are easily moved by the refrigerant flow so they travel through the entire A/C system. Most compressor remanufacturers consider PAG oil a better lubricant than ester oil. There are over 30 varieties of refrigerant oil, the use of which depends on the requirements of a particular compressor or system. Piston, scroll, and vane compressors often require a different oil viscosity because of the different operating characteristics and use internal pressures to circulate the oil.

Compressors normally contain a certain amount of oil (often just 2 oz. to 8 oz.). The oil level can only be checked by removing the compressor and draining all of the oil, then measuring how much oil came out. This is normally only done when a compressor is replaced or when major service is performed on the system.

R-1234yf REFRIGERANT OIL

The refrigerant oil required for HFO-1234yf is PAG-based oil with an additive package unique to R-1234yf. The additive package is designed to provide greater chemical stability because R-1234yf breaks down in just 11 days compared to 13 years for R-134a. The oil is backward compatible with R-134a systems but R-134a oils are not compatible with R-1234yf systems.

VISCOSITY OF REFRIGERANT OILS

Viscosity is a measurement of how thick the oil is and how easily it flows. The oil must be thick enough so that moving parts float on an oil film. Oil must also be fluid enough to flow into the tiny spaces between parts. Compressor manufacturers normally specify the oil type and their viscosity for each type of compressor. The viscosity is determined by the International Standards Organization (ISO) viscosities and is measured at 40°C. Refrigerant oils are commonly available in several viscosities, including

- **46**—Called low viscosity—typically used in Ford vehicles
- **100**—Called medium to high viscosity—typically used in Chrysler vehicles
- **150**—Called ultra-high viscosity—typically used in General Motors vehicles

CAUTION: Always check the under-hood decal or service information for the exact oil and viscosity to use. ● SEE FIGURE 64–16.

HYGROSCOPIC

It is important to keep oil containers closed so that the oil does not absorb water from the atmosphere. A mineral oil can absorb about 0.005% water by weight. PAG or ester oil is very **hygroscopic**, which means that it can absorb moisture directly from the air up to about 2% to 6%. Some synthetic oils undergo hydrolysis if exposed to too much water and revert back to their original components: acid and alcohol.

OIL FLOW IN THE SYSTEM

When a system operates, oil is either absorbed or pushed by the refrigerant and moves through the system. It does not stay in any particular component, but a certain amount of oil can be expected in each component. Oil can also move while a system is shut off because of temperature changes of its various parts. Damage will occur if the compressor is operated without the refrigerant or the oil through which the refrigerant circulates. The compressor is lubricated by the oil that is mixed with and circulates with the refrigerant.

- With R-12, oil was miscible in the refrigerant and the refrigerant carried the oil.
- With R-134a, and R-1234yf, the refrigerant pushes the oil.
- A loss of refrigerant will also mean a loss of lubricating oil and possible compressor failure.
- The use of a low-pressure switch prevents the operation of the compressor if the system is low on charge.

REVIEW QUESTIONS

1. What do the colors of the containers mean?
2. How can a refrigerant cause the breakup or depletion of the ozone layer?
3. What does the Clean Air Act mandate when it comes to servicing air-conditioning systems?
4. What is a SNAP refrigerant?
5. What precautions are necessary when working with refrigerants?

CHAPTER QUIZ

1. R-134a is in what color container?
   a. Red
   b. Light blue
   c. White
   d. Green
2. Where is the ozone layer?
   a. Near ground level
   b. In the stratosphere
   c. In the clouds
   d. Between the ground and the clouds
3. The lower the GWP number, the _________.
   a. lower the global warming potential
   b. higher the global warming potential
   c. closer it is to the ground
   d. more poisonous
4. What section of the Clean Air Act concerns work on air-conditioning systems in vehicles?
   a. 847
   b. 609
   c. 777
   d. 103a
5. Which refrigerant has the lowest global warming potential (GWP)?
   a. R-744
   b. R-134a
   c. R-1234yf
   d. R-12
6. What is true about a SNAP refrigerant?
   a. Requires unique set of fittings, and all ports not converted must be permanently disabled.
   b. Each refrigerant must have a label with a unique color that specifies pertinent information.
   c. All original refrigerants must be removed before charging with the new refrigerant.
   d. All of the above
7. Checking a container of refrigerant for pressure and temperature checks for _________.
   a. moisture
   b. air
   c. dirt
   d. All of the above
8. Precautions when working with refrigerants include _________.
   a. wear safety goggles or a clear face shield and protective clothing (gloves) when working with refrigerants
   b. always be in a well-ventilated shop area when working with refrigerants and avoid small, enclosed areas
   c. when refrigerant containers are filled, reserve room is left for expansion and the container is marked with its critical temperature
   d. All of the above
9. What type of refrigerant oil is used in R-134a systems?
   a. POE
   b. PAG
   c. Mineral
   d. Either a or b depending on the vehicle
10. Why is it important to keep refrigerant oil containers closed?
    a. To keep dirt out
    b. To keep it from evaporating
    c. To keep it from absorbing moisture from the air
    d. It can leak out by traveling upward through an open container

Chapter

65

REFRIGERANT RECOVERY, RECYCLING, AND RECHARGING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain A/C service safety practices.
- Explain SAE J standards.
- Discuss the procedure for identifying refrigerants in an A/C system.
- Describe the steps involved in A/C servicing.
- Explain the procedure for refrigerant recovery.
- Explain the procedure for recycling refrigerant.
- Discuss the purpose of flushing an A/C system.
- Describe component replacement including in-line filter and refrigerant oil.
- Explain the procedure for evacuating an A/C system.
- Explain the procedure for recharging an A/C system.
- Discuss sealants and stop leaks.

KEY TERMS:

Cubic feet per minute (cfm) 776 • Evacuation 775 • Flushing 772 • Identifier 768 • Mercury 776 • Micron 776 • Non-condensable gases (NCG) 769 • PPE 767 • Reclaimed refrigerant 771 • Recovery, recycling, and recharging (RRR) 770 • Recycled refrigerant 771 • Slugging 778

SAFETY FIRST

SUGGESTED GUIDELINES All service technicians that work on or around automotive air-conditioning systems should adhere to the following best practices for safety:

- Obtain, read, and understand the safety data sheet (SDS) information regarding the refrigerant being used.
- Work in well-ventilated area.
- Wear safety goggles or safety glasses with side shields to guard against eye exposure to refrigerant. ● **SEE FIGURE 65–1**.
- Avoid breathing refrigerant or refrigerant oil vapor.
- Avoid direct exposure to refrigerant because it can cause frostbite or difficulty breathing if exposed to vapors. Consult medical advice immediately if exposed.

FIGURE 65–1 Whenever working around refrigerant or chemicals such as dyes, always wear personal protective equipment **(PPE)**.

SAE J STANDARDS

PURPOSE Automotive service technicians are often overwhelmed with all of the various standards and specifications required for the equipment and procedure when working on the air-conditioning system. SAE (formally the Society of Automotive Engineers) has established guidelines and specifications. Each document has a "J" prefix and a number that makes searching for the details on the Internet easier. Before purchasing or using automotive air-conditioning test or service equipment, make sure that it meets the current standards for the vehicle being serviced.

COMMONLY CITED STANDARDS The most commonly referred to standards include the following:

- **J639**—Safety standards for motor vehicle refrigerant vapor compression systems. SAE J639 only addresses HFC-134a (R-134a), carbon dioxide (R-744), and HFO-1234yf (R-1234yf) refrigerants.
- **J1627**—Establishes the performance criteria for electronic refrigerant leak detectors.
- **J1628**—Establishes technician procedures for refrigerant leak detection for air-conditioning systems.
- **J1771**—This SAE standard establishes refrigerant identification equipment to be used for identifying refrigerant CFC-12 (R-12) and HFC-134a (R-134a) refrigerant when servicing a mobile A/C system. It also establishes standards for identifying refrigerant in a container to be used to charge a mobile A/C system.
- **J1991**—Establishes the standard of purity for use in mobile CFC-12 (R-12) air-conditioning systems.
- **J2099**—Sets the standard of purity for recycled R-134a (HFC-134a) and R-1234yf (HFO-1234yf).
- **J2210**—This SAE standard establishes specific minimum equipment standards for recovery/recycling equipment for HFC-134a (R-134a).
- **J2211**—This procedure provides guidelines for technicians for servicing mobile A/C systems and operating refrigerant recycling equipment designed for HFC-134a (R-134a) as described in SAE J2210.
- **J2788**—SAE Standard is to establish the specific minimum equipment performance requirements for recovery and recycling of HFC-134a (R-134a) recovery/recycling equipment. It also establishes requirements for equipment used to recharge HFC-134a to an accuracy level that meets section 9.0 of this document and SAE J2099.
- **J2791**—This SAE Standard establishes HFC-134a refrigerant electronic leak detectors, minimum performance criteria.
- **J2842**—This SAE Standard establishes design criteria and certification for mobile air-conditioning evaporator and service replacements for R-1234yf and R744.
- **J2843**—This SAE Standard establishes R-1234yf (HFO-1234yf) recovery/recycling/recharging equipment.
- **J2845**—This standard covers the technician training for service and containment of refrigerants used in mobile A/C systems for R-1234yf (HFO-1234yf).
- **J2912**—Performance requirements for R-134a and R-1234yf Refrigerant Diagnostic Identifiers (RDI) for use with mobile air-conditioning systems.
- **J2913**—This SAE Standard establishes refrigerant electronic leak detectors and minimum performance criteria for R-1234yf (HFO-1234yf).
- **J2927**—This SAE standard applies to refrigerant identification equipment to be used for identifying an acceptable level of R-1234yf purity in a refrigerant tank or vehicle system labeled as containing R-1234yf, and not misidentify other refrigerants.
- **J3030**—This SAE Standard specifies the minimum equipment requirements for recovery/recycling/recharge equipment intended for use with both R-1234yf and R-134a.

REFRIGERANT IDENTIFICATION

CROSS CONTAMINATION Cross contamination is when an unknown refrigerant is recovered and can cause the entire supply of refrigerant to become contaminated. Recovering an A/C system which is contaminated by a substance, such as R-22 or a hydrocarbon into the recovery container that is half full of R-134a will ruin the R-134a in the container. If the container is used to service another vehicle, the contaminated refrigerant will contaminate the other system(s) as well. Many compare a system with contaminated refrigerant to a virus that can sometimes spread from person to person at a very rapid rate.

At one time, contaminated refrigerant was rare, and the majority of the problems were caused by air from improper service procedures. Today, there are a variety of sealants, blends, hydrocarbons, and other refrigerants, along with recycled refrigerants available to both repair facilities and do-it-yourself (DIY) consumers that make the potential for contamination a much greater problem. The A/C industry defines the quality of refrigerant based on percentage of purity:

- 98% and better is considered pure.
- Less than 97% pure is contaminated.
- Between 97% and 98% is questionable.

REFRIGERANT IDENTIFIER Cross contamination is almost impossible to detect without the use of an electronic refrigerant **identifier**. An identifier meeting SAE standard J1771 should be used on any system using R12 or R134a. For R1234yf system, the refrigerant identifier should meet SAE standard J2843 (built into the RRR machine) or J2912 if a separate identifier is used. ● **SEE FIGURE 65–2**.

TYPES OF IDENTIFIERS To determine the correct refrigerant is for the system being serviced, inspect the service fittings and the refrigerant label. The label will list the type of refrigerant and the proper charge amount. Since each refrigerant requires

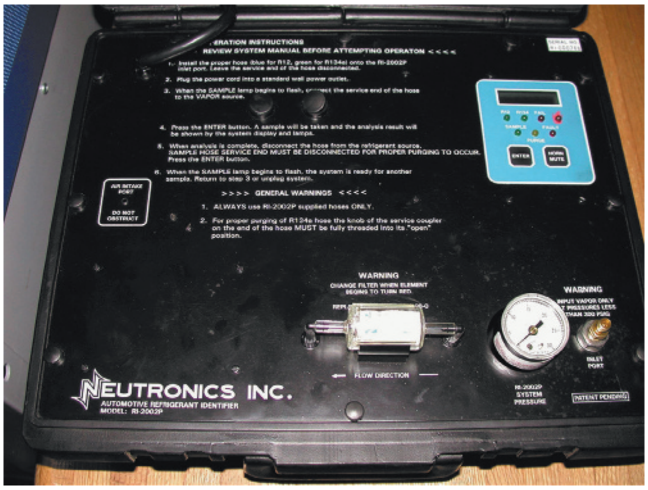


FIGURE 65–2 A typical refrigerant identification machine. The readout indicates what kind of refrigerant is in the system. If a blend or some other contaminated refrigerant is discovered, it should be recovered and stored in a separate container to keep it from contaminating fresh refrigerant.

unique fittings, the type of fittings can also help determine the proper refrigerant. There are two types of refrigerant identifiers:

1. A *go-no-go identifier* (accuracy to about 90% or better) indicates the purity of the refrigerant with lights that indicate pass or fail.
2. A *diagnostic identifier* (accuracy to 98% or better) displays the percentage by weight of R-12, R-134a, R-22, hydrocarbons, and air (displayed as NCG). If the contaminant is air, the refrigerant can be safely recovered and recycled for reuse. If the contaminant is another refrigerant or a hydrocarbon, then a special recovery procedure is required and the recovered mixture needs to be sent off for disposal or recycling.

Recycling machines cannot remove a foreign refrigerant, only air, water, oil, or particulates. Newer identifiers include a printer port, so hard-copy readouts can be printed for the customer's use.

STEPS TO IDENTIFY THE REFRIGERANT To identify the refrigerant in a system, perform the following steps:

STEP 1 The first step on all identifiers is a calibration process. Most units do not allow connection to the low-side line until the identifier shows what to do on the display.

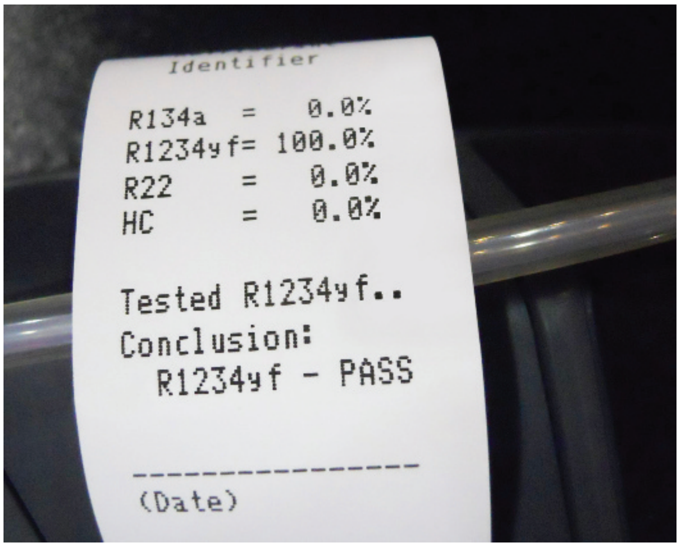
STEP 2 With the engine and the system shut off, connect the identifier to the low-side service port using the correct hose assembly for the system's refrigerant type.

STEP 3 Check the filter on the identifier for the incoming gas. It will show a color change when it needs to be changed.

STEP 4 Allow a gas sample to enter the unit. Some units include a warning device to make sure liquid refrigerant does not enter it. Many units include a warning device to indicate a flammable refrigerant.

STEP 5 Read the display to determine the nature of the refrigerant. Some units allow printing of the results at that time. If the refrigerant is good or is contaminated with air, it can be safely recovered and recycled.

STEP 6 When the analysis is complete, some units display instructions to disconnect the sampling hose and then bleed out the gas that was sampled. If the hose is not disconnected when prompted, the identifier can bleed all of the refrigerant from the system. ● **SEE FIGURE 65–3**.



```
Identifier

R134a   =   0.0%
R1234yf= 100.0%
R22     =   0.0%
HC      =   0.0%

Tested R1234yf..
Conclusion:
  R1234yf - PASS

-----------------
(Date)
```

FIGURE 65–3 A typical printout showing that the system has 100% R-1234yf refrigerant in the system.

DISPOSING OF UNKNOWN REFRIGERANT If an unknown refrigerant is detected, it is considered to be the best practice to recover the refrigerant using a dedicated recovery only unit. Do not use an R-12 or R-134a recovery machine to remove a contaminated or a blend refrigerant. One alternative is to convert an older R-12 machine and gauge set to recover refrigerant blends, but this equipment should be used only for blends from that point on unless it is decontaminated after each use. If the mixture contains more than 4% hydrocarbon, it should be considered explosive, and this mixture should not be recovered using an electric-powered machine. Air-powered recovery machines are available and can be safely used for explosive mixtures. Hydrocarbon refrigerants, blends, and unknown mixtures should be recovered into containers clearly labeled CONTAMINATED REFRIGERANT. The refrigerant should then be recovered and stored in a standard DOT-approved container that is gray with a yellow top that is the standard for unknown refrigerant. Best practice standard of operation also includes the following:

- Do not fill the recovery tank over 60% of its gross weight capacity.
- Check with state and local government agencies regarding the storage of combustible or hazardous materials.
- Check with local waste-processing companies as to the proper and legal way the contaminated refrigerant can be disposed of including the possibility of it being recycled or destruction.

NON-CONDENSABLE GASES (NCG) Any refrigerant that contains **non-condensable gases (NCG)**, usually air, or with 2% or greater of another material (foreign refrigerant) is considered contaminated. If the contamination is greater than 5%, problems such as excessive high-side pressures and incorrect clutch cycling rate result. Other unseen problems of oil breakdown, seal deterioration, or compressor wear can also occur. NCG contamination can be reduced by recycling the refrigerant, purging the air out, or diluting the contaminated refrigerant with pure refrigerant. Contamination from a foreign refrigerant requires that the refrigerant be sent off for reclaiming or disposal.

FREQUENTLY ASKED QUESTION

Why Evacuate an Air-Conditioning System?

Evacuation is used to not only remove and measure the amount of refrigerant that was in the system, but to remove any air that may have been trapped in the system during a previous repair or service procedure. Air in the system can be the root cause of many air-conditioning problems including the following causes:

- Higher than normal operating pressures
- Higher than normal condenser temperatures
- Reduced air-conditioning performance (air is not a good medium for the transfer of heat)
- Noisy compressor operation

Evacuation is also a way to remove moisture from the air-conditioning system. Moisture in the refrigerant system degrades the lubricant that can lead to compressor failure. Therefore, for all of these reasons, evacuation is a needed service procedure.

MOISTURE IN THE REFRIGERANT SYSTEM Moisture in an R-134a system mixes and reacts with the refrigerant and oil in the system. It forms hydrochloric acid (HCl) that can corrode refrigerant lines, clog screens, and damage other components in the system. Any moisture in an R-134a system mixes and reacts with the refrigerant and oil in the system. The moisture blends with the hygroscopic oils used in R-134a systems, reducing its ability to lubricate components like the compressor. Moisture can be eliminated from the system by evacuating the A/C system for at least 30 minutes to boil off any moisture.

SEALANT CONTAMINATION HVAC technicians believe that contamination is caused by chemicals that are intended to seal refrigerant leaks. A simple and relatively inexpensive sealant identifier is Quick Detect made by Neutronics. Recovering refrigerant that contains a sealant might cause damage to the recovery unit. There have been cases where sealant has cured inside the machine, causing loss of the machine or expensive repairs.

A/C SERVICING

STEPS INVOLVED The service and repair of heating and A/C systems consists of the following steps:

- Identifying the refrigerant in a system using an identifier
- Recovery and disposal of contaminated refrigerant
- Repair of the system as needed, including the replacement of system components
- Maintaining proper oil level when components are serviced
- Checking the oil level in a compressor or system
- Evacuating and recharging the system

Several important facts when servicing an A/C system include the following:

- A/C systems are designed to operate using a specific amount of a particular refrigerant.
- A/C systems are designed to operate using a specific amount of particular refrigerant oil.
- Adding any other chemical into a system can create a chemical problem that can cause system damage or failure. Most original equipment manufacturers (OEM) and aftermarket suppliers consider any chemical other than the refrigerant and oil to be a foreign material.

REFRIGERANT RECOVERY

EQUIPMENT NEEDED Most refrigerant recovery units are made as part of the **recovery, recycling, and recharging (RRR)** machine and contain two service hoses (a low and high side) that are connected to the system service ports. For R-134a systems, confirm that the service connector knurled knob is turned fully counterclockwise. Then slide the quick connect collar up the hose and press the fitting onto the system service fitting and release the collar. It should "snap into place" and not be able to be removed. Slowly tighten the knurled knob until fully opened. ● **SEE FIGURE 65–4.**

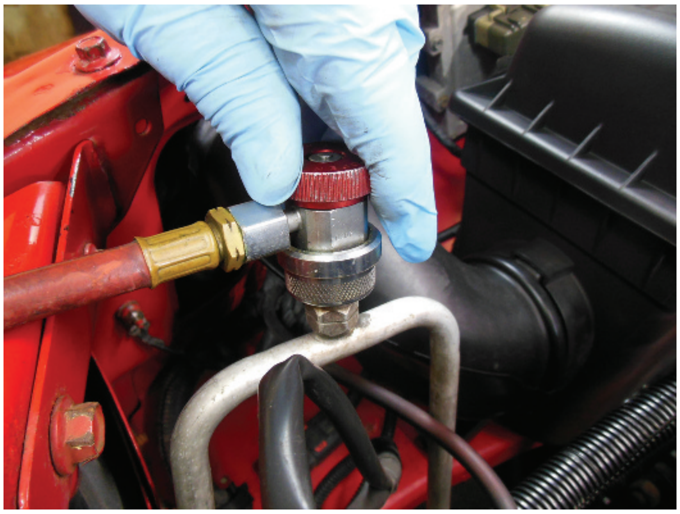


FIGURE 65–4 Installing the hoses to an RRR machine.

NOTE: Some recovery units are connected to the center hose (yellow hose) of a manifold gauge set that is used for adding refrigerant or evacuating the system.

The hoses should be equipped with shutoff valves within 12 inches of the ends and have end fittings to match the refrigerant used. Recovery units contain the following components:

- An oil separator
- A compressor-like pump
- A condenser-like heat exchanger

ENGINE PRE-HEAT PROCEDURE An engine pre-heat procedure can make the recovery process go faster and help in the complete removal of refrigerant during the recovery process if the shop area is cold. To perform pre-heat procedure, set the controls to:

- Compressor not operating
- Outside air (not MAX A/C)
- Blower on high

Operate the engine at idle for 15 minutes with the hood open so warm engine air can enter the cowl vents.

RECOVERY OPERATION Recovery units draw refrigerant vapor out of a system and convert it into liquid for storage. Recovery units weigh the amount of refrigerant that is recovered, which tells the technician if all refrigerant from a fully charged system has been recovered or whether the system was fully charged. Oil removed and separated during the recovery process is usually drained into a measuring cup and noted so that this amount of new oil can be replaced in the system as it is recharged. Oil recovery also gives an indication of the oil volume in the system. If no oil is recovered, the system was likely low on oil. If an excessive amount of oil is recovered, the system probably had too much oil. Some refrigerant in a system is absorbed in the oil and does not leave the oil immediately when a system is emptied. This trapped refrigerant *out-gases* or boils out of the oil later, after the pressure has been removed. Recovery units shut off automatically after the main refrigerant charge has been removed and the system drops into a slight vacuum. To completely remove the refrigerant, run the normal recovery procedure and recheck the pressure after a 5-minute wait. If the pressure has increased, restart the recovery process.

STORAGE CONTAINER CERTIFICATION If using older recovery equipment with a removable tank, the storage container for recovered refrigerant must be approved by the Department of Transportation (DOT) and carry the letters DOT and the certification numbers. The tank must also include the date for tank retesting. Recovery tanks must be inspected and certified to be in good condition every five years. Some rules to follow for refrigerant recovery storage tanks include

- Do not reuse disposable cylinders.
- Make sure that the recovery cylinder is labeled for the refrigerant being recovered.
- Make sure the *tank certification* is in order and the cylinder retest date has not expired.
- Inspect the cylinder for damage and do not fill if damaged.

STEPS TO RECOVER REFRIGERANT Recovering the refrigerant from a system usually includes the following steps:

STEP 1 Identify the refrigerant in the system.

STEP 2 Connect the recovery unit to the system following the instructions of the manufacturer.

STEP 3 Open the required valves and turn the machine on to start the recovery process, following the instructions of the machine's manufacturer.

STEP 4 Continue the recovery until the machine shuts off or the pressure reading has dropped into a vacuum.

STEP 5 Verify completion of recovery by shutting off all valves and watching the system pressure. If pressure rises above 0 PSI within 5 minutes, repeat steps 4 and 5 to recover the remaining refrigerant.

STEP 6 Drain, measure, and record the amount of oil removed from the system with the refrigerant and dispose of properly. This amount of new oil should be added during the recharging process. ● **SEE FIGURE 65–5**.

The system can now be repaired. Present standards and good work habits require that recovered refrigerant be recycled before reuse, even if it is to be returned to the system from which it was recovered.

FREQUENTLY ASKED QUESTION

What Is the Difference between Recycling and Reclaiming?

These terms are frequently heard and used almost interchangeability but there is a difference.

- **Recycled refrigerant**—Refrigerant that has been processed at a service facility (shop or dealership) by using recycling equipment that is SAE certified.
- **Reclaimed refrigerant**—Refrigerant that has been sent out to an EPA-certified reclamation facility where it has been processed and certified as if it were new refrigerant.

FREQUENTLY ASKED QUESTION

What Are the Concerns about Small Cans?

At one time, refrigerants were commonly sold in small cans that contained 12 oz or 15 oz of refrigerant. Refrigerant is available in larger containers, usually 10 or 30 pounds and these are commonly used by service shops. Small cans are commonly used by do-it-yourself (DIY) vehicle owners.

There are concerns that DIY service often results in the wasting or release of a substantial amount of unused refrigerant for several reasons:

- A tendency to not repair refrigerant leaks and instead just add additional refrigerant to the leaking system.
- Partially charged systems are topped off, so they probably end up over- or undercharged. A small can may not have the correct amount of refrigerant for the system, so charging is often stopped before the can is empty.
- The remaining refrigerant in the can will probably leak out over time.

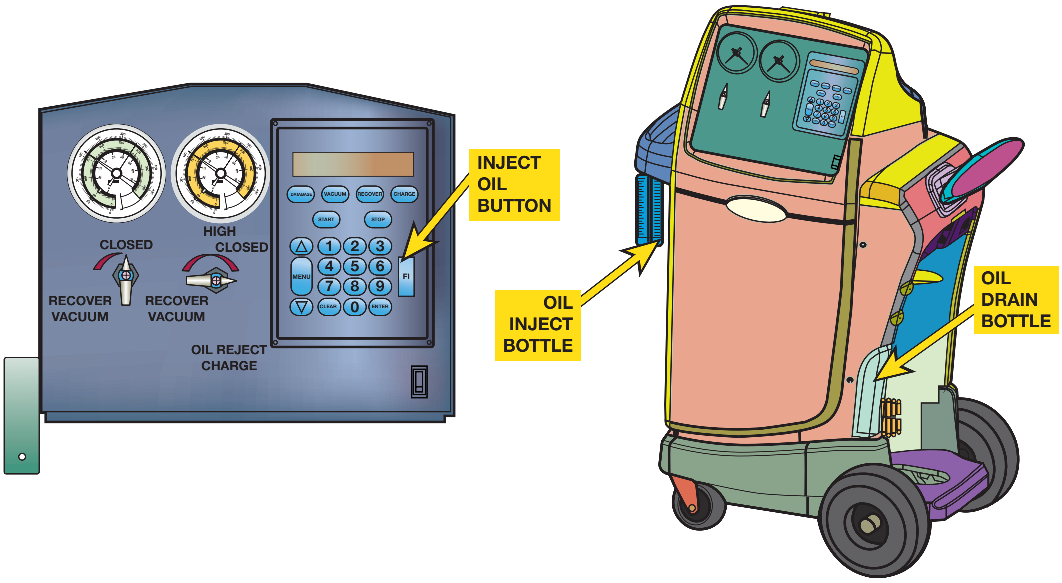


FIGURE 65–5 During the recovery process, oil from the system is separated into a container so the technician will know how much oil was removed.

RECYCLING REFRIGERANT

RECYCLING EQUIPMENT RRR equipment is used to perform the recycling process automatically, as the refrigerant is recovered from the system. There is no need for a separate recycling unit, as in the past.

During recycling the recovered refrigerant is pumped through a very fine filter to remove foreign particles, past a desiccant to remove water, and through an oil separator to remove any excess oil. Air is removed by venting it, using the non-condensable purge, from the top of the liquid refrigerant.

FILTER MAINTENANCE The filter is designed to trap acid and particulates, and to remove moisture from refrigerant. Some machines have a sight glass equipped with a moisture indicator so that the operator can tell when no more moisture can be removed. SAE 2788 recovery units are designed to stop operation if a filter or desiccant change is needed.

To meet the SAE standards for adequate moisture and contaminant removal, the filter must be replaced after 150 lb. (68 kg) of refrigerant has been filtered. The latest RRR machines give a warning when 125 lb. (57 kg) of the filter capacity has been used. When the 150 lb. (68 kg) filter capacity has been reached, the machine will lock down and cannot be used until the filter is changed. SAE 2788 recovery units are designed to stop operation if a filter or desiccant change is needed.

QUALITY STANDARDS Recycled refrigerant must meet the same purity standards as new (virgin) refrigerant including the following:

- Less than 15 ppm moisture
- Less than 4000 ppm oil
- Less than 330 ppm air

RECYCLE ONLY UNITS Some units can perform the recycling process in a single pass from the storage container through the cleaning process and back to the storage container. These machines often complete the recycling process while the system is being evacuated. Others require several passes, and the recovery process continues to circulate the refrigerant as long as necessary. ● **SEE FIGURE 65–6**.

The recycling machine is dedicated to a particular type of refrigerant, and a recycled blend can only be recharged back into the vehicle it came from or another vehicle from the same fleet.

PROCEDURE FOR RECYCLING To recycle a refrigerant, perform the following steps:

STEP 1 Open the valves or perform the programming steps required by the machine manufacturer and turn on the machine.

STEP 2 The machine operates until excess foreign particles and water have been removed or for a programmed length of time and shuts off. Check the moisture indicator to ensure that the refrigerant is dry. If the machine does not shut off in the proper amount of time, its internal filters or desiccant probably require service. ● **SEE FIGURE 65–7**.

NOTE: Sometimes all of the air will not be removed in one recycling pass. Repeat the recycling as needed to remove all of the excess air.

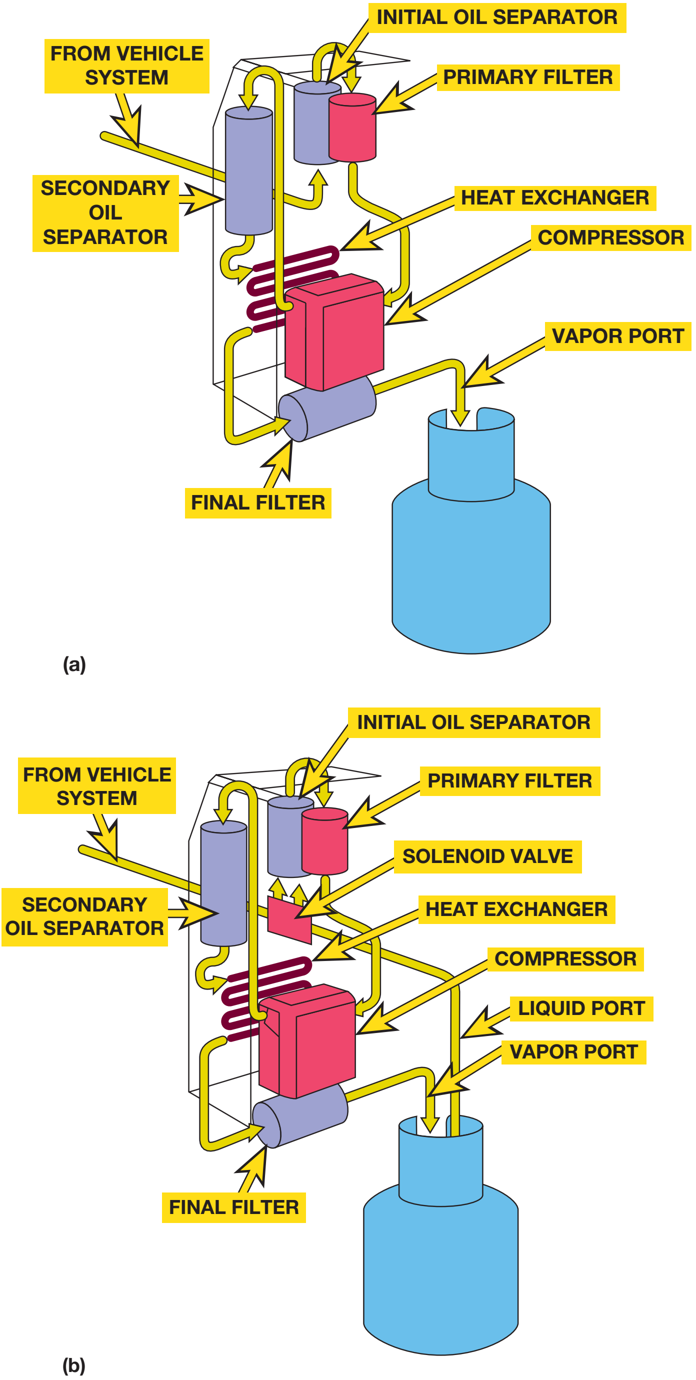


FIGURE 65–6 A single-pass recycling machine (a) cleans and filters the refrigerant as it is being recovered. A multipass machine (b) recovers the refrigerant in one operation and then cycles the refrigerant through filters and separators in another operation.

FLUSHING AN A/C SYSTEM

PURPOSE **Flushing** is using a liquid or a gas to clean the inside passages of an air-conditioning system. When a compressor fails, it usually sends solid compressor particles into the high and possibly the low sides, which can plug the condenser passages and orifice tube or TXV. It is always a good practice to check the orifice tube or TXV filter screen for debris when there is a compressor failure and to flush the system, install a filter, or both before completing the job. Flushing is done by pumping a liquid material through the passages in a reverse or normal flow direction. A gas, such as shop air or nitrogen, is not really effective in removing

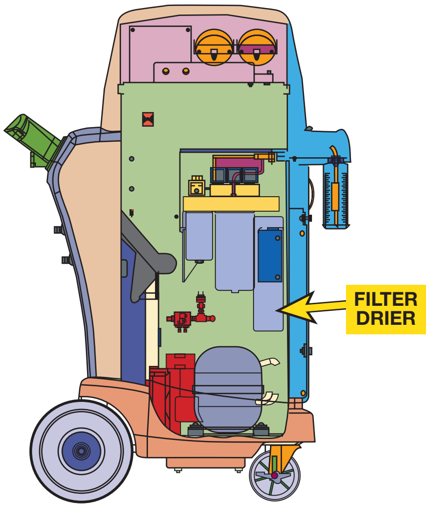


FIGURE 65–7 Recycling machines have a filter and desiccant that must be replaced after a certain amount of use.

solid material. Flushing agents can be a commercial flushing solution, liquid refrigerant, or very lightweight ester oil. However, ester oil has very little or no solvent action and remaining ester oil might be difficult to remove from the system.

NOTE: Manufacturers may not warranty a replacement compressor if the accumulator and orifice tube or receiver–drier is not also replaced.

CAUTIONS AND PRECAUTIONS No flushing operation will remove 100% of metal debris from a failed compressor. The very small metal particles can be stopped only by a filter.

- A compressor cannot be flushed.
- An accumulator or receiver–drier is not flushed and is simply replaced.
- If the evaporator is flushed, it is done to remove excessive refrigerant oil that may be trapped in the system during previous service.
- Most experts believe that the OT or TXV screen will filter out larger debris.
- Most flushing is done on the high side, from the compressor connection of the discharge line to the OT or receiver–drier fitting of the liquid line, or vice versa.

● **SEE FIGURE 65–8.**

Approved flush solvents for A/C systems are based on HFC refrigerants that have a fairly high boiling point such as Genesolv SF, which has a boiling point of 59°F (15°C). Technicians using flushing chemicals have a professional responsibility to do the following:

- Obtain, read, and understand the SDS for that chemical.
- Learn how that chemical works and how it should be used.
- Determine if that chemical will do no harm to the system and the materials like gaskets and seals.
- Determine how to remove that chemical from the system and how to properly recycle or dispose of it.

If the flush is needed only to remove oil, a low-pressure, low-flow method can be used to fill the component so the solvent can dissolve the oil. Some recovery–recycling machines can be fitted with a flushing kit that allows them to pump liquid refrigerant into one line and recover that refrigerant from the other line. If the flush is needed to remove solid debris or chemical sealants, there must be enough flow velocity to break the material loose and carry it out of the component. Better flush machines will pulsate the flow to increase the cleaning power. When the flush is completed, the chemical should be removed from the system by blowing nitrogen or clean, dry air through the system, and the chemical should be recycled or properly disposed of. The nitrogen/air should be blown through the system for 20 minutes to 30 minutes to evaporate the remaining solvent.

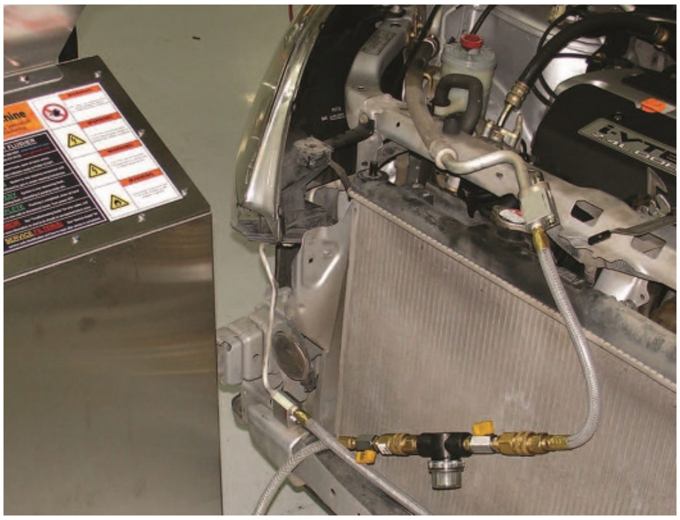


FIGURE 65–8 Portions of an A/C system can be flushed to remove debris and excess oil. Adapters are used to connect a flushing unit, which pumps the flushing material through the components. Most flushing machines are fully automated, meaning that it will vacuum, flush, recover, recycle, vacuum, and purge the cleaning solvent all automatically.

TECH TIP

The Coffee Filter Trick

Some technicians place a paper coffee filter to catch the debris in the flush material going to the catch container. This allows them to inspect the material being flushed from the system and to determine the effectiveness of the flushing process.

CAUTION: It is very difficult or impossible to flush a modern flat-tube condenser with its multiple, small passages without a flushing machine that can supply a strong, pulsating solvent flow. One or more of the small passages can be plugged so the flush material will pass through any open passages instead of clearing the plugged passages.

REPLACING COMPONENTS

GENERAL GUIDELINES After all refrigerant has been removed from the system, repairs can be accomplished. For example, the evaporator can be removed from the vehicle and replaced. Seal all openings of the system during service to prevent moisture and contaminants from entering. If the system has been opened to the atmosphere for a length of time (over 24 hours), most experts recommend replacing the drier to help prevent the possibility of damaging moisture being trapped in the system. After all repairs are completed, the system should be evacuated.

NOTE: Be sure to follow all instructions regarding the amount of oil that needs to be added to the system if components have been replaced.

O-RINGS The O-ring seal is part of a fitting that holds the ends of two refrigerant lines or hoses together inside a connector. ● **SEE FIGURE 65–9**.

The O-ring forms the seal between the lines or hoses and the connector. The O-rings usually are made of highly saturated nitriles (HSN) or neoprene rubber and remain flexible over a wide range of temperatures. The O-ring must be lubricated with clean refrigerant oil before assembly to ensure a good seal. ● **SEE FIGURES 65–10 AND 65–11**.

TIGHTENING CONNECTIONS All threaded connections should be started by hand to avoid cross-threading. Two wrenches, one on each threaded fitting, should be used to loosen or tighten O-ring fittings. Using two wrenches is often called using "double-wrenches" or a "backup wrench" and is specified to be used by most vehicle manufacturers.

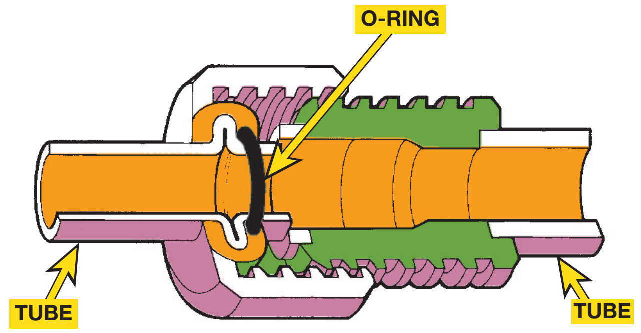


FIGURE 65–9 O-rings are usually made of neoprene rubber or highly saturated nitriles (HSN) to withstand high temperatures and flexing. O-rings should be changed during a retrofit procedure.

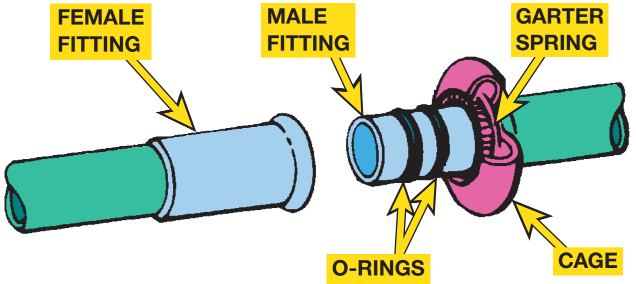


FIGURE 65–10 A typical spring-lock coupling.

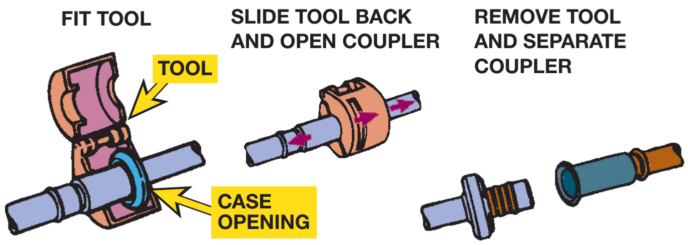

FIT TOOL
TOOL
CASE OPENING
SLIDE TOOL BACK AND OPEN COUPLER
REMOVE TOOL AND SEPARATE COUPLER

FIGURE 65–11 A special tool is needed to remove and install this spring-lock coupling.

SERVICE FITTINGS AND CAPS Each type of refrigerant has its own unique service fitting. This prevents accidental use of the wrong service equipment and/or the introduction of the wrong refrigerant. Service valves are found almost anywhere on the system. They may be located on the receiver–drier, accumulator, compressor, muffler, or in the lines themselves. All service valves should have plastic coverings called *service caps*.

Along with preventing dirt from entering the system, service valve caps have O-rings which become the primary seal if a valve leaks. Always reattach the caps after any service has been performed, and replace them if missing. Another built-in precaution is the refrigerant cut-off valve, which keeps the refrigerant in the service hose instead of allowing it to vent to the atmosphere.

SCHRADER VALVES A Schrader valve is similar to a tire valve. Internal pressure holds Schrader valves closed. There is also a small spring to keep the valve seated if the internal pressure becomes insufficient. When the service connection is made, the depressor in the end of the service hose or service coupling pushes on a small pin inside the valve which opens the valve. The valve opens only when the service line connection is nearly complete, preventing contamination of the system or the unnecessary release of refrigerant. Many experts recommend that the Schrader valves be replaced whenever the system is open after recovery of refrigerant. ● **SEE FIGURE 65–12**.

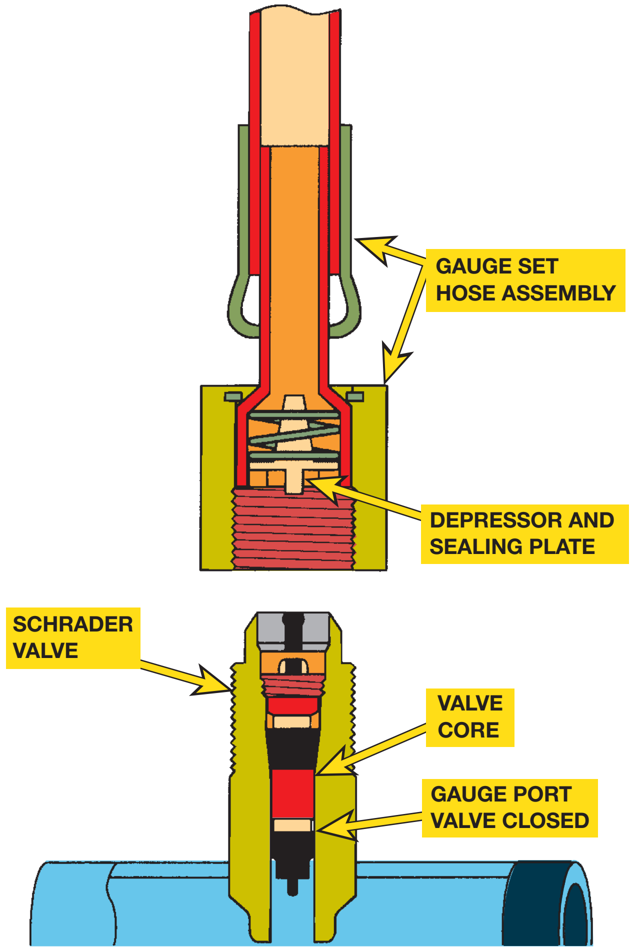


FIGURE 65–12 A depressor pin on the gauge set opens the Schrader valve when the connection is almost completely tightened. This prevents accidental refrigerant discharge.

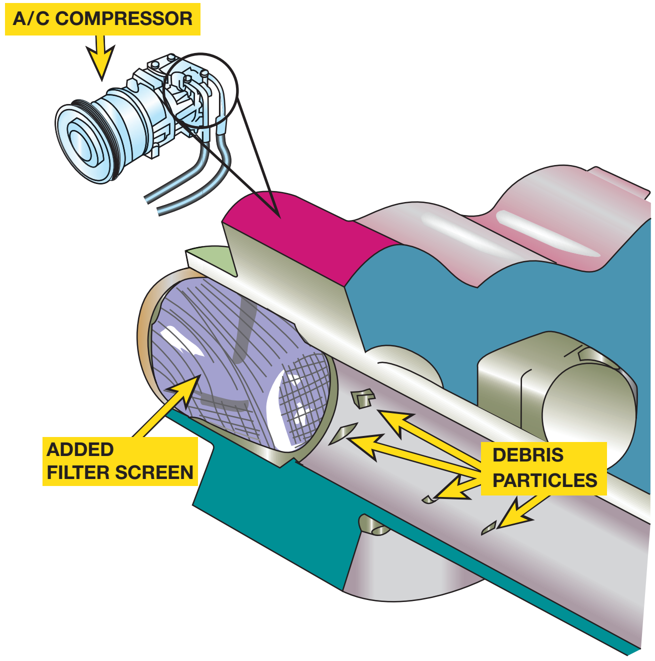


FIGURE 65–13 A typical aftermarket filter is installed in the suction line at the entrance to the compressor that is designed to catch any debris that could harm the compressor.

INLINE FILTER If a compressor fails, debris in the form of metal particles often travels downstream through the condenser and is trapped in the receiver–drier or orifice tube, where it can cause plugging. Some compressor failures send debris into the suction line. The technician can install an in-line filter in either the high side or low side to trap any debris still in the system to protect the new compressor. They are available with connections to fit different line sizes. Some filters include a new orifice tube. ● **SEE FIGURE 65–13**.

To install an in-line filter, perform the following steps:

STEP 1 Recover the refrigerant from the system.

STEP 2 Select the location for the filter. The flexibility of hose allows a great deal of freedom. With metal tubing, locate a straight section of tubing slightly longer than the filter's connections.

STEP 3 Evacuate and recharge the system after installation of the filter.

NOTE: Most aftermarket air-conditioning filters have a directional arrow that indicates refrigerant flow direction.

REFRIGERANT OIL When it is determined that additional oil must be added, several types of low-cost injectors can be used to push oil into a charged or empty system. The proper amount of oil can be kept in a system by adding oil to replace the amount of oil removed when a component is replaced. This is usually only a small amount. Compressor replacement requires a slightly larger amount. ● **SEE FIGURE 65–14**.

The amount of oil retained in a component varies with the size and design. ● **SEE CHART 65–1**.

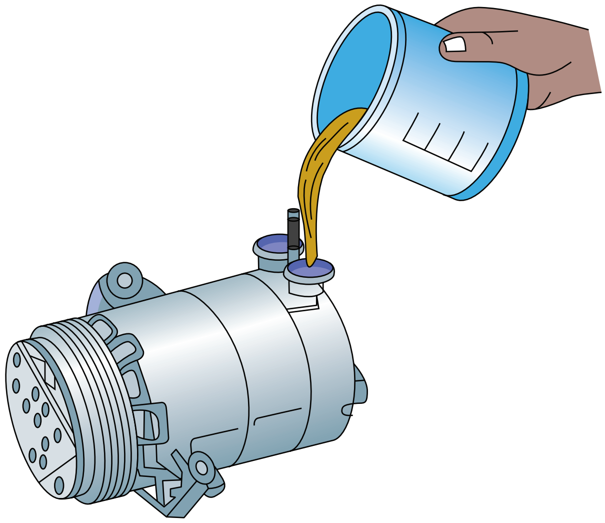


FIGURE 65–14 Always check service information and/or the instructions that accompany a new replacement compressor to determine the exact type and amount of refrigerant oil for the compressor.

COMPONENT	TYPICAL AMOUNT OF OIL IN FLUID OUNCES (FL OZ)	TYPICAL AMOUNT OF OIL IN CUBIC CENTIMETERS (CC)
Evaporator	2.0	60
Condenser	1.0	30
Receiver–Drier	0.5	15
Accumulator	2.0	60

CHART 65–1

The typical amount of refrigerant oil left in component. To convert from ounces to cubic centimeters multiply the ounces by 29.6.

EVACUATING THE SYSTEM

PURPOSE OF EVACUATING THE SYSTEM After a system has been repaired, all of the air and moisture that might have entered must be removed. **Evacuation** means that a vacuum will be applied to the system to remove the air and to vaporize any moisture that may be in the system. Although water boils at 212°F (100°C) at sea level, it can boil at much lower temperatures when the pressure is reduced. In other words, if a vacuum is applied to the air-conditioning system, the low pressure will cause any trapped moisture in the system to vaporize (boil). This water vapor is then removed from the system through the vacuum pump and released into the atmosphere. It is important to evacuate the system to at least 29-inch Hg of vacuum for at least 45 minutes to be assured that all of the moisture has been removed. For best results, the vacuum should be higher than 29.2-inch Hg. The higher the vacuum and the longer that it is allowed to evacuate, the better.

MICRON RATING Vacuum pumps are rated by both **cubic feet per minute (cfm)** and **micron** ratings:

- The cfm rating is the volume it can pump.
- The micron rating is how deep a vacuum the pump can pull.

An automotive A/C system requires about a 1.2-cfm to 1.5-cfm rating, whereas a larger system used in a bus or truck needs about a 5-cfm to 6-cfm vacuum pump. Using a vacuum pump that is too small requires a much longer evacuation time, which causes excess wear on the vacuum pump.

- A perfect vacuum is 29.92 inch Hg, or 0 microns (a micron is equal to one-millionth of a meter).
- A good vacuum pump will pull a system down to under 500 microns (29.90 inch Hg). This high vacuum drops the boiling point of water to around 0°F (–18°C). ● **SEE FIGURE 65–15**.

VACUUM PUMP SERVICE A vacuum pump must be maintained with the proper oil level and periodic oil changes to ensure proper operation. If service is neglected, it will not pump to its design capabilities. Some modern electronic units flash a warning if the oil has not been changed at the proper interval (about 10 hours).

Newer refrigerant service machines are equipped with oil-less vacuum pumps. These units eliminate the need to service the vacuum pump. To run without lubricating oil, the pump uses two high-temperature plastic pistons operating in anodized aluminum cylinders with a Teflon-type cup seal. The piston and connecting rod are one piece. The crankshaft and connecting rod bearings use a lubricated and sealed ball bearing.

EVACUATION TIME It is accepted practice to evacuate an automotive system for at least 45 minutes. Vacuum readings are affected by altitude and the drop in atmospheric pressure that occurs.

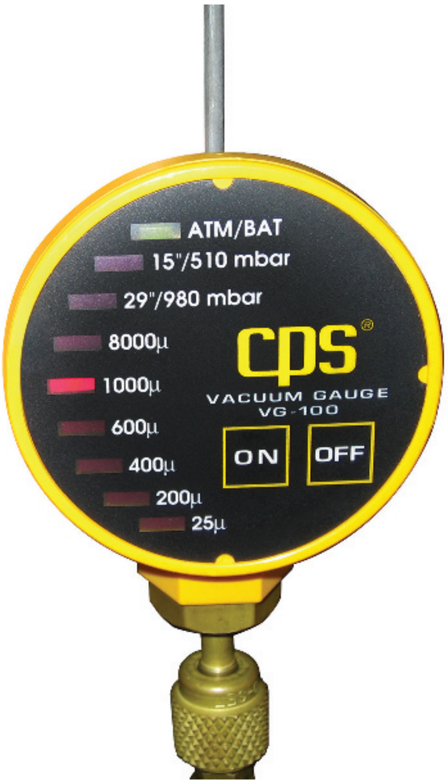


FIGURE 65–15 An air-conditioning vacuum gauge that reads in microns.

FREQUENTLY ASKED QUESTION

What Is a Micron?

A typical vacuum gauge reads in inches of **mercury** (inch Hg) and the recommended vacuum level needed to remove moisture from the system is a vacuum of 29.2 inch Hg or lower. However, many experts recommend using a vacuum gauge that measures the amount of air remaining in the system rather than just the vacuum.

- A micron is one millionth of a meter and there are about 760,000 microns of air at atmospheric pressure.
- The lower the pressure, the lower the number of microns of air.
- A vacuum reading of 29.72 inch Hg is about 5,000 microns.
- Many experts recommend that the micron level be 500 or less for best results.

This is particularly important when evacuating a dual-climate control system where two evaporators are used and there are long lengths of refrigerant lines. ● **SEE CHART 65–2**.

TEMPERATURE °F/°C	INCH HG	MICRONS*	PRESSURE (PSI)
212/100	0.00	759,068	14.7
205/96	5.00	536,000	12.3
194/90	9.81	525,526	10.2
176/80	16.0	355,092	6.9
158/70	20.8	233,680	4.5
140/60	24.1	149,352	2.9
122/50	26.4	92,456	1.8
104/40	27.9	55,118	1.1
86/30	28.8	31,750	0.6
80/27	29.0	25,400	0.5
76/24	29.1	22,860	0.4
72/22	29.2	20,320	0.4
69/21	29.3	17,780	0.3
64/18	29.4	15,240	0.3
59/15	29.5	12,700	0.2
53/12	29.6	10,160	0.2
45/7	29.7	7,620	0.1
32/0	29.8	4,572	0.1
21/–6	29.9	2,540	0.1
6/–14	29.9	1,270	0.1
–24/–31	30.0	254	0.0
–35/–37	30.0	127	0.0

** The remaining pressure in the system in microns.*

CHART 65–2

Boiling temperature of water at converted pressures.

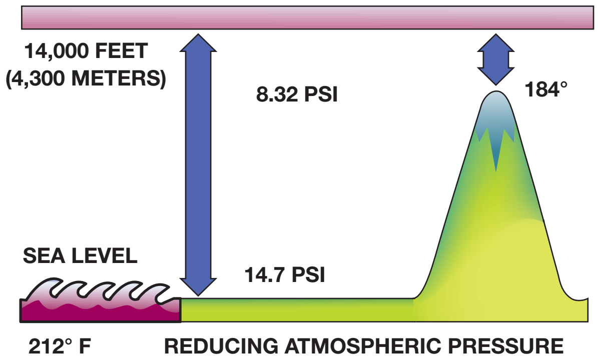


FIGURE 65–16 At sea level, water boils at 212°F (100°C), whereas at the top of Pike's Peak, at 14,000 feet, water boils at 184°F (84°C) because the atmospheric pressure is reduced from 14.7 PSI to just 8.32 PSI.

ALTITUDE ABOVE SEA LEVEL FEET (METERS)	VACUUM READING (INCH HG)
0 (0)	29.92
1000 (305)	28.86
2000 (610)	27.82
3000 (914)	26.82
4000 (1219)	25.84
5000 (1524)	24.90
6000 (1829)	23.99
7000 (2134)	23.10
8000 (2438)	22.23
9000 (2743)	21.39
10,000 (3048)	20.58

CHART 65–3

To evaporate any trapped moisture in the system, a vacuum of at least 29 inches of mercury (inch Hg) is needed. At shops located at higher elevations, the gauge reading will naturally be lower.

- At 1,000 feet (305 m) above sea level, a complete vacuum is 28.92 inch Hg, about 1 inch Hg less than at sea level.
- This pressure will decrease at a rate of about 1 inch Hg per 1,000-foot elevation increase. ● **SEE FIGURE 65–16.**

The absolute vacuum decreases as altitude increases but the gauge reading will show less. ● **SEE CHART 65–3.**

NOTE: Some vehicles with rear A/C use an electric solenoid valve to block flow through the rear unit when it is turned off. This solenoid should be activated so it will open and allow a more complete evacuation of the system.

EVACUATION PROCEDURE USING AN RRR MACHINE When using an A/C service unit (RRR machine), evacuation is often simply a matter of following instructions, assuming the service hoses are still connected from the recovery operation. Most recent machines use electric solenoids to control the flow inside the machine, and starting the evacuation process opens the solenoids needed for this process. Some also include a microprocessor that can be programmed to run the vacuum pump for the desired length of time. Some older charging stations are manually operated and, on these units, the proper valves must be opened as the vacuum pump is started.

Steps for evacuating with a typical RRR machine include the following:

STEP 1 Connect the service hoses to the air-conditioning service ports.

STEP 2 Open the service hose coupler valves by turning the collars clockwise.

STEP 3 Select VACUUM from the MAIN MENU.

STEP 4 Select VACUUM LEAK CHECK, if desired, to automatically perform a 5-minute pressure rise leak check after the vacuum.

STEP 5 Select to accept the 10-minute default evacuation time, or enter a desired vacuum time using the number keys.

NOTE: The vacuum process will halt if pressure rises above 0.35 bar (5 PSI). This means that there is still refrigerant in the system. Recover the refrigerant before proceeding.

The machine will then pull a vacuum on the A/C system for the programmed amount of time. The machine stops when the specified amount of time has elapsed.

RECHARGING THE SYSTEM

PROCEDURE After the system has been evacuated, it can be recharged with the correct amount of new or recycled refrigerant. Charge level is system specific, and as the volume of HVAC systems has been downsized, the amount of refrigerant has become critical. The charge level is normally found on a specification decal fastened to some location under the hood and includes both the type and volume of refrigerant used. The decal is attached to the compressor on some older systems. If the decal is missing or illegible, charge specifications are also given in service information from the vehicle manufacturer or aftermarket A/C component suppliers. ● **SEE FIGURE 65–17.**

UNIT CONVERSION Various vehicle manufacturers use various units for refrigerant oil capacities. When confronted with a unit of measure that is not known, use metric conversion calculator or Internet to convert from one unit to another. ● **SEE CHART 65–4.**

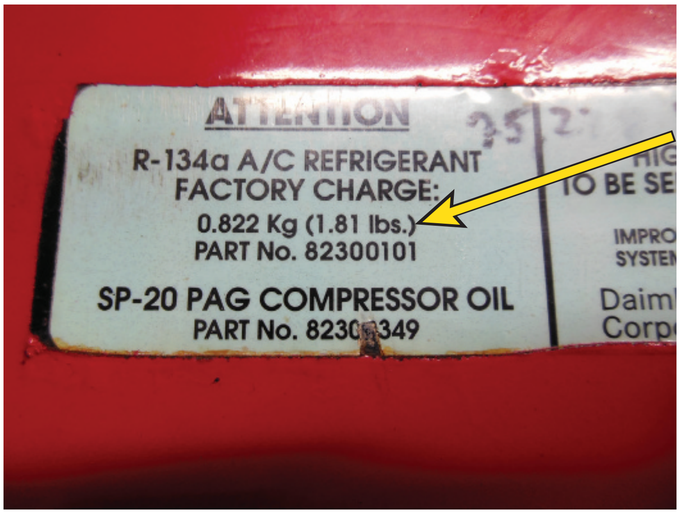


FIGURE 65–17 The underhood decal states that this vehicle requires 1.81 pounds (0.822 kg) of R-134a refrigerant.

SOURCE UNIT	DESIRED UNIT	HOW TO CONVERT
Ounces (oz)	Pounds (lb.)	Divide by 16
Pounds (lb.)	Ounces (oz)	Multiply by 16
Ounces (oz)	Grams (g)	Multiply by 28.4
Grams (g)	Ounces (oz)	Divide by 28.4
Pounds (lb.)	Kilogram (kg)	Divide by 2.2
Kilogram (kg)	Pounds (lb.)	Multiply by 2.2
Kilogram (kg)	Ounces (oz)	Multiply by 35.3
Ounces (oz)	Kilogram (kg)	Divide by 0.028

CHART 65–4

Some of the most commonly needed unit conversions.

TECH TIP

Check the Scale for Accuracy

Most charging scales can be calibrated to ensure accuracy. If a known amount of weight is placed on the scale, the weight indicator should show the correct amount of charge. If a test weight is not available use:

- 9 pennies weigh 1 ounce
- 27 pennies weigh 3 ounces

RECOMMENDED CHARGING PROCEDURE

The best method to charge a system is to start with an empty system and charge the specific amount of refrigerant as measured by accurate scales. The most commonly used A/C service machines have internal refrigerant tanks and electronic scales. ● **SEE FIGURE 65–18**.

Moving the refrigerant into the system requires that the charging container pressure be greater than the system pressure. Because the process begins with the system in a vacuum, the first portion goes rather quickly, but the first 1/2 lb. or so fills the internal volume and starts generating pressure. As refrigerant boils and leaves the container, it cools the remaining refrigerant and causes a pressure drop. Most charging stations and RRR machines include heaters that raise the internal pressure of the refrigerant container to help force refrigerant into the system. The pressure difference can be increased by starting the A/C system so the low-side pressure drops and then charging only into the low side.

With the system running, caution should be exercised if charging liquid is put into it to avoid **slugging** the compressor, which is allowing liquid refrigerant to enter a running compressor which can cause severe damage.

- If the container is upright, gas will exit.
- If the container is upside down, liquid will exit.

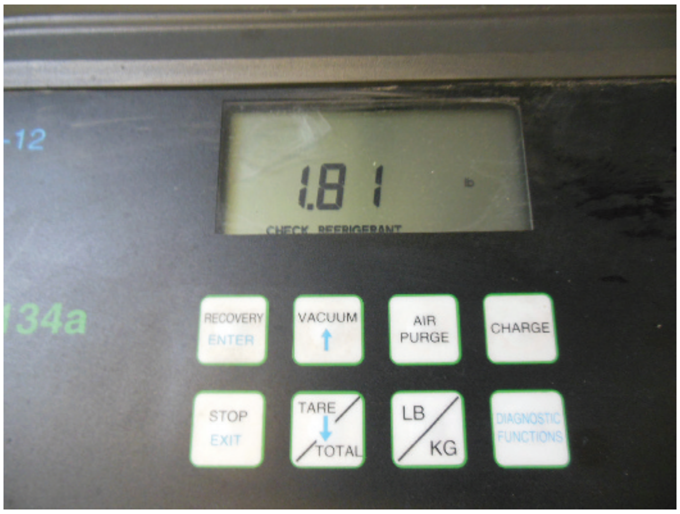


FIGURE 65–18 The calibrated scale on the RRR machine displayed the exact amount of refrigerant that was specified added to the system (1.81 lb.).

RECHARGING WITH AN RRR MACHINE

Recharging with an RRR machine usually is done as soon as the system is evacuated. During evacuation the machine will perform a vacuum leak check by holding for 5 minutes and watching for any pressure rise. Any pressure rise indicates that the system is leaking, and further repairs are needed.

NOTE: Newer RRR machines combine the evacuation, leak check, and recharge operations into a mandatory step-by-step process to prevent charging a system that is leaking. If the vacuum leak test does not pass the machine will not allow recharging.

The recharging process typically includes the following steps:

STEP 1 Connect both service hoses to the vehicle's service ports.

STEP 2 Select CHARGE from the MAIN MENU.

STEP 3 The user will be prompted to enter service data. This may include the charge amount and oil to add, if needed.

STEP 4 Select the ENTER key to start the charge process. Moving or bumping the machine at this point may result in an inaccurate charge. When the charge cycle gets close to the desired weight value, the machine slows down. It will charge, settle, charge again, settle, etc.

STEP 5 When prompted, select to perform hose equalization. Select to perform hose compensation.

NOTE: Hose equalization requires the user to start the vehicle. Hose compensation adds a preset amount of refrigerant to the charge to compensate for service hose volume.

STEP 6 When the CHARGE COMPLETE screen appears, it includes a summary of charge results.

STEP 7 The user will be prompted to close the coupler valves and disconnect the hoses from the vehicle. The machine will recover any remaining refrigerant from the hoses.

R-1234yf EVACUATE AND RECHARGE

As standards are tightened concerning refrigerants, many of the steps for evacuating and recharging systems are built into the software of the RRR machine. This helps to prevent charging refrigerant into a leaking system.

The RRR machines used to recover/recycle/recharge R-1234yf, must meet the SAE J2843 standard. The RRR machine must use either an internal or external refrigerant identifier. The identifier ensures that the refrigerant is at least 98% pure R-1234yf before the machine allows it to be recovered. The standard operating procedure when using the J2843 RRR machine to charge the system includes the following steps:

STEP 1 After the technician enters the correct charge amount, the machine first draws a vacuum on the system to 26.9 inches of mercury.

STEP 2 The machine monitors the applied vacuum to make sure that it does not degrade lower than 25.9 inches mercury in 5 minutes. If the vacuum drops more than allowed, the leak has to be repaired before the machine will allow refrigerant to be added to the system.

STEP 3 If the systems passed the vacuum test, the RRR machine will automatically add a small refrigerant charge to the system equal to about 10% of the capacity of the system and then monitors the system pressure for 5 minutes. If the pressure decreases by 10% or more, this indicates a leak is present and the machine will not add more refrigerant.

STEP 4 If the system is leak-free, the machine will proceed and fully charge the system.

SEALANTS AND STOP LEAKS

PURPOSE Sealants and stop leaks are included in many do-it-yourself (DIY) automotive air-conditioning charging products and are designed to plug or stop small refrigerant leaks. Most HVAC technicians dislike stop leaks as they are considered an inadequate or temporary repair method, and the best repair is to actually fix the leak.

SEALANT CONCERNS Sealants and stop leaks will not always be successful in stopping leaks and may damage the A/C system. Stop leaks also have a reputation of plugging up small orifices that might reduce the proper flow of refrigerant or oil. There is also a question of whether the stop leak material will contaminate the rather delicate chemical balance within an A/C system. In spite of these misgivings, sealants have become popular with do-it-yourselfers.

TYPES There are two types of sealants:

1. *Type I* is a rubber "conditioner," often called a "seal swell." It contains a hydrocarbon or alcohol that softens rubber that has hardened and causes it to swell. Type I sealants are generally low cost and will cause little harm and are often available combined in a small can of refrigerant. Other sealants are single- or two-part chemicals that are moisture-activated and remain fluid until in contact with moisture.
2. *Type II* is a stop-leak chemical that hardens when it contacts moisture as it escapes, which results in sealing the leak. Type II sealants have hardened and caused plugging inside a system and service machines. The sealant is purchased as a kit that includes the sealant with a valve and short adapter hose. The absence of moisture inside the A/C system along with the heat and pressure prevent the sealant from hardening inside the system. ● **SEE FIGURE 65–19**.

CAUTION: Refrigerant service machines have experienced problems of lines plugging up and solenoids sticking after recovering refrigerant from systems containing sealants. One compressor manufacturer will not warranty compressors if sealant residue is found in them.

PERMANENTLY SEALS
A/C STOP LEAK
WITH UV DYE
Reparador de Fugas para Acondicionadores de Aire
#1 In The Country!
CONDENSERS ★ CONNECTION HOSES
EVAPORATORS ★ GASKETS & O-RINGS
GUARANTEED MONEY BACK
Non Clogging Conditioner.
Works on R-134a & R-12
2 oz. (58ml) MADE IN U.S.A.

FIGURE 65–19 Use A/C stop leak with caution. To help prevent sealant from getting into the RRR machine, use a sealant filter. For more information, visit http://www.airsept.com.

REVIEW QUESTIONS

1. What safety precautions should be followed when working on air-conditioning systems?
2. What is considered to be a non-condensable gas (NCG)?
3. What are the steps to recover refrigerant?
4. What are the criteria for recycled refrigerant?
5. Why do A/C experts recommend using a micron meter to measure the vacuum in the system?

CHAPTER QUIZ

1. All of the following are SAE J standards for air-conditioning systems EXCEPT __________.
   - **a.** J639
   - **b.** J1630
   - **c.** J2099
   - **d.** J2211
2. What is the SAE specification number of an RRR machine that meets the 2006 and newer standards?
   - **a.** J-2788
   - **b.** J-2210
   - **c.** J-1930
   - **d.** J-0560
3. The storage container for recovered refrigerant must be approved by __________.
   - **a.** EPA
   - **b.** OSHA
   - **c.** DOT
   - **d.** MSDS
4. Why should service technicians check a system for the presence of sealant before recovering the refrigerant?
   - **a.** It can harm the recovery machine.
   - **b.** It can contaminate the refrigerant that is stored in the recovery container.
   - **c.** It can damage a refrigerant identifier.
   - **d.** All of the above
5. Present standards and good work habits require that recovered refrigerant be __________.
   - **a.** sent out to be discarded at an EPA-certified facility
   - **b.** recycled
   - **c.** sent back to the manufacturer
   - **d.** kept for 90 days
6. When is it acceptable to use a stop leak in an A/C system?
   - **a.** If the refrigerant leak is small
   - **b.** If the refrigerant leak is medium size
   - **c.** If the refrigerant leak is large
   - **d.** None of the above.
7. What component(s) cannot be flushed?
   - **a.** Compressor
   - **b.** Receiver–drier
   - **c.** Orifice tube
   - **d.** Any of the above
8. What is the primary seal in the service fitting?
   - **a.** Schrader valve
   - **b.** Valve cap O-ring
   - **c.** Cut-off valve
   - **d.** Valve spring
9. When charging, caution should be exercised if charging liquid into the system to avoid __________ the compressor.
   - **a.** vaporizing
   - **b.** slugging
   - **c.** condensing
   - **d.** Any of the above
10. Most experts recommend that the system be drawn down to how many microns?
    - **a.** 500 or lower
    - **b.** 10,000 or higher
    - **c.** 243
    - **d.** 127

Chapter

66

AIR-CONDITIONING SYSTEM DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the eight-step diagnostic procedure for an A/C system.
- Discuss the importance of verifying the customer concern.
- Describe the visual inspection.
- Explain how to check DTCs.
- Explain how to check TSBs.
- Discuss how to perform an A/C performance test.
- Describe how to find the root cause of a customer concern.
- Describe how to address system odor issues.
- Describe how to address noise issues.
- Describe how to repair a problem in an A/C system.
- Explain how to locate refrigerant leaks.

KEY TERMS:

After-blow module 789 • Body control module (BCM) 784 • Diagnostic trouble codes (DTCs) 784 • Electronic evaporator dryer (EED) 789 • Electronic leak detector 791 • Groundout 790 • Oil trap 791 • Technical service bulletin (TSB) 784 • Strategy-based diagnosis 781 • Visual inspection 782

DIAGNOSTIC PROCEDURE

STRATEGY-BASED DIAGNOSTICS

When diagnosing a heating and air-conditioning system problem, most vehicle manufacturers recommend that the following steps be performed. **Strategy-based diagnosis** is to follow the same steps given below each time an air-conditioning issue is found.

STEP 1 Verify the Customer Complaint (concern). ● **SEE FIGURE 66–1**.

STEP 2 Perform a Thorough Visual Inspection.

STEP 3 Check for Diagnostic Trouble Codes (DTCs).

STEP 4 Check for Related Technical Service Bulletins (TSBs).

STEP 5 Perform an A/C Performance Test.

STEP 6 Determine the Root Cause.

STEP 7 Repair the System.

STEP 8 Verify the Repair.

COMMON ISSUES WITH A/C SYSTEMS

Commonly found issues that cause a lack of cooling and how to find the root cause include the following conditions:

- **Undercharged**—This condition can be detected by using pressure gauges and looking at both the low-side and high-side pressure.
- **Overcharged**—This condition can be detected by using pressure gauges and looking at both the low-side and high-side pressure.
- **Non-condensable gas (air) in the refrigerant**—This condition can be detected by using pressure gauges and looking at both the low-side and high-side pressure and/or differential temperature measurements across components.
- **Restricted expansion device (TXV or OT)**—This condition can be detected by using pressure gauges and looking at both the low-side and high-side pressure and/or differential temperature measurements across components.

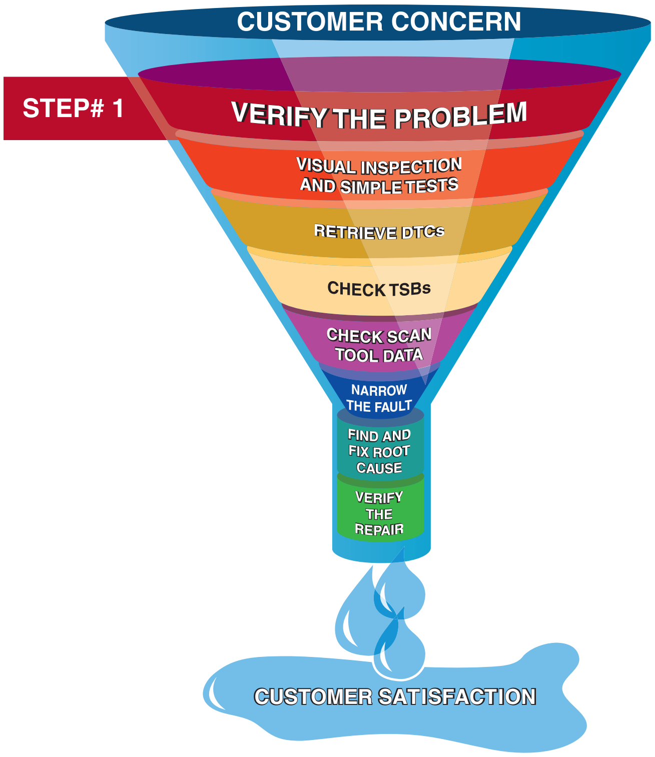


FIGURE 66–1 Step #1 is to verify the customer concern or problem. If the problem cannot be verified, then the repair cannot be verified.

- **Restricted or dirty condenser**—This condition can be detected by using pressure gauges and/or differential temperature measurements across components.
- **Restricted airflow thorough the evaporator**—This condition can be detected by using pressure gauges and/or differential temperature measurements across components.

VERIFY CUSTOMER CONCERN

UNDERSTAND THE EXACT FAULT The first step in the strategy-based diagnosis process is to verify the customer concern. The customer concern needs to be addressed. If a problem occurs and if it is intermittent, identify when it occurs. Sometimes an A/C system functions normally for the conditions that could include any of the following:

- Higher than normal outside air (ambient) temperature.
- High humidity level.
- A new vehicle that is larger or has more glass area than the customer's previous vehicle.
- A new vehicle that is black or dark in color compared with their previous vehicle that was a lighter color such as white or silver. A light-colored vehicle reflects light and the heat from the sun instead of being absorbed as with a dark-colored vehicle.

Other needed information includes the following:

1. What recent service work was performed on the vehicle? (Previous repairs could have somehow affected the HVAC system.)
2. Has the vehicle been in storage? (Animals like to build nests in HVAC ducts, which would affect A/C operation and airflow.)
3. Has the vehicle been involved in a collision? (Hidden damage could cause faults in the HVAC system, yet may not be visible from the outside.)
4. Has the A/C system been serviced before? (This may indicate that the system has sealant or other impurities in the system.)

The service adviser or shop owner should ask the customer to state their concern in their own words such as

- "Does not seem to cool as fast as last year."
- "Airflow through the driver's side vent appears to be blocked."
- "The fan noise is high but I can't feel much cool air coming from the vents."

FREQUENTLY ASKED QUESTION

What Does "Short Cycling" Mean?

If the system is low on refrigerant, it will short cycle, or rapidly cycle on and off. This is the result of the compressor pulling the refrigerant out of the low side quickly to open either the cycling switch or the low-pressure switch. With the compressor off, the flow into the evaporator raises the pressure enough to reclose the switch and restart the compressor. With a normal charge, the low-side pressure should be 15 PSI to 35 PSI and the clutch should be on for 45 seconds to 90 seconds and be off for only about 15 seconds to 30 seconds.

VISUAL INSPECTION

UNDERHOOD CHECKS The second step in the strategy-based diagnosis process is to perform a thorough visual inspection. A **visual inspection** of the underhood items includes the following checks:

1. Check the condition of the A/C compressor drive belt.
2. Check the tension of the A/C compressor drive belt and the automatic tensioner.
3. Inspect the refrigerant hoses and lines for signs of oily residue and damage. Oil residue with caked-on dirt indicates a probable leak. Check that each of the A/C service ports is capped.
4. While checking the hoses and lines, determine if the system uses a thermal expansion valve system (TXV) or an orifice tube (OT) system and if a variable displacement compressor is used. The compressor shape and model number are used for identification.
5. Check that the compressor mounting bolts are tight.
6. Check to make sure that the air gap of the A/C compressor clutch is correct.
7. Check the electrical wires to the clutch, blower motor, and any A/C switches for good, tight connections, and possible damage. ● **SEE FIGURE 66–2.**

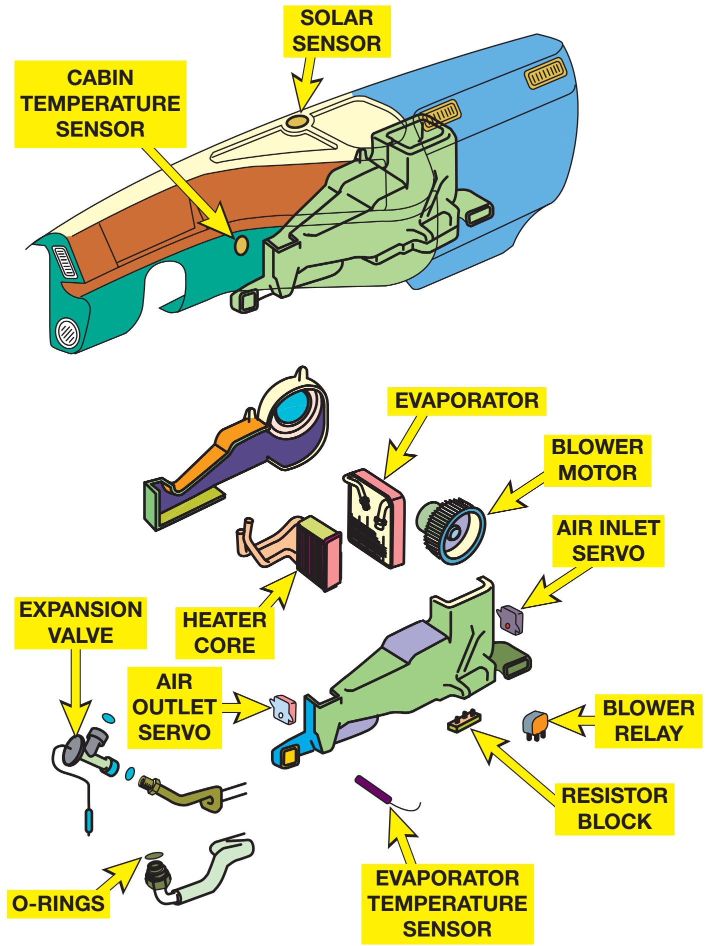


FIGURE 66–2 A visual inspection checks all of the visible, underhood components for possible wear or damage. The under-dash components are checked for noise and proper airflow.

8. Check the condition of any vacuum hoses between the intake manifold and bulkhead, if equipped.
9. Check the faces of the condenser and radiator core for restriction to airflow caused by debris and clean as needed.

IN-VEHICLE CHECKS With the engine off, the in-vehicle checks include the following:

1. Operate the blower switch through its various speeds while listening to the fan and motor for unusual noises. Note that some systems do not have blower operation unless the heat or A/C controls are on or unless the engine is running.
2. Move the temperature lever of mechanically operated doors to both ends of its travel. It should move smoothly and stop before making contact at the ends. An early or late stop indicates that adjustment is needed.

ENGINE RUNNING CHECKS With the engine running, the underhood checks include the following:

1. Make sure the compressor clutch is engaged and the compressor is running. Listen for any signs of improper compressor operation.
2. Turn off the A/C clutch to make sure it releases smoothly. With the clutch released, listen for proper clutch bearing operation.

TECH TIP

Broken Condenser Line?—Check the Engine Mounts!

Most air-conditioning systems use aluminum and flexible rubber lines between the compressor and the condenser. Because the compressor is mounted on and driven by the engine and the condenser is mounted to the body, these lines can break if the engine mounts are defective. The rubber hoses attached between the aluminum fittings of the compressor and condenser are designed to absorb normal engine movement. Worn engine mounts would allow the engine to move too much. Aluminum lines cannot be flexed without crushing and breaking.

Therefore, the wise technician will carefully inspect and replace any and all worn engine mounts if a broken aluminum condenser line is discovered to prevent a premature failure of a replacement condenser.

3. Feel the temperature of the A/C lines and hoses. Be cautious on the high side because the lines should be warm to hot, with the temperature increasing. All the lines on the low side should be cool to cold, with the temperature getting colder. ● **SEE FIGURE 66–3**.
4. Feel the temperature of the heater hoses. If the engine is at operating temperature, both hoses should feel hot. Expect a temperature difference on heater systems with a coolant flow control valve.
5. Check the engine cooling fan operation (if running). The fan should be turning smoothly, with good airflow.

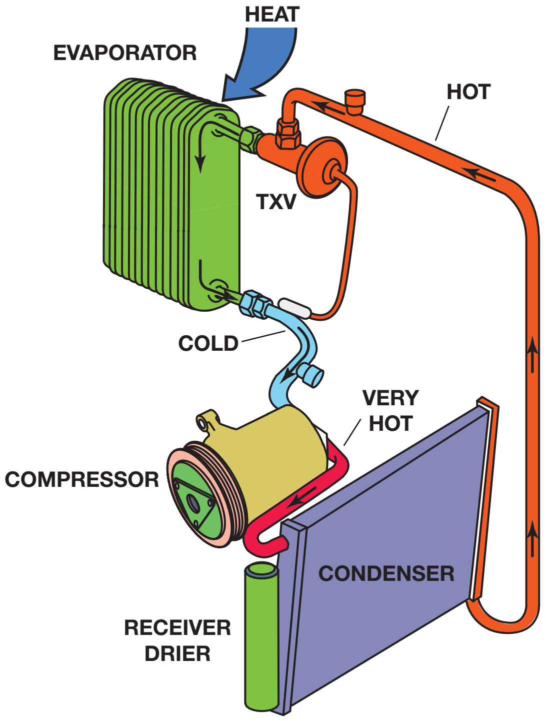


FIGURE 66–3 When a system is operating properly, the suction line to the compressor should be cool, and the discharge line should be hot to very hot. The liquid lines should also be hot.

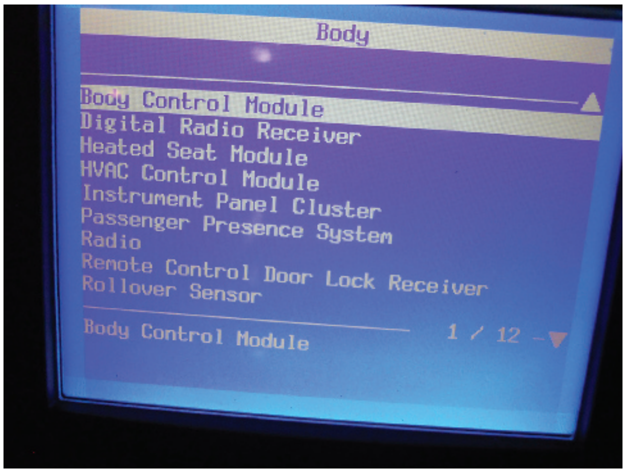
6. Check the evaporator drain. After a few minutes of operation on a humid day, there should be a small puddle of water under the evaporator area and drops of water coming from the drain. With some vehicles, the drain is routed through a frame member. Check the service information for the location of the drain.

NOTE: In areas with very low humidity, water may not drain out.

7. With the engine still running, check inside the vehicle for overall operation. By now the A/C system should be delivering cool to cold air from the instrument panel registers. Refer to performance check for actual expected temperatures. Moving the temperature control should cause a temperature change. Changing the function control to heat should move the air discharge to floor level.

CHECK DTCS

CHECK UNDER BODY OR CHASSIS The third step in the strategy-based diagnosis process is to check for **diagnostic trouble codes (DTCs)** under chassis and body systems and do not just look under engines. Therefore, a global or generic scan tool that can read only "P" codes is not suitable for diagnosing an HVAC system. Engine or emission control-type codes are "P" codes, whereas module communications are "U" codes. These are most often found when looking for DTCs under chassis or body systems. Chassis-related codes are labeled "C" and body system-related codes are labeled "B" codes, and these can cause an HVAC issue if they affect a sensor that is used by the system. ● **SEE FIGURE 66–5**.



Body

Body Control Module
Digital Radio Receiver
Heated Seat Module
HVAC Control Module
Instrument Panel Cluster
Passenger Presence System
Radio
Remote Control Door Lock Receiver
Rollover Sensor

Body Control Module 1 / 12

FIGURE 66–5 Under "Body" on most scan tools, select "HVAC Control Module" for access to the HVAC-related data and diagnostic trouble codes.

TECH TIP

Water on the Carpet? Check the Evaporator Water Drain

If the evaporator water drip tube becomes clogged with mud, leaves, or debris, water will build up inside the evaporator housing and spill out onto the carpet on the passenger side. Customers often think that the windshield or door seals are leaking. Most evaporator water drains are not visible unless the vehicle is hoisted. ● **SEE FIGURE 66–4**.

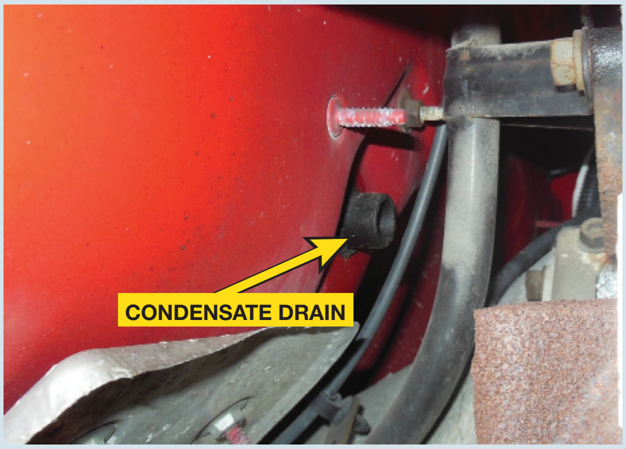


FIGURE 66–4 Check the condensate drain to be sure it is open if there is water on the carpet on the passenger side.

Check for any stored DTCs. While most HVAC-related trouble codes will be "B," "C," or "U" codes, there are some that are Powertrain-related P codes, including the following:

- P0645 A/C Clutch Relay Control Circuit
- P0646 A/C Clutch Relay Control Circuit Low
- P0647 A/C Clutch Relay Control Circuit High
- P0691 Fan 1 Control Circuit Low
- P0692 Fan 1 Control Circuit High
- P0693 Fan 2 Control Circuit Low
- P0694 Fan 2 Control Circuit High

These P codes can be read using global (generic) scan tools that are available at low cost. However, to get access to the codes set for most of the HVAC-related faults requires the use of a factory scan tool or an enhanced factory-level aftermarket scan tool. Many HVAC systems are controlled by the **body control module (BCM)**. The air-conditioning–related diagnostic trouble codes are usually found under "Body" or "Chassis," and if set, will NOT light the "check engine" warning light. The check engine light is called the *malfunction indicator light (MIL)* and is commanded on if there is a fault that can affect emissions. Because HVAC-related faults often do not affect emissions, a DTC will be stored and may light another warning lamp or a message on the dash, such as the "A/C on" lamp will flash to indicate that a fault has been detected with the HVAC system.

CHECK TSBs

FOURTH STEP The fourth step in the strategy-based diagnosis process is to check **technical service bulletins (TSBs)**. These are issued by vehicle and aftermarket manufacturers to inform technicians of a situation or technical problem and give the corrective steps and a list of parts needed to solve the problem. Any diagnostic trouble codes should be retrieved before looking at the technical service bulletins because many bulletins include what DTCs may or may not be present. TSBs are often released

Service Bulletin

FIGURE 66–6 After checking for stored DTCs, the wise technician checks service information for any technical service bulletins that may relate to the vehicle being serviced.

by new vehicle manufacturers to dealership service departments. ● **SEE FIGURE 66–6**.

While some of these TSBs concern minor problems covering few vehicles, many contain very helpful solutions to hard-to-find problems that cover many vehicles. TSBs can also be purchased through aftermarket companies that are licensed and available on a Web site. Visit the National Automotive Service Task Force (NASTF) Web site (www.NASTF.org) for a list of the Web addresses for all vehicle manufacturers' sites where the full text of TSBs can be purchased directly. Factory TSBs can often save the technician many hours of troubleshooting.

PERFORM A/C PERFORMANCE TEST

PROCEDURE The fifth step in the strategy-based diagnosis process is to perform an A/C performance test, which is used to determine if the system is capable of performing as designed. Most A/C performance tests include the following steps:

STEP 1 Install pressure gauges to the service ports.

STEP 2 Start the engine, set the parking brake, and raise the idle to 2000 RPM.

STEP 3 Measure ambient temperature 3 inches (80 mm) in front of the condenser and measure the humidity.

STEP 4 Place a thermometer in the air conditioner center vent. ● **SEE FIGURE 66–7**.

STEP 5 Set the air conditioner for maximum cooling.

STEP 6 Open the doors and set the blower speed to high, which applies the maximum load on the system.

STEP 7 Allow the system to operate for another five minutes before recording the gauge readings.

- Check the sight glass (if equipped). Clear? Bubbles? Foam?
- Check the A/C lines for frosting:
  - Low-Side Lines: Frosted (indicates low refrigerant level and should be corrected before continuing the test).
  - High-Side Lines: Frosted (indicates a restriction where the frost begins and should be corrected before continuing the test).

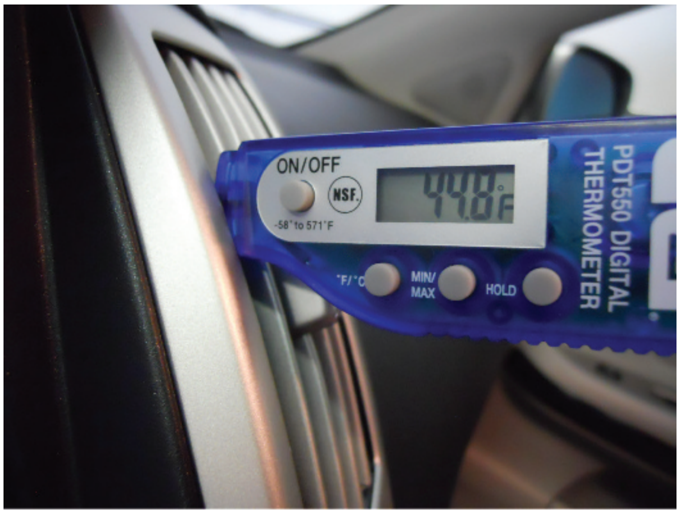


FIGURE 66–7 A digital thermometer checking the duct (vent) temperature.

LOW SIDE	HIGH SIDE	CONDITION (POSSIBLE CAUSE)
25–35 PSI	170–200 PSI	Normal
Low	Low	Low refrigerant charge level
Low	High	Restriction in high-side line
High	High	System is overcharged Expansion valve stuck open
High	Low	Restriction in the low-side line

CHART 66–1

Pressure gauge readings and possible causes.

SYSTEM TEST RESULTS Wait several minutes to allow the system to reach maximum output and observe the thermometer.

- If 35°F to 45°F (2°C to 7°C) or 30°F (15°C) cooler than the outside air temperature, the system is functioning normally.
- If over 45°F (7°C) or over 30°F (15°C) warmer than the outside air temperature, continue with pressure gauge testing.

If pressures are okay and the sight glass is clear, but vent temperature is high, check for a blend door or heater control valve problem, or look for a possible system oil overcharge. If pressures vary from specifications, perform further tests to locate the problem. ● **SEE CHART 66–1**.

ROOT CAUSE

TEMPERATURE AND PRESSURE MEASUREMENTS The sixth step in the strategy-based diagnosis process is to find the root cause of the customer concern. Temperature and pressure are directly related in A/C systems. As the ambient temperature

FREQUENTLY ASKED QUESTION

What Is the Center Yellow Hose Used For on a Gauge Set?

The center (yellow hose) port to the utility chamber (hose) is to

- add or remove refrigerant
- pull a vacuum on the system
- transfer refrigerant to cylinder.

The utility hose is where these accessories are connected. ● **SEE FIGURE 66–8**.

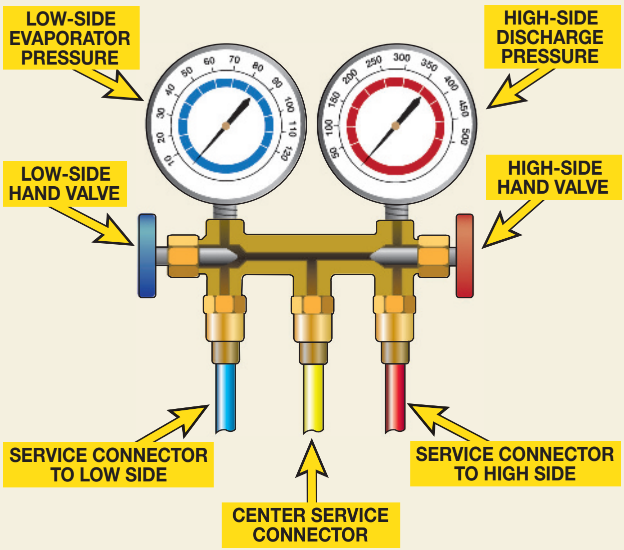

LOW-SIDE EVAPORATOR PRESSURE
HIGH-SIDE DISCHARGE PRESSURE
LOW-SIDE HAND VALVE
HIGH-SIDE HAND VALVE
SERVICE CONNECTOR TO LOW SIDE
SERVICE CONNECTOR TO HIGH SIDE
CENTER SERVICE CONNECTOR

FIGURE 66–8 The center, yellow hose is used to connect the air-conditioning system to a vacuum pump or refrigerant cans. When the hose is not being used, it should be attached to the blanks fitting to seal the system.

AMBIENT AIR TEMPERATURE	HUMIDITY	LOW-SIDE PRESSURE (PSI)	HIGH-SIDE PRESSURE (PSI)
70°F/21°C	Low	25–30	140–190
	High	28–35	165–220
80°F/27°C	Low	26–33	150–200
	High	30–36	190–260
90°F/32°C	Low	31–37	170–220
	High	37–45	210–290
100°F/38°C	Low	35–44	195–245
	High	38–48	230–320
110°F/43°C	Low	40–50	235–285
	High	42–52	260–350

CHART 66–2

The average R-134a pressure–temperature readings during a performance test. The pressures for R-1234yy will be similar.

LOW SIDE	HIGH SIDE	DUCT (VENT) TEMPERATURE	POSSIBLE CAUSE
Normal	Normal	Cold/normal	Operating as designed
Low	Low	Warm	Low refrigerant charge
High	High	Warm	Overcharged
High	High	Slightly cool	Overcharged or air in the system
Normal	Normal	Warm	Moisture in the system
Low	Low	Warm	High side restriction
Low	Low	Warm	Expansion valve stuck closed or orifice tube clogged
High	Low	Warm	Compressor or control valve failure

CHART 66–3

Diagnostic chart that can help determine the root cause of a lack-of-cooling customer concern.

increases, the high-side pressure must also increase to have a heat transfer at the condenser.

The temperature of the vapor must be higher than the ambient temperature to allow enough heat to be removed for condensation. Also, higher ambient temperatures, and high humidity, usually mean a higher heat load on the evaporator. This means a larger quantity of heat has to be removed at the condenser.

- The high-side pressure is directly related to the amount of heat that needs to be removed, and the heat transfer at the condenser.
- Low-side pressure indicates the boiling point of the temperature of the evaporator. If the pressure is too high, the boiling point of the refrigerant and temperature of the evaporator are too high. Low-side pressure that is too low indicates the evaporator is too cold and may ice, or that there is not enough boiling refrigerant in the evaporator to remove an adequate amount of heat. ● **SEE CHARTS 66–2 AND 66–3**.

Insufficient heat transfer at the condenser is usually the cause of high-side pressure that is too high. The number 1 cause of poor heat transfer is lack of airflow across the condenser.

The vehicle is dependent upon portable fans to move enough air when testing in the shop. It may be necessary to drive the vehicle at 30 MPH (48 km/h) to get the ram air necessary to determine if lack of airflow is the reason for the poor heat transfer.

Another cause of excessive high-side pressure is contamination with a different refrigerant. Mixing R-12 and R-134a raises the condensing pressure of the mixture. If the system is contaminated with R22, the pressures can become extremely high. At 150°F, the pressure of R-12 is 235 PSI (1,620 kPa), R-134a is 263 PSI (1,813 kPa), and R-22 is 381 PSI (2,627 kPa).

This is an important reason to use a refrigerant identifier. ● **SEE FIGURES 66–9 THROUGH 66–15**.

TEMPERATURE DIFFERENCES ACROSS COMPONENTS Test for heat transfer at the evaporator and the condenser.

- Temperature change across the evaporator—The temperature difference between the inlet and outlet of the evaporator should be the same or within 5° (−5° to +5°). If the temperature at the evaporator outlet is more than 6° different than the inlet temperature, the system is overcharged.

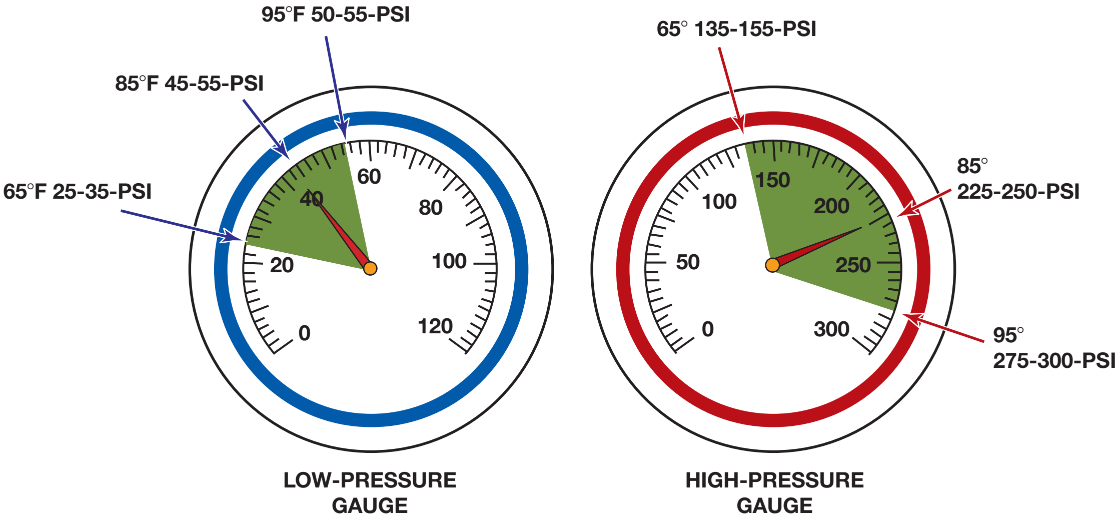

95°F 50-55-PSI
85°F 45-55-PSI
65°F 25-35-PSI
20
40
60
80
100
120
0
LOW-PRESSURE GAUGE
65° 135-155-PSI
85° 225-250-PSI
95° 275-300-PSI
0
50
100
150
200
250
300
HIGH-PRESSURE GAUGE

FIGURE 66–9 Normal R-134a A/C pressures. High humidity and airflow velocity across the evaporator and condenser will affect the pressure readings.

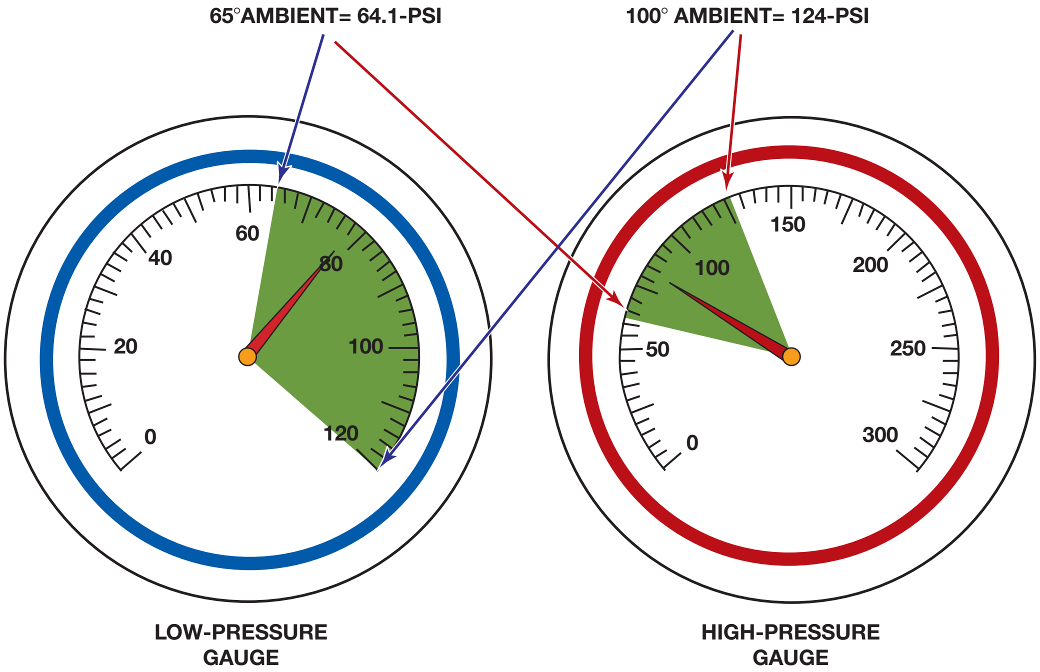

65°AMBIENT= 64.1-PSI
100° AMBIENT= 124-PSI
0
20
40
60
80
100
120
LOW-PRESSURE GAUGE
0
50
100
150
200
250
300
HIGH-PRESSURE GAUGE

FIGURE 66–10 Static pressure with the A/C not operating and the system equalized.

- Temperature change across the condenser—The temperature difference between the inlet and outlet of the condenser should be 20°F to 50°F (10°C to 30°C).
- If the temperature difference is higher than 50°, the system is undercharged or has a restriction.
- If the temperature difference is less than 19°, the system is overcharged.

ADDRESSING SYSTEM ODORS

SOURCE OF ODORS Some systems develop a musty, moldy smell, which is not really a fault of the system.

Some sources classify these odors into two types:

- "Dirty socks/gym locker" odor, which has an organic cause
- "Refrigerator, cement, or dusty room" odor, which is caused by chemicals

The organic odor problem is most common in areas with high relative humidity, and it is caused by mildew-type fungus growth on the evaporator and in the evaporator plenum. Modern evaporators have more fins that are closer together, and they tend to trap more moisture and bacterial growth.

The cool surface of the evaporator collects moisture as it dehumidifies the air, and most of this moisture runs out the bottom of the case. After a vehicle is shut off, the moist surface of the evaporator warms up, and this warm, wet area becomes an ideal environment for fungus and bacteria growth. A coating is applied to many evaporators to speed up water runoff, which helps dry the evaporator and reduce bacterial growth. Airborne bacteria also collect on this surface, and if the surface stays moist, these bacteria will live and grow, creating the unpleasant smell. Then when the air-conditioning or blower motor is turned on, that smell blows through the vehicle.

Several companies market chemicals, essentially fungicides, to kill the bacterial growth, or detergents to clean the evaporator

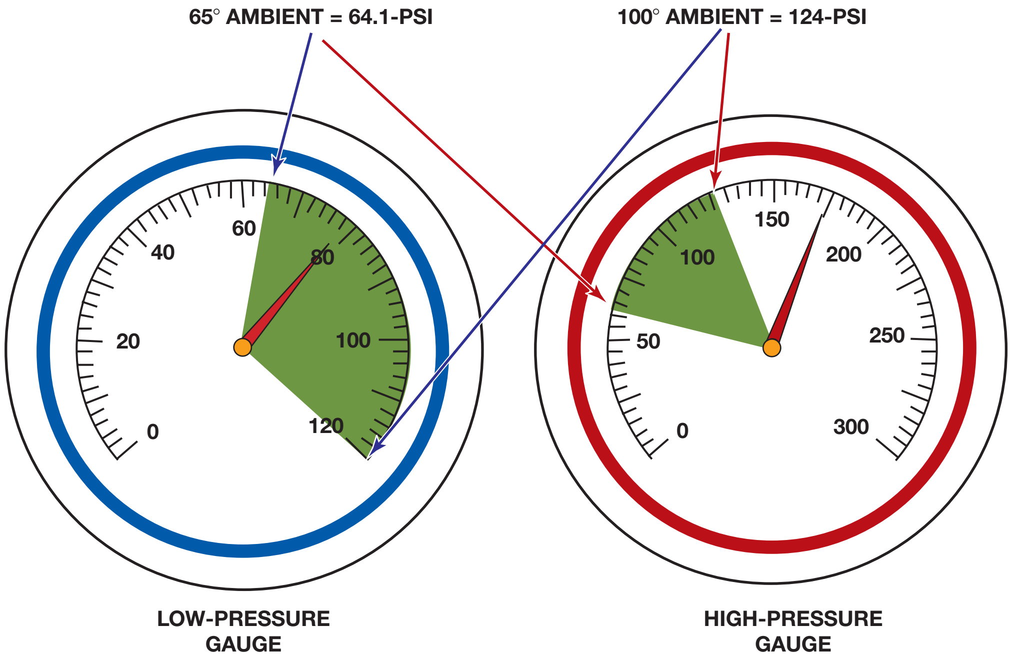

65° AMBIENT = 64.1-PSI
100° AMBIENT = 124-PSI
0
20
40
60
80
100
120
0
50
100
150
200
250
300
LOW-PRESSURE GAUGE
HIGH-PRESSURE GAUGE

FIGURE 66–11 Static pressure with the A/C not operating and the system NOT equalized.

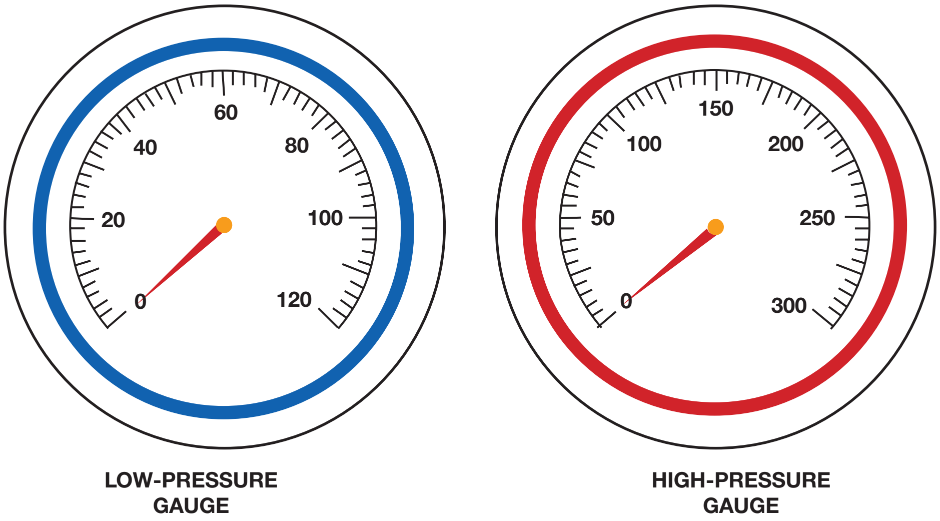

0
20
40
60
80
100
120
0
50
100
150
200
250
300
LOW-PRESSURE GAUGE
HIGH-PRESSURE GAUGE

FIGURE 66–12 If the system is empty of refrigerant, both pressure gauge readings will show zero or very low. The A/C clutch will not engage, and if forced to engage the lack of refrigerant will damage the compressor.

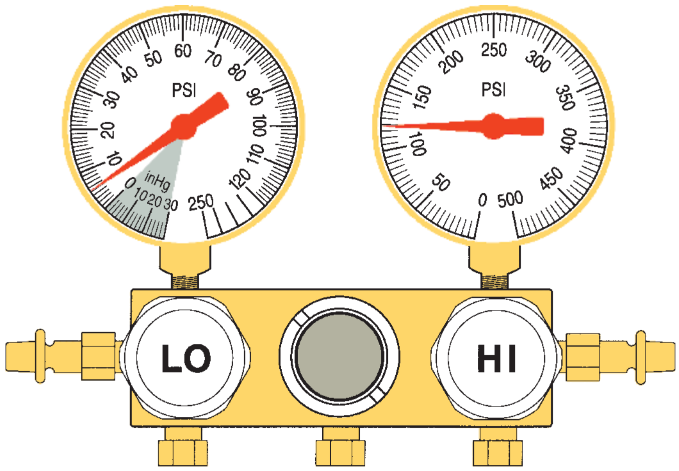

PSI
inHg
PSI
LO
HI

FIGURE 66–13 When both low- and high-side pressures are low, the system is undercharged with refrigerant.

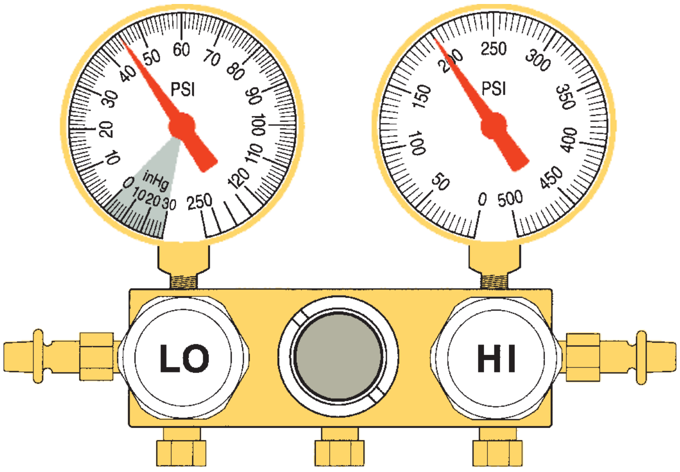

PSI
inHg
PSI
LO
HI

FIGURE 66–14 Both low- and high-side pressures higher than normal indicate that the system is overcharged with refrigerant.

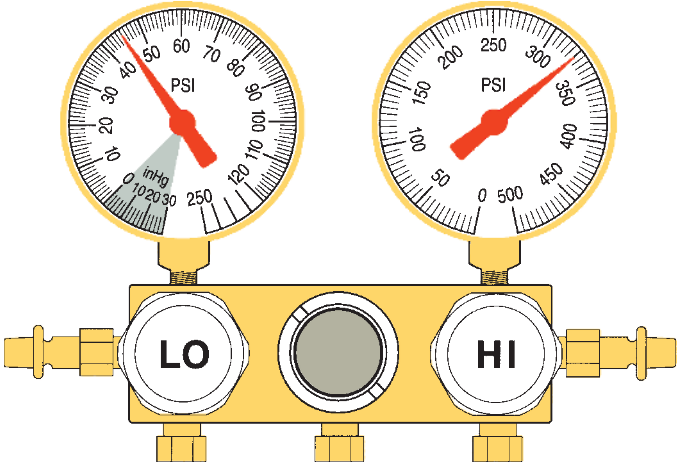


FIGURE 66–15 Lack of proper airflow across the condenser is usually the cause of high low-side and higher high-side pressures.

TECH TIP

The Clogged Orifice Tube Test

A clogged orifice tube is a common air-conditioning system failure. When the orifice tube becomes clogged, it blocks the flow of refrigerant through the evaporator, which causes a reduced cooling of the passenger compartment. To check for a possible restriction in the system, follow these easy steps:

STEP 1 Connect the A/C pressure gauge to both low- and high-side pressure fittings.

STEP 2 Operate the A/C system for 5 minutes to 10 minutes.

STEP 3 Shut off the A/C system and watch the pressure gauges. If the pressures do not equalize quickly, there is a restriction in the system. Normal time needed to equalize is often 15 seconds to 30 seconds, depending on the amount of refrigerant. ● **SEE FIGURE 66–16.**

NOTE: To locate a restriction anywhere in the system, feel along the system lines. The restriction exists at the point of greatest temperature difference. "Frosting" is a good indication of a restriction.

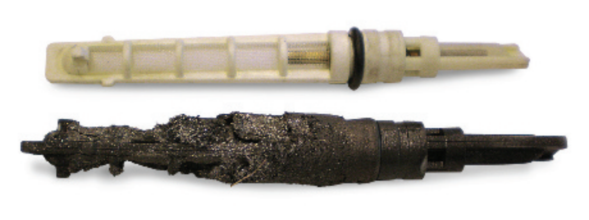
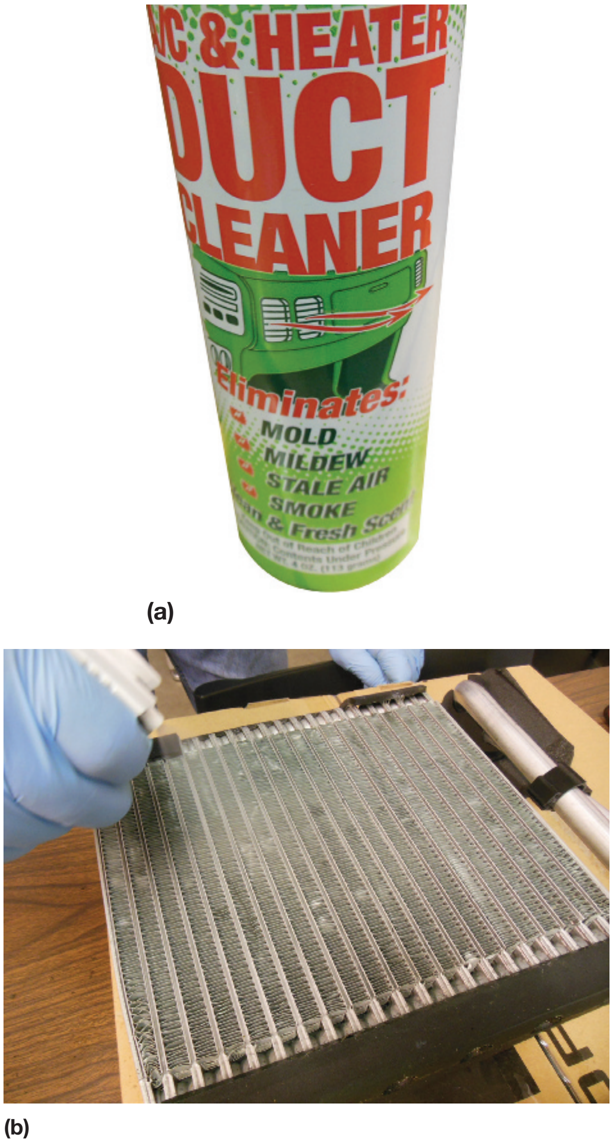


FIGURE 66–16 A new orifice tube (top) compared to a clogged orifice tube (bottom).



(a)

(b)

FIGURE 66–17 (a) A spray can of mold and mildew eliminator available at local parts stores and used on the evaporator before installing it into the vehicle is good insurance against HVAC-related odors. (b) Spraying the clear liquid mold and mildew eliminator onto the surface of the replacement evaporator prior to installation.

core. Some of these chemicals and a procedure to use them have been approved by vehicle manufacturers. These chemicals are sprayed into the ductwork or onto the evaporator fins. ● **SEE FIGURE 66–17.**

Some manufacturers install an **electronic evaporator dryer (EED)**, also called an **after-blow module**. In some vehicles, the A/C control module is programmed to operate the blower for a drying cycle after the car is shut off. This device turns on the blower (with the ignition switched off for 30 minutes to 50 minutes) and lets it run long enough to dry off the evaporator after the vehicle has been shut off. One system waits 10 minutes, runs the blower on high for 10 seconds, shuts down for another 10 minutes, and then repeats the 10-second operation and 10-minute pause for 10 cycles. The objective is to blow the moist air out of the evaporator without discharging the battery. EED modules are available for vehicles with either ground or B+ side blower switch systems.

NOISE ISSUES

COMMON CAUSES The A/C system is the potential source for several noise problems, and the compressor and clutch are the main culprits.

- A moaning or growling noise is a relatively low-frequency noise caused by something moving slowly.
- A whine or squeal is a high-pitch and high-frequency noise produced by something moving rapidly.

Another problem can be **groundout**, in which a vibrating metal A/C line contacts another surface (flat surfaces produce the most noise). Groundout problems also occur when the exhaust pipes make metal-to-metal contact with the vehicle body.

REPAIR THE SYSTEM

PURPOSE The purpose of any repair is to restore the system to like-new condition. Typical repairs include the replacement of components, such as the accumulator, compressor, evaporator, condenser, and refrigerant lines/hoses.

TYPICAL REPAIRS Many repairs require the proper identification, recovery, evacuation, and charging of the refrigerant. After the repairs, the system should function and operate as designed and the repair should be performed according to established industry and vehicle manufacturer's recommendations. All safety precautions should be adhered to and the refrigerant handled according to federal and local laws.

VERIFY THE REPAIR After the repairs or service procedures have been performed, verify that the system is working as designed. If needed, drive the vehicle under the same conditions as when the customer concern was corrected to verify the repair. Document the work order and return the vehicle to the customer in clean condition.

LEAK DETECTION

PURPOSE If the A/C system is low on a charge of refrigerant, the sources of the leak should be found and corrected. Look for oily areas that are formed when refrigerant leaks and some refrigerant oil is lost. It is this oil that indicates a refrigerant leak. ● **SEE FIGURE 66–18**.

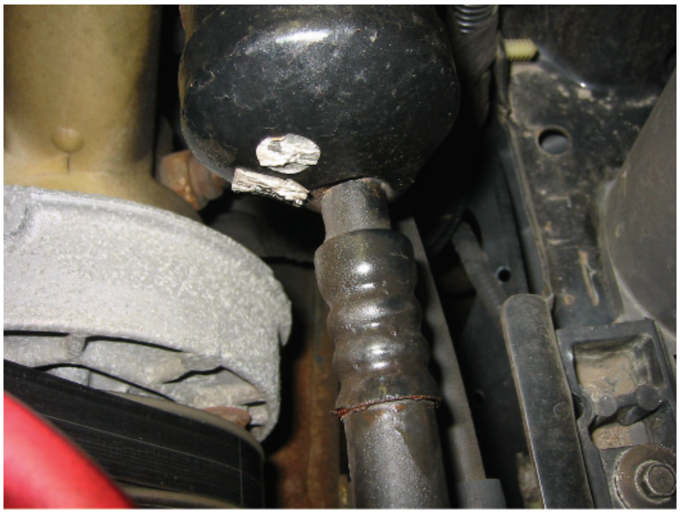


FIGURE 66–18 A through visual inspection is used to locate refrigerant leaks by looking for oily areas usually near fittings.

FREQUENTLY ASKED QUESTION

What Is the Procedure to Retrofit an Air-Conditioning System from R-12 to R-134a?

To retrofit a system, perform the following steps:

STEP 1 Visually inspect the system to ensure good condition, install a gauge set, and operate the system to bring it up to operating temperatures. Check for proper operation and note any needed repairs. Record the high-side pressure for later comparison.

STEP 2 Recover the R-12 from the system and remove as much oil-dissolved R-12 as possible.

STEP 3 Make any repairs to the system to cure problems that were found in step 1.

STEP 4 If the compressor failed, remove the failed compressor, flush the system and/or install a high-side filter, and install the replacement compressor along with a new accumulator or receiver–drier.

STEP 5 Check the system to determine whether a high-pressure relief valve is used. If it has one, a high-pressure cutoff switch must be installed to stop the compressor before pressure relief valve release pressures occur. The switch is installed so it senses high-side pressure and is wired into the clutch circuit or relay so it can interrupt clutch operation.

STEP 6 If directed, replace the receiver–drier or accumulator.

STEP 7 Replace any line-fitting O-rings on connections that were disturbed, or as directed.

STEP 8 Replace any switches and valves as directed.

STEP 9 Add the proper type and amount of oil—ester or PAG—into the compressor oil fill port or suction port. If the accumulator or receiver–driver is replaced, pour part of the oil into the inlet port.

STEP 10 Install the R-134a service fittings. Old Schrader valves that remain in service should be replaced with new R-134a valves.

STEP 11 Fill out and install the identifying decal to properly identify the system. The old label must be rendered unreadable.

STEP 12 Connect a vacuum pump to the system and pull a minimum vacuum of 29 inch Hg (500 microns) for at least 30 minutes to evacuate the system.

STEP 13 Recharge the system using R-134a. Charge the system with 80% to 90% of the specified amount of R-12.

STEP 14 Operate the system and check for proper operation, paying careful attention to the high-side pressure.

STEP 15 Test for leaks.

ELECTRONIC LEAK DETECTION

The use of an **electronic leak detector** meeting SAE J1628 is the most used method that experts and vehicle manufacturers recommend to find refrigerant leaks. Detector devices that are the most sensitive are capable of finding smaller leaks. SAE standards and their use and sensitivity include the following:

- **J1627**—Detectors certified under this standard are capable of detecting leaks that result in a loss of refrigerant of 0.5 oz per year at a distance of 0.25 inch (6 mm).
- **J2791**—Detectors certified under this standard are for use with R134a systems and are capable of detecting leaks as small as 0.15 oz at a distance of 0.375 inch (10 mm).
- **J2913**—Detectors certified under this standard are for use with R1234yf systems and are capable of detecting leaks as small as 0.15 oz at a distance of 0.375 inch (10 mm).

Before using an electronic leak detector, perform a visual inspection and check the entire refrigerant system for traces of oil, which usually indicates the location of a refrigerant leak.

According to the SAE J1628 service procedure, the system does not need to be fully charged. The system just needs a few ounces of refrigerant to achieve a pressure of at least 50 PSIG for most detectors to find leaks.

Perform leak detection by pointing the sensor above, below, and around each hose, component, and refrigerant line. ● **SEE FIGURE 66–19**.

CAUTION: If less than a full refrigerant charge, do not start the engine and operate to the A/C compressor to avoid possible compressor damage due to a lack of refrigerant oil being circulated through the system.

DYE LEAK DETECTION

Ultraviolet (UV) fluorescent trace dye is added to some refrigerant to help the technician visually spot a leak in the refrigerant system. A typical UV dye leak kit contains the following components:

- Dye formulated for use in an air-conditioning refrigerant
- Dye injector usually a hand-operated injector used to introduce the dye into the system
- UV flashlight used to light the area so that the dye is easily seen
- Special yellow-colored goggles to protect the eyes from the UV and also helps the user to see the dye's fluorescence.

Always follow the instructions that came with the dye kit. To successfully use dye, the system should be fully charged with refrigerant.

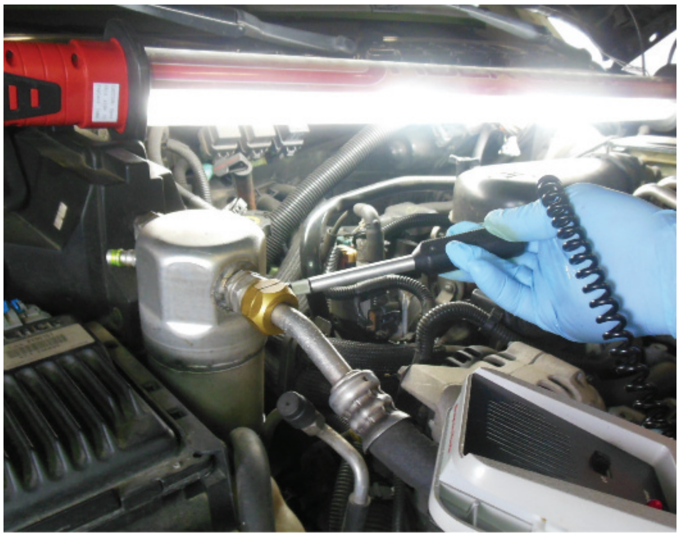


FIGURE 66–19 An electronic leak detector being used to locate a possible leak in a system. For best results, move the detector probe completely around each fitting and connection.

USING DYE

Dye is very corrosive so most dye kit instructions state to only use ¼ ounce (7 grams). The dye is added to the low side using the supplied installation device. The air-conditioning system should be operated to allow the dye to circulate through the system. The refrigerant leaks out as a gas and escapes into the atmosphere, but the dye circulates throughout the system with the refrigerant oil. Leaks can be viewed by the technician using the light supplied with the dye kit. It may take just a few minutes for the dye to be seen from a leak if a large leak is present or it can take several days for a smaller leak to be seen. Many A/C compressors use an **oil trap** to help the oil in the compressor. This method is not as efficient as it has been in the past when used with older systems. Dye works well except for leaks in the evaporator, which are usually not visible unless the UV light is used at the evaporator drain. ● **SEE FIGURE 66– 20**.

SOAPY WATER

Mix a few drops of liquid soap or detergent into a small glass of water. Using a small brush or a small spray bottle, apply the soapy solution to all fittings and other areas such as the condenser and compressor, which often are sources of leaks. Using soapy water is a safe and low-cost method but it is not very accurate at finding refrigerant leaks, especially small leaks.

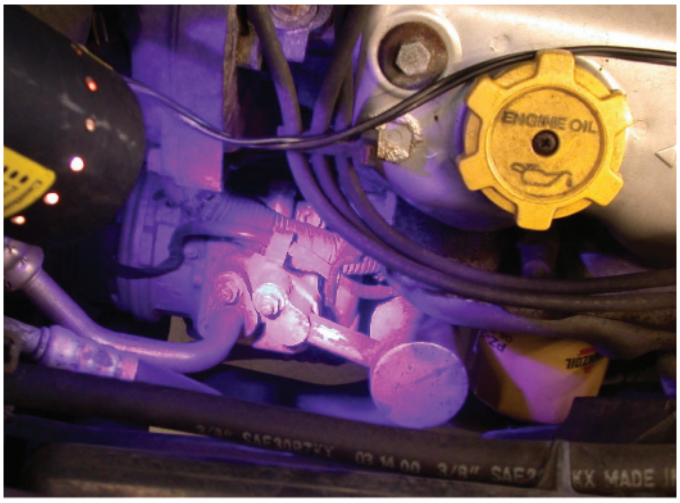
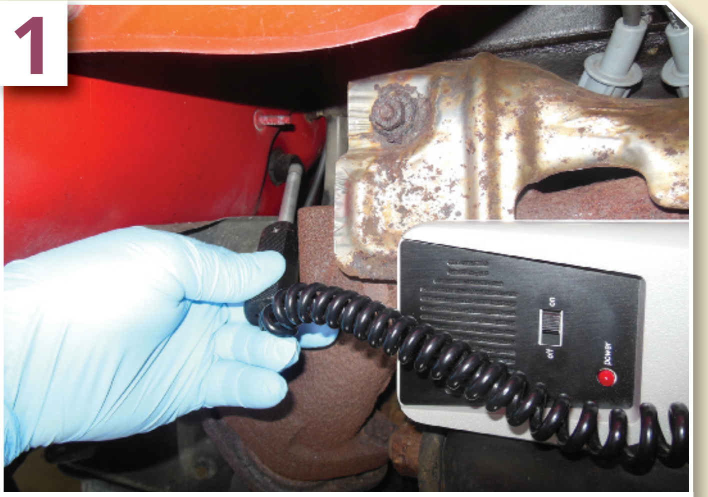


FIGURE 66–20 An ultraviolet (UV) light being used to look for refrigerant leakage after a fluorescent dye was installed in the system.

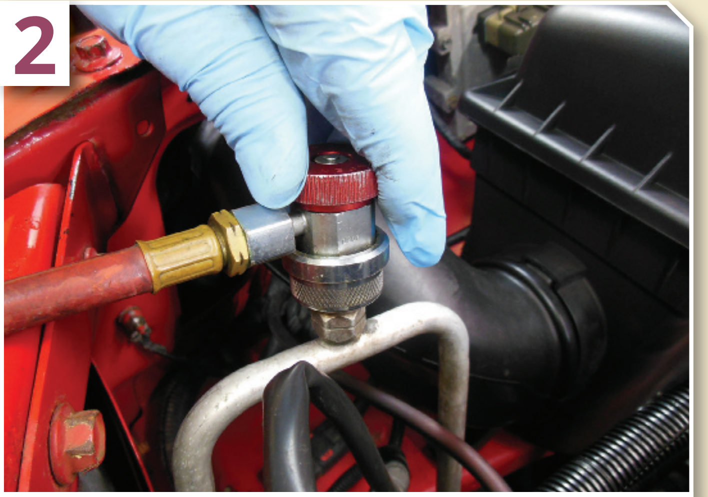
LACK OF COOLING DIAGNOSIS AND REPAIR

1


on
off
power

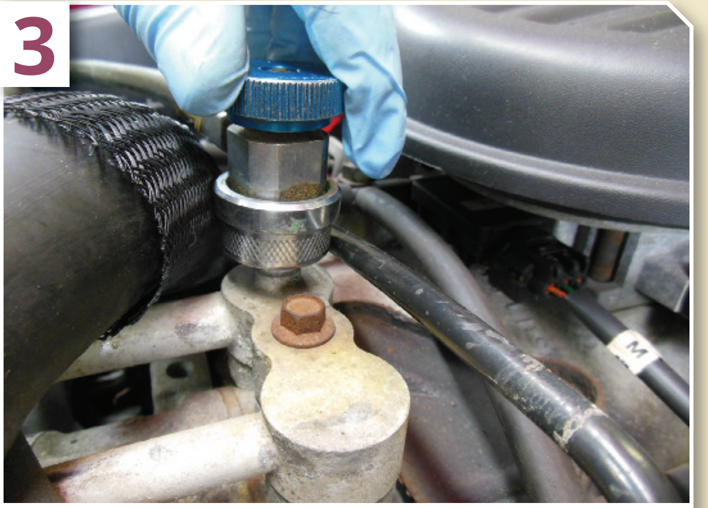
The lack of cooling was diagnosed using a leak detector, which showed the evaporator was leaking when tested at the condensate drain.

2



The recovery process was started by connecting an RRR machine to the high-side fitting.

3



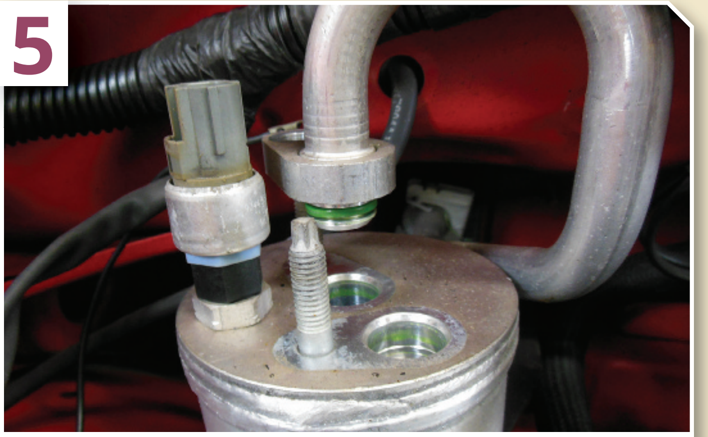
The low-side fitting was connected and the recovery was begun.

4

0.1
lb
RECOVER
RECOVERY
ENTER
VACUUM
AIR
PURGE
CHARGE
34a

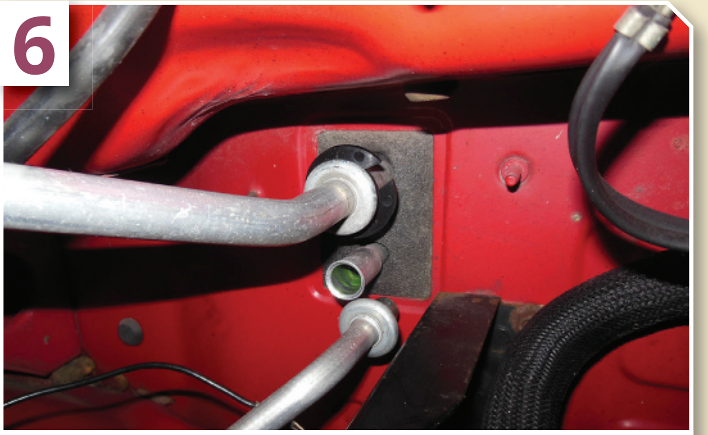
Very little refrigerant was left in the system (0.1 pound) but it was recovered.

5



The lines to the accumulator were removed.

6



The lines to the evaporator were disconnected using a quick connect tool to release the fitting.

7

The retaining nuts were removed that held the HVAC case to the bulkhead from under the hood. In one case, the entire stud came out instead of just the nut.

8

Before going into the passenger compartment, the negative battery cable was disconnected from the battery.

9

The dash assembly is being removed, and this process includes disconnecting the airbag wiring connectors.

10

The driver/passenger side of the dash is removed to gain access to the additional fasteners.

11

The two retaining fasteners that hold the steering column to the dash are removed and the steering column lowered into the seat, which is protected using a fender cover.

12

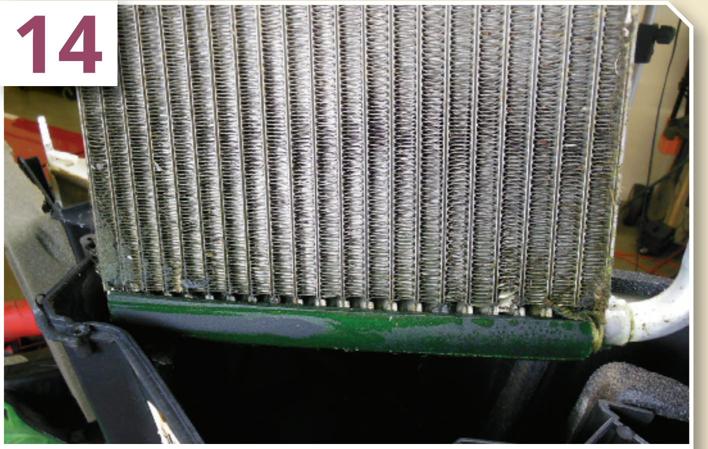
The entire dash assembly is being gently removed.

LACK OF COOLING DIAGNOSIS AND REPAIR

13

The HVAC case is being disassembled after being removed from the vehicle.

14

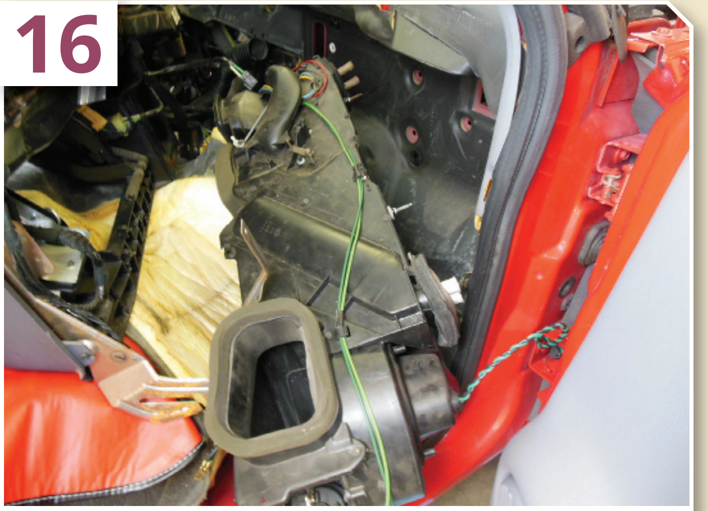


The evaporator is removed, and it shows signs of leaking. The root cause of the lack of cooling has been found.

15

The heater core was also removed and replaced at the same time as insurance against possible future leaks from this unit.

16



The reassembled HVAC case is now being installed back into the vehicle.

17

A new accumulator is installed.

18

Snap-on
Pro-Set
LO
Snap-on
Pro-Set
H
134a

The system was evacuated and charged to the specified amount, and the pressure gauge and temperature reading indicated that the system was restored to like-new performance.

REVIEW QUESTIONS

1. What are the steps that a technician should follow when diagnosing and repairing an air-conditioning–related problem?
2. What should be checked as part of a visual inspection?
3. Why should the diagnostic trouble codes be checked before checking for technical service bulletins?
4. What does the temperature difference across the condenser and evaporator tell the technician?
5. What is required if retrofitting an air-conditioning system from R-12 to R-134a?

CHAPTER QUIZ

1. When should the service technician check for technical service bulletins?
   - **a.** As soon as the work order is received with the customer complaint shown
   - **b.** Before performing a visual inspection
   - **c.** After checking for any stored diagnostic trouble codes
   - **d.** After making the repair
2. Clear water is seen dripping from beneath the vehicle on the passenger side. This means __________.
   - **a.** normal operation
   - **b.** possible clogged evaporator
   - **c.** possible restricted condenser
   - **d.** receiver–drier is at the end of its normal life
3. What should the technician use when checking for diagnostic trouble codes?
   - **a.** Any global (generic) scan tool that can read body and/or chassis codes
   - **b.** Any enhanced scan tool that can read body and/or chassis codes
   - **c.** Only a factory scan tool can be used
   - **d.** A paper clip because it is needed to read codes
4. What could be wrong if the A/C compressor clutch cycles on and off rapidly?
   - **a.** Defective A/C compressor
   - **b.** Defective A/C compressor clutch
   - **c.** Low refrigerant charge
   - **d.** Shorted compressor clutch diode
5. The low-side pressure is low and the high-side pressure is higher than normal. What is the most likely cause?
   - **a.** Low refrigerant charge level
   - **b.** System is overcharged; expansion valve stuck open
   - **c.** Restriction in the low-side line
   - **d.** Restriction in high-side line
6. The temperature difference between the inlet and outlet of the condenser should be __________.
   - **a.** equal
   - **b.** 10°F to 30°F
   - **c.** 20°F to 50°F
   - **d.** greater than 60°
7. Most A/C performance tests include __________.
   - **a.** start the engine, set the parking brake, and raise the idle to 2000 RPM
   - **b.** measure ambient temperature 3 inches (80 mm) in front of the condenser and measure the humidity
   - **c.** open the doors and set the blower speed to high, which applies the maximum load on the system
   - **d.** All of the above
8. Where should a leak detector be used when checking for refrigerant leaks?
   - **a.** Around hoses and fittings
   - **b.** At the condensate drain
   - **c.** Around the compressor and lines
   - **d.** All of the above
9. The temperature outside is 90°F (32°C) and the humidity is high. With the A/C operating, what should the high side gauge read?
   - **a.** 31–37 PSI
   - **b.** 210–290 PSI
   - **c.** Less than 150 PSI
   - **d.** 170–210 PSI
10. A musty, moldy smell in the air-conditioning system is usually due to __________.
    - **a.** mildew-type fungus growth
    - **b.** a restricted evaporator
    - **c.** a clogged condenser
    - **d.** a weak or defective AC compressor

SECTION IX

ENGINE PERFORMANCE (A8)

CHAPTERS

67 Gasoline, Alternative Fuels, and Diesel Fuels
68 Ignition System Parts and Operation
69 Ignition System Diagnosis and Service
70 Computer Fundamentals
71 Temperature and Throttle Position Sensors
72 MAP and MAF Sensors
73 Oxygen Sensors
74 Fuel Pumps, Lines, and Filters
75 Fuel-Injection Parts and Operation
76 Gasoline Direct-Injection Systems
77 Electronic Throttle Control System
78 Fuel-Injection System Diagnosis and Service
79 Vehicle Emissions Standards and Testing
80 Evaporative Emissions Control and EGR Systems
81 Positive Crankcase Ventilation and Secondary Air-Injection Systems
82 Catalytic Converters
83 Onboard Diagnosis
84 Module Reprogramming
85 Strategy-Based Diagnosis

Chapter 67

GASOLINE, ALTERNATIVE FUELS, AND DIESEL FUELS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the characteristics of gasoline and refining of gasoline.
- Discuss the volatility of gasoline.
- Explain air–fuel ratios.
- Explain normal and abnormal combustion.
- Explain octane rating.
- Discuss gasoline additives.
- Discuss testing gasoline for alcohol content.
- Discuss general gasoline recommendations.
- Discuss E85.
- Discuss alternative fuel vehicles.
- Discuss propane.
- Discuss compressed natural gas fuels.
- Discuss diesel fuel.
- Discuss biodiesel.

KEY TERMS:

AFV 805 • Air–fuel ratio 798 • Antiknock index (AKI) 800 • API gravity 810 • ASTM 798 • B5 810 • B20 810 • Biodiesel 810 • Catalytic cracking 797 • Cetane number 809 • Cloud point 809 • Cold Filter Plugging Point (CFPP) 810 • Compressed natural gas (CNG) 807 • Cracking 797 • Detonation 799 • Distillation 797 • E10 801 • E85 804 • Ethanol 801 • Ethyl alcohol 804 • FFV 805 • Flex fuel 805 • Fuel compensation sensor 805 • Fungible 797 • Gasoline 797 • Grain alcohol 804 • Hydrocracking 797 • Liquified petroleum gas (LPG) 806 • LP gas 806 • NGV 807 • Octane rating 799 • Oxygenated fuels 801 • Ping 799 • PPO 811 • Propane 806 • RVP 798 • Spark knock 799 • Stoichiometric 799 • SVO 811 • UCO 811 • ULSD 810 • Variable fuel sensor 805 • V-FFV 806 • Volatility 798 • WVO 811 • WWFC 803

GASOLINE

REFINING **Gasoline** is a term used to describe a complex mixture of various hydrocarbons refined from crude petroleum oil for use as a fuel in engines. Gasoline and air burns in the cylinder of the engine and produces heat and pressure, which is transferred to rotary motion inside the engine and eventually powers the drive wheels of a vehicle. When the combustion process in the engine is perfect, all of the fuel and air are consumed and only carbon dioxide and water are produced.

DISTILLATION In the late 1800s, crude was separated into different products by boiling in a process called **distillation**. Distillation works because crude oil is composed of hydrocarbons with a broad range of boiling points.

In a distillation column, the vapor of the lowest boiling hydrocarbons, propane and butane, rises to the top. The straight-run gasoline (also called naphtha), kerosene, and diesel fuel cuts are drawn off at successively lower positions in the column.

CRACKING **Cracking** is the process during which hydrocarbons with higher boiling points can be broken down (cracked) into lower boiling hydrocarbons by treating them to very high temperatures. This process, called *thermal cracking,* was used to increase gasoline production starting in 1913.

Today, instead of high heat, cracking is performed using a catalyst and is called **catalytic cracking**. A catalyst is a material that speeds up or otherwise facilitates a chemical reaction without undergoing a permanent chemical change itself. Catalytic cracking produces gasoline of higher quality than thermal cracking.

Hydrocracking is similar to catalytic cracking in that it uses a catalyst, but the catalyst is in a hydrogen atmosphere. Hydrocracking can break down hydrocarbons that are resistant to catalytic cracking alone and it is used to produce diesel fuel rather than gasoline.

Other types of refining processes include the following:

- Reforming
- Alkylation
- Isomerization
- Hydrotreating
- Desulfurization

● **SEE FIGURE 67–1**.

SHIPPING The gasoline is transported to regional storage facilities by tank railway car or by pipeline. In the pipeline method, all gasoline from many refiners is often sent through the same pipeline and can become mixed. All gasoline is said to be **fungible**, meaning that it is capable of being interchanged because each

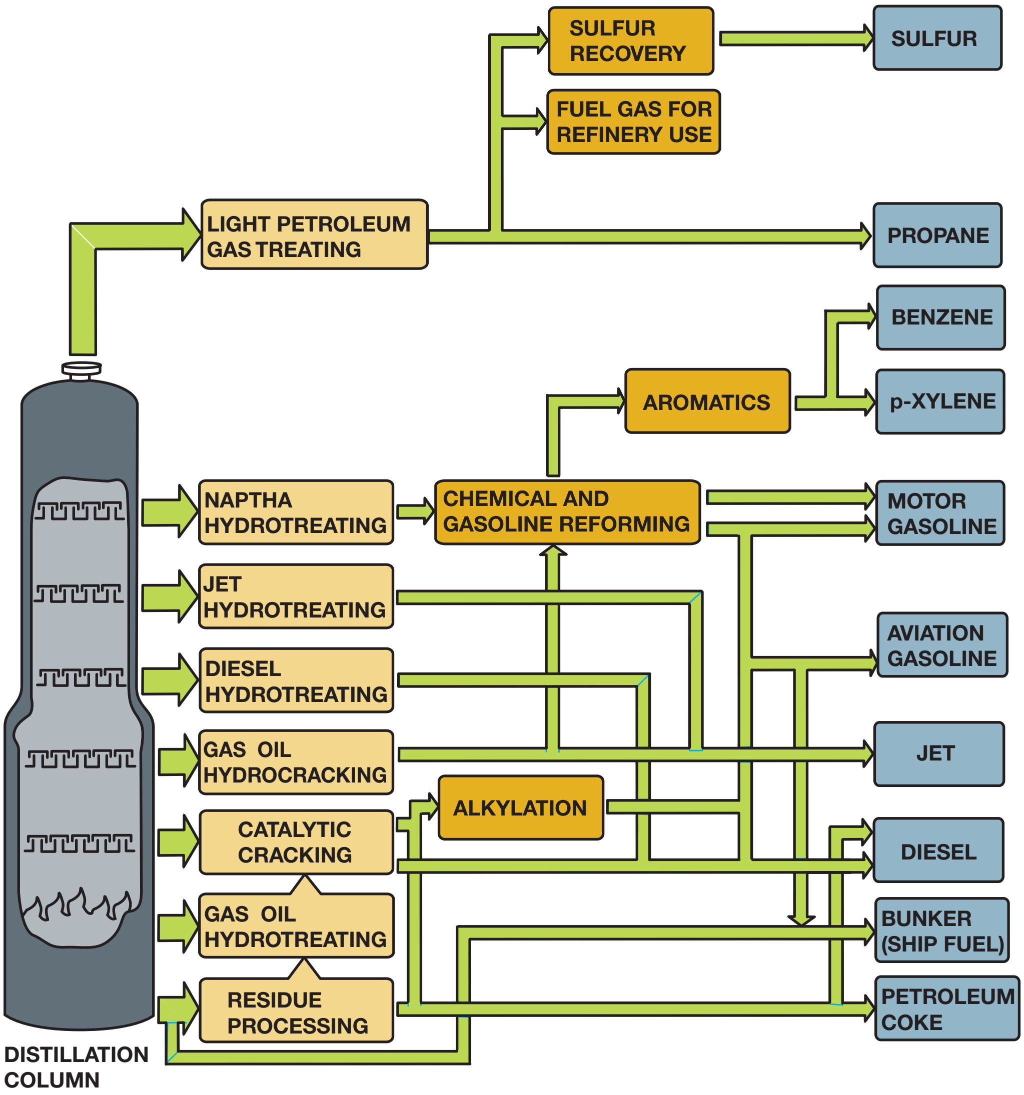

SULFUR RECOVERY
SULFUR
FUEL GAS FOR REFINERY USE
LIGHT PETROLEUM GAS TREATING
PROPANE
BENZENE
AROMATICS
p-XYLENE
NAPTHA HYDROTREATING
CHEMICAL AND GASOLINE REFORMING
MOTOR GASOLINE
JET HYDROTREATING
AVIATION GASOLINE
DIESEL HYDROTREATING
GAS OIL HYDROCRACKING
JET
ALKYLATION
CATALYTIC CRACKING
DIESEL
GAS OIL HYDROTREATING
BUNKER (SHIP FUEL)
RESIDUE PROCESSING
PETROLEUM COKE
DISTILLATION COLUMN

FIGURE 67–1 The crude oil refining process showing most of the major steps and processes.

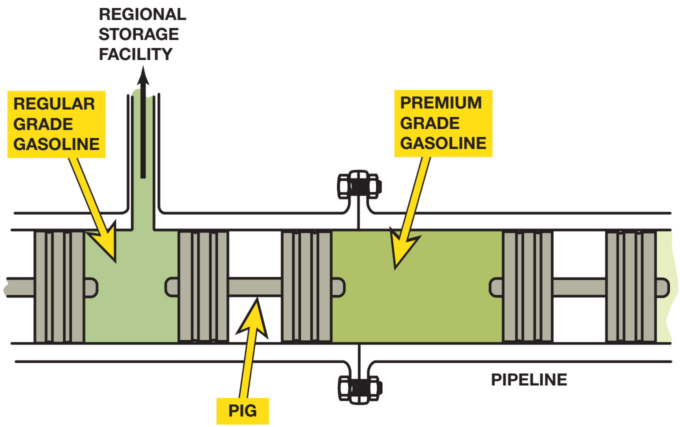


FIGURE 67–2 A pig is a plug-like device that is placed in a pipeline to separate two types or grades of fuel.

grade is created to specification so there is no reason to keep the different gasoline brands separated except for grade. Regular grade, midgrade, and premium grades are separated by using a device, called a *pig*, in the pipeline and sent to regional storage facilities. ● **SEE FIGURE 67–2**.

It is at these regional or local storage facilities where the additives and dye (if any) are added and then shipped by truck to individual gas stations.

VOLATILITY

DEFINITION **Volatility** describes how easily the gasoline evaporates (forms a vapor). The definition of volatility assumes that the vapors will remain in the fuel tank or fuel line and will cause a certain pressure based on the temperature of the fuel.

REID VAPOR PRESSURE **Reid vapor pressure (RVP)** is the pressure of the vapor above the fuel when the fuel is at 100°F (38°C). Increased vapor pressure permits the engine to start in cold weather. Gasoline without air will not burn. Gasoline must be vaporized (mixed with air) to burn in an engine. ● **SEE FIGURE 67–3**.

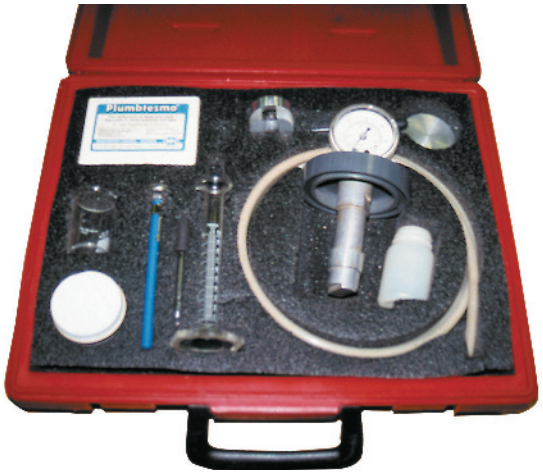


FIGURE 67–3 A gasoline testing kit, including an insulated container where water at 100°F is used to heat a container holding a small sample of gasoline. The reading on the pressure gauge is the Reid vapor pressure (RVP).

FREQUENTLY ASKED QUESTION

Why Do I Get Lower Gas Mileage in the Winter?

Several factors cause the engine to use more fuel in the winter than in the summer:

- Gasoline that is blended for use in cold climates is designed for ease of starting and contains fewer heavy molecules, which contribute to fuel economy. The heat content of winter gasoline is lower than summer-blend gasoline.
- In cold temperatures, all lubricants are stiff, causing more resistance. These lubricants include the engine oil, as well as the transmission and differential gear lubricants.
- Heat from the engine is radiated into the outside air more rapidly when the temperature is cold, resulting in longer run time until the engine has reached normal operating temperature.
- Road conditions, such as ice and snow, can cause tire slippage or additional drag on the vehicle.

SEASONAL BLENDING Cold temperatures reduce the normal vaporization of gasoline; therefore, winter-blended gasoline is specially formulated to vaporize at lower temperatures for proper starting and driveability at low ambient temperatures.

- **Winter blend.** The **American Society for Testing and Materials (ASTM)** standards for winter-blend gasoline allow volatility of up to 15 pounds per square inch (PSI) RVP.
- **Summer blend.** At warm ambient temperatures, gasoline vaporizes easily. However, the fuel system (fuel pump, fuel-injector nozzles, etc.) is designed to operate with liquid gasoline. The volatility of summer-grade gasoline should be about 7 PSI RVP. According to ASTM standards, the maximum RVP should be 10.5 PSI for summer-blend gasoline.

VOLATILITY-RELATED PROBLEMS If using winter-grade fuel during warm weather, the following may occur:

- Heat causes some fuel to evaporate, thereby causing bubbles.
- When the fuel is full of bubbles (sometimes called *vapor lock*), the engine is not being supplied with enough fuel and the engine runs lean. A lean engine will lead to the following:
  1. Rough idle
  2. Stalling
  3. Hesitation on acceleration
  4. Surging

If using summer-grade fuel in cold temperatures, the engine will be hard to start (long cranking before starting) due to the lack of volatility to allow the engine to start easily.

AIR–FUEL RATIOS

DEFINITION The **air–fuel ratio** is the proportion by weight of air and gasoline that the injection system mixes as needed for engine combustion. Air–fuel ratios in which a gasoline engine can operate without stalling range from 8:1 to 18.5:1. ● **SEE FIGURE 67–4**.

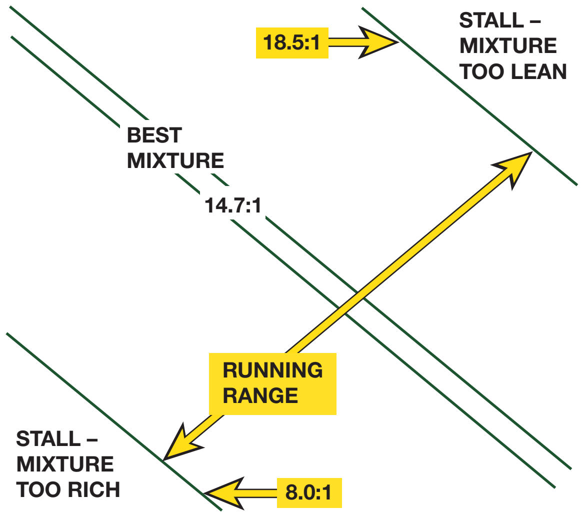


FIGURE 67–4 An engine will not run if the air–fuel mixture is either too rich or too lean.

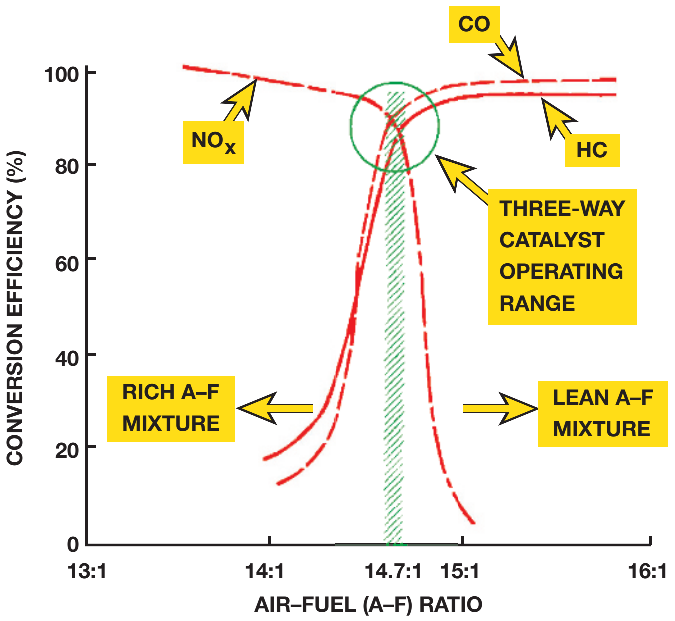


FIGURE 67–5 With a three-way catalytic converter, emission control is most efficient with an air–fuel ratio between 14.65:1 and 14.75:1.

These ratios are usually stated by weight, as follows:

- 8 parts of air by weight combined with 1 part of gasoline by weight (8:1), which is the richest mixture that an engine can tolerate and still fire reliably
- 18.5 parts of air mixed with 1 part of gasoline (18.5:1), which is the leanest practical ratio

Richer or leaner air–fuel ratios cause the engine to misfire badly or not run at all.

STOICHIOMETRIC AIR–FUEL RATIO The ideal mixture or ratio at which all of the fuel combines with all of the oxygen in the air and burns completely is called the **stoichiometric** ratio, a chemically perfect combination. In theory, this ratio for gasoline is an air–fuel mixture of 14.7:1. The stoichiometric ratio is a compromise between maximum power and maximum economy. ● **SEE FIGURE 67–5**.

NORMAL AND ABNORMAL COMBUSTION

TERMINOLOGY The **octane rating** of gasoline is the measure of its antiknock properties. **Spark knock** (also called **detonation** or **ping**) is a metallic noise an engine makes, usually during acceleration, resulting from abnormal or uncontrolled combustion inside the cylinder. Normal combustion occurs smoothly and progresses across the combustion chamber from the point of ignition. ● **SEE FIGURE 67–6**.

Normal flame-front combustion travels between 45 and 90 mph (72 and 145 km/h). The speed of the flame front depends on air–fuel ratio, combustion chamber design (determining amount of turbulence), and temperature.

ABNORMAL COMBUSTION During periods of abnormal combustion, called spark knock or detonation, the combustion speed increases by up to 10 times to near the speed of sound. The increased combustion speed also causes increased temperatures and pressures, which can damage pistons, gaskets, and cylinder heads. ● **SEE FIGURE 67–7**.

CONTROLLING SPARK KNOCK Spark knock was commonly heard in older engines, especially when under load and in warm weather temperatures. Most engines built since the 1990s are equipped with a knock sensor that is used to signal the powertrain control module (PCM) to retard the ignition timing if knock is detected. Using the proper octane fuel helps to ensure that spark knock does not occur.

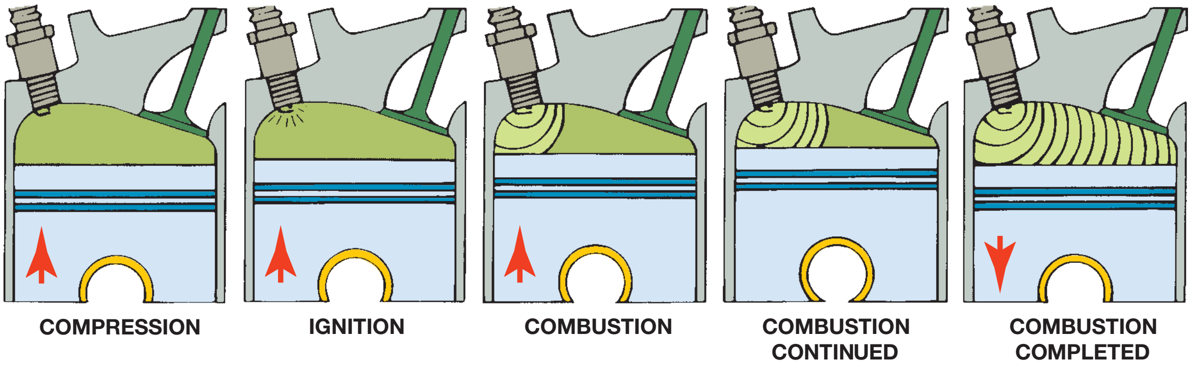


FIGURE 67–6 Normal combustion is a smooth, controlled burning of the air–fuel mixture.

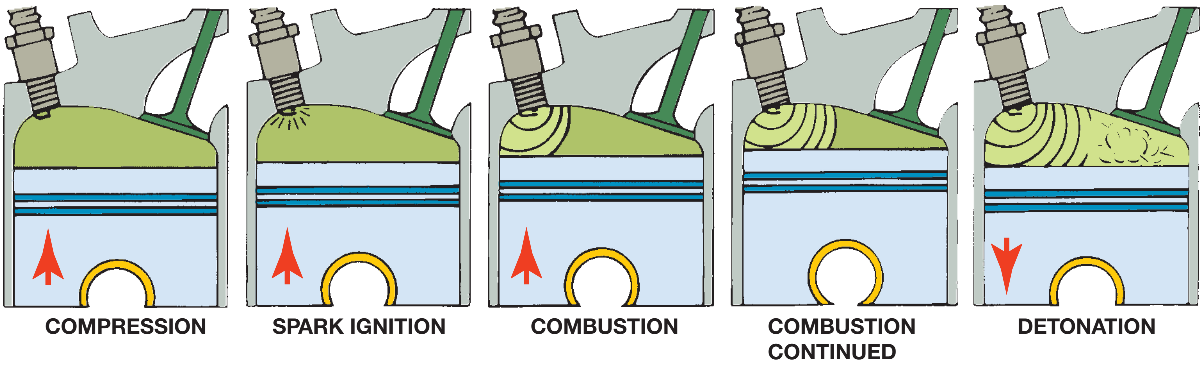

COMPRESSION
SPARK IGNITION
COMBUSTION
COMBUSTION CONTINUED
DETONATION

FIGURE 67–7 Detonation is a secondary ignition of the air–fuel mixture. It is also called spark knock or pinging.

OCTANE RATING

RATING METHODS The two basic methods used to rate gasoline for antiknock properties (octane rating) include the *Research method* and the *Motor method.*

Each uses a model of the special *cooperative fuel research* (CFR) single-cylinder engine to test the octane of a fuel sample, and the two methods use different engine settings. The research method typically results in readings that are 6 to 10 points higher than those of the motor method. For example, a fuel with a research octane number (RON) of 93 might have a motor octane number (MON) of 85.

GASOLINE GRADES The octane rating posted on pumps in the United States is the average of the two methods and is referred to as R + M ÷ 2, meaning that, for the fuel used in the previous example, the rating posted on the pumps would be the following:

$$\frac{\text{RON} + \text{MON}}{2} = \frac{93 + 85}{2} = 89$$

This pump octane rating is often called the **antiknock index (AKI)**.

● **SEE FIGURE 67–8.**

Except in high-altitude areas, the grades and octane ratings are shown in ● **CHART 67–1**.

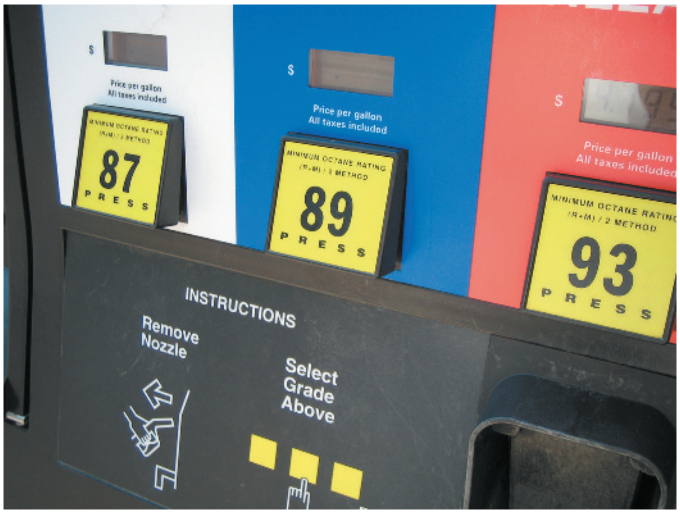

Price per gallon All taxes included
MINIMUM OCTANE RATING (R+M)/2 METHOD
87
PRESS
Price per gallon All taxes included
MINIMUM OCTANE RATING (R+M)/2 METHOD
89
PRESS
Price per gallon All taxes included
MINIMUM OCTANE RATING (R+M)/2 METHOD
93
PRESS
INSTRUCTIONS
Remove Nozzle
Select Grade Above

FIGURE 67–8 A pump showing regular with a pump octane of 87, plus rated at 89, and premium rated at 93. These ratings can vary with brand, as well as in different parts of the country.

GRADES	OCTANE RATING
Regular	87
Midgrade (also called Plus)	89
Premium	91 or higher

CHART 67–1

The octane rating displayed on the fuel pumps can vary depending on climate.

FREQUENTLY ASKED QUESTION

What Grade of Gasoline Does the EPA Use When Testing Engines?

Due to the various grades and additives used in commercial fuel, the government (EPA) uses a liquid called indolene, which has a research method octane number of 96.5 and a motor method octane rating of 88, resulting in a (R + M) ÷ 2 rating of 92.25.

TECH TIP

Horsepower and Fuel Flow

To produce 1 hp, the engine must be supplied with 0.50 lb of fuel per hour (lb/hr). Fuel injectors are rated in pounds per hour. For example, a V-8 engine equipped with 25 lb/hr fuel injectors could produce 50 hp per cylinder (per injector) or 400 hp. Even if the cylinder head or block is modified to produce more horsepower, the limiting factor may be the injector flow rate.

The following are flow rates and resulting horsepower for a V-8 engine:

- 30 lb/hr: 60 hp per cylinder, or 480 hp
- 35 lb/hr: 70 hp per cylinder, or 560 hp
- 40 lb/hr: 80 hp per cylinder, or 640 hp

Of course, injector flow rate is only one of many variables that affect power output. Installing larger injectors without other major engine modifications could decrease engine output and drastically increase exhaust emissions.

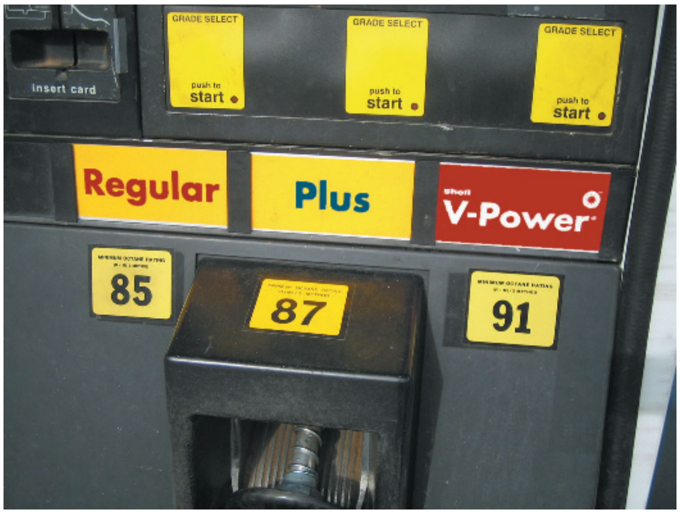


FIGURE 67–9 The posted octane rating in most high-altitude areas shows regular at 85 instead of the usual 87.

OCTANE EFFECTS OF ALTITUDE As the altitude increases, atmospheric pressure drops. The air is less dense because a pound of air takes more volume. The octane rating of fuel does not need to be as high because the engine cannot take in as much air. This process will reduce the combustion (compression) pressures inside the engine. In mountainous areas, gasoline (R + M) ÷ 2 octane ratings are two or more numbers lower than normal (according to the SAE, about one octane number lower per 1,000 ft (300 m) in altitude). ● **SEE FIGURE 67–9**.

A second reason for the lowered octane requirement of engines running at higher altitudes is the normal enrichment of the air–fuel ratio and lower engine vacuum with the decreased air density. Some problems, therefore, may occur when driving out of high-altitude areas into lower areas where the octane rating must be higher. Most electronic fuel injection systems can compensate for changes in altitude and modify air–fuel ratio and ignition timing for best operation.

VOLATILITY EFFECTS OF ALTITUDE High altitude also allows fuel to evaporate more easily. The volatility of fuel should be reduced at higher altitudes to prevent vapor from forming in sections of the fuel system, which can cause driveability and stalling problems. The extra heat generated in climbing to higher altitudes plus the lower atmospheric pressure at higher altitudes combine to cause possible driveability problems as the vehicle goes to higher altitudes.

GASOLINE ADDITIVES

DYE Dye is usually added to gasoline at the distributor to help identify the grade and/or brand of fuel. Fuels are required to be colored using a fuel soluble dye in many countries. In the United States and Canada, diesel fuel used for off-road use and not taxed is required to be dyed red for identification. Gasoline sold for off-road use in Canada is dyed purple.

OXYGENATED FUEL ADDITIVES **Oxygenated fuels** contain oxygen in the molecule of the fuel itself. Examples of oxygenated fuels include the following:

- **Methyl tertiary butyl ether (MTBE).** This fuel is manufactured by means of the chemical reaction of methanol and isobutylene. Unlike methanol, MTBE does not increase the volatility of the fuel, and is not as sensitive to water as are other alcohols. The maximum allowable volume level, according to the EPA, is 15% but is currently being phased out due to health concerns, as well as MTBE contamination of drinking water if spilled from storage tanks.

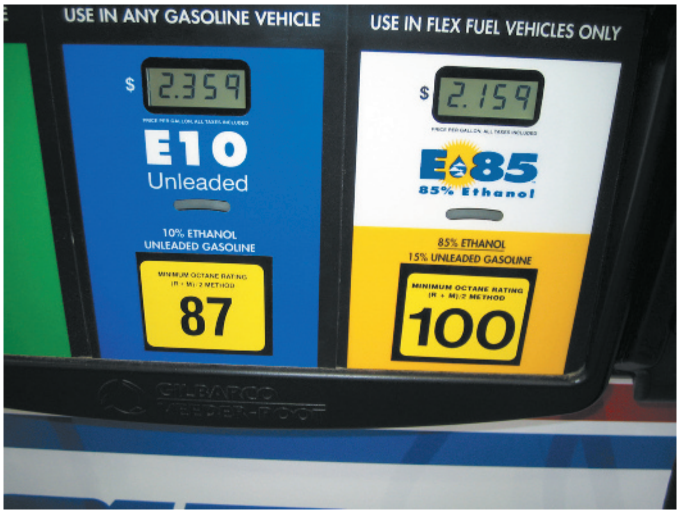

USE IN ANY GASOLINE VEHICLE
USE IN FLEX FUEL VEHICLES ONLY
$ 2.359
$ 2.159
E10
Unleaded
10% ETHANOL UNLEADED GASOLINE
E85
85% Ethanol
85% ETHANOL 15% UNLEADED GASOLINE
MINIMUM OCTANE RATING (R + M)/2 METHOD
87
100

FIGURE 67–10 This fuel pump indicates that the gasoline is blended with 10% ethanol (ethyl alcohol) and can be used in any gasoline vehicle. E85 contains 85% ethanol and can only be used in vehicles specifically designed to use it.

- **Tertiary-amyl methyl ether (TAME).** This fuel contains an oxygen atom bonded to two carbon atoms, and is added to gasoline to provide oxygen to the fuel. It is slightly soluble in water, very soluble in ethers and alcohol, and soluble in most organic solvents including hydrocarbons.
- **Ethyl tertiary butyl ether (ETBE).** This fuel is derived from ethanol. The maximum allowable volume level is 17.2%. The use of ETBE is the cause of much of the odor from the exhaust of vehicles if using reformulated gasoline, as mandated for use in some parts of the country.
- **Ethanol.** Also called *ethyl alcohol,* **ethanol** is drinkable alcohol and is usually made from grain. Adding 10% ethanol (ethyl alcohol or grain alcohol) increases the (R + M) ÷ 2 octane rating by three points.

The alcohol added to the base gasoline, however, also raises the volatility of the fuel about 0.5 PSI. Most automobile manufacturers permit up to 10% ethanol if driveability problems are not experienced.

The oxygen content of a 10% blend of ethanol in gasoline, called **E10**, is 3.5% oxygen by weight. ● **SEE FIGURE 67–10**.

TESTING GASOLINE FOR ALCOHOL CONTENT

Take the following steps when testing gasoline for alcohol content:

STEP 1 Pour suspect gasoline into a graduated cylinder.

STEP 2 Carefully fill the graduated cylinder to the 90 mL mark.

STEP 3 Add 10 mL of water to the graduated cylinder by counting the number of drops from an eyedropper.

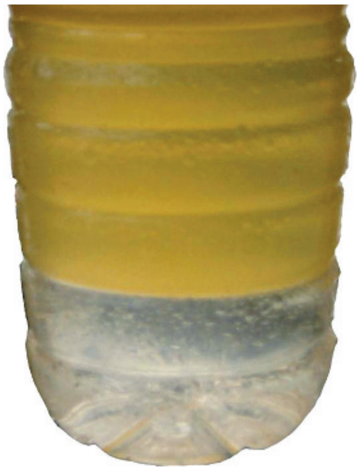


FIGURE 67–11 A container with gasoline containing water and alcohol. Notice the separation line where the alcohol–water mixture separated from the gasoline and sank to the bottom.

FREQUENTLY ASKED QUESTION

What Is Meant by “Phase Separation”?

All alcohols absorb water, and the alcohol–water mixture can separate from the gasoline and sink to the bottom of the fuel tank. This process is called phase separation. To help avoid engine performance problems, try to keep at least a quarter tank of fuel at all times, especially during seasons when there is a wide temperature span between daytime highs and nighttime lows. These conditions can cause moisture to accumulate in the fuel tank as a result of condensation of the moisture in the air. Keeping the fuel tank full reduces the amount of air and moisture in the tank. ● **SEE FIGURE 67–11**.

FREQUENTLY ASKED QUESTION

Is Water Heavier than Gasoline?

Yes. Water weighs about 8 lb per gallon, whereas gasoline weighs about 6 lb per gallon. The density as measured by specific gravity includes the following:

Water = 1.000 (the baseline for specific gravity)

Gasoline = 0.730 to 0.760

This means that any water that gets into the fuel tank will sink to the bottom.

WARNING

Do not smoke or run the test around sources of ignition!

STEP 4 Put the stopper in the cylinder and shake vigorously for one minute. Relieve built-up pressure by occasionally removing the stopper. Alcohol dissolves in water and will drop to the bottom of the cylinder.

STEP 5 Place the cylinder on a flat surface and let it stand for two minutes.

STEP 6 Take a reading near the bottom of the cylinder at the boundary between the two liquids.

STEP 7 For percentage of alcohol in gasoline, subtract 10 to get the percentage.

For example,

The reading is 20 mL: 20 − 10 = 10% alcohol

If the increase in volume is 0.2% or less, it may be assumed that the test gasoline contains no alcohol. ● **SEE FIGURE 67–12**.

Alcohol content can also be checked using an electronic tester. See the photo sequence at the end of the chapter.

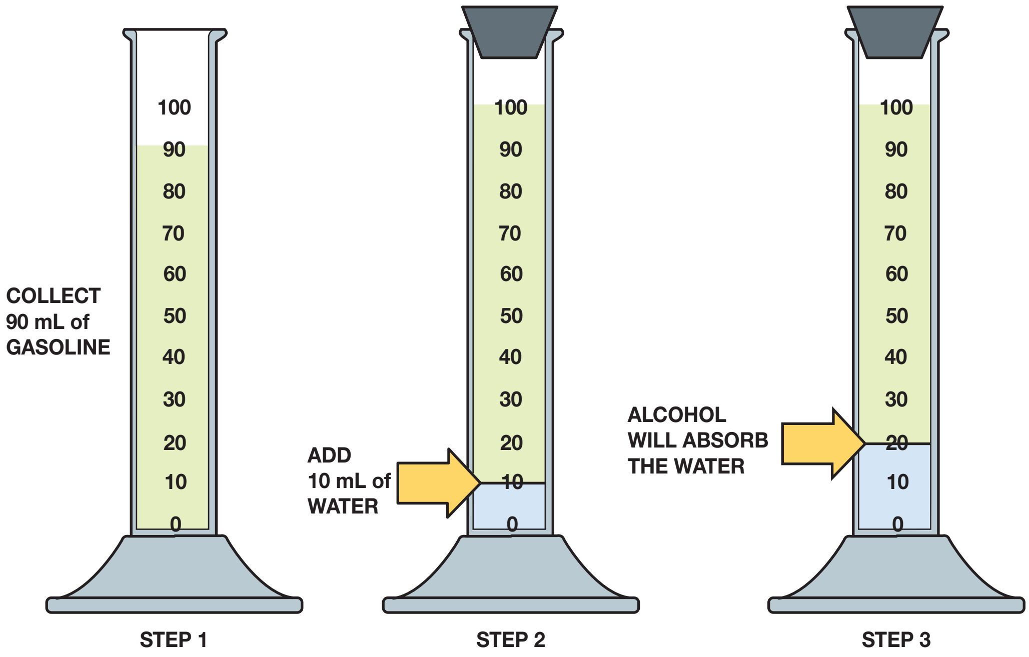


FIGURE 67–12 Checking gasoline for alcohol involves using a graduated cylinder and adding water to check if the alcohol absorbs the water.

GENERAL GASOLINE RECOMMENDATIONS

The fuel used by an engine is a major expense in the operation cost of the vehicle. The proper operation of the engine depends on clean fuel of the proper octane rating and vapor pressure for the atmospheric conditions.

To help ensure proper engine operation and keep fuel costs to a minimum, follow these guidelines:

1. Purchase fuel from a busy station to help ensure that it is fresh and less likely to be contaminated with water or moisture.
2. Keep the fuel tank above one-quarter full, especially during seasons in which the temperature rises and falls by more than 20°F between daytime highs and nighttime lows. This helps to reduce condensed moisture in the fuel tank and could prevent gas line freeze-up in cold weather.

NOTE: Gas line freeze-up occurs when the water in the gasoline freezes and forms an ice blockage in the fuel line.

3. Do not purchase fuel with a higher octane rating than is necessary. Try using premium high-octane fuel to check for operating differences. Most newer engines are equipped with a detonation (knock) sensor that signals the vehicle computer to retard the ignition timing when spark knock occurs. Therefore, an operating difference may not be noticeable to the driver when using a low-octane fuel, except for a decrease in power and fuel economy. In other words, the engine with a knock sensor will tend to operate knock free on regular fuel, even if premium, higher octane fuel is specified. Using premium fuel may result in more power and greater fuel economy. The increase in fuel economy, however, would have to be substantial to justify the increased cost of high-octane premium fuel. Some drivers find a good compromise by using midgrade (plus) fuel to benefit from the engine power and fuel economy gains without the cost of using premium fuel all the time.
4. Try to avoid using gasoline with alcohol in warm weather, even though many alcohol blends do not affect engine driveability. If warm-engine stumble, stalling, or rough idle occurs, change brands of gasoline.
5. Do not purchase fuel from a retail outlet when a tanker truck is filling the underground tanks. During the refilling procedure, dirt, rust, and water may be stirred up in the underground tanks. This undesirable material may be pumped into your vehicle's fuel tank.
6. Do not overfill the gas tank. After the nozzle clicks off, add just enough fuel to round up to the next dime. Adding additional gasoline will cause the excess to be drawn into the charcoal canister. This can lead to engine flooding and excessive exhaust emissions.
7. Be careful when filling gasoline containers. Always fill a gas can on the ground to help prevent the possibility of static electricity buildup during the refueling process. ● **SEE FIGURE 67–14**.

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TOP TIER® Detergent Gasoline

FIGURE 67–13 Not all top-tier gas stations mention that they are top-tier like this station. For more information and the list of top-tier gasoline stations, visit www.toptiergas.com.

FREQUENTLY ASKED QUESTION

What Is "Top-Tier" Gasoline?

Top-tier gasoline has specific standards for quality, including enough detergent to keep all intake valves clean. Four automobile manufacturers (BMW, General Motors, Honda, and Toyota) developed the standards. Top-tier gasoline exceeds the quality standards developed by the **World Wide Fuel Charter (WWFC)** in 2002 by vehicle and engine manufacturers. The gasoline companies that agreed to make fuel that matches or exceeds the standards as a top-tier fuel include ChevronTexaco, Shell, and ConocoPhillips. ● **SEE FIGURE 67–13**.

TECH TIP

The Sniff Test

Problems can occur with stale gasoline from which the lighter parts of the gasoline have evaporated. Stale gasoline usually results in a no-start situation. If stale gasoline is suspected, sniff it. If it smells rancid, replace it with fresh gasoline.

NOTE: If storing a vehicle, boat, or lawnmower over the winter, put some gasoline stabilizer into the gasoline to reduce the evaporation and separation that can occur during storage. Gasoline stabilizer is frequently available at most automotive parts stores.

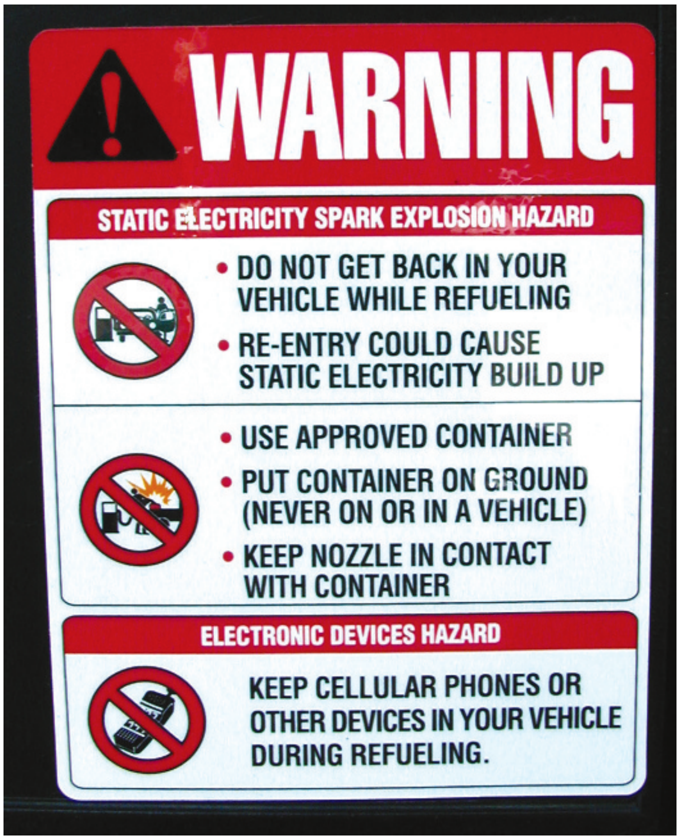

WARNING
STATIC ELECTRICITY SPARK EXPLOSION HAZARD
• DO NOT GET BACK IN YOUR VEHICLE WHILE REFUELING
• RE-ENTRY COULD CAUSE STATIC ELECTRICITY BUILD UP
• USE APPROVED CONTAINER
• PUT CONTAINER ON GROUND (NEVER ON OR IN A VEHICLE)
• KEEP NOZZLE IN CONTACT WITH CONTAINER
ELECTRONIC DEVICES HAZARD
KEEP CELLULAR PHONES OR OTHER DEVICES IN YOUR VEHICLE DURING REFUELING.

FIGURE 67–14 Many service stations have signs posted warning customers to place plastic fuel containers on the ground while filling. If placed in a trunk or pickup truck bed equipped with a plastic liner, static electricity could buildup during fueling and discharge from the container to the metal nozzle, creating a spark and possible explosion. Some service stations have warning signs not to use cell phones while fueling to help avoid the possibility of an accidental spark creating a fire hazard.

FREQUENTLY ASKED QUESTION

Why Should I Keep the Fuel Gauge above One-Quarter Tank?

The fuel pickup inside the fuel tank can help keep water from being drawn into the fuel system unless water is all that is left at the bottom of the tank. Over time, moisture in the air inside the fuel tank can condense, causing liquid water to drop to the bottom of the fuel tank. (Recall that water is heavier than gasoline—about 8 pound per gallon for water and about 6 pound per gallon for gasoline.) If alcohol-blended gasoline is used, the alcohol can absorb the water and the alcohol–water combination can be burned inside the engine. However, when water combines with alcohol, a separation layer occurs between the gasoline at the top of the tank and the alcohol–water combination at the bottom. When the fuel level is low, the fuel pump will draw from this concentrated level of alcohol and water. Because alcohol and water do not burn as well as pure gasoline, severe driveability problems can occur such as stalling, rough idle, hard starting, and missing.

TECH TIP

Do Not Overfill the Fuel Tank

Gasoline fuel tanks have an expansion volume area at the top. The volume of this expansion area is equal to 10% to 15% of the volume of the tank. This area is normally not filled with gasoline, but rather is designed to provide a place for the gasoline to expand into, if the vehicle is parked in the hot sun and the gasoline expands. This prevents raw gasoline from escaping from the fuel system. Valves in the evaporative system control how much vapor is sent to the charcoal cannister.

This volume area could be filled with gasoline if the fuel is slowly pumped into the tank. Since it can hold an extra 10% (2 gallons in a 20 gallon tank), some people deliberately try to fill the tank completely. When this expansion volume is filled, liquid fuel (rather than vapors) can be drawn into the charcoal canister. When the purge valve opens, liquid fuel can be drawn into the engine, causing an excessively rich air–fuel mixture. Not only can this liquid fuel harm vapor recovery parts, but overfilling the gas tank could also cause the vehicle to fail an exhaust emission test, particularly during an enhanced test when the tank could be purged while on the rollers.

E85

WHAT IS E85? Vehicle manufacturers have available vehicles that are capable of operating on gasoline plus ethanol or a combination of gasoline and ethanol called **E85**, composed of 85% ethanol and 15% gasoline. Ethanol is also called **ethyl alcohol** or **grain alcohol** because it is usually made from grain and is the type of alcohol found in alcoholic drinks such as beer, wine, and distilled spirits like whiskey. Ethanol is composed of two carbon atoms and six hydrogen atoms with one added oxygen atom. ● **SEE FIGURE 67–15**.

Pure ethanol has an octane rating of about 113. E85, which contains 35% oxygen by weight, has an octane rating of 100 to 105. This compares to a regular unleaded gasoline which has a rating of 87. ● **SEE FIGURE 67–16**.

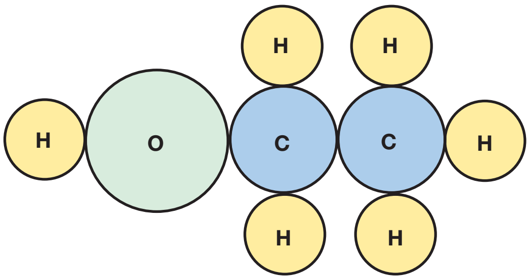


FIGURE 67–15 The ethanol molecule showing two carbon atoms, six hydrogen atoms, and one oxygen atom.

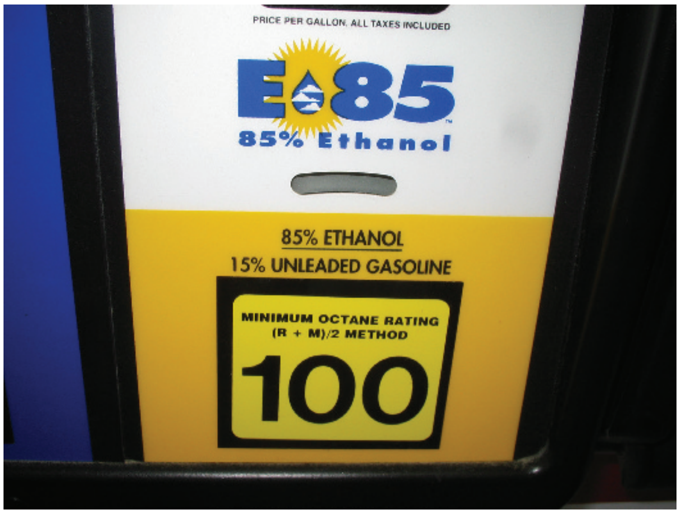


FIGURE 67–16 E85 has 85% ethanol mixed with 15% gasoline.

TECH TIP

Purchase a Flex Fuel Vehicle

If purchasing a new or used vehicle, try to find a flex fuel vehicle. Even though you may not want to use E85, a flex fuel vehicle has a more robust fuel system than a conventional fuel system designed for gasoline or E10. The enhanced fuel system components and materials usually include

- Stainless steel fuel rail
- Graphite commutator bars instead of copper in the fuel pump motor (ethanol can oxidize into acetic acid, which can corrode copper)
- Diamondlike carbon (DLC) corrosion-resistant fuel injectors
- Alcohol resistant O-rings and hoses

The cost of a flex fuel vehicle compared with the same vehicle designed to operate on gasoline is a no-cost or a low-cost option.

NOTE: The octane rating of E85 depends on the exact percentage of ethanol used, which can vary from 81% to 85%. It also depends on the octane rating of the gasoline used to make E85.

HEAT ENERGY OF E85 E85 has less heat energy than gasoline.

Gasoline: 114,000 BTUs per gallon

E85: 87,000 BTUs per gallon

This means that the fuel economy is reduced by 20% to 30% if E85 is used instead of gasoline.

Example: A Chevrolet Tahoe 5.3-liter V-8 with an automatic transmission has an EPA rating using gasoline of 15 mpg in the city and 20 mpg on the highway. If this same vehicle is fueled with E85, the EPA fuel economy rating drops to 11 mpg in the city and 15 mpg on the highway.

ALTERNATIVE FUEL VEHICLES

The 15% gasoline in the E85 blend helps the engine start, especially in cold weather. Vehicles equipped with this capability are commonly referred to as the following:

- **Alternative fuel vehicles (AFVs)**
- **Flex fuels**
- **Flexible fuel vehicles (FFVs)**

Using E85 in a flex fuel vehicle can result in a power increase of about 5%. For example, an engine rated at 200 hp using gasoline or E10 could produce 210 hp if using E85.

NOTE: E85 may test as containing less than 85% ethanol if tested because it is often blended according to outside temperature. A lower percentage of ethanol with a slightly higher percentage of gasoline helps engines start in cold climates.

These vehicles are equipped with an electronic sensor in the fuel supply line that detects the presence and percentage of ethanol. The PCM then adjusts the fuel injector on-time and ignition timing to match the needs of the fuel being used.

E85 contains less heat energy, and therefore will use more fuel, but the benefits include a lower cost of the fuel and less environmental impact associated with using an oxygenated fuel.

E85 vehicles use fuel system parts designed to withstand the additional alcohol content, modified driveability programs that adjust fuel delivery and timing to compensate for the various percentages of ethanol fuel, and a **fuel compensation sensor** that measures both the percentage of ethanol blend and the temperature of the fuel. This sensor is also called a **variable fuel sensor**. ● **SEE FIGURES 67–17 AND 67–18**.

E85 FUEL SYSTEM REQUIREMENTS Most E85 vehicles are very similar to non-E85 vehicles. Fuel system components may be redesigned to withstand the effects of higher concentrations of ethanol. In addition, since the stoichiometric point for ethanol is 9:1 instead of 14.7:1 as for gasoline, the air–fuel mixture has to be adjusted for the percentage of ethanol present in the fuel tank.

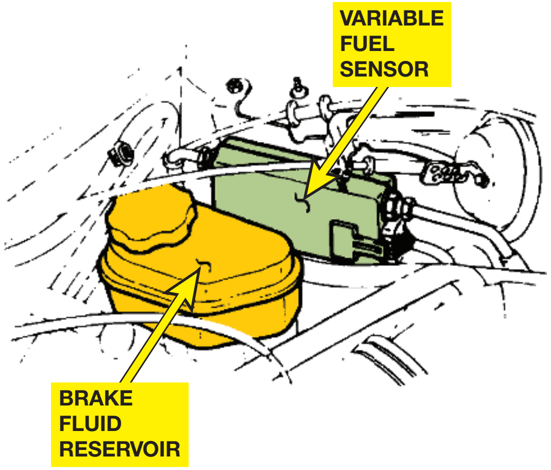


FIGURE 67–17 The location of the variable fuel sensor can vary, depending on the make and model of vehicle, but it is always in the fuel line between the fuel tank and the fuel injectors.

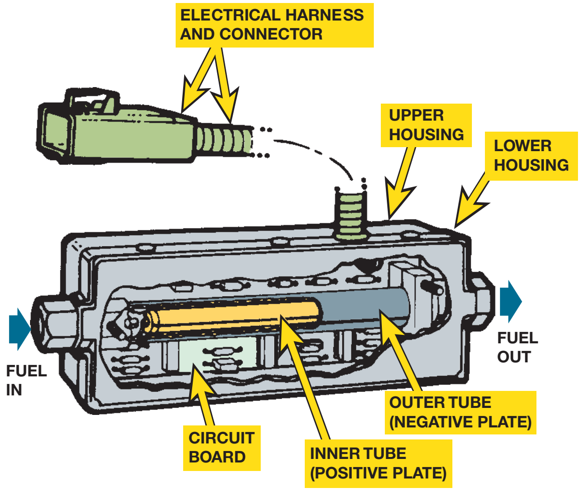

ELECTRICAL HARNESS AND CONNECTOR
UPPER HOUSING
LOWER HOUSING
FUEL IN
FUEL OUT
OUTER TUBE (NEGATIVE PLATE)
CIRCUIT BOARD
INNER TUBE (POSITIVE PLATE)

FIGURE 67–18 A cutaway view of a typical variable fuel sensor.

FREQUENTLY ASKED QUESTION

How Does a Sensorless Flex Fuel System Work?

Many General Motors flex fuel vehicles do not use a fuel compensation sensor and instead use the oxygen sensor to detect the presence of the lean mixture and the extra oxygen in the fuel.

The powertrain control module (PCM) then adjusts the injector pulse width and the ignition timing to optimize engine operation to the use of E85. This type of vehicle is called a **virtual flexible fuel vehicle (V-FFV)**. It can operate on pure gasoline or blends up to 85% ethanol.

FREQUENTLY ASKED QUESTION

How Long Can Oxygenated Fuel Be Stored before All of the Oxygen Escapes?

The oxygen in oxygenated fuels, such as E10 and E85, is not in a gaseous state like the CO_2 in soft drinks. The oxygen is part of the molecule of ethanol or other oxygenates and does not bubble out of the fuel. Oxygenated fuels, like any fuel, have a shelf life of about 90 days.

The benefits of E85 vehicles include the following:

- Reduced pollution
- Less CO_2 production
- Less dependence on imported oil

FLEX FUEL VEHICLE IDENTIFICATION Flexible fuel vehicles (FFVs) can be identified by the following:

- Emblems on the side, front, and/or rear of the vehicle
- Yellow fuel cap showing E85/gasoline (● **SEE FIGURE 67–19**.)
- Vehicle emission control information (VECI) label under the hood (● **SEE FIGURE 67–20**.)
- Vehicle identification number (VIN)

NOTE: For additional information on E85 and for the location of E85 stations in your area, go to www.e85fuel.com.

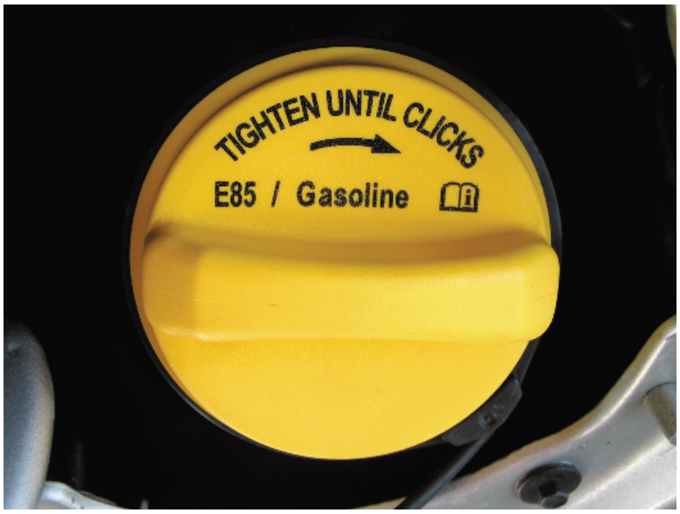
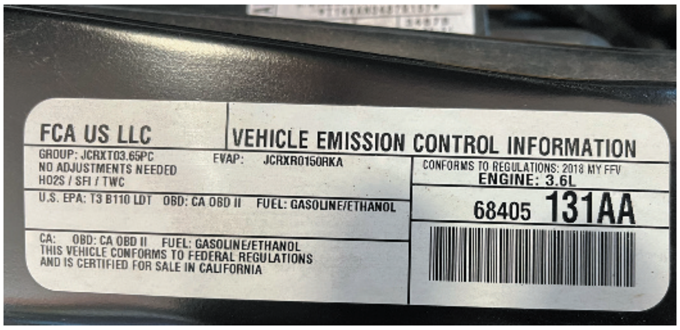


FIGURE 67–19 A flex fuel vehicle often has a yellow gas cap, which is labeled E85/gasoline.



FCA US LLC
VEHICLE EMISSION CONTROL INFORMATION
GROUP: JCRXT03.65PC EVAP: JCRXR0150RKA
NO ADJUSTMENTS NEEDED
HO2S / SFI / TWC
CONFORMS TO REGULATIONS: 2018 MY FFV
ENGINE: 3.6L
U.S. EPA: T3 B110 LDT OBD: CA OBD II FUEL: GASOLINE/ETHANOL
68405 131AA
CA: OBD: CA OBD II FUEL: GASOLINE/ETHANOL
THIS VEHICLE CONFORMS TO FEDERAL REGULATIONS
AND IS CERTIFIED FOR SALE IN CALIFORNIA

FIGURE 67–20 This flexible fuel vehicle (FFV) vehicle emission control information (VECI) sticker located under the hood indicates that it can operate on either gasoline or ethanol.

PROPANE

Propane is the most widely used of all the alternative fuels mainly because of its use in fleets, which utilize a central refueling station. Propane is a by-product of petroleum refining of natural gas. In order to liquefy the fuel, it is stored in strong tanks at about 300 PSI (2,000 kPa). When sold as a fuel, it is also known as **liquified petroleum gas (LPG)** or **LP gas** because the propane is often mixed with about 10% of other gases, including the following:

- Butane
- Propylene
- Butylenes
- Mercaptan, to give the colorless and odorless propane a smell

Propane is nontoxic, but if inhaled can cause asphyxiation through lack of oxygen. Propane is heavier than air and lays near the floor if released into the atmosphere. Propane is commonly used in forklifts and other equipment located inside warehouses and factories because the exhaust from the engine using propane is not harmful. The heating value of propane is less than that of gasoline; therefore, more is required, which reduces the fuel economy. ● **SEE FIGURE 67–21**.

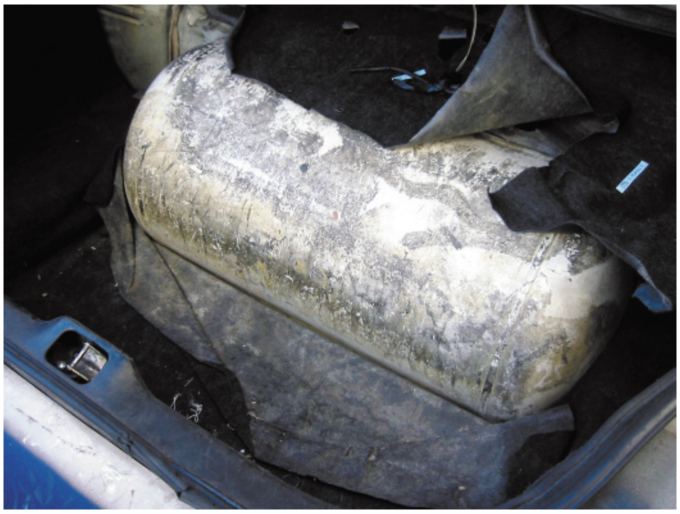


FIGURE 67–21 Propane fuel storage tank in the trunk of a Ford taxi.

COMPRESSED NATURAL GAS

CNG VEHICLE DESIGN Another alternative fuel that is often used in fleet vehicles is **compressed natural gas (CNG)**. Vehicles using this fuel are often referred to as **natural gas vehicles (NGVs)**. Look for the blue CNG label on vehicles designed to operate on compressed natural gas. ● **SEE FIGURE 67–22**.

Because natural gas must be compressed to 3,000 PSI (20,000 kPa) or more, the weight and cost of the storage container are major factors when it comes to preparing a vehicle to run on CNG. The tanks needed for CNG are typically constructed of 0.5 inch (3 mm) thick aluminum reinforced with fiberglass. ● **SEE FIGURE 67–23**.

The octane rating of CNG is about 130 and the cost per gallon is roughly half of the cost of gasoline. However, the heat value of CNG is also less, and therefore more is required to produce the same power; and the miles per gallon is less.

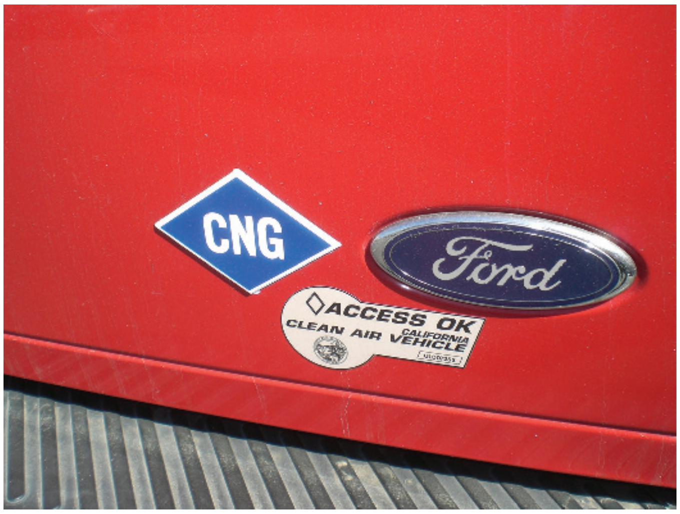


FIGURE 67–22 The blue sticker on the rear of this vehicle indicates that it is designed to use compressed natural gas. This Ford truck also has a sticker that allows it to be driven in the high occupancy vehicle (HOV) lane, even if there is just the driver because it is a CNG vehicle.

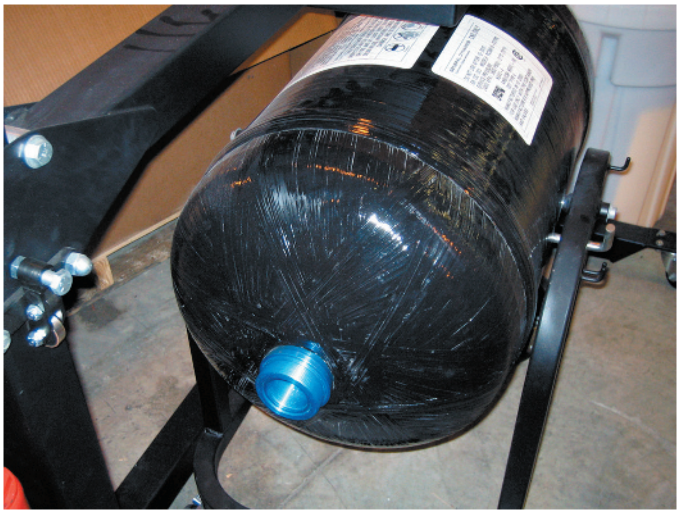


FIGURE 67–23 A CNG storage tank from a Honda Civic GX shown with the fixture used to support it while it is being removed or installed in the vehicle. Honda specifies that three technicians be used to remove or install the tank through the rear door of the vehicle due to the size and weight of the tank.

FREQUENTLY ASKED QUESTION

What Is the Amount of CNG Equal to in Gasoline?

To achieve the amount of energy of 1 gallon of gasoline, 122 ft^3 of compressed natural gas (CNG) is needed. While the octane rating of CNG is much higher than gasoline (130 octane), using CNG instead of gasoline in the same engine would result in a 10% to 20% reduction of power due to the lower heat energy that is released when CNG is burned in the engine.

CNG COMPOSITION Compressed natural gas is a blend of the following:

- Methane
- Propane
- Ethane
- N-butane
- Carbon dioxide
- Nitrogen

Once it is processed, compressed natural gas is at least 93% methane. Natural gas is nontoxic, odorless, and colorless in its natural state. It is odorized during processing, using ethyl mercaptan (“skunk”), to allow for easy leak detection. Natural gas is lighter than air and will rise when released into the air. Since CNG is already a vapor, it does not need heat to vaporize before it will burn, which improves cold start-up and results in lower emissions during cold operation. However, because it is already in a gaseous state, it displaces some of the air charge in the intake manifold, leading to a 10% reduction in engine power as compared to an engine operating on gasoline. Natural gas also burns slower than gasoline; therefore, the ignition timing must be advanced

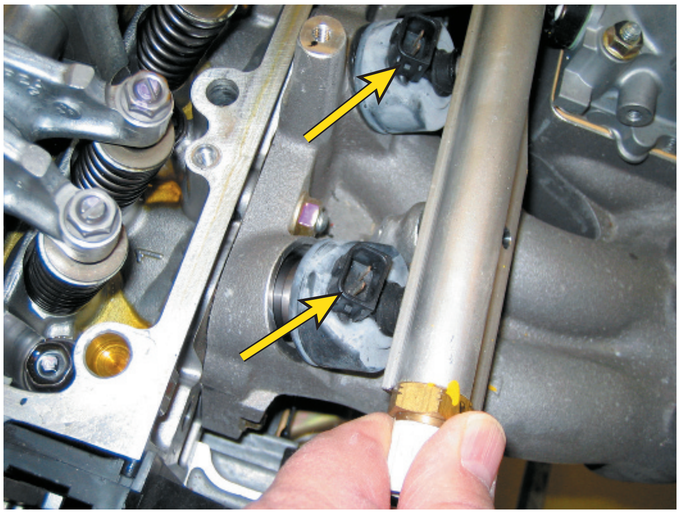


FIGURE 67–24 The fuel injectors used on this Honda Civic GX CNG engine are designed to flow gaseous fuel instead of liquid fuel and cannot be interchanged with any other type of injector.

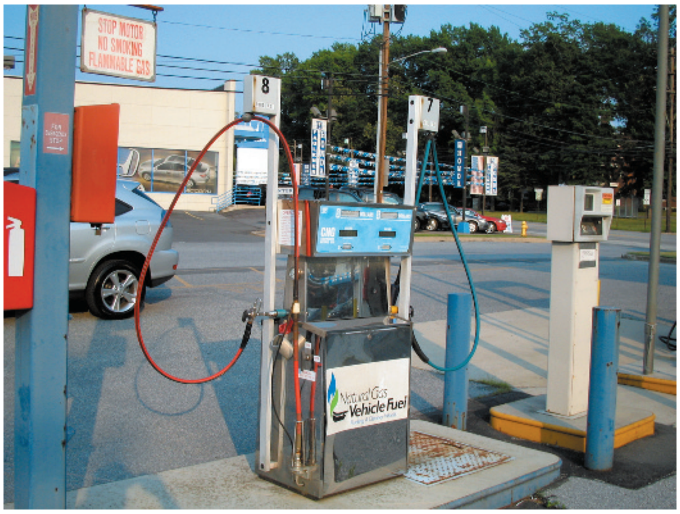


FIGURE 67–25 This CNG pump is capable of supplying compressed natural gas at either 3,000 PSI or 3,600 PSI. The price per gallon is higher for the higher pressure.

more when the vehicle operates on natural gas. The stoichiometric ratio, the point at which all the air and fuel is used or burned, is 16.5:1 compared to 14.7:1 for gasoline. This means that more air is required to burn 1 pound of natural gas than is required to burn 1 pound of gasoline. ● **SEE FIGURE 67–24**.

The CNG engine is designed to include

- Increased compression ratio
- Strong pistons and connecting rods
- Heat-resistant valves
- Fuel injectors designed for gaseous fuel instead of liquid fuel

CNG FUEL SYSTEMS When completely filled, the CNG tank has 3,600 PSI of pressure in the tank. When the ignition is turned on, the alternate fuel electronic control unit activates the high-pressure lock-off, which allows high-pressure gas to pass to the high-pressure regulator.

- The high-pressure regulator reduces the high-pressure CNG to approximately 150 to 170 PSI and sends it to the low-pressure lock-off. The low-pressure lock-off is also controlled by the alternate fuel electronic control unit and is activated at the same time as the high-pressure lock-off.
- From the low-pressure lock-off, the CNG is directed to the low-pressure regulator. This is a two-stage regulator that first reduces the pressure to approximately 4 to 6 PSI in the first stage and then to about 0.5 PSI in the second stage.
- From here, the low-pressure gas is delivered to the gas mass sensor/mixture control valve. This valve controls the air–fuel mixture. The CNG gas distributor adapter then delivers the gas to the intake stream.

CNG vehicles are designed for fleet use that usually have their own refueling capabilities. One of the drawbacks to using CNG is the time that it takes to refuel a vehicle. The ideal method of refueling is the slow-fill method. The slow filling method compresses the natural gas as the tank is being fueled. This method ensures that the tank will receive a full charge of CNG; however, this method can take three to five hours to accomplish. If more than one vehicle needs filling, the facility will need multiple CNG compressors to refuel the vehicles.

⚠ WARNING

Do not smoke or have an open flame in the area when working around or refueling any vehicle.

There are three commonly used CNG refilling station pressures:

P24: 2,400 PSI
P30: 3,000 PSI
P36: 3,600 PSI

Try to find and use a station with the highest refilling pressure. Filling at lower pressures will result in less compressed natural gas being installed in the storage tank, thereby reducing the driving range. ● **SEE FIGURE 67–25**.

The fast-fill method uses CNG that is already compressed. However, as the CNG tank is filled rapidly, the internal temperature of the tank will rise, which causes a rise in tank pressure. Once the temperature drops in the CNG tank, the pressure in the tank also drops, resulting in an incomplete charge in the CNG tank. This refueling method may take only about five minutes, but it will result in an incomplete charge to the CNG tank, reducing the driving range. ● **SEE CHART 67–2** for a comparison of the most frequently used alternative fuels.

DIESEL FUEL

FEATURES OF DIESEL FUEL Diesel fuel must meet an entirely different set of standards than gasoline. Diesel fuel contains 12% more heat energy than the same amount of gasoline. The fuel in a diesel engine is not ignited with a spark, but is ignited by the heat generated by high compression. The pressure of compression (400 to 700 PSI, or 2,800 to 4,800 kPa) generates temperatures of 1,200°F to 1,600°F (700°C to 900°C), which speeds the preflame reaction to start the ignition of fuel injected into the cylinder.

ALTERNATE FUEL COMPARISON CHART

CHARACTERISTIC	PROPANE	CNG	ETHANOL	REGULAR UNLEADED GAS
Octane	104	130	100	87–93
BTU per gallon	91,000	NA	83,000	114,000–125,000
Gallon equivalent	1.15	122 $ft^3 = 1$ gallon of gasoline	1.5	1
Onboard fuel storage	Liquid	Gas	Liquid	Liquid
Miles/gallon as compared to gas	85%	Varies with pressure	70%	100%
Relative tank size required to yield driving range equivalent to gas	Tank is 1.25 times larger	Tank is 3.5 times larger	Tank is 1.5 times larger	
Pressure	200 PSI	3,000–3,600 PSI	NA	NA
Cold weather capability	Good	Good	Poor	Good
Vehicle power	5%–10% power loss	10%–20% power loss	5% power increase	Standard
Toxicity	Nontoxic	Nontoxic	Toxic	Toxic
Corrosiveness	Noncorrosive	Noncorrosive	Corrosive	Minimally corrosive
Source	Natural gas/ petroleum refining	Natural gas/ crude oil	Sugar and starch crops/biomass	Crude oil

CHART 67–2

The characteristics of alternative fuels compared to regular unleaded gasoline show that all have advantages and disadvantages.

DIESEL FUEL REQUIREMENTS All diesel fuel must have the following characteristics:

- **Cleanliness.** It is imperative that the fuel used in a diesel engine be clean and free from water. Unlike the case with gasoline engines, the fuel is the lubricant and coolant for the diesel injector pump and injectors. Good-quality diesel fuel contains additives, such as oxidation inhibitors, detergents, dispersants, rust preventatives, and metal deactivators.
- **Low-temperature fluidity.** Diesel fuel must be able to flow freely at all expected ambient temperatures. One specification for diesel fuel is its “pour point,” which is the temperature below which the fuel will stop flowing.
- **Cloud point.** Another concern with diesel fuel at lower temperatures concerns **cloud point**, the low-temperature point when the waxes present in most diesel fuels tend to form crystals that can clog the fuel filter. Most diesel fuel suppliers distribute fuel with the proper pour point and cloud point for the climate conditions of the area.

CETANE NUMBER The cetane number for diesel fuel is the opposite of the octane number for gasoline. The **cetane number** is a measure of the ease with which the fuel can be ignited. The cetane rating of the fuel determines, to a great extent, its ability to start the engine at low temperatures and to provide smooth warmup and even combustion. The cetane rating of diesel fuel should be between 45 and 50. The higher the cetane rating, the more easily the fuel is ignited.

SULFUR CONTENT The sulfur content of diesel fuel is very important to the life of the engine. Sulfur in the fuel creates sulfuric acid during the combustion process, which can damage engine components and cause piston ring wear. Federal regulations are getting extremely tight on sulfur content to less than 15 parts per million (ppm). High-sulfur fuel contributes to acid rain.

DIESEL FUEL COLOR Diesel fuel intended for use on the streets and highways is either clear or green. Diesel fuel to be used on farms and off-road use is dyed red. ● **SEE FIGURE 67–26.**

GRADES OF DIESEL FUEL ASTM also classifies diesel fuel by volatility (boiling range) into the following grades:

Grade 1	This grade of diesel fuel has the lowest boiling point and the lowest cloud and pour points, as well as a lower BTU content (less heat per pound of fuel). As a result, grade 1 is suitable for use during low-temperature (winter) operation. Grade 1 produces less heat per pound of fuel compared to grade 2, and may be specified for use in diesel engines involved in frequent changes in load and speed, such as those found in city buses and delivery trucks.
Grade 2	This grade has a higher boiling point, cloud point, and pour point as compared with grade 1. It is usually specified where constant speed and high loads are encountered, such as in long-haul trucking and automotive diesel applications.

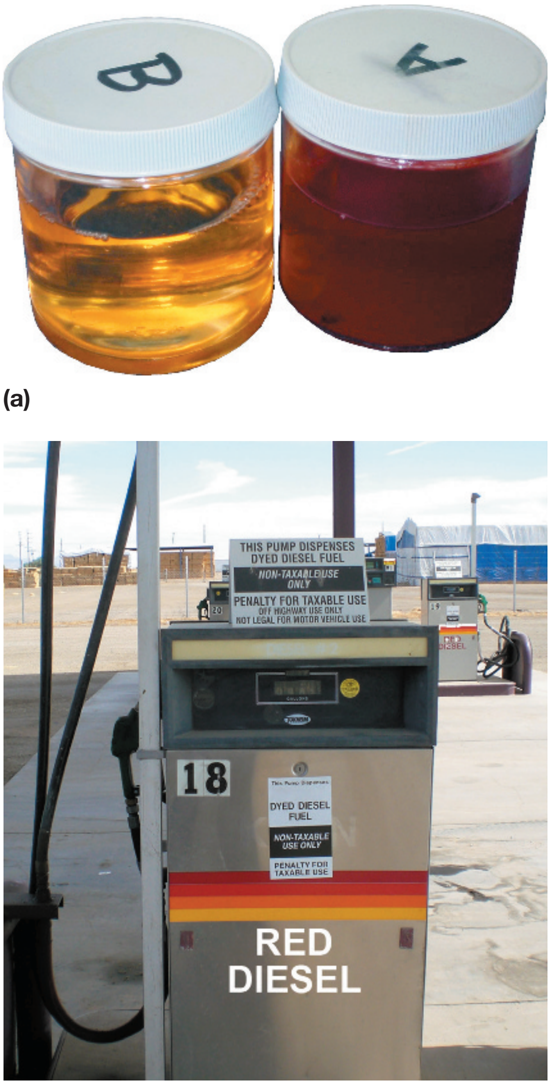


FIGURE 67–26 (a) Regular diesel fuel on the left has a clear or greenish tint, whereas fuel for off-road use is tinted red for identification. (b) This fuel pump in a farming area clearly states the red diesel fuel is for off-road use only because it is not taxed.

DIESEL FUEL SPECIFIC GRAVITY TESTING The density of diesel fuel should be tested whenever there is a driveability concern. The density or specific gravity of diesel fuel is measured in units of **API gravity**, which is an arbitrary scale expressing the gravity or density of liquid petroleum products devised jointly by the American Petroleum Institute and the National Bureau of Standards. The measuring scale is calibrated in terms of degrees API. Oil with the least specific gravity has the highest API gravity. The formula for determining API gravity is as follows:

$$\textbf{Degrees API gravity} = (141.5 \div \textbf{Specific gravity at } 60^\circ\text{F}) - 131.5$$

The normal API gravity for grade 1 diesel fuel is 39 to 44 (typically 40). The normal API gravity for grade 2 diesel fuel is 30 to 39 (typically 35). A hydrometer calibrated in API gravity units should be used to test diesel fuel. ● **SEE FIGURE 67–27**.

ULTRA-LOW-SULFUR DIESEL FUEL Diesel fuel is used in diesel engines and is usually readily available throughout the United States, Canada, and Europe, where many more cars are equipped with diesel engines. Diesel engines manufactured to 2007 or newer standards must use **ultra-low-sulfur diesel (ULSD)** fuel containing less than 15 ppm of sulfur compared to the older, low-sulfur specification of 500 ppm. The purpose of the lower sulfur amount in diesel fuel is to reduce emissions of sulfur oxides (SOx) and particulate matter (PM) from heavy-duty highway engines and vehicles that use diesel fuel. The emission controls used on 2007 and newer diesel engines require the use of ULSD for reliable operation.

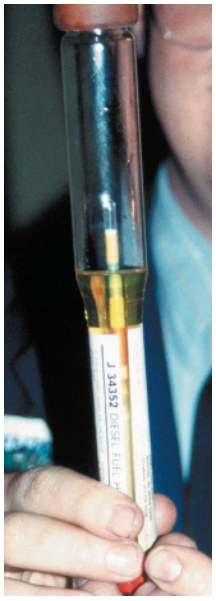


FIGURE 67–27 Testing the API viscosity of a diesel fuel sample using a hydrometer.

DIESEL FUEL ADDITIVES These types of additives include

Winter Conditioners—Winter conditioners are designed to reduce the **Cold Filter Plugging Point (CFPP)**. CFPP is lowest temperature at that a specified volume of diesel type of fuel can pass through a standardized filtration device in a specified time when cooled under certain conditions.

Multifunctional Conditioners—Many multifunctional additives increase the cetane rating of the fuel and helps keep injectors clean. By raising the cetane rating of the diesel fuel, engine power and fuel economy is improved. This type of additive is designed to be used year-round.

Microbicide—Microbes can grow in diesel fuel at the junction between the water and the diesel. Water is heavier than the diesel fuel and is near the bottom of the tank. Water in the fuel can be caused by condensation of moist air in the fuel tank and during transport and storage. A microbicide is designed to kill microorganisms including bacteria and fungi.

BIODIESEL

DEFINITION OF BIODIESEL **Biodiesel** is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant greases. Biodiesel refers to the pure fuel before blending with diesel fuel. ● **SEE FIGURE 67–28**.

Biodiesel blends are denoted as BXX, with the "XX" representing the percentage of biodiesel contained in the blend (i.e., **B20** is 20% biodiesel, 80% petroleum diesel). Blends of 5% biodiesel with 95% petroleum diesel, called **B5**, can generally be used in

FREQUENTLY ASKED QUESTION

I Thought Biodiesel Was Vegetable Oil?

Biodiesel is vegetable oil with the glycerin component removed by means of reacting the vegetable oil with a catalyst. The resulting hydrocarbon esters are 16 to 18 carbon atoms in length, almost identical to the petroleum diesel fuel atoms. This allows the use of biodiesel fuel in a diesel engine with no modifications needed. Biodiesel-powered vehicles do not need a second fuel tank, whereas vehicles powered with vegetable oil do.

There are three main types of fuel used in diesel engines:

- Petroleum diesel, a fossil hydrocarbon with a carbon chain length of about 16 carbon atoms
- Biodiesel, a hydrocarbon with a carbon chain length of 16 to 18 carbon atoms
- Vegetable oil, a triglyceride with a glycerin component joining three hydrocarbon chains of 16 to 18 carbon atoms each, called **straight vegetable oil (SVO)**

Other terms used when describing vegetable oil include the following:

- **Pure plant oil (PPO)**, a term most often used in Europe to describe SVO
- **Waste vegetable oil (WVO)**, which could include animal or fish oils from cooking
- **Used cooking oil (UCO)**, a term used when the oil may or may not be pure vegetable oil

Vegetable oil is not liquid enough at common ambient temperatures for use in a diesel engine fuel delivery system designed for the lower viscosity petroleum diesel fuel. Vegetable oil needs to be heated to obtain a similar viscosity to biodiesel and petroleum diesel. This means a heat source needs to be provided before the fuel can be used in a diesel engine. This is achieved by starting on petroleum diesel or biodiesel fuel until the engine heat can be used to sufficiently warm a tank containing the vegetable oil. It also requires purging the fuel system of vegetable oil with petroleum diesel or biodiesel fuel prior to stopping the engine to avoid the vegetable oil thickening and solidifying in the fuel system away from the heated tank. The use of vegetable oil in its natural state does, however, eliminate the need to remove the glycerin component.

Many vehicle and diesel engine fuel system suppliers permit the use of biodiesel fuel that is certified as meeting testing standards. None permit the use of vegetable oil in its natural state.

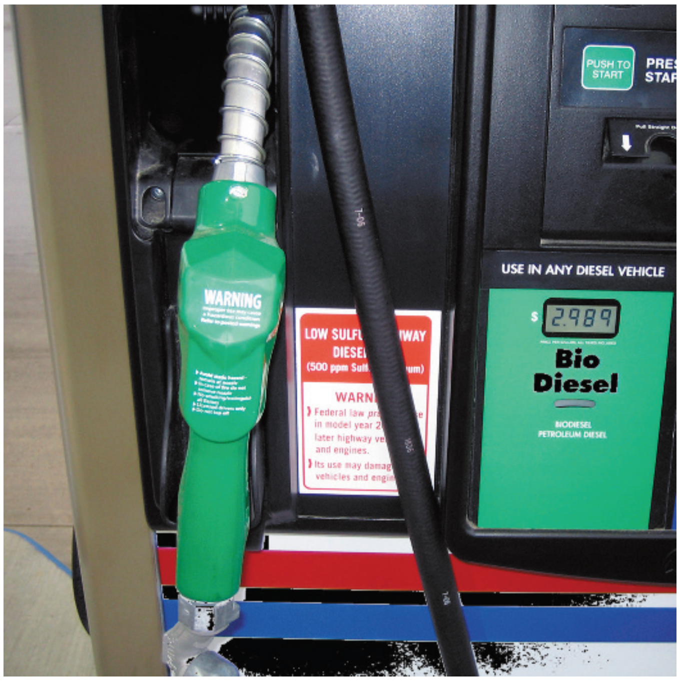


FIGURE 67–28 A biodiesel pump decal.

FUEL	NOZZLE DIAMETER	PUMP HANDLE COLOR (VARIES–NO ESTABLISHED STANDARD)
Gasoline	13/16 inch (21 mm)	Black, red, white, green, or blue
E10	13/16 inch (21 mm)	Black, red, white, green, or blue
E85	13/16 inch (21 mm)	Yellow or black
Diesel fuel	15/16 inch (24 mm)	Yellow, green, or black
Biodiesel	15/16 inch (24 mm)	Green
Truckstop diesel	1 1/4 or 1 1/2 inch (32 or 38 mm)	Varies

CHART 67–3

Fuel pump nozzle size is standardized except for use by over-the-road truckstops where high fuel volumes and speedy refills require larger nozzle sizes compared to passenger vehicle filling station nozzles.

FREQUENTLY ASKED QUESTION

What Are the Pump Nozzle Sizes?

Unleaded gasoline nozzles are smaller than those used for diesel fuel to help prevent fueling errors. However, it is still possible to fuel a diesel vehicle with gasoline.

● **SEE CHART 67–3** for the sizes and colors used for fuel pump nozzles.

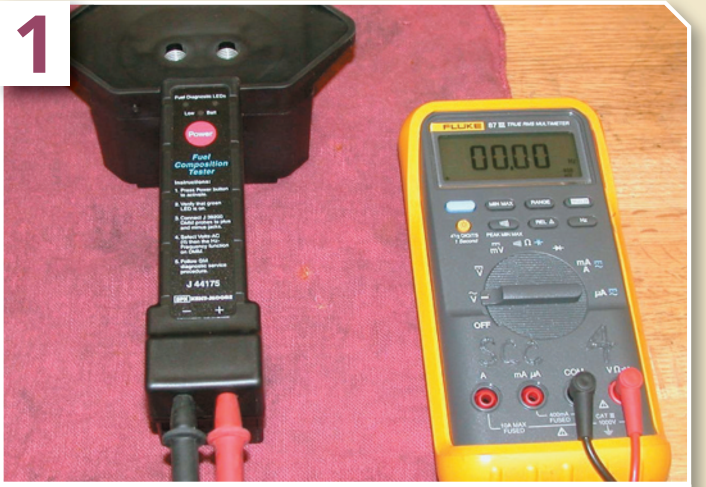
unmodified diesel engines. Some diesel-powered vehicles can use B20 (20% biodiesel). Dodge, for example, allows the use of B5 in all diesel vehicles and B20 only if the optional additional fuel filter is installed. Users should consult their engine warranty statement for more information on fuel blends of greater than 20% biodiesel.

In general, B20 costs 30 to 40 cents more per gallon than conventional diesel. Although biodiesel costs more than regular diesel fuel, fleet managers can make the switch to alternative fuels without purchasing new vehicles, acquiring new spare parts inventories, rebuilding refueling stations, or hiring new service technicians.

NOTE: For additional information on biodiesel and the locations where it can be purchased, visit www.biodiesel.org.

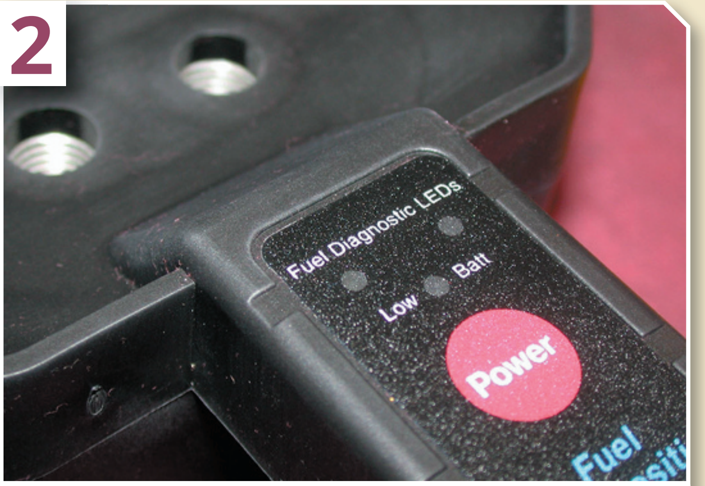
TESTING FOR ALCOHOL CONTENT IN GASOLINE

1


Fuel Composition Tester
J 44175
FLUKE
00.00

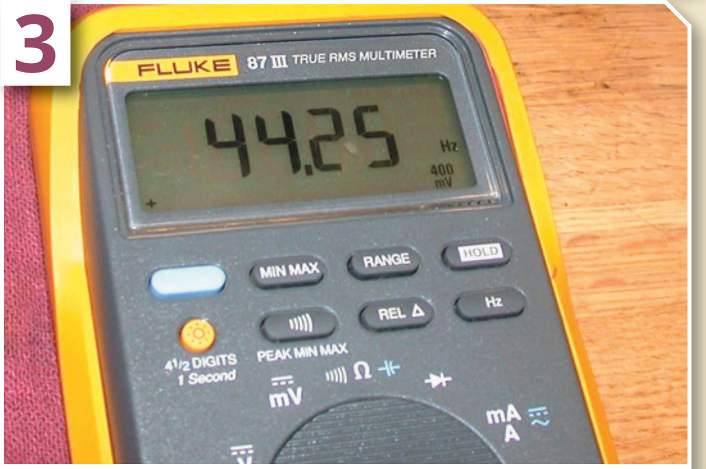
A fuel composition tester (SPX Kent-Moore J-44175) is the recommended tool to use to test the alcohol content of gasoline.

2


Fuel Diagnostic LEDs
Low
Batt
Power
Fuel

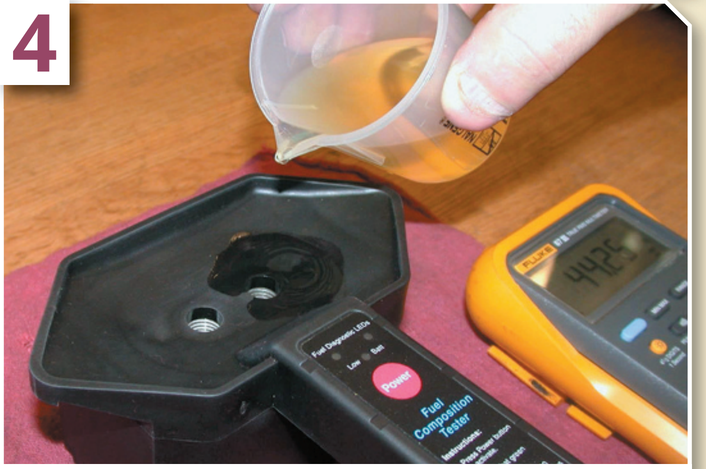
This battery-powered tester uses light-emitting diodes (LEDs), meter lead terminals, and two small openings for the fuel sample.

3


FLUKE 87 III TRUE RMS MULTIMETER
44.25
Hz
MIN MAX
RANGE
HOLD
REL Δ
Hz
PEAK MIN MAX
4½ DIGITS 1 Second
mV
mA A

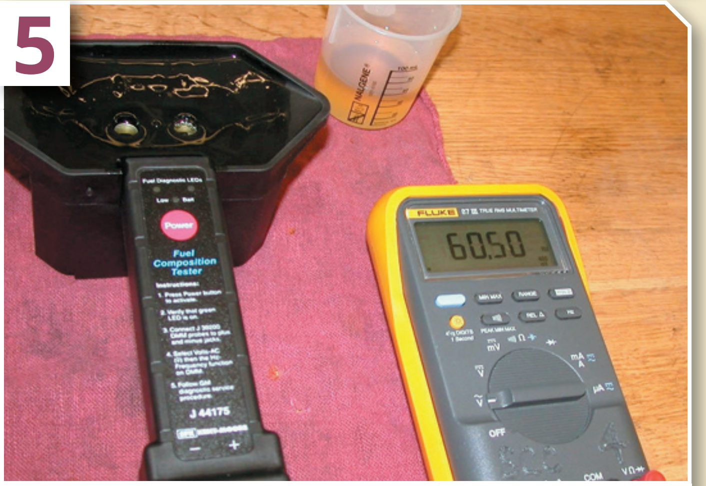
The first step is to verify the proper operation of the tester by measuring the air frequency by selecting AC hertz on the meter. The air frequency should be between 35 Hz and 48 Hz.

4


44.25
Power
Fuel Composition Tester

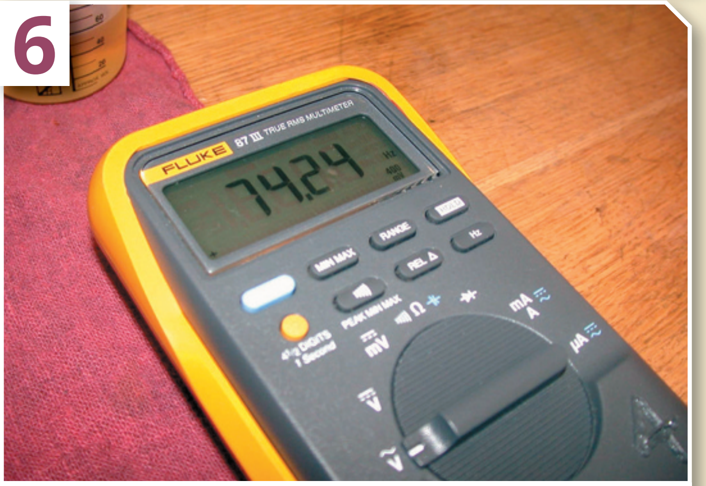
After verifying that the tester is capable of correctly reading the air frequency, gasoline is poured into the testing cell of the tool.

5


Fuel Composition Tester
J 44175
FLUKE
60.50

Record the AC frequency as shown on the meter and subtract 50 from the reading (e.g., 60.50 − 50.00 = 10.5). This number (10.5) is the percentage of alcohol in the gasoline sample.

6


FLUKE 87 III TRUE RMS MULTIMETER
74.24

Adding additional amounts of ethyl alcohol (ethanol) increases the frequency reading.

REVIEW QUESTIONS

1. What does the (R + M) ÷ 2 gasoline pump octane rating indicate?
2. What is stoichiometric?
3. How is a flexible fuel vehicle identified?
4. What are the sizes of the fuel nozzles for gasoline and diesel?
5. Biodiesel blends are identified by what designation?

CHAPTER QUIZ

1. Winter-blend gasoline ____________.
   - **a.** vaporizes more easily than summer-blend gasoline
   - **b.** has a higher RVP
   - **c.** can cause engine driveability problems if used during warm weather
   - **d.** All of the above
2. Technician A says that spark knock, ping, and detonation are different names for abnormal combustion. Technician B says that any abnormal combustion raises the temperature and pressure inside the combustion chamber and can cause severe engine damage. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Technician A says to fill the gas tank as full as possible. Technician B says to stop filling the tank as soon as the nozzle clicks off. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Technician A says that in going to high altitudes, engines produce lower power. Technician B says that most engine control systems can compensate the air–fuel mixture for changes in altitude. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Propane gives ____________ miles per gallon when compared to gasoline.
   - **a.** more
   - **b.** less
   - **c.** the same
   - **d.** increased
6. What can be used to measure the alcohol content in gasoline?
   - **a.** Graduated cylinder
   - **b.** Electronic tester
   - **c.** Scan tool
   - **d.** Both a and b
7. E85 means that the fuel is made from ____________.
   - **a.** 85% gasoline and 15% ethanol
   - **b.** 85% ethanol and 15% gasoline
   - **c.** ethanol that has 15% water
   - **d.** pure ethyl alcohol
8. A flex fuel vehicle can be identified by ____________.
   - **a.** emblems on the side, front, and/or rear of the vehicle
   - **b.** VECI
   - **c.** VIN
   - **d.** All of the above
9. Which statement is true?
   - **a.** Propane and CNG are different name for the same fuel
   - **b.** All vehicles can use CNG
   - **c.** CNG is mostly methane
   - **d.** CNG has more energy per pound than gasoline
10. What is true about diesel fuel?
    - **a.** B5 is 95% biodiesel
    - **b.** If red in color, this means that fuel is untaxed and used for off-road only
    - **c.** Both gasoline and diesel fuel use the octane rating system
    - **d.** All of he above

Chapter

68

IGNITION SYSTEM PARTS AND OPERATION

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss ignition systems.
- Discuss ignition coils.
- Discuss ignition switching and triggering.
- Describe ignition system operation.
- Describe the operation of waste-spark ignition systems.
- Describe the operation of coil-on-plug ignition systems.
- Discuss ignition timing.
- Discuss knock sensors.
- Describe the different types of spark plugs.

KEY TERMS:

Coil-on-plug (COP) ignition (also coil-by-plug, coil-near-plug, coil-over-plug) 819 • Companion cylinder 818 • Crankshaft position (CKP) sensor 817 • Camshaft position (CMP) sensor 817 • Detonation 821 • Electromagnetic interference (EMI) 819 • Hall-effect switch 817 • Igniter 816 • Ignition coil 815 • Ignition control module (ICM) 816 • Ignition timing 821 • Inductive reactance 816 • Initial timing 821 • Iridium spark plugs 823 • Knock sensor (KS) 822 • Magnetic sensor 817 • Mutual induction 816 • Paired cylinder 818 • Ping 821 • Platinum spark plugs 823 • Primary ignition circuit 816 • Saturation 816 • Schmitt trigger 817 • Secondary ignition circuit 816 • Self-induction 816 • Spark knock 821 • Switching 816 • Transistor 817 • Turns ratio 815 • Waste-spark ignition 818

IGNITION SYSTEM

PURPOSE AND FUNCTION The ignition system includes components and wiring necessary to create and distribute a high voltage (up to 40,000 volts or more) and send to the spark plug. A high-voltage arc occurs across the gap of a spark plug inside the combustion chamber. The spark raises the temperature of the air–fuel mixture and starts the combustion process inside the cylinder.

BACKGROUND All ignition systems apply battery voltage (close to 12 volts) to the positive side of the ignition coil(s) and pulse the negative side to ground on and off.

EARLY IGNITION SYSTEMS Before the mid-1970s, ignition systems used a mechanically opened set of contact points to make and break the electrical connection to ground. A cam lobe, located and driven by the distributor, opened the points. There was one lobe for each cylinder. The points used a rubbing block that was lubricated by applying a thin layer of grease on the cam lobe at each service interval. Each time the points opened, a spark was created in the ignition coil. The high-voltage spark then traveled to each spark plug through the distributor cap and rotor and the spark plug wires. The distributor was used twice in the creation of the spark.

1. The distributor was connected to the camshaft that rotated the distributor cam causing the points to open and close.
2. The distributor used a rotor to direct the high-voltage spark from the coil entering the center of the distributor cap to inserts connected to spark plug wires to each cylinder. ● **SEE FIGURE 68–1**.

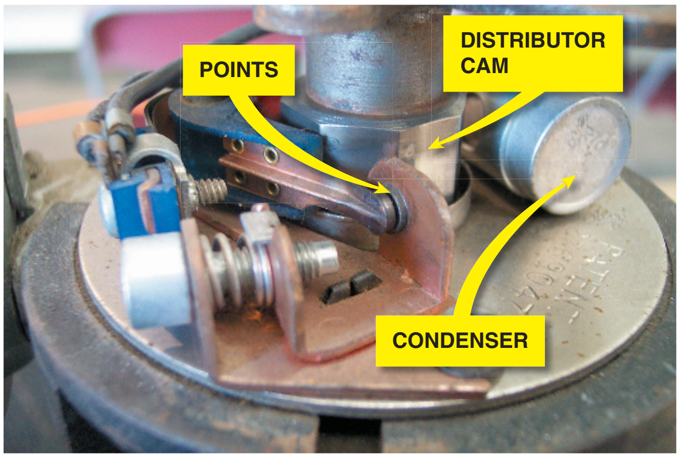


FIGURE 68–1 A point-type ignition system showing the distributor cam which opens the points.

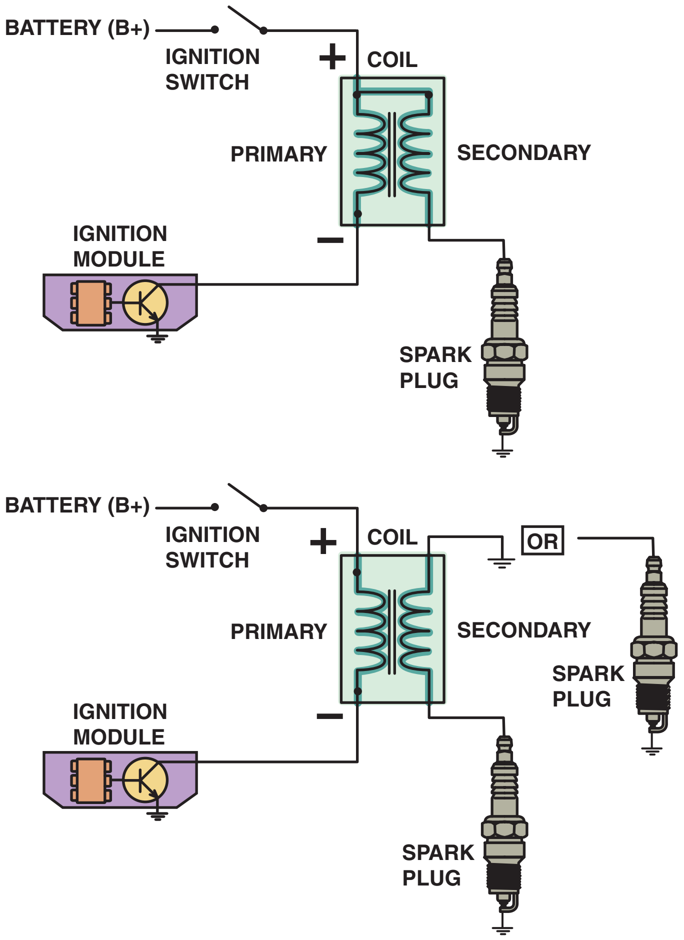


FIGURE 68–2 Some ignition coils are electrically connected, called married (top figure), whereas others use separate primary and secondary windings, called divorced (lower figure). The polarity (positive or negative) of a coil is determined by the direction in which the coil is wound.

DISTRIBUTOR IGNITION (DI) is the term specified by the Society of Automotive Engineers (SAE) for an ignition system that uses a distributor.

ELECTRONIC IGNITION (EI) is the term specified by the SAE for an ignition system that does not use a distributor. Types of EI systems include

1. **Waste-spark system.** This type of system uses one ignition coil to fire the spark plugs for two cylinders at the same time. ● **SEE FIGURE 68–2**.
2. **Coil-on-plug system.** This type of system uses a single ignition coil for each cylinder with the coil placed above or near the spark plug.

The ignition system includes components and wiring necessary to create and distribute a high voltage (up to 40,000 volts or more). All ignition systems apply voltage close to battery voltage (12 volts) to the positive side of the ignition coil and pulse the negative side to ground. When the coil negative lead is grounded, the primary (low-voltage) circuit of the coil is complete and a magnetic field is created around the coil windings. When the circuit is opened, the magnetic field collapses and induces a high-voltage spark in the secondary winding of the ignition coil. Early ignition systems used a mechanically opened set of contact points to make and break the electrical connection to ground. Electronic ignition uses a sensor, such as a pickup coil and reluctor (trigger wheel), or trigger to signal an electronic module that makes and breaks the primary connection of the ignition coil.

IGNITION COILS

PURPOSE AND FUNCTION The heart of any ignition system is the **ignition coil**. The coil creates a high-voltage spark by electromagnetic induction. Many ignition coils contain two separate, but electrically connected, windings of copper wire. Other coils are true transformers in which the primary and secondary windings are not electrically connected.

COIL CONSTRUCTION The center of an ignition coil contains a core of laminated soft iron (thin strips of soft iron). This core increases the magnetic strength of the coil. Surrounding the laminated core are approximately 20,000 turns of fine wire (approximately 42 gauge). These windings are called the secondary coil windings. Surrounding the secondary windings are approximately 150 turns of heavy wire (approximately 21 gauge). These windings are called the primary coil windings. The secondary winding has about 100 times the number of turns of the primary winding, referred to as the **turns ratio** (approximately 100:1). The E coil is so named because the laminated, soft-iron core is E-shaped, with the coil wire turns wrapped around the center "finger" of the E and the primary winding wrapped inside the secondary winding. ● **SEE FIGURES 68–3 AND 68–4**.

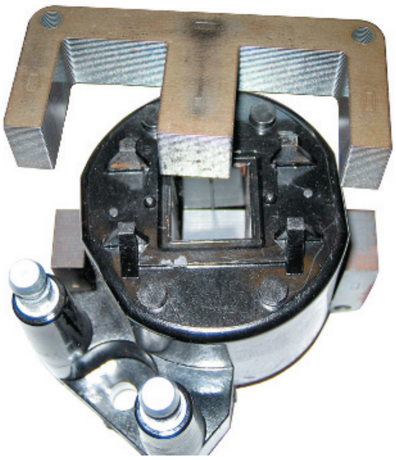


FIGURE 68–3 The steel lamination used in an E coil helps increase the magnetic field strength, which helps the coil produce higher energy output for a more complete combustion in the cylinders.

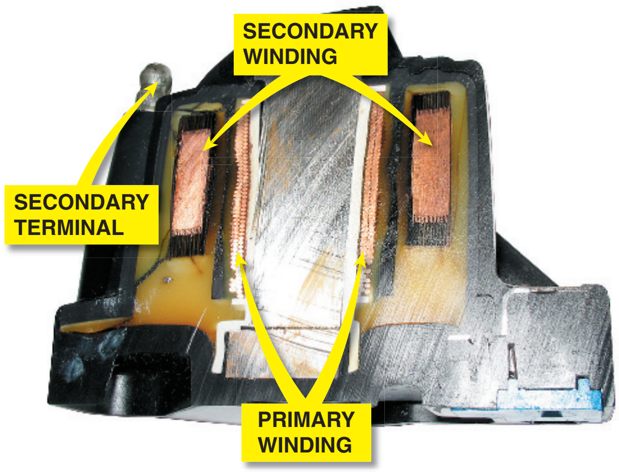


FIGURE 68–4 The primary windings are inside the secondary windings on this General Motors coil.

The primary windings of the coil extend through the case of the coil and are labeled as "positive" and "negative." The positive terminal of the coil attaches to the ignition switch, which supplies current from the positive battery terminal. The negative terminal is attached to an **ignition control module (ICM** or **igniter**), which opens and closes the primary ignition circuit by opening or closing the ground return path of the circuit. When the ignition switch is on, voltage should be available at *both* the positive terminal and the negative terminal of the coil if the primary windings of the coil have continuity.

SELF-INDUCTION When current starts to flow into a coil, an opposing current is created in the windings of the coil. This opposing current generation is caused by **self-induction** and is called **inductive reactance**. Inductive reactance is similar to resistance because it opposes any changes (increase or decrease) in current flow in a coil. Therefore, when an ignition coil is first energized, there is a slight delay of approximately 0.01 second before the ignition coil reaches its maximum magnetic field strength. The point at which a coil's maximum magnetic field strength is reached is called **saturation**.

MUTUAL INDUCTION In an ignition coil there are two windings, a primary and a secondary winding. When a *change* occurs in the magnetic field of one coil winding, a change also occurs in the other coil winding. Therefore, if the current is stopped from flowing (circuit is opened), the collapsing magnetic field cuts across the turns of the secondary winding and creates a high voltage in the secondary winding. This generation of an electric current in both coil windings is called **mutual induction**. The collapsing magnetic field also creates a voltage of up to 250 volts in the primary winding.

HOW IGNITION COILS CREATE 40,000 VOLTS All ignition systems use electromagnetic induction to produce a high-voltage spark from the ignition coil. Electromagnetic induction means that a current can be created in a conductor (coil winding) by a moving magnetic field. The magnetic field in an ignition coil is produced by current flowing through the primary windings of the coil. The current for the primary winding is supplied through the ignition switch to the positive terminal of the ignition coil. The negative terminal is connected to the ground return through an electronic ignition module (igniter).

If the primary circuit is completed, current (approximately 2 to 6 A) can flow through the primary coil windings. This flow creates a strong magnetic field inside the coil. When the primary coil winding ground return path connection is opened, the magnetic field collapses and induces a voltage of 250 to 400 volts in the primary winding of the coil, and a high-voltage (20,000 to 40,000 volts) low-amperage (20 to 80 mA) current in the secondary coil windings. This high-voltage pulse flows through the coil wire (if the vehicle is so equipped), distributor cap, rotor, and spark plug wires to the spark plugs. For each spark that occurs, the coil must be charged with a magnetic field and then discharged. The ignition components that regulate the current in the coil primary winding by turning it on and off are known collectively as the **primary ignition circuit**. The components necessary to create and distribute the high voltage produced in the secondary windings of the coil are called the **secondary ignition circuit**. ● **SEE FIGURE 68–4.** These circuits include the following components:

FREQUENTLY ASKED QUESTION

How Does the Computer Control the Ignition?

The powertrain control module (PCM) plays a key role in the final functioning of the ignition circuits. The PCM receives signals from all of the engine sensors and based on this information, uses an algorithm (computer program) to determine the best time to fire the spark plugs. For example, the sensors and how they could affect when the spark occurs include

Engine coolant temperature (ECT) sensor—The colder the engine, the more spark advance may be needed to achieve the highest possible engine output torque with lowest exhaust emissions.

Throttle position (TP) sensor—The PCM uses the TP sensor information to not only determine where the accelerator position is located but also at what rate it is changing. If the accelerator pedal is rapidly being depressed, spark timing may be delayed (retarded slightly) to help prevent spark knock.

Manifold absolute pressure (MAP) sensor—The MAP sensor is used to detect engine load. During a heavy load, less spark advance is needed to help prevent spark knock, whereas more spark advance is needed under light load conditions for the engine to achieve maximum fuel economy and the lowest possible exhaust emissions.

PRIMARY IGNITION CIRCUIT

1. Battery
2. Ignition switch
3. Primary windings of coil
4. Pickup coil (crank sensor)
5. Ignition module (igniter)
6. PCM

SECONDARY IGNITION CIRCUIT

1. Secondary windings of coil
2. Distributor cap and rotor (if the vehicle is so equipped)
3. Spark plug wires
4. Spark plugs

● **SEE FIGURE 68–5.**

IGNITION SWITCHING AND TRIGGERING

For any ignition system to function, the primary current must be turned on to charge the coil and off to allow the coil to discharge, creating a high-voltage spark. This turning on and off of the primary circuit is called **switching**. The unit that does the switching is an electronic switch, such as a power transistor.

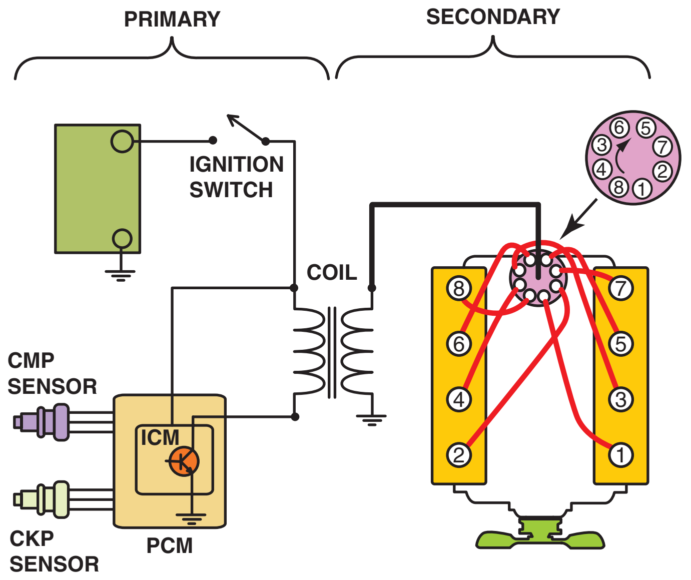


FIGURE 68–5 The primary ignition system is used to trigger, and therefore create the secondary (high-voltage) spark from the ignition coil.

This power transistor can be located in any of the following locations:

- In the ignition control module (ICM) as part of the coil-on-plug assembly
- In the ignition control module (ICM)
- In the powertrain control module (PCM)

The device that signals the switching of the coil on and off, or just on in most instances, is called the trigger. A trigger is typically a pickup coil in some distributor-type ignitions and a crankshaft position (CKP) sensor on electronic (waste-spark and coil-on-plug) and many distributor-type ignitions. There are two types of devices used for triggering, including the magnetic sensor or Hall-effect switch, and optical sensor.

IGNITION SYSTEM OPERATION

PRIMARY CIRCUIT To get a spark out of an ignition coil, the primary coil circuit must be turned on and off. This primary circuit current is controlled by a **transistor** (electronic switch) inside the ignition module (igniter).

The following are used as **crankshaft position (CKP) sensors** or **camshaft position (CMP) sensors**.

- **Hall-effect switch**—A **Hall-effect switch** also uses a stationary sensor and rotating trigger wheel (shutter). The Hall-effect switch requires a small input voltage to generate an output or signal voltage. Hall effect is the ability to generate a voltage signal in semiconductor material (gallium arsenate crystal) by passing current through it in one direction, and applying a magnetic field to it at a right angle to its surface. If the input current is held steady and the magnetic field fluctuates, an output voltage is produced that changes in proportion to field strength. Most Hall-effect switches have a Hall element or device, a permanent magnet, and a rotating ring of metal blades (shutters) similar to a trigger wheel (another method uses a stationary sensor with a rotating magnet). When the shutter blade enters the gap between the magnet and the Hall element, it creates a magnetic shunt that changes the field strength through the Hall element. This analog signal is sent to a **Schmitt trigger** inside the sensor itself, which converts the analog signal into a digital signal. A digital (on or off) voltage signal is created at a varying frequency to the ignition module or onboard computer. ● **SEE FIGURES 68–6 AND 68–7**.
- **Magnetic crankshaft position sensor**—A **magnetic sensor** uses the changing strength of the magnetic field surrounding a coil of wire to signal the module and computer. This signal is used by the electronics in the module and computer as to piston position and engine speed (RPM). ● **SEE FIGURES 68–8 AND 68–9**.

FREQUENTLY ASKED QUESTION

What Is Meant by the Firing Order?

Firing order means the order that the spark is distributed to the correct spark plug at the right time. The firing order of an engine is determined by crankshaft and camshaft design. The firing order is determined by the location of the spark plug wires in the distributor cap of an engine equipped with a distributor. The firing order is often cast into the intake manifold for easy reference. ● **SEE FIGURE 68–10**.

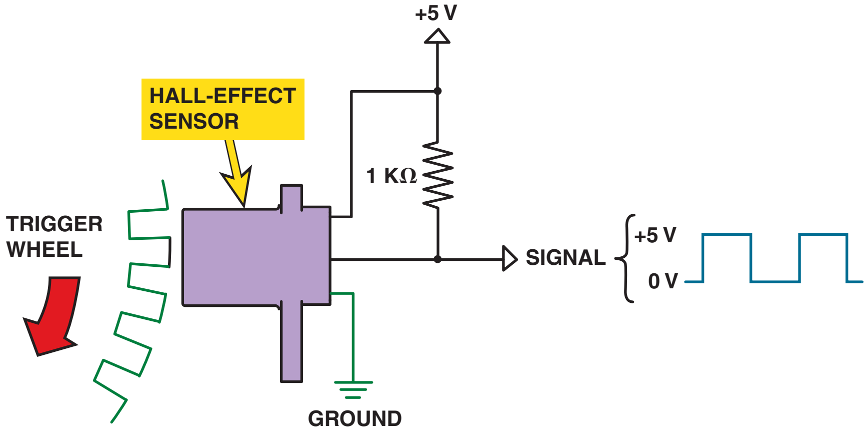


FIGURE 68–6 A Hall-effect sensor produces a digital on-off voltage signal whether it is used with a blade or a notched wheel.

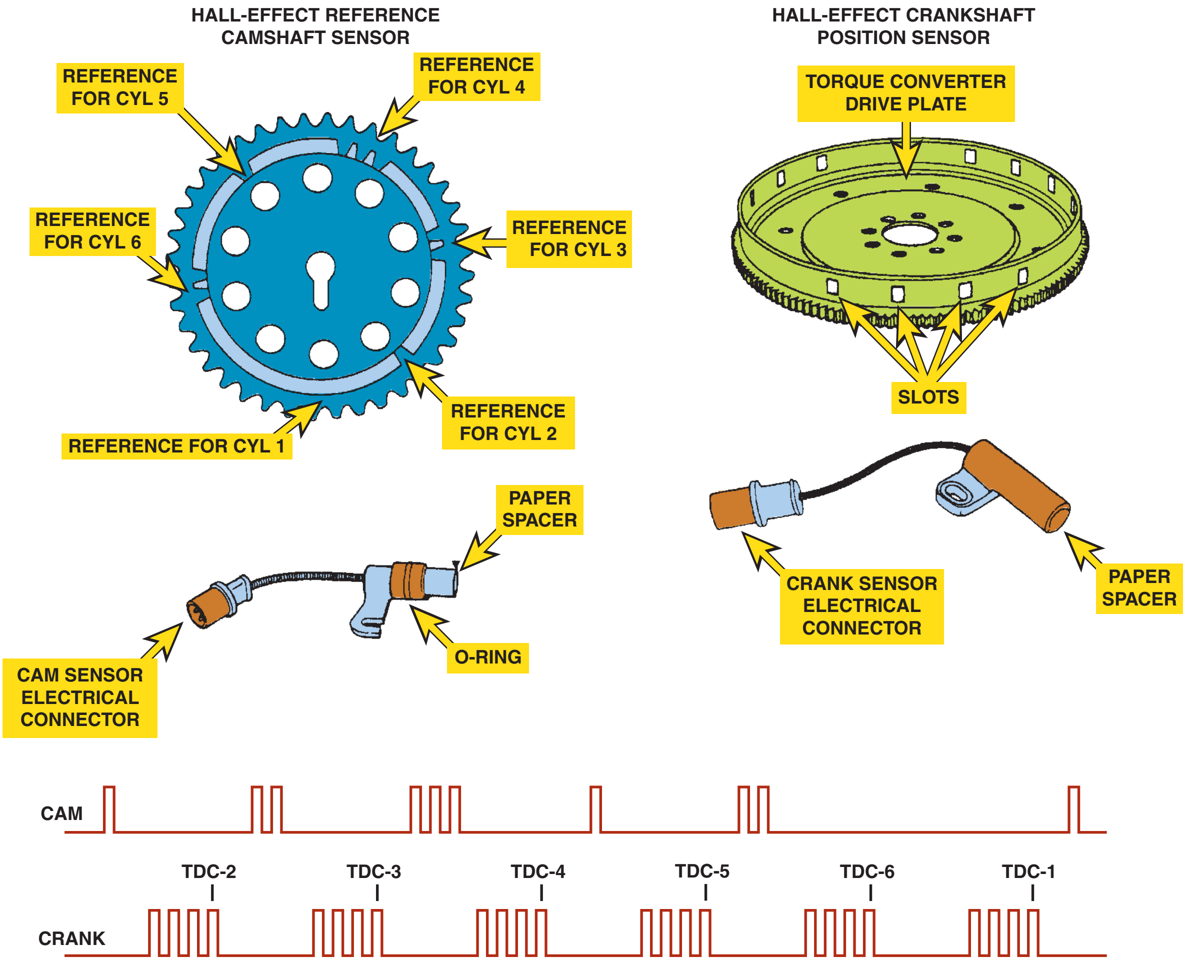

HALL-EFFECT REFERENCE CAMSHAFT SENSOR
REFERENCE FOR CYL 5
REFERENCE FOR CYL 4
REFERENCE FOR CYL 6
REFERENCE FOR CYL 3
REFERENCE FOR CYL 1
REFERENCE FOR CYL 2
PAPER SPACER
O-RING
CAM SENSOR ELECTRICAL CONNECTOR
HALL-EFFECT CRANKSHAFT POSITION SENSOR
TORQUE CONVERTER DRIVE PLATE
SLOTS
CRANK SENSOR ELECTRICAL CONNECTOR
PAPER SPACER
CAM
TDC-2
TDC-3
TDC-4
TDC-5
TDC-6
TDC-1
CRANK

FIGURE 68–7 Some Hall-effect sensors look like magnetic sensors. This Hall-effect camshaft reference sensor and crankshaft position sensor have an electronic circuit built in that creates a 0 to 5 volt signal as shown at the bottom. These Hall-effect sensors have three wires: a power supply (8 volts) from the computer (controller); a signal (0 to 5 volts); and a signal ground.

TECH TIP

The Tachometer Trick

When diagnosing a no-start or intermittent misfire condition, check the operation of the tachometer. If the tachometer does not indicate engine speed (no-start condition) or drops toward zero (engine misfire), the problem is due to a defect in the *primary* ignition circuit. The tachometer gets its signal from the pulsing of the primary winding of the ignition coil or the crankshaft position (CKP) sensor. The following components in the primary circuit could cause the tachometer to not work when the engine is cranking:

- Pickup coil
- Crankshaft position sensor
- Ignition module (igniter)
- Coil primary wiring

If the vehicle is not equipped with a tachometer, connect a scan tool and monitor engine RPM. Remember the following:

- No tachometer reading means the problem is in the primary ignition circuit.
- Tachometer reading okay means the problem is in the secondary ignition circuit or is a fuel-related problem.

WASTE-SPARK IGNITION SYSTEMS

OPERATION **Waste-spark ignition** is another name for distributorless-ignition system (DIS) or electronic ignition (EI). Waste-spark-ignition was introduced in the mid-1980s and uses the onboard computer to fire the ignition coils. These systems were first used on some Saabs and General Motors engines. A four-cylinder engine uses two ignition coils and a six-cylinder engine uses three ignition coils. Each coil is a true transformer in which the primary winding and secondary winding are not electrically connected. Each end of the secondary winding is connected to a cylinder exactly opposite the other in the firing order, which is called a **companion (paired) cylinder**.

● **SEE FIGURE 68–11**. This means that *both* spark plugs fire at the same time (within nanoseconds of each other). When one cylinder (e.g., 6) is on the compression stroke, the other cylinder (3) is on the exhaust stroke. This spark that occurs on the exhaust stroke is called the waste spark, because it does no useful work and is only used as a ground path for the secondary winding of the ignition coil. The voltage required to jump the spark plug gap on cylinder 3 (the exhaust stroke) is only 2 to 3 kV and provides the *ground circuit* for the secondary coil circuit. The remaining coil energy is used by the cylinder on the compression stroke. One spark plug of each pair always fires straight polarity and the other cylinder always fires reverse polarity. Spark plug life is not greatly-affected by the reverse polarity. If there is only one defective spark plug wire or spark plug, two cylinders may be affected.

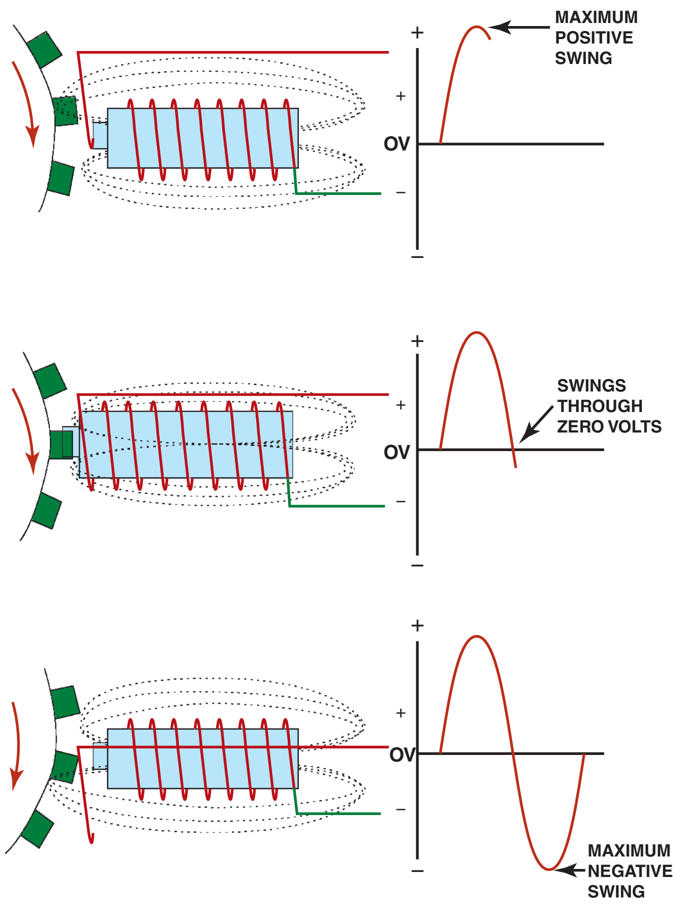

MAXIMUM
POSITIVE
SWING
+
+
OV
–
–
+
+
SWINGS
THROUGH
ZERO VOLTS
OV
–
–
+
+
OV
–
–
MAXIMUM
NEGATIVE
SWING

FIGURE 68–8 A magnetic sensor uses a permanent magnet surrounded by a coil of wire. The notches of the crankshaft (or camshaft) create a variable magnetic field strength around the coil. When a metallic section is close to the sensor, the magnetic field is stronger because metal is a better conductor of magnetic lines of force than air.

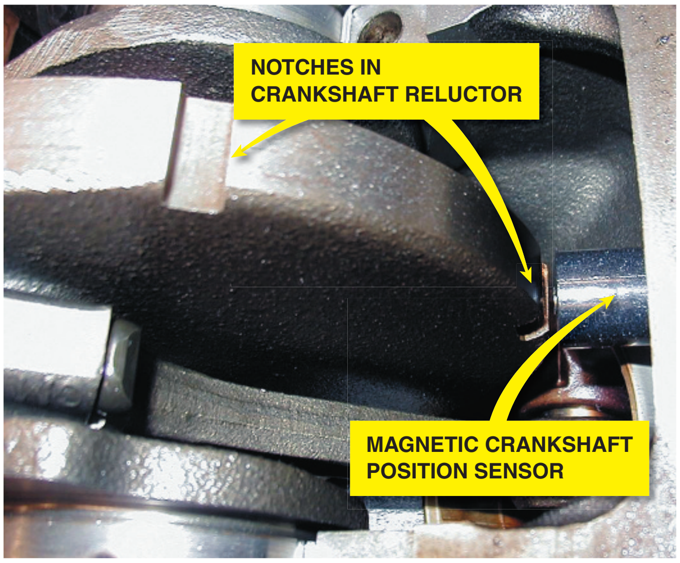

NOTCHES IN
CRANKSHAFT RELUCTOR
MAGNETIC CRANKSHAFT
POSITION SENSOR

FIGURE 68–9 A typical magnetic crankshaft position sensor.

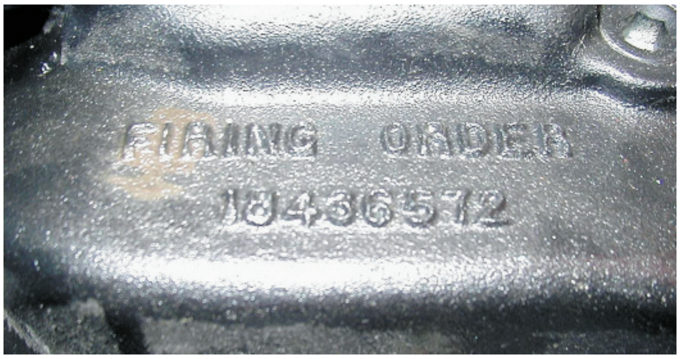

FIRING ORDER
18436572

FIGURE 68–10 The firing order is cast or stamped on the intake manifold on most engines that have a distributor ignition.

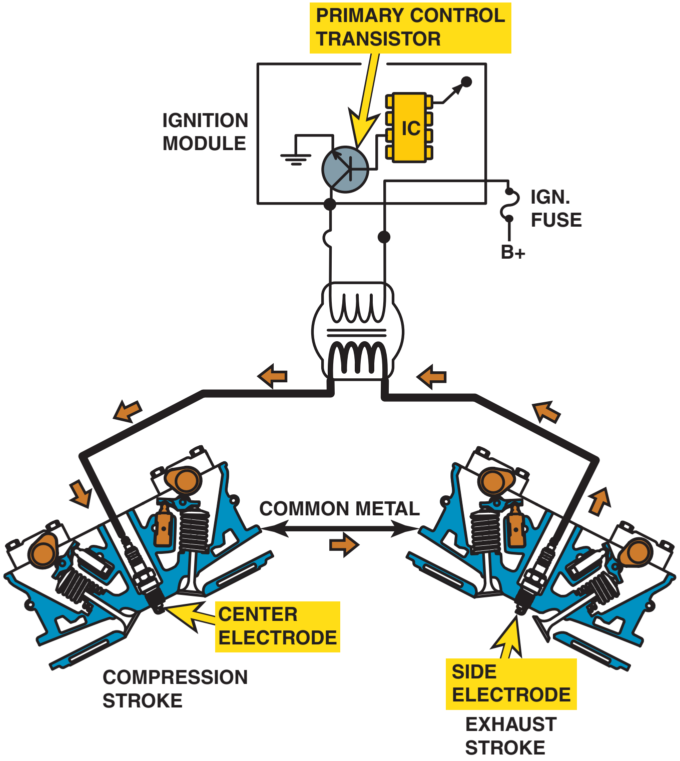

PRIMARY CONTROL
TRANSISTOR
IGNITION
MODULE
IC
IGN.
FUSE
B+
COMMON METAL
CENTER
ELECTRODE
COMPRESSION
STROKE
SIDE
ELECTRODE
EXHAUST
STROKE

FIGURE 68–11 A waste-spark system fires one cylinder while its piston is on the compression stroke and into paired or companion cylinders while it is on the exhaust stroke. In a typical engine, it requires only about 2 to 3 kV to fire the cylinder on the exhaust strokes. The remaining coil energy is available to fire the spark plug under compression (typically about 8 to 12 kV).

COIL-ON-PLUG IGNITION

Coil-on-plug (COP) ignition uses one ignition coil for each spark plug. This system is also called coil-by-plug, coil-near-plug, or coil-over-plug ignition. ● **SEE FIGURES 68–12, 68–13 AND 68–14.** The coil-on-plug system eliminates the spark plug wires, which are often sources of **electromagnetic interference (EMI)** that can cause problems to some computer signals. The vehicle computer controls the timing of the spark. Ignition timing also can be changed (retarded or advanced) on a cylinder-by-cylinder basis for maximum performance and to respond to knock sensor signals.

There are two basic types of coil-on-plug ignition:

- **Two-wire**—This design uses the vehicle computer to control the firing of the ignition coil. The two wires include ignition voltage feed and the pulse ground wire, which is controlled by the computer. All ignition timing and dwell control are handled by the computer.
- **Three-wire**—This design includes an ignition module at each coil. The three wires are:
    - Ignition voltage
    - Ground
    - Pulse from the computer to the built-in module

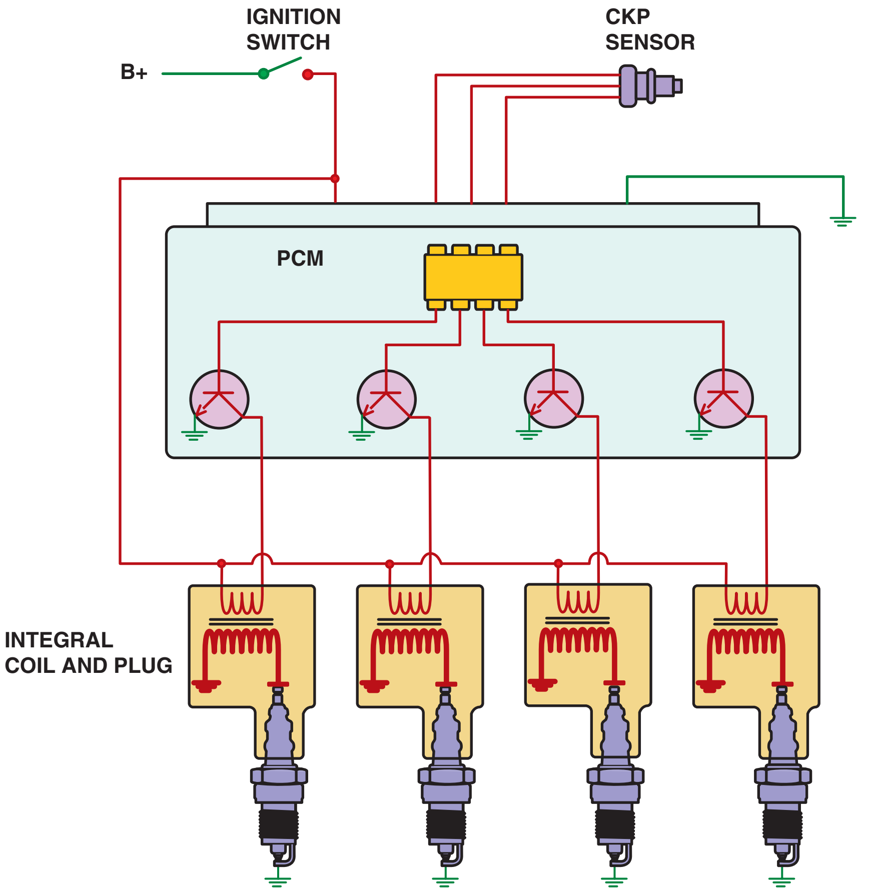


FIGURE 68–12 A typical two-wire coil-on-plug ignition system showing the triggering and the switching being performed by the PCM from input from the crankshaft position sensor.

TECH TIP

Odds Fire Straight

Waste-spark ignition systems fire two spark plugs at the same time. Most vehicle manufacturers use a waste-spark system that fires the odd-numbered cylinders (1, 3, and 5) by straight polarity (current flow from the top of the spark plug through the gap and to the ground electrode). The even-numbered -cylinders (2, 4, and 6) are fired reverse polarity, meaning that the spark jumps from the side electrode to the -center electrode. Some vehicle manufacturers equip their vehicles with platinum plugs with the expansive -platinum alloy only on one electrode as follows:

- On odd-numbered cylinders (1, 3, 5), the platinum is on the center electrode.
- On even-numbered cylinders (2, 4, 6), the platinum is on the ground electrode.

Replacement spark plugs use platinum on both electrodes (double platinum) and can, therefore, be placed in any cylinder location.

General Motors vehicles use a variety of coil-on-plug-type ignition systems. Many V-8 engines use a coil-near-plug system with individual coils and modules for each individual cylinder that are placed on the valve covers. Short secondary ignition spark plug wires are used to connect the output terminal of the ignition coil to the spark plug.

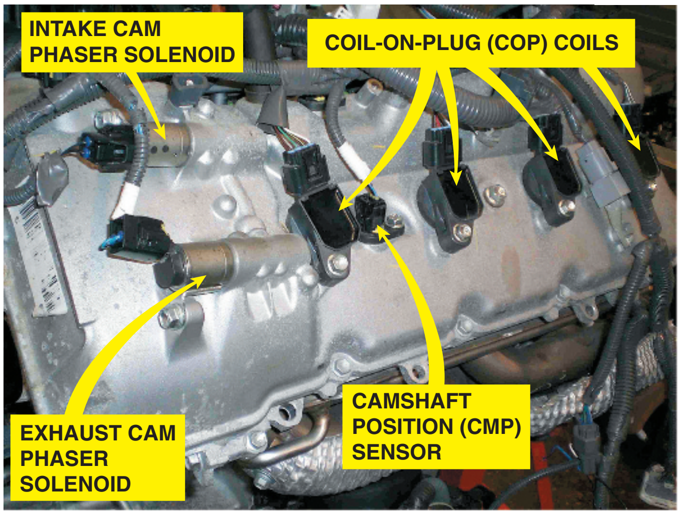

INTAKE CAM PHASER SOLENOID
COIL-ON-PLUG (COP) COILS
EXHAUST CAM PHASER SOLENOID
CAMSHAFT POSITION (CMP) SENSOR

FIGURE 68–13 An overhead camshaft engine equipped with variable valve timing on both the intake and exhaust camshafts and coil-on-plug ignition.

Most newer Chrysler engines use coil-over-plug-type ignition systems. Each coil is controlled by the PCM, which can vary the ignition timing separately for each cylinder based on signals the PCM receives from the knock sensor(s). For example, if the knock sensor detects that a spark knock has occurred after firing cylinder 3, then the PCM will continue to monitor cylinder 3 and retard timing on just this one cylinder if necessary to prevent-engine-damaging detonation.

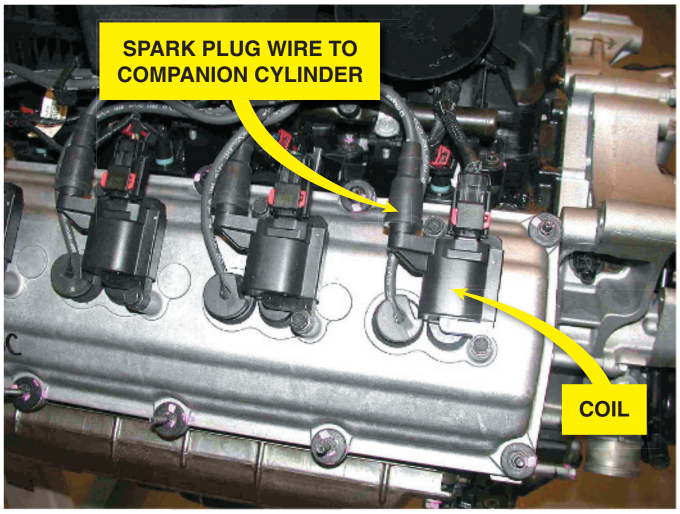


FIGURE 68–14 Chrysler Hemi V-8 that has two spark plugs per cylinder. The coil on top of one spark fires that plug plus, through a spark plug wire, fires a plug in the companion cylinder.

SAFETY TIP

Never Disconnect a Spark Plug Wire When the Engine Is Running!

Ignition systems produce a high-voltage pulse necessary to ignite a lean air–fuel mixture. If you disconnect a spark plug wire when the engine is running, this high-voltage spark could cause personal injury or damage to the ignition coil and/or ignition module.

IGNITION TIMING

THE NEED FOR SPARK ADVANCE **Ignition timing** refers to when the spark plug fires in relation to piston position. The time when the spark occurs depends on engine speed, and therefore, must be advanced (spark plugs fire some) as the engine rotates faster. The ignition in the cylinder takes a certain amount of time, usually 30 milliseconds (30/1000 of a second). This burning time is relatively constant throughout the entire engine speed range. For maximum efficiency from the expanding gases inside the combustion chamber, the burning of the air–fuel mixture should end by about 10 degrees after top dead center (ATDC). If the burning of the mixture is still occurring after that point, the expanding gases do not exert much force on the piston because it is moving away from the gases (the gases are "chasing" the piston).

Therefore, to achieve the goal of having the air–fuel mixture be completely burned by the time the piston reaches 10 degrees after top dead center, the spark must be advanced (occur sooner) as the engine speed increases. This timing advance is determined and controlled by the PCM on most vehicles. ● **SEE FIGURE 68–15.**

INITIAL TIMING If the engine is equipped with a distributor, it may be possible to adjust the base or the **initial timing**. The initial timing is usually set to fire the spark plug between zero degrees (top dead center or TDC) or slightly before TDC (BTDC). Ignition timing does change as the timing chain or gear wears and readjustment is often necessary on high-mileage engines. ● **SEE FIGURE 68–16**. Waste-spark and coil-on-plug ignitions cannot be adjusted.

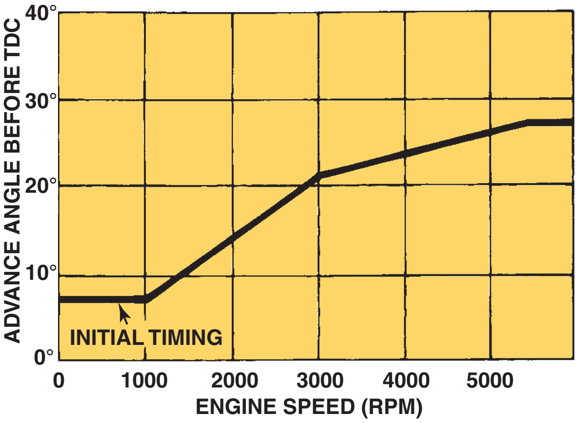


FIGURE 68–15 The initial timing is where the spark plug fires at idle speed. The computer then advances the timing based on engine speed and other factors.

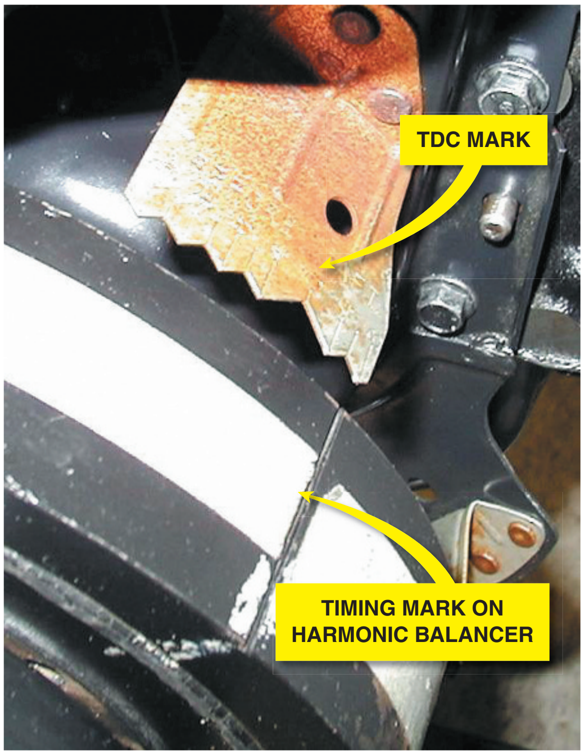


FIGURE 68–16 Ignition timing marks are found on the harmonic balancers that are equipped with distributor ignition.

KNOCK SENSORS

OPERATION Knock sensors are used to detect abnormal combustion, often called **ping**, **spark knock**, or **detonation**. Whenever abnormal combustion occurs, a rapid pressure increase occurs in the cylinder, creating a vibration in the engine block. It is this vibration that is detected by the knock sensor. The signal from the knock sensor is used by the PCM to retard the

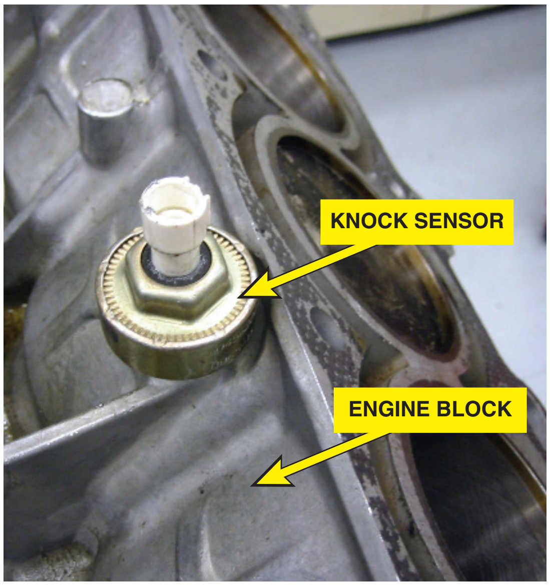


FIGURE 68–17 A knock sensor which is used by the powertrain control module (PCM) to detect engine detonation.

ignition timing until the knock is eliminated, thereby reducing the damaging effects of the abnormal combustion on pistons and other engine parts.

Inside the knock sensor is a piezoelectric element that generates a voltage when pressure or a vibration is applied to the unit. The knock sensor is tuned to the engine knock frequency, which ranges from 5 to 10 kHz, depending on the engine design. The voltage signal from the **knock sensor (KS)** is sent to the PCM. The PCM retards the ignition timing until the knocking stops. ● **SEE FIGURE 68–17**.

DIAGNOSING THE KNOCK SENSOR If a knock sensor diagnostic trouble code (DTC) is present, follow the specified testing procedure in the service information. A scan tool can be used to check the operation of the knock sensor, using the following procedure:

STEP 1 Start the engine and connect a scan tool to monitor ignition timing and/or knock sensor activity.

STEP 2 Create a simulated engine knocking sound by tapping on the engine block or cylinder head with a soft-faced mallet.

STEP 3 Observe the scan tool display. The vibration from the tapping should have been interpreted by the knock sensor as a knock, resulting in a knock sensor signal and a reduction in the spark advance.

A knock sensor also can be tested using a digital storage oscilloscope. ● **SEE FIGURE 68–18**.

NOTE: Some engine computers are programmed to ignore knock sensor signals when the engine is at idle speed to avoid having the noise from a loose accessory drive belt, or other accessory, interpreted as engine knock. Always follow the vehicle manufacturer's recommended testing procedure.

REPLACING A KNOCK SENSOR If replacing a knock sensor, be sure to purchase the exact replacement needed, because they often look the same, but the frequency range can vary according to engine design, as well as where it is located on the engine. Always tighten the knock sensor using a torque wrench and tighten to the specified torque to avoid causing damage to the piezoelectric element inside the sensor.

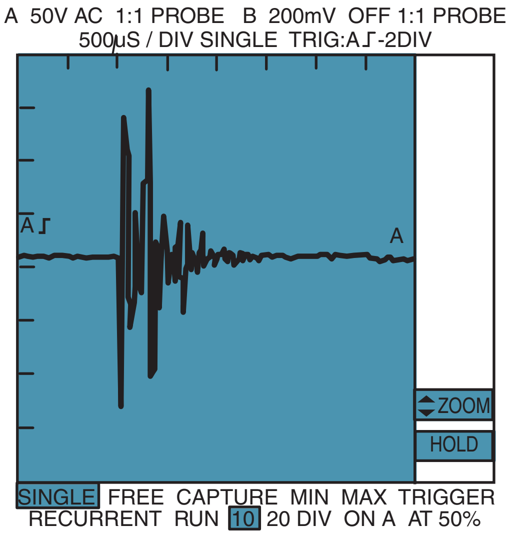


FIGURE 68–18 A typical waveform from a knock sensor during a spark knock event. This signal is sent to the computer which in turn retards the ignition timing. This timing retard is accomplished by an output command from the computer to either a spark advance control unit or directly to the ignition module.

SPARK PLUGS

TERMINOLOGY Spark plugs are manufactured from ceramic insulators inside a steel shell. The threads of the shell are rolled and a seat is formed to create a gastight seal with the cylinder head. ● **SEE FIGURE 68–19**. The physical difference in spark plugs includes

- **Reach.** This is the length of the threaded part of the plug.
- **Heat range.** The heat range of the spark plug refers to how rapidly the heat created at the tip is transferred to

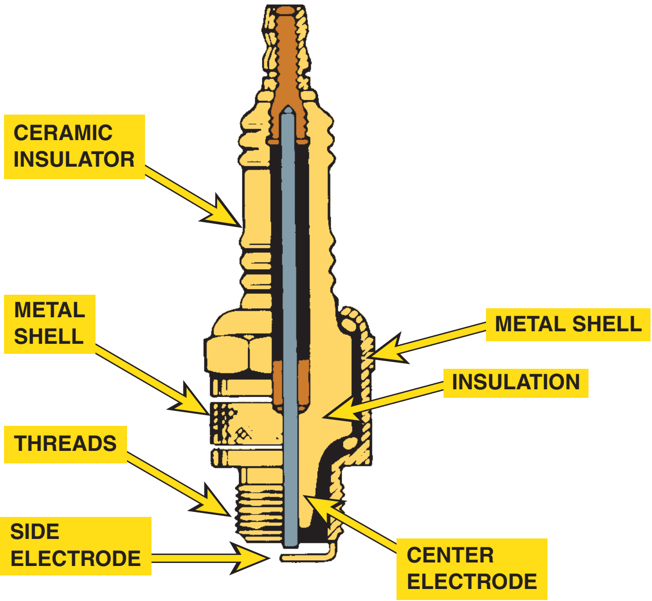


FIGURE 68–19 Parts of a typical spark plug.

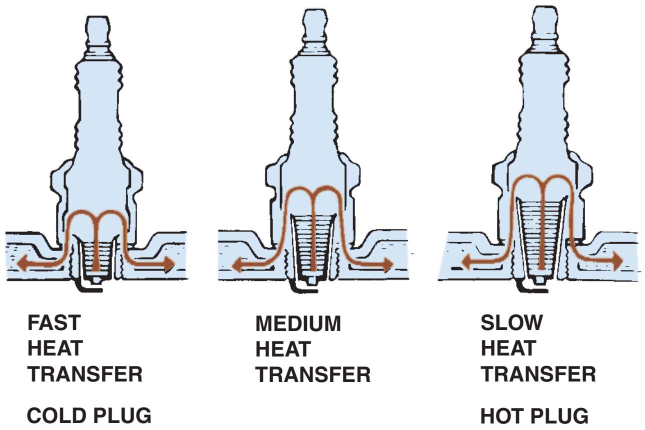


FIGURE 68–20 The heat range of a spark plug is determined by the distance the heat has to flow from the tip to the cylinder head.

the cylinder head. A plug with a long ceramic insulator path will run hotter at the tip than a spark plug that has a shorter path because the heat must travel farther. ● **SEE FIGURE 68–20**.

- **Type of seat.** Some spark plugs use a gasket and others rely on a tapered seat to seal.

RESISTOR SPARK PLUGS Most spark plugs include a resistor in the center electrode, which helps to reduce electromagnetic noise or radiation from the ignition system. The closer the resistor is to the actual spark or arc, the more effective it becomes. The value of the resistor is usually between 2,500 and 7,500 ohms.

PLATINUM SPARK PLUGS **Platinum spark plugs** have a small amount of the precious metal platinum welded onto the end of the center electrode, as well as on the ground or side electrode. Platinum is a grayish-white metal that does not react with oxygen and therefore, will not erode away as can occur with conventional nickel alloy spark plug electrodes. Platinum is also used as a catalyst in catalytic converters where it is able to start a chemical reaction without itself being consumed.

IRIDIUM SPARK PLUGS Iridium is a white precious metal and is the most corrosion-resistant metal known. Most **iridium spark plugs** use a small amount of iridium welded onto the tip of a small center electrode 0.0015 to 0.002 inches (0.4 to 0.6 mm) in diameter. The small diameter reduces the voltage required to jump the gap between the center and the side electrode, thereby reducing possible misfires. The ground or side electrode is usually tipped with platinum to help reduce electrode gap wear.

REVIEW QUESTIONS

1. How can 12 volts from a battery be changed to 40,000 volts for ignition?
2. How does a magnetic sensor work?
3. How does a Hall-effect sensor work?
4. How does a waste-spark ignition system work?
5. What does the heat range of a spark plug refer to?

CHAPTER QUIZ

1. The primary (low-voltage) ignition system must be working correctly before any spark occurs from a coil. Which component is not in the primary ignition circuit?
   a. Spark plug wiring
   b. Ignition module (igniter)
   c. Pickup coil (pulse generator)
   d. Ignition switch
2. An ignition coil contains _________.
   a. one coil winding
   b. two coil windings
   c. three coil windings
   d. four coil windings
3. A married ignition coil has _________.
   a. the secondary winding attached to separate spark plugs
   b. the primary winding connected to one side of the secondary winding
   c. the primary winding attached to the spark plug(s)
   d. Both a and c
4. A magnetic sensor uses a permanent magnet surrounded by a _________.
   a. shield
   b. coil of wire
   c. notched wheel
   d. plastic insulation
5. A _________ uses a stationary sensor and rotating trigger wheel (shutter).
   a. Schmitt trigger
   b. spark plug
   c. Hall-effect sensor
   d. PCM
6. The PCM uses what sensor(s) to determine when to fire the spark plug?
   a. ECT
   b. TP
   c. MAP
   d. All of the above
7. A COP ignition system can be called _________.
   a. coil-by-plug
   b. coil-near-plug
   c. coil-over-plug
   d. Any of the above
8. BTDC means _________.
   a. bottom top dead center
   b. before top dead center
   c. beyond top dead center
   d. Any of the above
9. What term describes the length of the threaded portion of a spark plug?
   a. Reach
   b. Range
   c. Seat angle
   d. None of these
10. What tools or equipment are needed to test a knock sensor?
   a. A soft-faced mallet
   b. Scan tool
   c. Both a and b
   d. Neither a nor b

Chapter

69

IGNITION SYSTEM DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the procedure used to check for spark.
- Describe the electronic ignition troubleshooting procedure.
- Describe ignition coil testing using an ohmmeter.
- Describe how to test magnetic sensors.
- Describe how to test Hall-effect sensors.
- Discuss visual inspection of the ignition system.
- Explain how to test for poor performance.
- Explain how to test for a no-start condition.
- Inspect and test ignition system secondary circuits.
- Describe spark plug service.
- Describe secondary ignition tests.
- Describe how to test the ignition system using an oscilloscope.
- Describe how to scope-test a waste-spark ignition system.
- Describe how to scope-test a coil-on-plug ignition system.
- Diagnose ignition system-related problems.

KEY TERMS:

Automatic shutdown (ASD) relay 825 • Dwell section 834 • Firing line 833 • Intermediate oscillations 834 • Remove and replace (R & R) 830 • Spark line 833 • Spark tester 824

CHECKING FOR SPARK

In the event of a no-start condition, the first step should be to check for secondary voltage out of the ignition coil or to the spark plugs. If the engine is equipped with a separate ignition coil, remove the coil wire from the center of the distributor cap, install a **spark tester**, and crank the engine. See the Tech Tip "Always Use a Spark Tester." A good coil and ignition system should produce a blue spark at the spark tester. ● **SEE FIGURES 69–1 AND 69–2**.

If the ignition system being tested does not have a separate ignition coil, disconnect any spark plug wire from a spark plug and, while cranking the engine, test for spark available at the spark plug wire, again using a spark tester.

NOTE: An intermittent spark should be considered a no-spark condition.

Typical causes of a no-spark (intermittent spark) condition include the following:

1. Weak ignition coil
2. Low or no voltage to the primary (positive) side of the coil
3. High resistance or open coil wire, or spark plug wire
4. Negative side of the coil not being pulsed by the ignition module, also called an ignition control module (ICM)
5. Defective pickup coil
6. Defective module

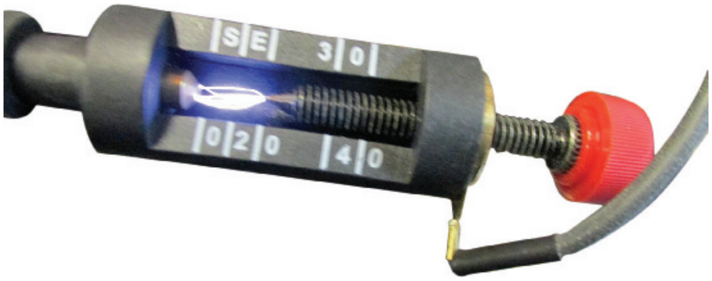


FIGURE 69–1 An adjustable spark tester that can be adjusted and should be set to at least 25,000 volts. The tester is connected to a disconnected spark plug wire or coil and the pigtail clipped to a good chassis ground. Cranking the engine should cause a spark to be seen from the spark tester.

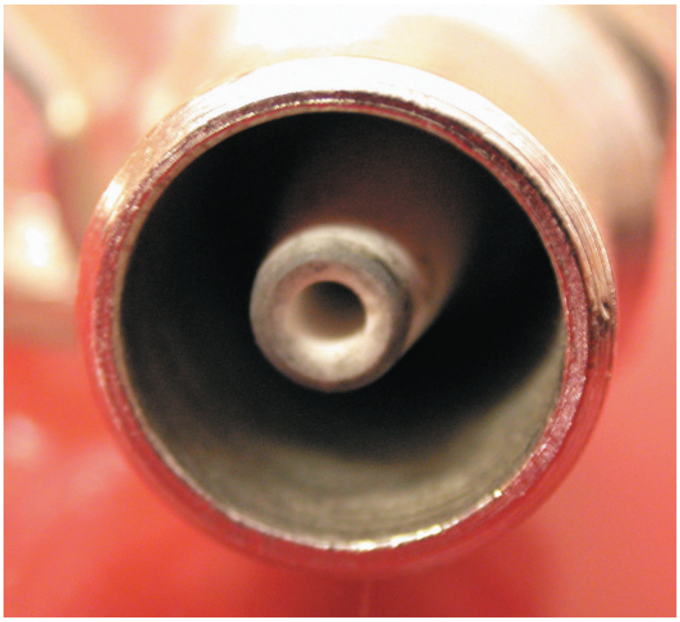


FIGURE 69–2 A close-up showing the recessed center electrode on a spark tester. It is recessed 3/8 inch into the shell and the spark must then jump another 3/8 inch to the shell for a total gap of 3/4 inch.

TECH TIP

Always Use a Spark Tester

A spark tester looks like a spark plug except it has a recessed center electrode and no side electrode. The tester commonly has an alligator clip attached to the shell so that it can be clamped on a good ground connection on the engine. A good ignition system should be able to cause a spark to jump this wide gap at atmospheric pressure. Without a spark tester, a technician might assume that the ignition system is okay because it can spark across a normal, grounded spark plug. The voltage required to fire a standard spark plug when it is out of the engine and not under pressure is about 3,000 volts or less. An electronic ignition spark tester requires a minimum of 25,000 volts to jump the 3/4 inch gap. Therefore, never assume that the ignition system is okay because it fires a spark plug–always use a spark tester. *Remember that an intermittent spark across a spark tester should be interpreted as a no-spark condition.*

CASE STUDY

The Weird Running Chevrolet Truck

An older Chevrolet pickup truck equipped with a V-8 engine was towed into a shop because it would not start. A quick check of the ignition system showed that the pickup coil had a broken wire between it and the ignition control module. The distributor was removed from the engine and the distributor shaft was removed, cleaned, and a replacement pickup coil was installed. The engine started, but ran rough and hesitated when the accelerator pedal was depressed. After an hour of troubleshooting, a careful inspection of the new pickup coil showed that the time core had six instead of eight points, meaning that the new pickup coil was meant for a V-6 instead of a V-8 engine. Replacing the pickup coil again solved the problem.

Summary:

Complaint—Customer stated that the truck would not start.
Cause—A visual inspection was used to determine a that a pickup coil wire was broken and was replaced but with the wrong part that was in the correct box.
Correction—Replacing the pickup coil with the right part fixed the truck.

ELECTRONIC IGNITION TROUBLESHOOTING PROCEDURE

When troubleshooting any electronic ignition system for no spark, follow these steps to help pinpoint the exact cause of the problem:

STEP 1 Turn the ignition on (engine off) and, using either a voltmeter or a test light, test for battery voltage available at the positive terminal of the ignition coil. If the voltage is not available, check for an open circuit at the ignition switch or wiring. Also check the condition of the ignition fuse (if used).

NOTE: Many Chrysler group products use an automatic shutdown (ASD) relay to power the ignition coil. The ASD relay will not supply voltage to the coil unless the engine is cranking and the computer senses a crankshaft sensor signal. This little known fact has fooled many technicians.

STEP 2 Connect the voltmeter or test light to the negative side of the coil and crank the engine. The voltmeter should fluctuate or the test light should blink, indicating that the primary coil current is being turned on and off. If there is no pulsing of the negative side of the coil, the problem is a defective pickup, electronic control module, or wiring.

IGNITION COIL TESTING USING AN OHMMETER

If an ignition coil is suspected of being defective, a simple ohmmeter check can be performed to test the resistance of the primary and secondary winding inside the coil. For accurate resistance measurements, the wiring to the coil should be removed before testing. To test the primary coil winding resistance, take the following steps (● **SEE FIGURE 69–3**):

STEP 1 Set the meter to read low ohms.

STEP 2 Measure the resistance between the positive terminal and the negative terminal of the ignition coil. Most coils

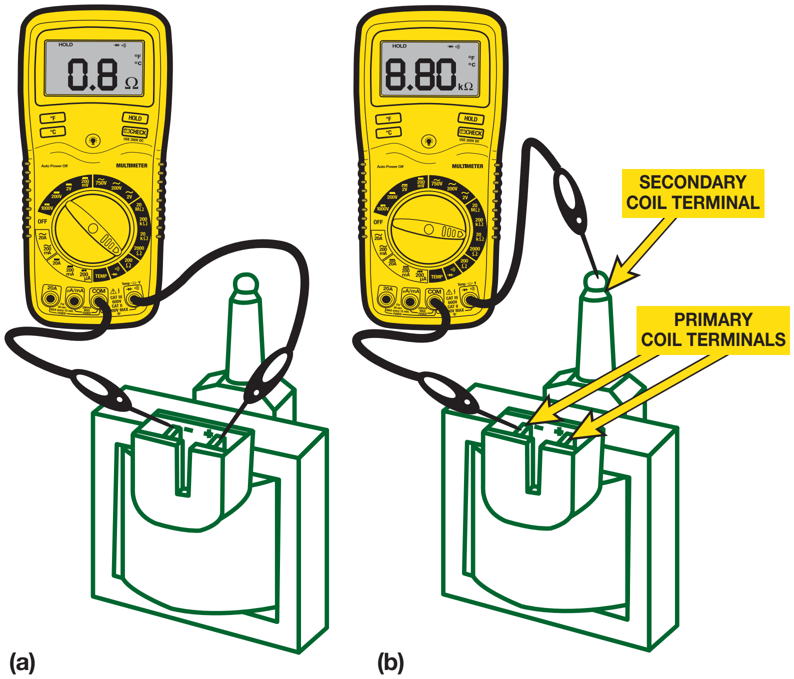


FIGURE 69–3 (a) Set the digital meter to read Ohms and measure between the two primary terminals of the coil. Most coils are less than 1 ohm. (b) To measure the secondary winding, connect 1 meter lead to one of the primary terminals and the other to the secondary terminal.

will give a reading between 1 and 3 ohms; however, some coils should indicate less than 1 ohm. Check the manufacturer's specifications for the exact resistance values.

To test the secondary coil winding resistance, follow these steps:

STEP 1 Set the meter to read kilohms (kΩ).

STEP 2 Measure the resistance between primary terminal and the secondary coil tower. The normal resistance of most coils ranges between 6,000 and 30,000 ohms. Check the manufacturer's specifications for the exact resistance values.

TESTING MAGNETIC SENSORS

First of all, magnetic sensors must be tested to see if they will stick to iron or steel, indicating that the magnetic strength of the sensors is okay. If the permanent magnet inside the sensor has cracked, the result is two weak magnets.

If the sensor is removed from the engine, hold a metal (steel) object against the end of the sensor. It should exert a strong magnetic pull on the steel object. If not, replace the sensor. Second, the sensor can be tested using a digital meter set to read ohms or AC volts. ● **SEE FIGURE 69–4**.

TESTING HALL-EFFECT SENSORS

As with any other sensor, the output of the Hall-effect sensor should be tested first. Using a digital voltmeter, check for the presence of changing voltage (pulsed on and off or digital DC) when the engine is being cranked. The best test is to use an oscilloscope and observe the waveform. ● **SEE FIGURE 69–5**.

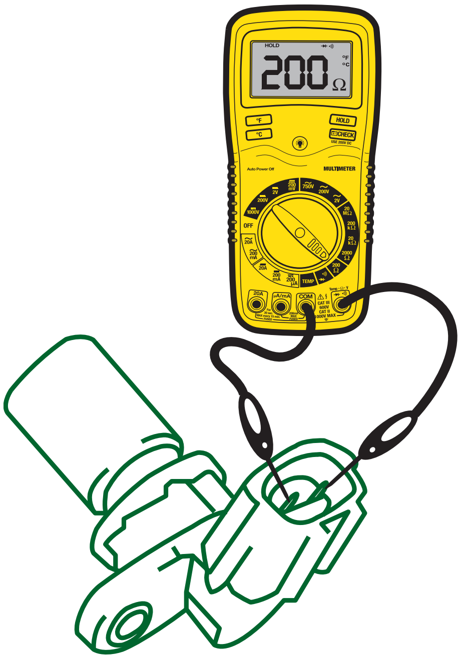


FIGURE 69–4 Measuring the resistance of an magnetic crankshaft position (CKP) sensor using an ohmmeter.

IGNITION SYSTEM DIAGNOSIS USING VISUAL INSPECTION

One of the first steps in the diagnosis process is to perform a thorough visual inspection of the ignition system, including the following:

- Check all spark plug wires for proper routing. All plug wires should be in the factory wiring separator and be clear of any metallic object that could cause damage to the insulation and cause a short-to-ground fault.

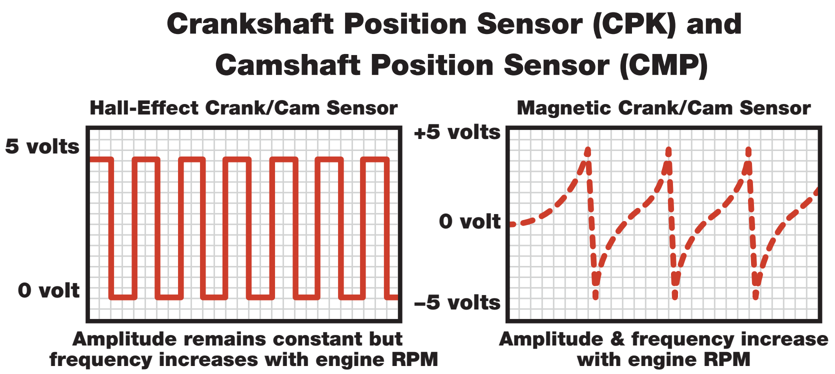


FIGURE 69–5 A Hall-effect sensor produces a square waveform, whereas a magnetic sensor produces an analog waveform when viewed on the scope.

TECH TIP

Bad Wire? Replace the Coil!

When performing engine testing (such as a compression test), always ground the coil wire. Never allow the coil to discharge without a path to ground for the spark. High-energy electronic ignition systems can produce 40,000 volts or more of electrical pressure. If the spark cannot arc to ground, the coil energy can (and usually does) arc inside the coil itself, creating a low-resistance path to the primary windings or the steel laminations of the coil. ● **SEE FIGURE 69–6**. This low-resistance path is called a track and could cause an engine misfire under load even though all of the remaining component parts of the ignition system are functioning correctly. Often these tracks do not show up on any coil test, including most scopes. Because the track is a lower-resistance path to ground than normal, it requires that the ignition system be put under a load for it to be detected, and even then, the problem (engine misfire) may be intermittent.

Therefore, when disabling an ignition system, perform one of the following procedures to prevent possible ignition coil damage:

1. Remove the power source wire from the ignition system to prevent any ignition operation.
2. On distributor-equipped engines, remove the secondary coil wire from the center of the distributor cap and connect a jumper wire between the disconnected coil wire and a good engine ground. This ensures that the secondary coil energy will be safely grounded and prevents high-voltage coil damage.

TECH TIP

The Magnetic Pickup Tool Test

All ignition coils are pulsed on and off by the ignition control module or PCM. When the coil charges and discharges, the magnetic field around the coil changes. This pulsing of the coil can be observed by holding the magnetic end of a pickup tool near an operating ignition coil. The magnet at the end of the pickup tool will move as the magnetic field around the coil changes. ● **SEE FIGURE 69–7**.

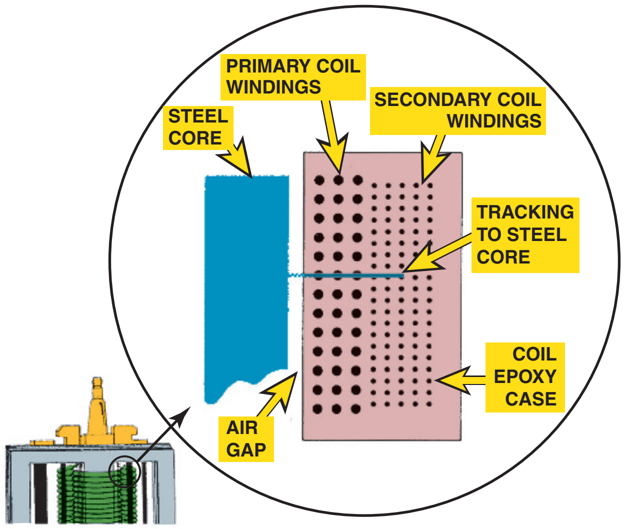


FIGURE 69–6 A track inside an ignition coil is not a short, but rather it is a low-resistance path or hole that has been burned through from the secondary wiring to the steel core.

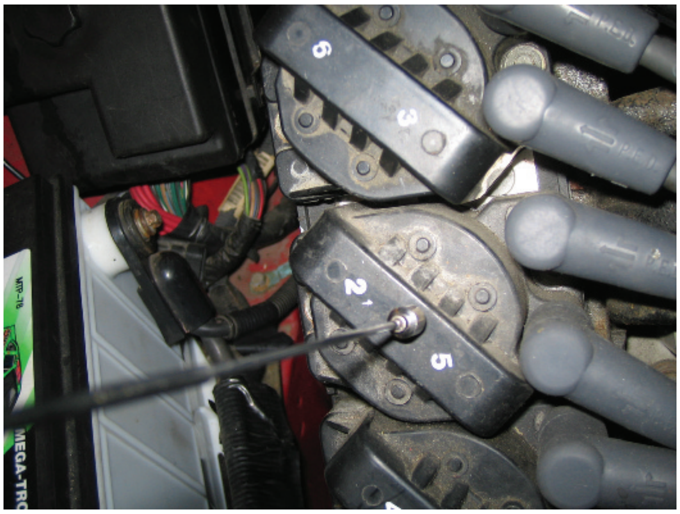


FIGURE 69–7 If the coil is working, the end of the magnetic pickup tool will move with the changes in the magnetic field around the coil.

- Check that all spark plug wires are securely attached to the spark plugs and to the distributor cap or ignition coil(s).
- Remove the spark plugs and check for excessive wear or other visible faults. Replace if needed.

NOTE: According to research conducted by General Motors, about one-fifth (20%) of all faults are detected during a *thorough visual inspection!*

TESTING FOR POOR PERFORMANCE

A simple method of testing distributorless (waste-spark systems) ignition with the engine off involves removing the spark plug wires (or connectors) from the spark plugs (or coils or distributor cap) and installing short lengths (2 inches) of rubber vacuum hose in series.

NOTE: For best results, use rubber hose that is electrically conductive. Measure the vacuum hose with an ohmmeter. Suitable vacuum hose should give a reading of less than 10,000 ohms (10 kΩ) for a length of about 2 inches. ● SEE FIGURES 69–7 AND 69–8.

STEP 1 Start the engine and ground out each cylinder one at a time by touching the tip of a grounded test light to the rubber vacuum hose. Even though the computer will increase idle speed and fuel delivery to compensate for the grounded spark plug wire, a technician should watch for a change in the operation of the engine. If no change is observed or heard, the cylinder being grounded is obviously weak or defective. Check the spark plug wire or connector with an ohmmeter to be certain of continuity.

STEP 2 Check all cylinders by grounding them out one at a time. If one weak cylinder is found (very little RPM drop), check the other cylinder using the same ignition coil (except on engines that use an individual coil for each cylinder). If both cylinders are affected, the problem could be an open spark plug wire, defective spark plug, or defective ignition coil.

STEP 3 To help eliminate other possible problems and determine exactly what is wrong, switch the suspected ignition coil to another position (if possible).

- If the problem now affects the other cylinders, the ignition coil is defective and must be replaced.
- If the problem does not "change positions" with changing the position of the ignition coil, the control module affecting the suspected coil or either cylinder's spark plug or spark plug wire could be defective.

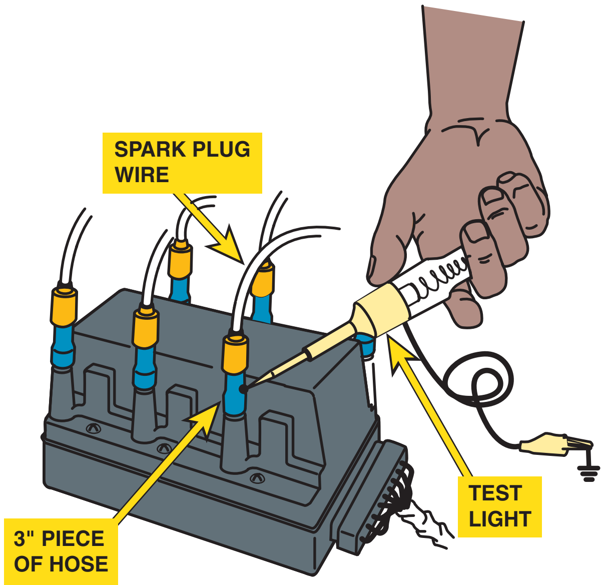


FIGURE 69–8 Using a vacuum hose and a grounded testlight to ground one cylinder at a time on a DIS. This works on all types of ignition systems and provides a method for grounding out one cylinder at a time without fear of damaging any component. Use a standard 12-volt test light that uses a bulb because if an LED test light is used, the high-voltage with harm the electronic circuit inside the test light.

TESTING FOR A NO-START CONDITION

A no-start condition (with normal engine cranking speed) can be the result of either no spark or no fuel delivery.

Computerized engine control systems use the ignition primary pulses as a signal to inject fuel–a port or throttle-body injection (TBI) style of fuel–injection system. If there is no pulse, there is no squirt of fuel. To determine exactly what is wrong, follow these steps:

STEP 1 Test the output signal from the crankshaft sensor. Most computerized engines with distributorless ignitions use a crankshaft position sensor. These sensors are either the Hall-effect type or the magnetic type. The sensors must be able to produce either a sine or a digital signal. A meter set on AC volts should read a voltage across the sensor leads when the engine is being cranked. If there is no AC voltage output, replace the sensor.

STEP 2 If the sensor tests okay in step 1, check for a changing AC voltage signal at the ignition module.

NOTE: Step 2 checks the wiring between the crankshaft position sensor and the ignition control module.

STEP 3 If the ignition control module is receiving a changing signal from the crankshaft position sensor, it must be capable of switching the power to the ignition coils on and off. Remove a coil or coil package, and with the ignition switched to on (run), check for voltage at the positive terminal of the coil(s).

NOTE: Several manufacturers program the current to the coils to be turned off within several seconds of the ignition being switched to on if no pulse is received by the computer. This circuit design helps prevent ignition coil damage in the event of a failure in the control circuit or driver error, by keeping the ignition switch on (run) without operating the starter (start position). Some Chrysler engines do not supply power to the positive (+) side of the coil until a crank pulse is received by the computer, which then energizes the coil(s) and injectors through the automatic shutdown (ASD) relay.

STEP 4 If the module is not pulsing the negative side of the coil or not supplying battery voltage to the positive side of the coil, replace the ignition control module.

NOTE: Before replacing the ignition control module, be certain that it is properly grounded (where applicable) and that the module is receiving ignition power from the ignition circuit.

CAUTION: Most distributorless (waste-spark) ignition systems can produce 40,000 volts or more, with energy levels high enough to cause personal injury. Do not open the circuit of an electronic ignition secondary wire because damage to the system (or to you) can occur.

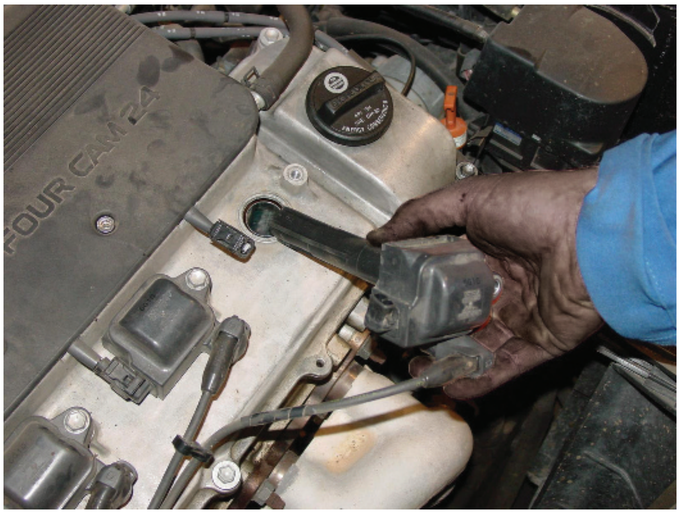


FIGURE 69–9 When checking a coil-on-plug (COP) assembly, check that the primary and secondary wiring looks normal and that the coil is not discolored from arcing or corrosion.

SECONDARY IGNITION INSPECTION

COP AND WASTE SPARK INSPECTION If a misfire is being diagnosed, perform a thorough visual inspection of the coil-on-plug (COP) assembly and look for evidence of carbon track or heat-related faults to the plug boot. ● **SEE FIGURE 69–9.**

Check ignition coils of waste spark and coil-on-plug (COP) systems for signs of carbon tracks (black lines) or corrosion.

When checking a waste spark-type ignition system, check that the coils are clean and that the spark plug wires are attached to the specified coil and coil terminal. ● **SEE FIGURES 69–10 AND 69–11**.

SPARK PLUG WIRE INSPECTION Spark plug wires should be visually inspected for cuts or defective insulation and checked for resistance with an ohmmeter. Good spark plug wires should measure less than 10,000 ohms per foot of length. ● **SEE FIGURES 69–12 AND 69–13**. Faulty spark plug wire insulation can cause hard starting or no starting in damp weather conditions.

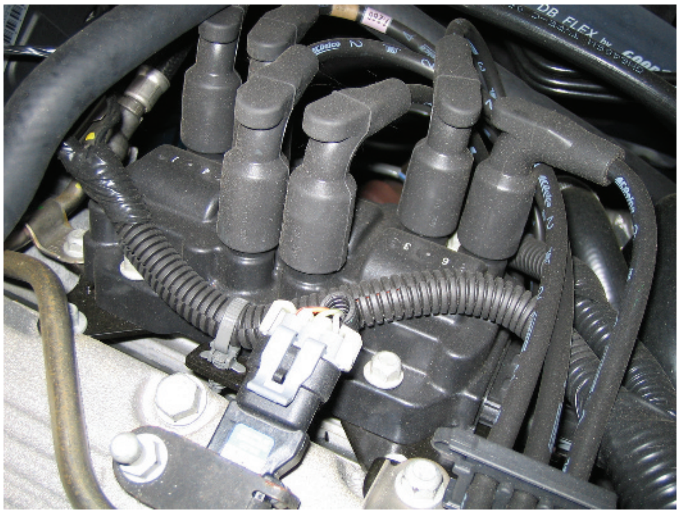


FIGURE 69–10 When checking a waste spark-type ignition system, check that the secondary wires are attached to the correct coil terminal and that the wiring is correctly routed to help avoid cross-fire.

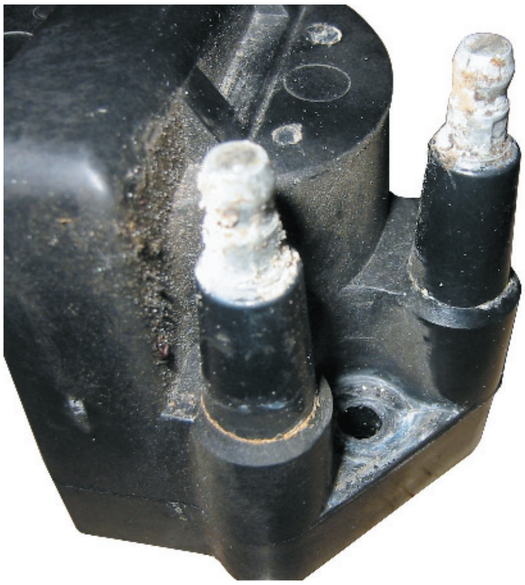


FIGURE 69–11 Corroded terminals on a waste-spark coil can cause misfire diagnostic trouble codes to be set.

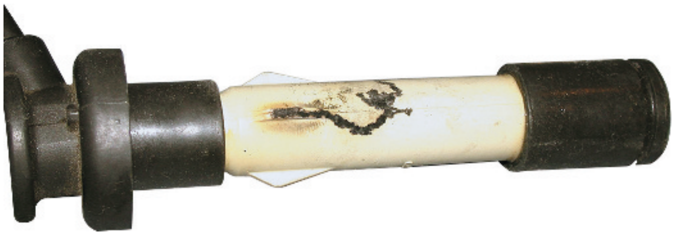


FIGURE 69–12 This spark plug boot on an overhead camshaft engine has been arcing to the valve cover causing a misfire to occur.

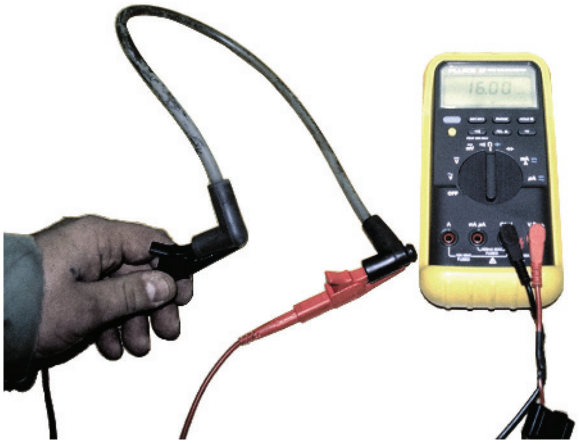


FIGURE 69–13 Measuring the resistance of a spark plug wire with a multimeter set to the ohms position. The reading of 16.03 kΩ (16,030 ohms) is okay because the wire is about 2 feet long. Maximum allowable resistance for a spark plug wire this long would be 20 kΩ (20,000 ohms). High resistance spark plug wires can cause an engine misfire especially during acceleration.

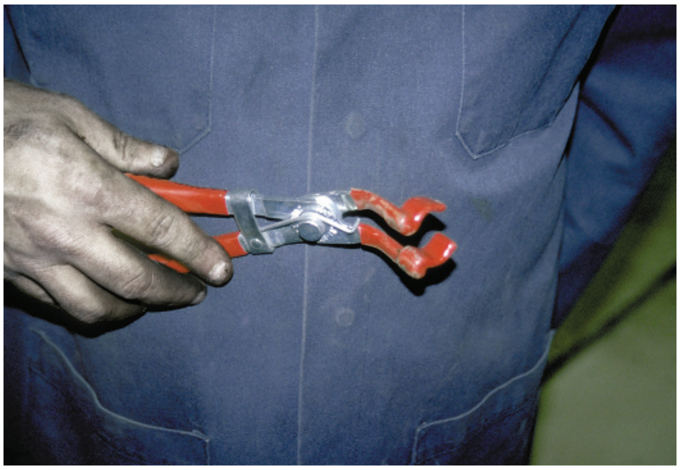


FIGURE 69–14 Spark plug wire boot pliers are a handy addition to any tool box.

TECH TIP

Spark Plug Wire Pliers Are a Good Investment

Spark plug wires are often difficult to remove. Using a good-quality spark plug wire plier, such as shown in ● **SEE FIGURE 69–14**, saves time and reduces the chance of harming the wire during removal..

TECH TIP

Route the Wires Right!

High voltage is present through spark plug wires when the engine is running. Surrounding the spark plugs in a magnetic field that can affect other circuits or components of the vehicle. For example, if a spark plug wire is routed too closely to the signal wire from a mass airflow (MAF) sensor, the induced signal from the ignition wire could create a false MAF signal to the computer. The computer, not able to detect that the signal was false, would act on the MAF signal and command the appropriate amount of fuel based on the false MAF signal.

To prevent any problems associated with high-voltage spark plug wires, be sure to route them as manufactured, using all the factory holding brackets and wiring combs. ● **SEE FIGURE 69–15**. If the factory method is unknown, most factory service information shows the correct routing.

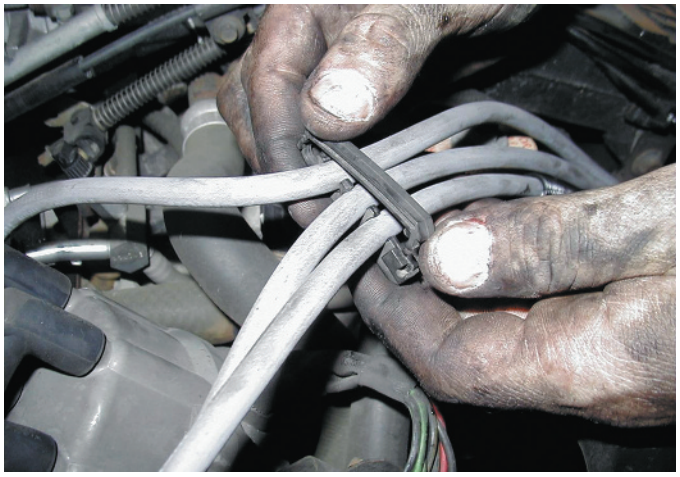


FIGURE 69–15 Always take the time to install spark plug wires back into the original holding brackets (wiring combs).

SPARK PLUG SERVICE

THE NEED FOR SERVICE Spark plugs should be inspected when an engine performance problem occurs and should be replaced at specified intervals to ensure proper ignition system performance. Most spark plugs have a service life of over 20,000 miles (32,000 kilometers). Platinum-tipped original equipment spark plugs have a typical service life of 60,000 to 100,000 miles (100,000 to 160,000 kilometers). Used spark plugs should *not* be cleaned and reused unless absolutely necessary. The labor required to **remove and replace (R & R)** spark plugs is the same whether the spark plugs are replaced or cleaned. Although cleaning spark plugs often restores proper engine operation, the service life of cleaned spark plugs is definitely shorter than that of new spark plugs. *Platinum-tipped spark plugs should not be regapped!* Using a gapping tool can break the platinum after it has been used in an engine.

Be certain that the engine is cool before removing spark plugs, especially on engines with aluminum cylinder heads. To help prevent dirt from getting into the cylinder of an engine while removing a spark plug, use compressed air or a brush to remove dirt from around the spark plug before removal. ● **SEE FIGURES 69–16 THROUGH 69–18**.

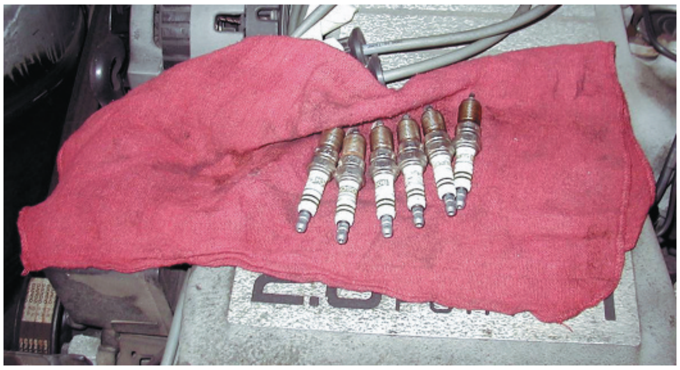


FIGURE 69–16 When removing spark plugs, it is wise to arrange them so that they can be compared and any problem can be identified with a particular cylinder.

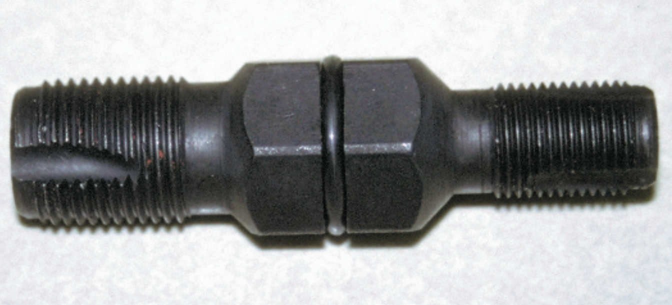


FIGURE 69–17 A spark plug thread chaser is a low-cost tool that hopefully will not be used often, but is necessary to use to clean the threads before new spark plugs are installed.

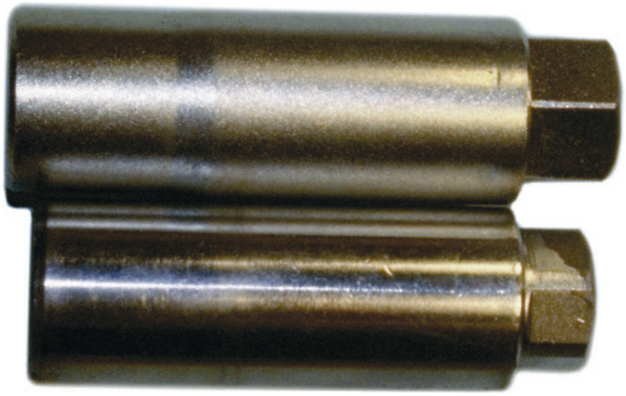


FIGURE 69–18 Since 1991, General Motors engines have been equipped with slightly (1/8 inch or 3 mm) longer spark plugs. This requires that a longer spark plug socket should be used to prevent the possibility of cracking a spark plug during installation. The longer socket is shown next to a normal 5/8 inch spark plug socket.

SPARK PLUG INSPECTION Spark plugs are the windows to the inside of the combustion chamber. A thorough visual inspection of the spark plugs often can lead to the root cause of an engine performance problem. Two indications on spark plugs and their possible root causes in engine performance include the following:

1. **Carbon fouling.** If the spark plug(s) has *dry black carbon* (soot), the usual causes include
   - Excessive idling
   - Slow-speed driving under light loads that keeps the spark plug temperatures too low to burn off the deposits
   - Overrich air–fuel mixture
   - Weak ignition system output
2. **Oil fouling.** If the spark plug has *wet, oily* deposits with little electrode wear, oil may be getting into the combustion chamber from the following:
   - Worn or broken piston rings
   - Defective or missing valve stem seals

NOTE: If the deposits are heavier on the side of the plug facing the intake valve, the cause is usually due to excessive valve stem clearance or defective intake valve stem seals.

When removing spark plugs, place them in order so that they can be inspected to check for engine problems that might affect one or more cylinders. All spark plugs should be in the same condition, and the color of the center insulator should be light tan or gray. If all the spark plugs are black or dark, the engine should be checked for conditions that could cause an overly rich air–fuel mixture or possible oil burning. If only one or a few spark plugs are black, check those cylinders for proper firing (possible defective spark plug wire) or an engine condition affecting only those particular cylinders. ● **SEE FIGURES 69–19 THROUGH 69–22**.

If all spark plugs are white, check for possible overadvanced ignition timing or a vacuum leak causing a lean air–fuel mixture. If only one or a few spark plugs are white, check for a vacuum leak affecting the fuel mixture only to those particular cylinders.

NOTE: The engine computer "senses" rich or lean air–fuel ratios by means of input from the oxygen sensor. If one cylinder is lean, the computer may make all other cylinders richer to compensate.

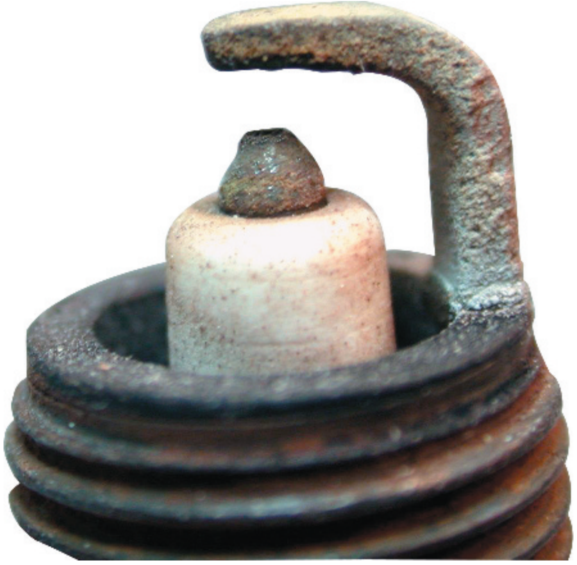


FIGURE 69–19 A normally worn spark plug that has a tapered platinum-tipped center electrode.

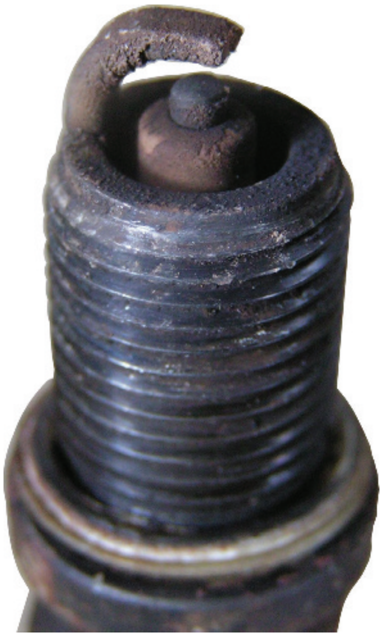


FIGURE 69–20 A worn spark plug showing fuel and/or oil deposits.

Inspect all spark plugs for wear by first checking the condition of the center electrode. As a spark plug wears, the center electrode becomes rounded. If the center electrode is rounded, higher ignition system voltage is required to fire the spark plug. When installing spark plugs, always use the correct tightening torque to ensure proper heat transfer from the spark plug shell to the cylinder head. ● **SEE CHART 69–1**.

NOTE: General Motors does not recommend the use of antiseize compound on the threads of spark plugs being installed in an aluminum cylinder head because the spark plug will be overtightened. This excessive tightening torque places the threaded portion of the spark plug too far into the combustion chamber where carbon can accumulate and result in the spark plugs being difficult to remove. If antiseize compound is used on spark plug threads, reduce the tightening torque by 40%. Always follow the vehicle manufacturer's recommendations.

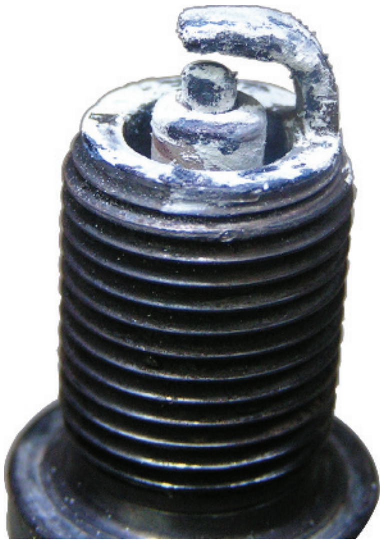


FIGURE 69–21 A spark plug from an engine that had a blown head gasket. The white deposits could be from the additives in the coolant.

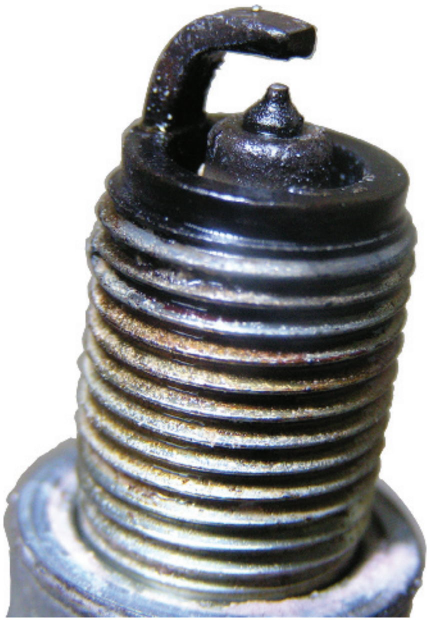


FIGURE 69–22 A platinum tipped spark plug that is fuel soaked indicating a fault with the fuel system or the ignition system causing the spark plug to not fire.

	TORQUE WITH TORQUE WRENCH (LB-FT)		TORQUE WITHOUT TORQUE WRENCH (TURNS)	
SPARK PLUG	CAST-IRON HEAD	ALUMINUM HEAD	CAST-IRON HEAD	ALUMINUM HEAD
Gasket				
14 mm	26–30	18–22	1/4	1/4
18 mm	32–38	28–34	1/4	1/4
Tapered seat				
14 mm	7–15	7–15	1/16 (snug)	1/16 (snug)
18 mm	15–20	15–20	1/16 (snug)	1/16 (snug)

CHART 69–1

Typical spark plug tightening torque based on type of spark plug and the cylinder head material.

TECH TIP

Two-Finger Trick

To help prevent overtightening a spark plug when a torque wrench is not available, simply use two fingers on the ratchet handle. Even the strongest service technician cannot overtighten a spark plug by using two fingers.

TECH TIP

Use Original Equipment Manufacturer's Spark Plugs

A technician at an independent service center replaced the spark plugs in a Buick with new Champion brand spark plugs of the correct size, reach, and heat range. When the customer returned to pay the bill, he inquired as to the brand name of the replacement parts used for the tune-up. When told that Champion spark plugs were used, he stopped signing his name on the check he was writing. He said that he owned 1,000 shares of General Motors stock and he owned two General Motors vehicles and he expected to have General Motors parts used in his General Motors vehicles. The service manager had the technician replace the spark plugs with AC brand spark plugs because this brand was used in the engine when the vehicle was new. Even though most spark plug manufacturers produce spark plugs that are correct for use, many customers prefer that original equipment manufacturer (OEM) spark plugs be used in their engines.

QUICK AND EASY SECONDARY IGNITION TESTS

Engine running problems often are caused by defective or out-of-adjustment ignition components. Many ignition problems involve the high-voltage secondary ignition circuit. Following are some quick and easy secondary ignition tests:

TEST 1 If there is a crack in a distributor cap, coil, or spark plug, or if there is a defective spark plug wire, a spark may be visible at night. Because the highest voltage is required during partial throttle acceleration, the technician's assistant should accelerate the engine slightly with the gear selector in drive or second gear (if manual transmission) and the brake firmly applied. If any spark is visible or a "snapping" sound is heard, the location should be closely inspected and the defective parts replaced. A blue glow or "corona" around the shell of the spark plug is normal and not an indication of a defective spark plug.

TEST 2 For intermittent problems, use a spray bottle to apply a water mist to the spark plugs, and spark plug wires. ● **SEE FIGURE 69–23**. With the engine running, the water may cause an arc through any weak insulating materials and cause the engine to misfire or stall.

FIGURE 69–23 A water spray bottle is an excellent diagnostic tool to help find an intermittent engine misfire caused by a break in a secondary ignition circuit component.

NOTE: Adding a little salt or liquid soap to the water makes the water more conductive and also makes it easier to find those hard-to-diagnose intermittent ignition faults.

TEST 3 To determine if the rough engine operation is due to secondary ignition problems, connect a 12-volt test light to the negative side (sometimes labeled "tach") of the coil. Connect the other lead of the test light to the positive lead of the coil. With the engine running, the test light should be dim and steady in brightness. If there is high resistance in the secondary circuit (such as that caused by a defective spark plug wire), the test light will pulse brightly at times. If the test light varies noticeably, this indicates that the secondary voltage cannot find ground easily and is feeding back through the primary windings of the coil. This feedback causes the test light to become brighter.

SCOPE-TESTING THE IGNITION SYSTEM

Any automotive scope with the correct probes or adapters will show an ignition system pattern. All ignition systems must charge and discharge an ignition coil. With the engine off, most scopes will display a horizontal line. With the engine running, this horizontal (zero) line is changed to a pattern that will have sections both above and below the zero line. Sections of this pattern that are above the zero line indicate that the ignition coil is discharging. Sections of the scope pattern below the zero line indicate charging of the ignition coil. The height of the scope pattern indicates voltage. The length (from left to right) of the scope pattern indicates time.

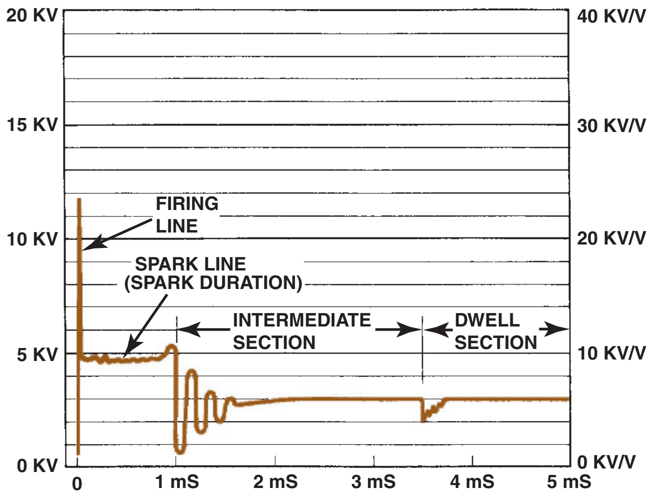


FIGURE 69–24 Typical secondary ignition oscilloscope pattern.

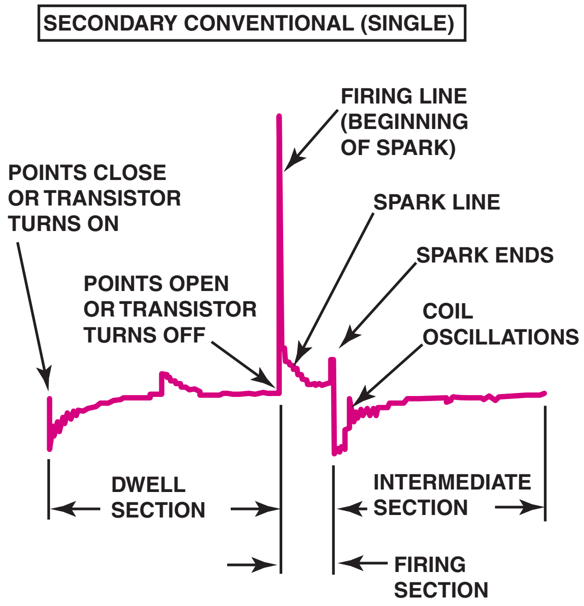

SECONDARY CONVENTIONAL (SINGLE)
FIRING LINE (BEGINNING OF SPARK)
POINTS CLOSE OR TRANSISTOR TURNS ON
SPARK LINE
SPARK ENDS
POINTS OPEN OR TRANSISTOR TURNS OFF
COIL OSCILLATIONS
DWELL SECTION
INTERMEDIATE SECTION
FIRING SECTION

FIGURE 69–25 The scope shows one cylinder at a time on a COP-type ignition system.

FIRING LINE The leftmost vertical (upward) line is called the **firing line**. The height of the firing line should be between 5,000 and 15,000 volts (5 and 15 kV) with not more than a 3 kV difference between the highest and the lowest cylinder's firing line. ● **SEE FIGURES 69–24 AND 69–25.**

The height of the firing line indicates the *voltage* required to fire the spark plug. It requires a high voltage to make the air inside the cylinder electrically conductive (to ionize the air). A higher than normal height (or height higher than that of other cylinders) can be caused by one or more of the following:

1. Spark plug gapped too wide
2. Lean fuel mixture
3. Defective spark plug wire

If the firing lines are higher than normal for *all* cylinders, possible causes include one or more of the following:

1. Excessive wearing of all spark plugs
2. Defective coil wire (the high voltage could still jump across the open section of the wire to fire the spark plugs)

SPARK LINE The **spark line** is a short horizontal line immediately after the firing line. The height of the spark line represents the voltage required to maintain the spark across the spark plug after the spark has started. The height of the spark line should be one-fourth of the height of the firing line (between 1.5 and 2.5 kV). The length (from left to right) of the line represents the length of time for which the spark lasts (duration or burn time). The spark duration should be between 0.8 and 2.2 milliseconds (usually between 1.0 and 2.0 ms). The spark stops at the end (right side) of the spark line.

INTERMEDIATE OSCILLATIONS After the spark has stopped, some energy remains in the coil. This remaining energy dissipates in the coil windings and the entire secondary circuit. The **intermediate oscillations** are also called the "ringing" of the coil as it is pulsed.

The secondary pattern amplifies any voltage variation occurring in the primary circuit because of the turns ratio between the primary and secondary windings of the ignition coil. A correctly operating ignition system should display five or more "bumps" (oscillations) (three or more for a GM HEI system).

TRANSISTOR-ON POINT After the intermediate oscillations, the coil is empty (not charged), as indicated by the scope pattern being on the zero line for a short period. When the transistor turns on an electronic system, the coil is being charged. Note that the charging of the coil occurs slowly (coil-charging oscillations) because of the inductive reactance of the coil.

DWELL SECTION Dwell is the amount of time that the current is charging the coil from the transistor-on point to the transistor-off point. At the end of the **dwell section** is the beginning of the next firing line. This point is called "transistor off" and indicates that the primary current of the coil is stopped, resulting in a high-voltage spark out of the coil.

Many scopes are equipped with a **millisecond (ms) sweep**. This means that the scope will sweep only that portion of the pattern that can be shown during a 5- or 25-ms setting. Following are guidelines for spark line length:

- 0.8 ms—too short
- 1.5 ms—average
- 2.2 ms—too long

If the spark line is too short, possible causes include the following:

1. Spark plug(s) gap is too wide
2. High-resistance spark plug wire
3. Air–fuel mixture too lean (vacuum leak, broken valve spring, etc.)

If the spark line is too long, possible causes include the following:

1. Fouled spark plug(s)
2. Spark plug(s) gap is too narrow
3. Shorted spark plug or spark plug wire

Many scopes do not have a millisecond scale. Some scopes are labeled in degrees and/or percentage (%) of dwell. The following chart can be used to determine acceptable spark line length. ● **SEE CHART 69–2**.

NORMAL SPARK LINE LENGTH (AT 700 TO 1,200 RPM)			
NUMBER OF CYLINDERS	MILLISECONDS	PERCENTAGE (%) OF DWELL SCALE	DEGREES (°)
4	1.0–2.0	3–6	3–5
6	1.0–2.0	4–9	2–5
8	1.0–2.0	6–13	3–6

CHART 69–2

Spark line length depends on the number of cylinders and the engine speed.

SPARK LINE SLOPE Downward-sloping spark lines indicate that the voltage required to maintain the spark duration is decreasing during the firing of the spark plug. This downward slope usually indicates that the spark energy is finding ground through spark plug deposits (the plug is fouled) or other ignition problems. ● **SEE FIGURE 69–26**.

An upward-sloping spark line usually indicates a mechanical engine problem. A defective piston ring or valve would tend to seal better in the increasing pressures of combustion. As the spark plug fires, the effective increase in pressures increases the voltage required to maintain the spark, and the height of the spark line rises during the duration of the spark. ● **SEE FIGURE 69–27**.

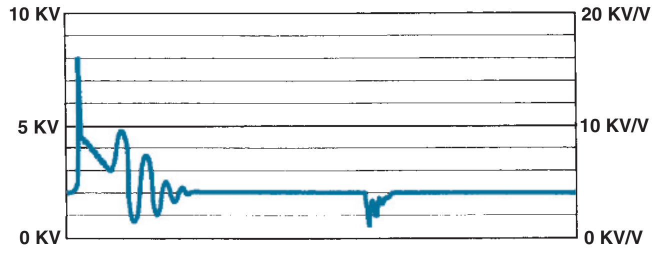


FIGURE 69–26 A downward-sloping spark line usually indicates high secondary ignition system resistance or an excessively rich air–fuel mixture.

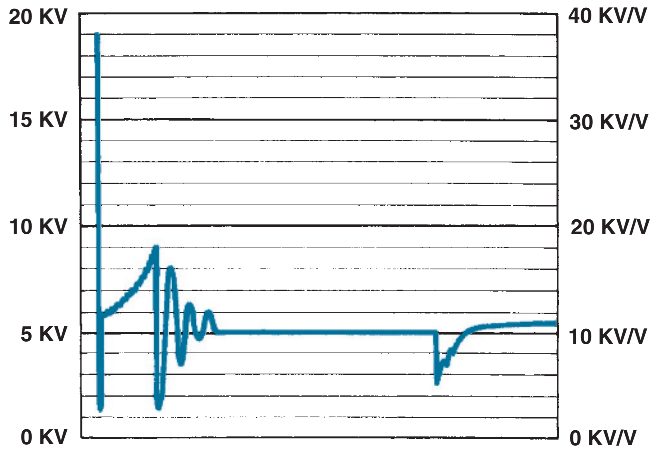


FIGURE 69–27 An upward-sloping spark line usually indicates a mechanical engine problem or a lean air–fuel mixture.

An upward-sloping spark line can also indicate a lean air–fuel mixture. Typical causes include

1. Clogged injector(s)
2. Vacuum leak
3. Sticking intake valve

● **SEE FIGURE 69–28** for an example showing the relationship between the firing line and the spark line.

READING THE INTERMEDIATE SECTION The intermediate section should have three or more oscillations (bumps) for a correctly operating ignition system. Because approximately 250 volts are in the primary ignition circuit when the spark stops flowing across the spark plugs, this voltage is reduced by about 75 volts per oscillation. Additional resistances in the primary circuit would decrease the number of oscillations. If there are fewer than three oscillations, possible problems include the following:

1. Shorted ignition coil
2. Loose or high-resistance primary connections on the ignition coil or primary ignition wiring

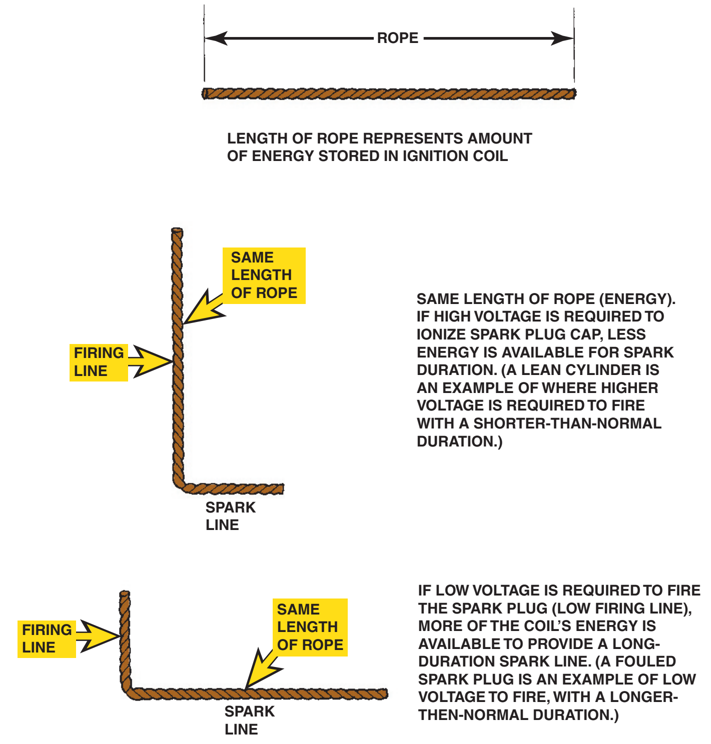

ROPE
LENGTH OF ROPE REPRESENTS AMOUNT OF ENERGY STORED IN IGNITION COIL
SAME LENGTH OF ROPE
FIRING LINE
SPARK LINE
SAME LENGTH OF ROPE (ENERGY). IF HIGH VOLTAGE IS REQUIRED TO IONIZE SPARK PLUG CAP, LESS ENERGY IS AVAILABLE FOR SPARK DURATION. (A LEAN CYLINDER IS AN EXAMPLE OF WHERE HIGHER VOLTAGE IS REQUIRED TO FIRE WITH A SHORTER-THAN-NORMAL DURATION.)
FIRING LINE
SAME LENGTH OF ROPE
SPARK LINE
IF LOW VOLTAGE IS REQUIRED TO FIRE THE SPARK PLUG (LOW FIRING LINE), MORE OF THE COIL'S ENERGY IS AVAILABLE TO PROVIDE A LONG-DURATION SPARK LINE. (A FOULED SPARK PLUG IS AN EXAMPLE OF LOW VOLTAGE TO FIRE, WITH A LONGER-THAN-NORMAL DURATION.)

FIGURE 69–28 The relationship between the height of the firing line and length of the spark line can be illustrated using a rope. Because energy cannot be destroyed, the stored energy in an ignition coil must dissipate totally, regardless of engine operating conditions.

SCOPE-TESTING A WASTE-SPARK IGNITION SYSTEM

A handheld digital storage oscilloscope can be used to check the pattern of each individual cylinder. Some larger scopes can be connected to all spark plug wires, and therefore are able to display both power and waste-spark waveforms. ● **SEE FIGURE 69–29**. Because the waste spark does not require as high a voltage level as the cylinder on the power stroke, the waste form will be normally lower.

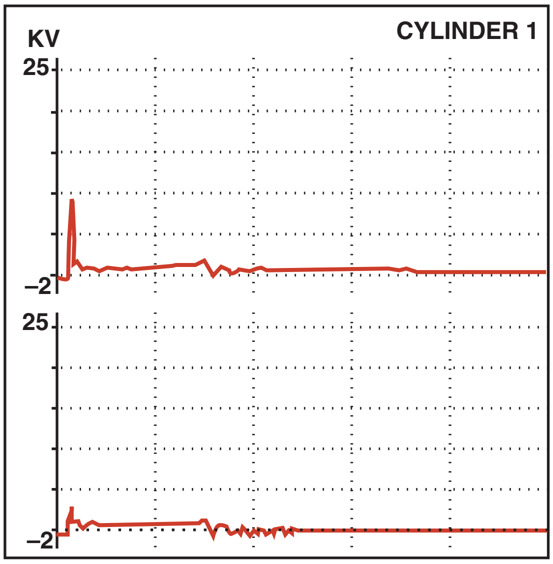


FIGURE 69–29 A dual-trace scope pattern showing both the power and the waste spark from the same coil (cylinders 1 and 6). Note that the firing line is higher on the cylinder that is under compression (power); otherwise, both patterns are almost identical.

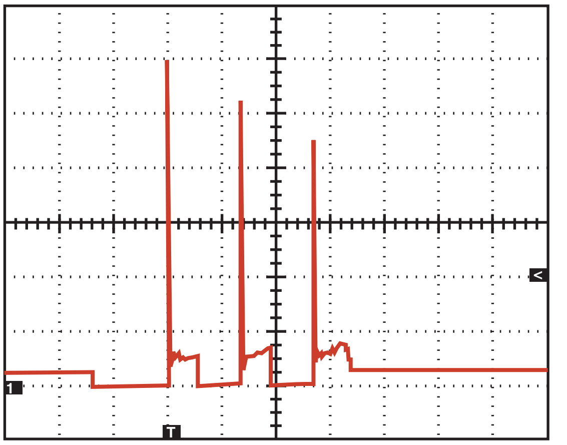


FIGURE 69–30 A secondary waveform of a Ford 4.6 liter V-8, showing three sparks occurring at idle speed.

SCOPE-TESTING A COIL-ON-PLUG IGNITION SYSTEM

In a coil-on-plug type of ignition system, each individual coil can be shown on a scope. By using a multichannel scope and the proper cables and adapters, the waveform for all of the cylinders can be viewed at the same time. Always follow the scope equipment manufacturer's instructions. ● **SEE FIGURE 69–30**.

IGNITION SYSTEM SYMPTOM GUIDE

PROBLEM	POSSIBLE CAUSES AND/OR SOLUTIONS
No spark out of the coil	• Possible open in the ignition switch circuit • Possible defective ignition module (if electronic ignition coil) • Possible defective pickup coil or Hall-effect switch (if electronic ignition) • Possible shorted condenser
Weak spark out of the coil	• Possible high-resistance coil wire or spark plug wire • Possible poor ground between the distributor or module and the engine block
Engine misfire	• Possible defective (open) spark plug wire • Possible worn or fouled spark plugs • Possible defective pickup coil • Possible defective module • Possible poor electrical connections at the pickup coil and/or module

REVIEW QUESTIONS

1. Why should a spark tester be used to check for spark rather than a standard spark plug?
2. How do you test a pickup coil for resistance and AC voltage output?
3. What harm can occur if the engine is cranked or run with an open (defective) spark plug wire?
4. What are the sections of a secondary ignition scope pattern?
5. What can the slope of the spark line indicate about the engine?

CHAPTER QUIZ

1. A spark tester should be used to check for spark because ______________.
   - **a.** a spark tester requires at least 25,000 volts to fire
   - **b.** it is connected to the CKP sensor to check its output
   - **c.** it can detect a cracked spark plug
   - **d.** it can detect the gap of the spark plugs
2. An engine misfire could be the result of a ______________.
   - **a.** defective coil
   - **b.** fouled spark plug
   - **c.** defective spark plug wire
   - **d.** Any of the above
3. A CKP sensor can be checked with a DMM set to measure ______________.
   - **a.** ohms
   - **b.** DC volts
   - **c.** AC volts
   - **d.** Both a and c
4. Typical primary coil resistance specifications usually range from ______________ ohms.
   - **a.** 100 to 450
   - **b.** 500 to 1,500
   - **c.** less than 1 to 3
   - **d.** 6,000 to 30,000
5. Typical secondary coil resistance specifications usually range from ______________ ohms.
   - **a.** 100 to 450
   - **b.** 500 to 1,500
   - **c.** 1 to 3
   - **d.** 6,000 to 30,000
6. What should be inspected as part of a visual inspection of the ignition system?
   - **a.** Spark plug wires for proper routing
   - **b.** Spark plug gap
   - **c.** Coil polarity
   - **d.** All of the above
7. What part of the scope pattern shows the duration of the spark?
   - **a.** Firing line
   - **b.** Spark line
   - **c.** Intermediate section
   - **d.** Dwell section
8. Which can be used to test for a fault with a cylinder on a waste-spark system?
   - **a.** Using a timing light to check for spark
   - **b.** Using short sections of rubber hose attached to the coil terminals
   - **c.** An LED test light
   - **d.** Any of the above
9. Two technicians are discussing a no-start (no-spark) condition. Technician A says that an open pickup coil could be the cause. Technician B says that a defective ignition control module (ICM) could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. A water spray bottle is often used to find ______________.
    - **a.** leaking secondary insulation
    - **b.** a cracked spark plug
    - **c.** an improperly tightened spark plug
    - **d.** Both a and b

Chapter 70

COMPUTER FUNDAMENTALS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and function of onboard computers.
- Explain the parts and characteristics of digital computers.
- List input sensors to an automotive computer.
- List output devices (actuators) controlled by the computer.

KEY TERMS:

Actuator 838 • Analog-to-digital (AD) converter 838 • Clock generator 839 • Controller 837 • CPU 839 • Digital computer 839 • Duty cycle 842 • E^2PROM 838 • ECA 837 • ECM 837 • ECU 837 • EEPROM 838 • Engine mapping 839 • Input 838 • Input conditioning 838 • KAM 838 • Nonvolatile RAM 838 • Output drivers 841 • Powertrain control module (PCM) 837 • PROM 838 • PWM 841 • RAM 838 • ROM 838 • SAE 837

COMPUTER FUNDAMENTALS

PURPOSE AND FUNCTION Modern automotive control systems consist of a network of electronic sensors, actuators, and computer modules designed to regulate the powertrain and vehicle support systems. The onboard automotive computer has many names. It may be called an **electronic control unit (ECU)**, **electronic control module (ECM)**, **electronic control assembly (ECA)**, or a **controller**, depending on the manufacturer and the computer application. The **Society of Automotive Engineers (SAE)** bulletin J1930 standardizes the name as a **powertrain control module (PCM)**. The PCM coordinates engine and transmission operation, processes data, maintains communications, and makes the control decisions needed to keep the vehicle operating. Not only is it capable of operating the engine and transmission, but it is also able to perform the following:

- Undergo self-tests (40% of the computing power is devoted to diagnosis)
- Set and store diagnostic trouble codes (DTCs)
- Communicate with the technician using a scan tool

VOLTAGE SIGNALS Automotive computers use voltage to send and receive information. Voltage is electrical pressure and does not flow through circuits, but it can be used as a signal. A computer converts input information or data into voltage signal combinations that represent number combinations. A computer processes the input voltage signals it receives by computing what they represent, and then delivering the data in computed or processed form.

BASIC FUNCTIONS The operation of every computer can be divided into four basic functions. ● **SEE FIGURE 70–1**.

- **Input.** Receives voltage signals from sensors
- **Processing.** Performs mathematical calculations

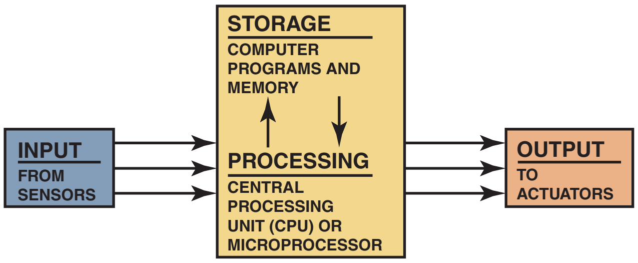

STORAGE
COMPUTER PROGRAMS AND MEMORY
INPUT
FROM SENSORS
PROCESSING
CENTRAL PROCESSING UNIT (CPU) OR MICROPROCESSOR
OUTPUT
TO ACTUATORS

FIGURE 70–1 All computer systems perform four basic functions: input, processing, storage, and output.

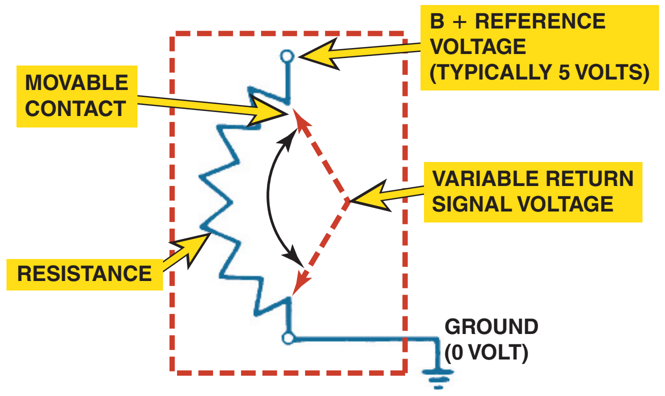

B + REFERENCE VOLTAGE (TYPICALLY 5 VOLTS)
MOVABLE CONTACT
VARIABLE RETURN SIGNAL VOLTAGE
RESISTANCE
GROUND (0 VOLT)

FIGURE 70–2 A potentiometer uses a movable contact to vary resistance and send an analog voltage right to the PCM.

- **Storage.** Includes short-term and long-term memory
- **Output.** Controls an output device by either turning it on or off

INPUT FUNCTIONS First, the computer receives a voltage signal (input) from an input device. **Input** is a signal from a device that can be as simple as a button or a switch on an instrument panel, or a sensor on an automotive engine. ● **SEE FIGURE 70–2** for a typical type of automotive sensor.

Vehicles use various mechanical, electrical, and magnetic sensors to measure factors, such as vehicle speed, throttle position, engine RPM, air pressure, oxygen content of exhaust gas, airflow, engine coolant temperature, and status of electrical circuits (on-off). Each sensor transmits its information in the form of voltage signals. The computer receives these voltage signals, but before it can use them, the signals must undergo a process called **input conditioning**. This process includes amplifying voltage signals that are too small for the computer circuitry to handle. Input conditioners generally are located inside the computer, but a few sensors have their own input conditioning circuitry.

A digital computer changes the analog input signals (voltage) to digital bits (*bi*nary digi*ts*) of information through an **analog-to-digital (AD) converter** circuit. The binary digital number is used by the computer in its calculations or logic networks. ● **SEE FIGURE 70–3**.

PROCESSING The term *processing* is used to describe how input voltage signals received by a computer are handled through a series of electronic logic circuits maintained in its programmed instructions. These logic circuits change the input voltage signals, or data, into output voltage signals or commands.

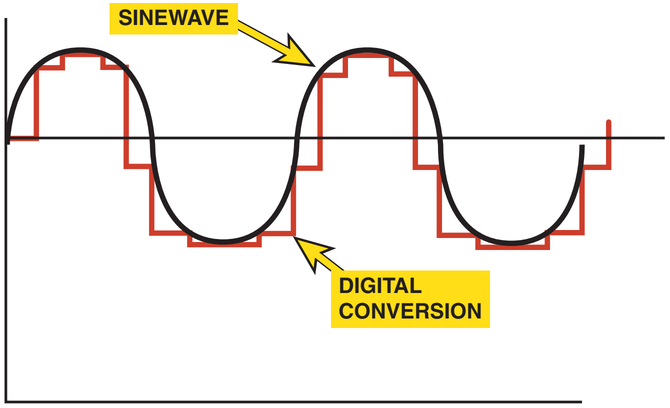


FIGURE 70–3 An AD converter changes analog (variable) voltage signals into digital signals that the PCM can process.

STORAGE Storage is the place where the program instructions for a computer are stored in electronic memory. Some programs may require that certain input data be stored for later reference or future processing. In others, output commands may be delayed or stored before they are transmitted to devices elsewhere in the system.

Computers have two types of memory.

1. Permanent memory is called **read-only memory (ROM)** because the computer can only read the contents; it cannot change the data stored in it. This data is retained even when power to the computer is shut off. Part of the ROM is built into the computer, and the rest is located in an integrated circuit (IC) chip called a **programmable read-only memory (PROM)** or calibration assembly. Many chips are erasable, meaning that the program can be changed. These chips are called erasable programmable read-only memory, or EPROM. Since the early 1990s, most programmable memory has been electronically erasable, meaning that the program in the chip can be reprogrammed by using a scan tool and the proper software. This computer reprogramming is usually called *reflashing*. These chips are electrically erasable programmable read-only memory, abbreviated **EEPROM** or **E^{2}PROM.**

   All vehicles equipped with onboard diagnosis second generation, called OBD-II, are equipped with EEPROMs.

2. Temporary memory is called **random-access memory (RAM)**, because the computer can write or store new data into it as directed by the computer program, as well as read the data already in it. Automotive computers use two types of RAM memory.

   - Volatile RAM memory is lost whenever the ignition is turned off. However, a type of volatile RAM called **keep-alive memory (KAM)** can be wired directly to battery power. This prevents its data from being erased when the ignition is turned off. One example of RAM and KAM is the loss of station settings in a programmable radio when the battery is disconnected. Because all the settings are stored in RAM, they have to be reset when the battery is reconnected. System trouble codes are commonly stored in RAM and can be erased by disconnecting the battery.
   - **Nonvolatile RAM** memory can retain its information even when the battery is disconnected. One use for this type of RAM is the storage of odometer information in an electronic speedometer. The memory chip retains the mileage accumulated by the vehicle. When speedometer replacement is necessary, the odometer chip is removed and installed in the new speedometer unit. KAM is used primarily in conjunction with adaptive strategies.

OUTPUT FUNCTIONS After the computer has processed the input signals, it sends voltage signals or commands to other devices in the system, such as system actuators. An **actuator** is an electrical or mechanical output device that converts electrical energy into a mechanical action, such as:

- Adjusting engine idle speed
- Operating fuel injectors

- Ignition timing control
- Altering suspension height

COMPUTER COMMUNICATION A typical vehicle can have many computers, also called modules or controllers. Computers also can communicate with, and control, each other through their output and input functions. This means that the output signal from one computer system can be the input signal for another computer system through a data network.

DIGITAL COMPUTERS

PARTS OF A COMPUTER The software consists of the programs and logic functions stored in the computer's circuitry. The hardware is the mechanical and electronic parts of a computer.

- **Central processing unit.** The microprocessor is the **central processing unit (CPU)** of a computer. Because it performs the essential mathematical operations and logic decisions that make up its processing function, the CPU can be considered the brain of a computer. Some computers use more than one microprocessor, called a coprocessor. The digital computer can process thousands of digital signals per second because its circuits are able to switch voltage signals on and off in billionths of a second. It is called a **digital computer** because it processes zeros and ones (digits) and needs to have any variable input signals, called analog inputs, converted to digital form before it can function. ● **SEE FIGURE 70–4**.
- **Computer memory.** Other integrated circuit (IC) devices store the computer operating program, system sensor input data, and system actuator output data—information that is necessary for CPU operation.
- **Computer programs.** By operating a vehicle on a dynamometer and manually adjusting the variable factors such as speed, load, and spark timing, it is possible to determine the optimum output settings for the best driveability, economy, and emission control. This is called engine mapping. ● **SEE FIGURE 70–5**.

Engine mapping creates a three-dimensional performance graph that applies to a given vehicle and powertrain combination. Each combination is mapped in this manner to produce a PROM or EEPROM calibration. This allows an automaker to use one basic computer for all models.

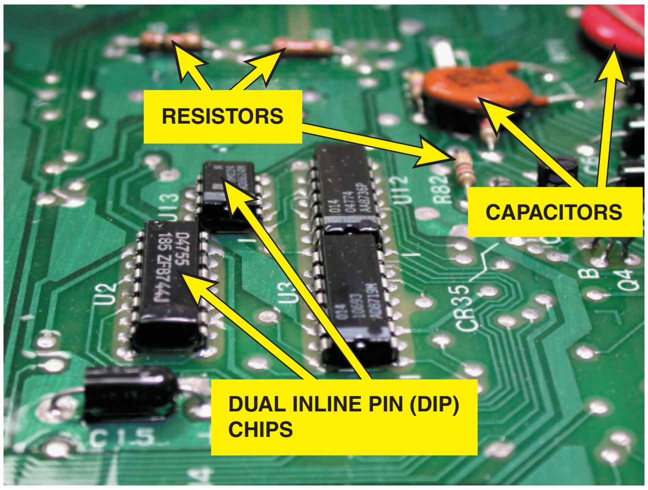


FIGURE 70–4 Many electronic components are used to construct a typical vehicle computer including chips, resistors, and capacitors.

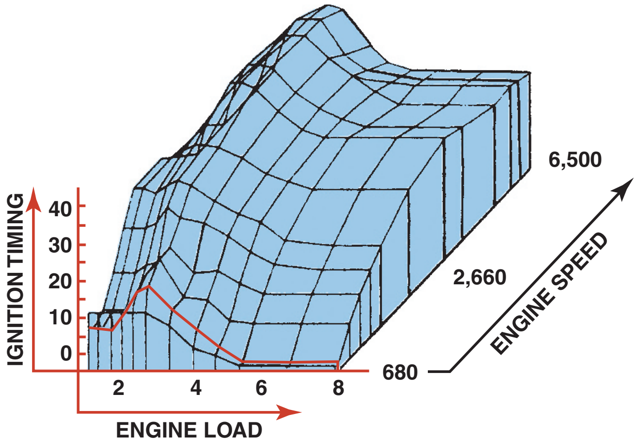


FIGURE 70–5 Typical engine map developed from testing and used by the vehicle computer to provide the optimum ignition timing for all engine speeds and load combinations.

Many older-vehicle computers used a single PROM that plugged into the computer.

NOTE: If the computer needs to be replaced, the PROM or calibration module must be removed from the defective unit and installed in the replacement computer. Since the mid-1990s, PCMs do not have removable calibration PROMs, and must be programmed or flashed using a scan tool before being put into service.

CLOCK RATES AND TIMING The microprocessor receives sensor input voltage signals, processes them by using information from other memory units, and then sends voltage signals to the appropriate actuators. The microprocessor communicates by transmitting long strings of 0s and 1s in a language called binary code; but the microprocessor must have some way of knowing when one signal ends and another begins. That is the job of a crystal oscillator called a **clock generator**. ● **SEE FIGURE 70–6**.

The computer's crystal oscillator generates a steady stream of one-bit-long voltage pulses. Both the microprocessor and the

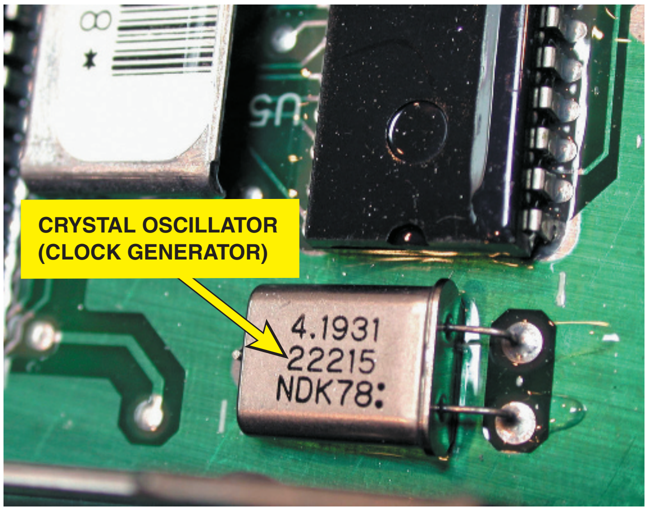


FIGURE 70–6 The clock generator produces a series of pulses that are used by the microprocessor and other components to stay in step with each other at a steady rate.

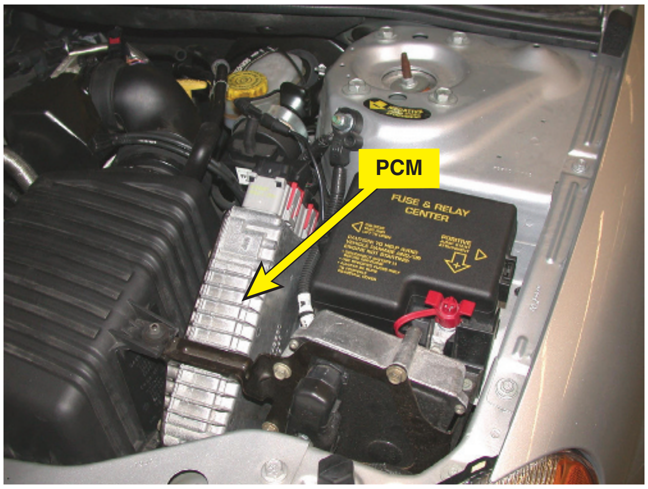


FIGURE 70–7 A powertrain control module (PCM) under the hood where it can be exposed to air for cooling.

memories monitor the clock pulses while they are communicating. Because they know how long each voltage pulse should be, they can distinguish between a 01 and a 0011. To complete the process, the input and output circuits also watch the clock pulses.

COMPUTER SPEEDS Not all computers operate at the same speed; some are faster than others. The speed at which a computer operates is specified by the cycle time, or clock speed, required to perform certain measurements. Cycle time or clock speed is measured in megahertz (4.7 MHz, 8 MHz, 15 MHz, 18 MHz, and 32 MHz, which is the clock speed of most vehicle computers today).

CONTROL MODULE LOCATIONS Onboard computers vary in size from a small module to a notebook-size box. Most other computers are installed in the passenger compartment either under the instrument panel or in a side kick panel where they can be shielded from physical damage caused by temperature extremes, dirt, and vibration, or interference by the high currents and voltages of various underhood systems. ● **SEE FIGURE 70–7**.

COMPUTER INPUT SENSORS

The vehicle computer uses signals (voltage levels) from the following sensors:

- **Engine speed (revolutions per minute, or RPM) sensor.** This signal comes from the primary ignition signal in the ignition control module (ICM) or directly from the crankshaft position (CKP) sensor.
- **Switches or buttons for accessory operation.** Many accessories use control buttons that signal the body computer to turn on or off an accessory, such as the windshield wiper or heated seats.
- **Manifold absolute pressure (MAP) sensor.** This sensor detects engine load by using a signal from a sensor that measures the vacuum in the intake manifold.
- **Mass airflow (MAF) sensor.** This sensor measures the mass (weight and density) of the air flowing through the sensor and entering the engine.
- **Engine coolant temperature (ECT) sensor.** This sensor measures the temperature of the engine coolant. This is a sensor used for engine controls and for automatic air-conditioning control operation.
- **Oxygen sensor (O2S).** This sensor measures the oxygen in the exhaust stream. There are as many as four oxygen sensors in some vehicles.
- **Throttle position (TP) sensor.** This sensor measures the throttle opening and is used by the computer for engine control and the shift points of the automotive transmission/transaxle.
- **Vehicle speed (VS) sensor.** This sensor measures the vehicle speed using a sensor located at the output of the transmission/transaxle or by monitoring sensors at the wheel speed sensors. This sensor is used by the speedometer, cruise control, and airbag systems.

COMPUTER OUTPUTS

OUTPUT CONTROLS After the computer has processed the input signals, it sends voltage signals or commands to other devices in the system. A vehicle computer can do only two things.

1. Turn a device on.
2. Turn a device off.

Typical output devices include the following:

- **Operate actuators.** An actuator is an electrical or mechanical device that converts electrical energy into heat, light, or motion to control engine idle speed, suspension height, ignition timing, and other output devices.
- **Network communication.** Computers also can communicate with another computer system through a network.
- **Fuel injectors.** The computer can vary the amount of time in milliseconds the injectors are held open, thereby controlling the amount of fuel supplied to the engine.
- **Blower motor control.** Many blower motors are controlled by the body computer by pulsing the current on and off to maintain the desired speed.
- **Transmission shifting.** The computer provides a ground to the shift solenoids and torque converter clutch (TCC) solenoid. The operation of the automatic transmission/transaxle is optimized based on vehicle sensor information.
- **Idle speed control.** The computer can control the idle air control (IAC) or electronic throttle control (ETC) to maintain engine idle speed and to provide an increased idle speed as needed.
- **Evaporative emission control solenoids.** The computer can control the flow of gasoline fumes from the charcoal canister to the engine and seal off the system to perform a fuel system leak detection test as part of the OBD-II system requirements.

Most outputs work electrically in one of three ways:

1. Digital
2. Pulse-width modulated
3. Switched

Digital control is mostly used for computer communications and involves voltage signals that are transmitted and received in packets.

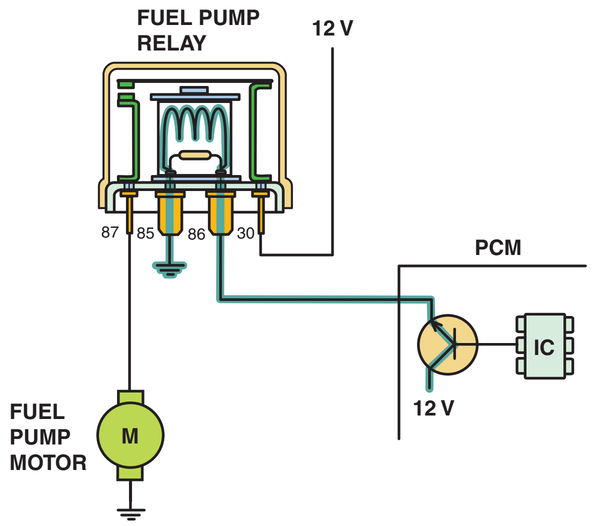


FIGURE 70–8 A typical output driver. In this case, the PCM applies voltage to the fuel pump relay coil to energize the fuel pump.

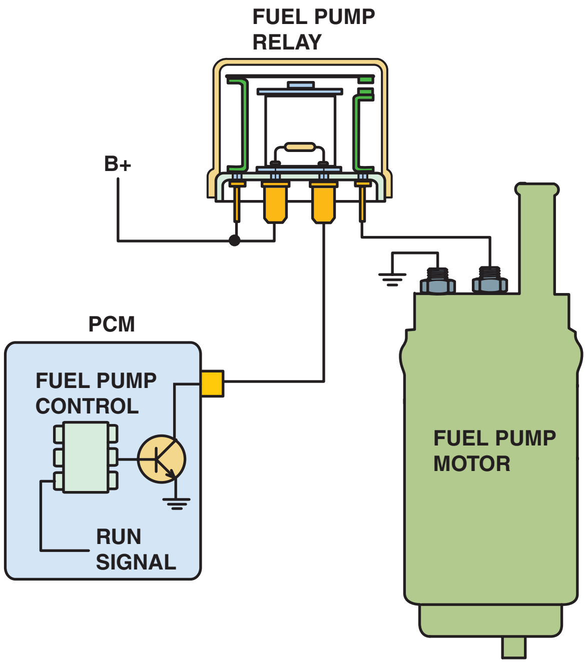


FIGURE 70–9 A typical low-side driver (LSD) which uses a control module to control the ground side of the relay coil.

Pulse-width control allows a device, such as a blower motor, to be operated at variable speed by changing the amount of time electrical power is supplied to the device.

A switched output is an output that is either on or off. In many circuits, the PCM uses a relay to switch a device on or off, because the relay is a low-current device that can switch to a higher current device. Most computer circuits cannot handle high amounts of current. By using a relay circuit, the PCM provides the output control to the relay, which in turn provides the output control to the device. The relay coil, which the PCM controls, typically draws less than 0.5 ampere. The device that the relay controls may draw 30 amperes or more.

OUTPUT DRIVERS

The PCM switches are actually transistors, and are often called **output drivers**. ● **SEE FIGURE 70–8**.

There are two basic types of output drivers:

1. **Low-side drivers.** The low-side drivers (LSDs) are transistors inside the computer that complete the ground path of the relay coil. Ignition (key-on) voltage and battery voltage are supplied to the relay. The ground side of the relay coil is connected to the transistor inside the computer. In the example of a fuel pump relay, when the transistor turns "on," it will complete the ground for the relay coil, and the relay will then complete the power circuit between the battery power and the fuel pump. A relatively low current flows through the relay coil and transistor that is inside the computer. This causes the relay to switch and provides the fuel pump with battery voltage. The majority of switched outputs have typically been low-side drivers. ● **SEE FIGURE 70–9**.

   Low-side drivers can often perform a diagnostic circuit check by monitoring the voltage from the relay to check that the control circuit for the relay is complete. A low-side driver, however, cannot detect a short-to-ground.
2. **High-side drivers.** The high-side drivers (HSDs) control the power side of the circuit. In these applications when the transistor is switched on, voltage is applied to the device. A ground has been provided to the device so when the high-side driver switches, the device will be energized. In some applications, high-side drivers are used instead of low-side drivers to provide better circuit protection. General Motors vehicles use a high-side driver to control the fuel pump relay instead of a low-side driver. In the event of an accident, should the circuit to the fuel pump relay become grounded, a high-side driver will cause a short circuit, which will cause the fuel pump relay to de-energize. High-side drivers inside modules can detect electrical faults such as a lack of continuity when the circuit is not energized. ● **SEE FIGURE 70–10**.

PULSE-WIDTH MODULATION

Pulse-width modulation (PWM) is a method of controlling an output using a digital signal. Instead of just turning devices on or off, the computer can control the amount of on-time. For example, a solenoid could be a PWM device. If, for

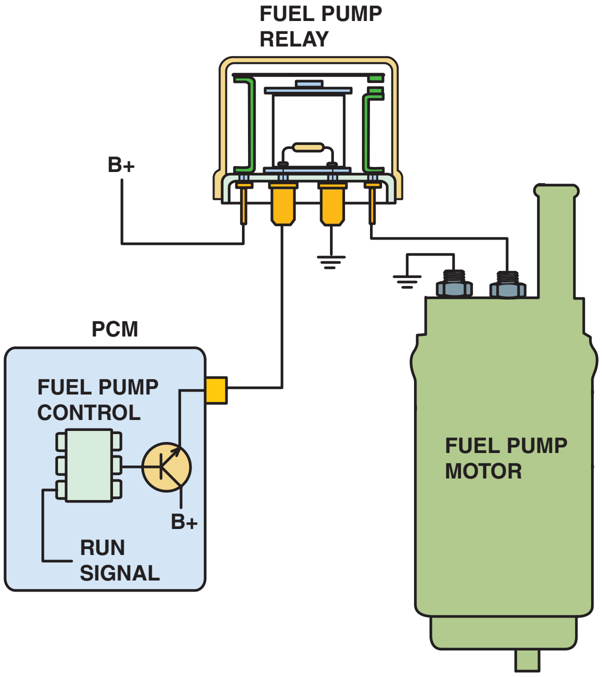


FIGURE 70–10 A typical module-controlled high-side driver (HSD) where the module itself supplies the electrical power to the device. The logic circuit inside the module can detect circuit faults including continuity of the circuit and if there is a short-to-ground in the circuit being controlled.

example, a vacuum solenoid is controlled by a switched driver, switching either on or off would mean that either full vacuum would flow through the solenoid or no vacuum would flow through the solenoid. However, to control the amount of vacuum that flows through the solenoid, pulse-width modulation could be used. A PWM signal is a digital signal, usually 0 and 12 volts, which is cycling at a fixed frequency. Varying the length of time that the signal is on provides a signal that can vary the on- and off-time of an output. The ratio of on-time relative to the period of the cycle is referred to as **duty cycle**. ● **SEE FIGURE 70–11**.

Depending on the frequency of the signal, which is usually fixed, this signal will turn the device on and off a fixed number of times per second. When, for example, the voltage is high (12 volts) 90% of the time and low (0 volt) the other 10% of the time, the signal has a 90% duty cycle. In other words, if this signal were applied to the vacuum solenoid, the solenoid would be on 90% of the time. This would allow more vacuum to flow through the solenoid. The computer has the ability to vary this on- and off-time or pulse-width modulation at any rate between 0% and 100%. A good example of pulse-width modulation is the cooling fan speed control. The speed of the cooling fan is controlled by varying the amount of on-time that the battery voltage is applied to the cooling fan motor.

- 100% duty cycle: fan runs at full speed
- 75% duty cycle: fan runs at 3/4 speed
- 50% duty cycle: fan runs at 1/2 speed
- 25% duty cycle: fan runs at 1/4 speed

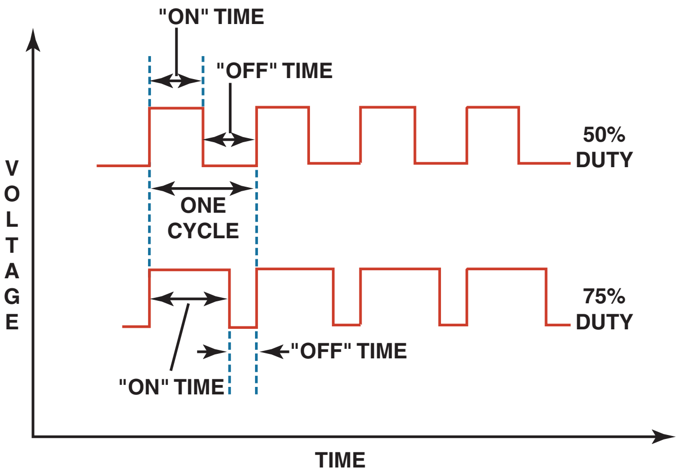


FIGURE 70–11 Both the top and bottom pattern have the same frequency. However, the amount of on-time varies. Duty cycle is the percentage of the time during a cycle that the signal is turned on.

The use of PWM, therefore, results in precise control of an output device to achieve the amount of cooling needed and conserve electrical energy compared to simply timing the cooling fan on high when needed. PWM may be used to control vacuum through a solenoid, the amount of purge of the evaporative purge solenoid, the speed of a fuel pump motor, control of a linear motor, or even the intensity of a lightbulb.

REVIEW QUESTIONS

1. What part of the vehicle computer is considered to be the brain?
2. What is the difference between volatile and nonvolatile RAM?
3. What are four input sensors?
4. What are four output devices?
5. How does using pulse-width modulation control devices?

CHAPTER QUIZ

1. What unit of electricity is used as a signal for a computer?
   a. Volt
   b. Ohm
   c. Ampere
   d. Watt
2. The four basic computer functions include ________________.
   a. writing, processing, printing, and remembering
   b. input, processing, storage, and output
   c. data gathering, processing, output, and evaluation
   d. sensing, calculating, actuating, and processing
3. All OBD-II vehicles use what type of read-only memory?
   a. ROM
   b. PROM
   c. EPROM
   d. EEPROM
4. The "brain" of the computer is the ________________.
   a. PROM
   b. RAM
   c. CPU
   d. AD converter
5. Which of these is NOT a function of the PCM?
   a. Self-tests
   b. Communicate with a scan tool
   c. Tire inflation
   d. Store DTCs
6. Which item is a computer input sensor?
   a. RPM
   b. Throttle position
   c. Engine coolant temperature
   d. All of the above
7. Which item is a computer output device?
   a. Fuel injector
   b. Transmission shift solenoid
   c. Evaporative emission control solenoid
   d. All of the above
8. The SAE term for the vehicle computer is ________________.
   a. PCM
   b. ECM
   c. ECA
   d. controller
9. What two things can a vehicle computer actually perform (output)?
   a. Store and process information
   b. Turn something on or turn something off
   c. Calculate and vary temperature
   d. Control fuel and timing only
10. Analog signals from sensors are changed to digital signals for processing by the computer through which type of circuit?
   a. Digital
   b. Analog
   c. Analog-to-digital converter
   d. PROM

Chapter 71

TEMPERATURE AND THROTTLE POSITION SENSORS

LEARNING OBJECTIVES:

After studying this chapter, the reader will be able to:

- Describe the purpose and function of engine coolant temperature sensors.
- Describe how to inspect and test temperature sensors.
- Explain the function and testing of intake air temperature sensors, including sensor DTCs.
- Discuss the other temperature sensors that may be found on vehicles.
- Describe the construction and function of a TP sensor.
- Discuss TP sensor input.
- Discuss the PCM uses for the TP sensor.
- Describe how to test the TP sensor, including sensor DTCs.

KEY TERMS:

Cylinder head temperature (CHT) 848 • Engine coolant temperature (ECT) 843 • Engine fuel temperature (EFT) 848 • Negative temperature coefficient (NTC) 844 • Potentiometer 849 • Skewed 851 • Throttle position (TP) sensor 849 • Throttle-body temperature (TBT) 847 • Transmission fluid temperature (TFT) 848

ENGINE COOLANT TEMPERATURE SENSORS

PURPOSE AND FUNCTION Computer-equipped vehicles use an **engine coolant temperature (ECT)** sensor. When the engine is cold, the fuel mixture must be richer to prevent stalling and engine stumble. When the engine is warm, the fuel mixture can be leaner to provide maximum fuel economy with the lowest possible exhaust emissions. Because the computer controls spark timing and fuel mixture, it will need to know the engine temperature. An engine coolant temperature sensor screwed into the engine coolant passage will provide the computer with this information. ● **SEE FIGURE 71–1**. This will be the most important (high-authority) sensor while the engine is cold. The ignition timing can also be tailored to engine (coolant) temperature. A hot engine cannot have the spark timing as far advanced as can a cold engine. The ECT sensor is also used as an important input for the following:

- Idle air control (IAC) position
- Oxygen sensor closed-loop status
- Canister purge on/off times
- Idle speed

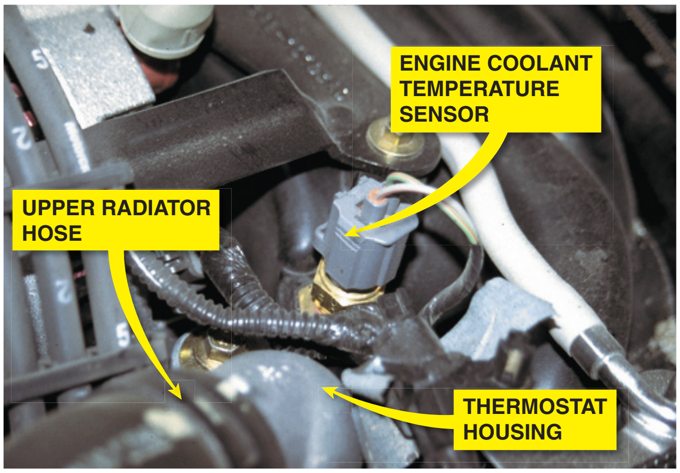


FIGURE 71–1 A typical engine coolant temperature (ECT) sensor. ECT sensors are located near the thermostat housing on most engines.

ECT SENSOR CONSTRUCTION Engine coolant temperature sensors are constructed of a semiconductor material that decreases in resistance as the temperature of the sensor increases. Coolant sensors have very high resistance when the coolant is cold and low resistance when the coolant is hot.

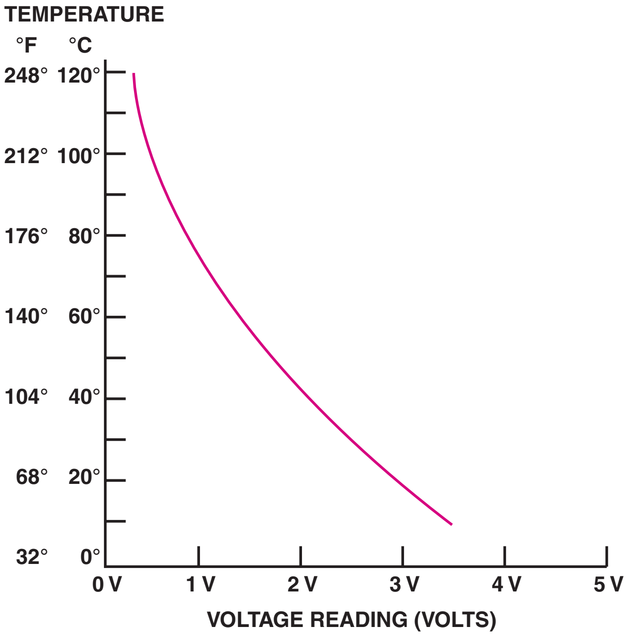


FIGURE 71–2 A typical ECT sensor temperature versus voltage curve.

This is referred to as having a **negative temperature coefficient (NTC)**, which is opposite to the situation with most other electrical components. ● **SEE FIGURE 71–2**. Therefore, if the coolant sensor has a poor connection (high resistance) at the wiring connector, the computer will supply a richer-than-normal fuel mixture based on the resistance of the coolant sensor. Poor fuel economy and a possible-rich code can be caused by a defective sensor or high resistance in the sensor wiring. If the sensor was shorted or defective and had too low a resistance, a leaner-than-normal fuel mixture would be supplied to the engine. A too-lean fuel mixture can cause driveability problems and a possible-lean computer code.

STEPPED ECT CIRCUITS Some vehicle manufacturers use a step-up resistor to effectively broaden the range of the ECT sensor. Chrysler and General Motors vehicles use the same sensor as a non-stepped ECT circuit, but instead apply the sensor voltage through two different resistors.

- When the temperature is low, usually below 120°F (50°C), the ECT sensor voltage is applied through a high-value resistor inside the PCM.
- When the temperature is high, usually above 120°F (50°C), the ECT sensor voltage is applied through a much lower resistance value inside the PCM. ● **SEE FIGURE 71–3**.

The purpose of this extra circuit is to give the PCM a more accurate reading of the engine coolant temperature compared to the same sensor with only one circuit. ● **SEE FIGURE 71–4**.

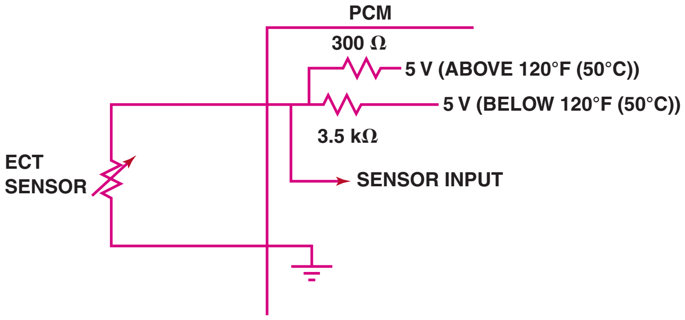


FIGURE 71–3 A typical two-step ECT circuit showing that when the coolant temperature is low, the PCM applies a 5-volt reference voltage to the ECT sensor through a higher resistance compared to when the temperature is higher.

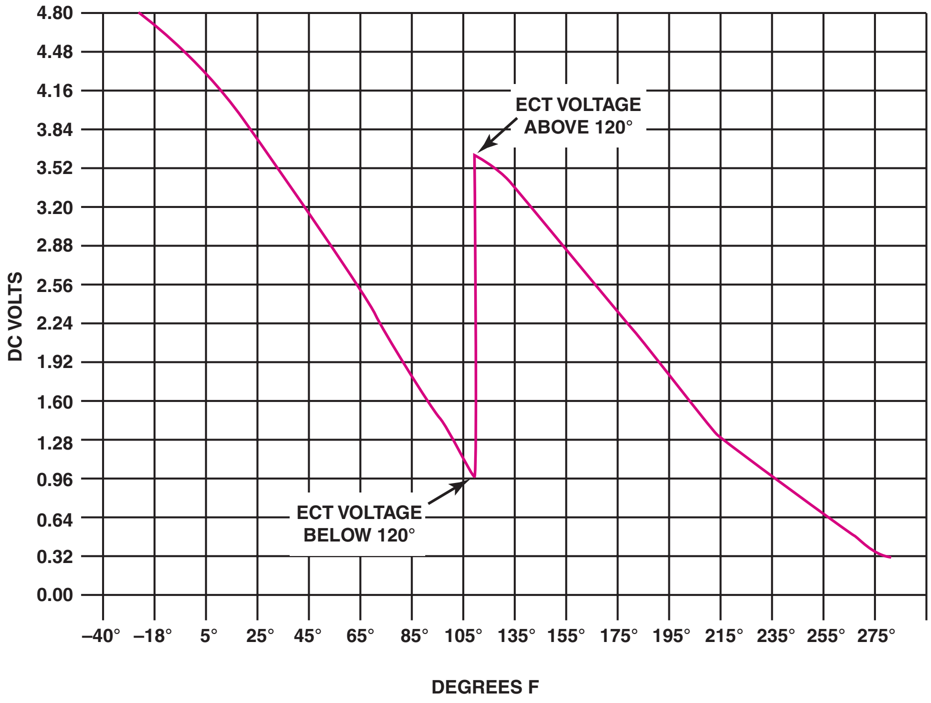


FIGURE 71–4 The transition between steps usually occurs at a temperature that would not interfere with cold engine starts or the cooling fan operation. In this example, the transition occurs when the sensor voltage is about 1 volt and rises to about 3.6 volts.

TESTING THE ENGINE COOLANT TEMPERATURE SENSOR

TESTING THE ENGINE COOLANT TEMPERATURE BY VISUAL INSPECTION The correct functioning of the engine coolant temperature sensor depends on the following items that should be checked or inspected:

- **Properly filled cooling system.** Check that the radiator reservoir bottle is full and that the radiator itself is filled to the top.

CAUTION: Be sure that the radiator is cool before removing the radiator cap to avoid being scalded by hot coolant.

The ECT sensor must be submerged in coolant to be able to indicate the proper coolant temperature.

- **Proper pressure maintained by the radiator cap.** If the radiator cap is defective and cannot allow the cooling system to become pressurized, air pockets could develop. These air pockets could cause the engine to operate at a hotter-than-normal temperature and prevent proper temperature measurement, especially if the air pockets occur around the sensor.
- **Proper antifreeze–water mixture.** Most vehicle manufacturers recommend a 50/50 mixture of antifreeze and water as the best compromise between freezing protection and heat transfer ability.
- **Proper operation of the cooling fan.** If the cooling fan does not operate correctly, the engine may get overheated.

TESTING THE ECT USING A MULTIMETER Both the resistance (in ohms) and the voltage drop across the sensor can be measured and compared with specifications. ● **SEE FIGURE 71–5.** Some vehicles use the PCM to attach another resistor in the ECT circuit to provide a more accurate measure of the engine temperature. ● **SEE FIGURE 71–6.** ● **SEE CHART 71–1** for an example of typical ECT sensor specifications.

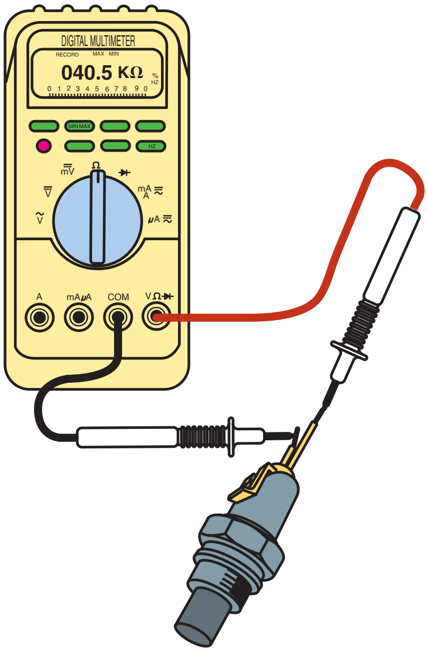


FIGURE 71–5 Measuring the resistance of the ECT sensor. The resistance measurement can then be compared with specifications. (Courtesy of Fluke Corporation)

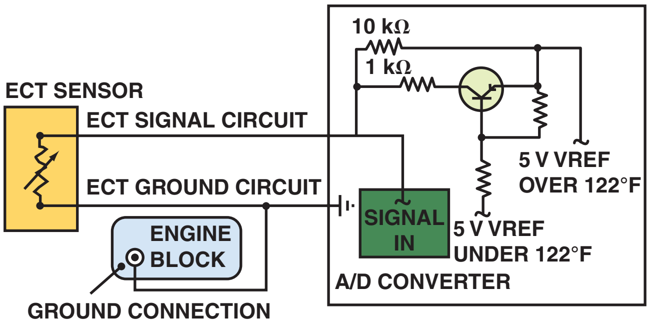


FIGURE 71–6 When the voltage drop reaches approximately 1.20 volts, the PCM turns on a transistor. The transistor connects a 1 kΩ resistor in parallel with the 10 kΩ resistor. Total circuit resistance now drops to around 909 ohms. This function allows the PCM to have full binary control at cold temperatures up to approximately 122°F and a second full binary control at temperatures greater than 122°F.

GENERAL MOTORS ECT SENSOR WITHOUT PULL-UP RESISTOR

°F	°C	OHMS	VOLTAGE DROP ACROSS SENSOR
−40	−40	100,000 +	4.95
18	−8	14,628	4.68
32	0	9,420	4.52
50	10	5,670	4.25
68	20	3,520	3.89
86	30	2,238	3.46
104	40	1,459	2.97
122	50	973	2.47
140	60	667	2.00
158	70	467	1.59
176	80	332	1.25
194	90	241	0.97
212	100	177	0.75

CHART 71–1

If resistance values match the approximate coolant temperature and there is still a coolant sensor trouble code, the problem is generally in the wiring between the sensor and the computer. Always consult the manufacturers' recommended procedures for checking this wiring. If the resistance values do not match, the sensor may need to be replaced.

Normal operating temperature varies with vehicle make and model. Some vehicles are equipped with a thermostat with an opening temperature of 180°F (82°C) whereas other vehicles use a thermostat that is 195°F (90°C) or higher. Before replacing the ECT sensor, be sure that the engine is operating at the temperature specified by the manufacturer. Most manufacturers recommend checking the ECT sensor after the cooling fan has cycled twice, indicating a fully warmed engine. To test for voltage at the ECT sensor, select DC volts on a digital meter and carefully back probe the sensor wire and read the voltage. ● **SEE FIGURE 71–7.**

TESTING THE ECT SENSOR USING A SCAN TOOL Follow the scan tool manufacturer's instructions and connect a scan tool to the data link connector (DLC) of the vehicle. Comparing the

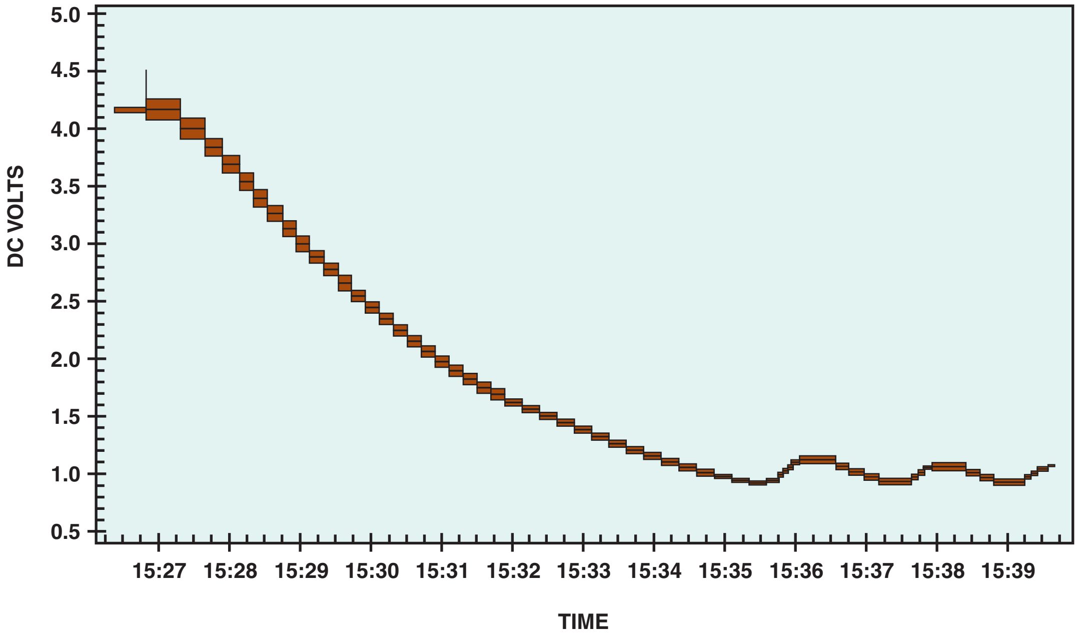


FIGURE 71–7 An ECT sensor being tested using a digital meter set to DC volts. A chart showing the voltage decrease of the ECT sensor as the temperature increases from a cold start. The bumps at the bottom of the waveform represent temperature decreases when the thermostat opens and is controlling coolant temperature.

temperature of the engine coolant as displayed on a scan tool with the actual temperature of the engine is an excellent method to test an engine coolant temperature sensor.

1. Record the scan tool temperature of the coolant (ECT).
2. Measure the actual temperature of the coolant using an infrared pyrometer or contact-type temperature probe.

NOTE: Often the coolant temperature gauge in the dash of the vehicle can be used to compare with the scan tool temperature. Although not necessarily accurate, it may help to diagnose a faulty sensor, especially if the temperature shown on the scan tool varies greatly from the temperature indicated on the dash gauge.

The maximum difference between the two readings should be 10℉ (5℃) If the actual temperature varies by more than 10℉ from the temperature indicated on the scan tool, check the ECT sensor wiring and connector for damage or corrosion. If the connector and wiring are okay, check the sensor with a DVOM for resistance and compare with the actual engine temperature chart. If that checks out okay, check the computer.

NOTE: Some manufacturers use two coolant sensors, one for the dash gauge and one for the computer.

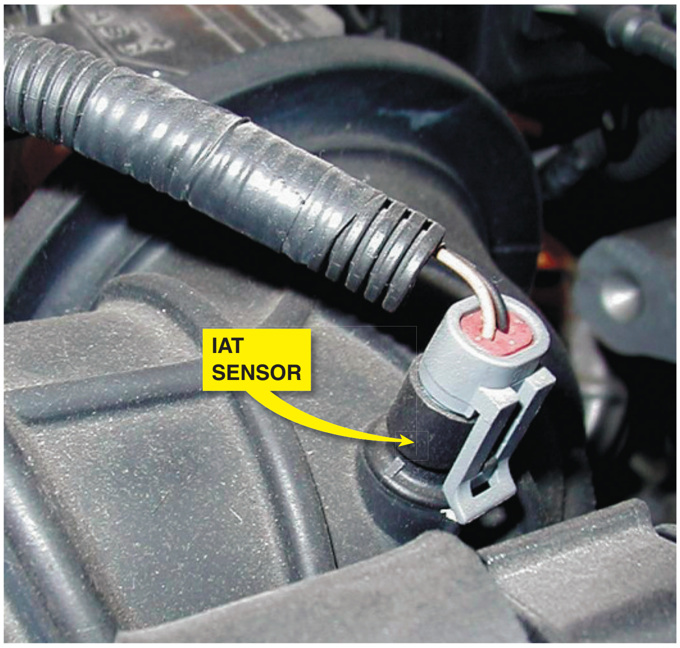


FIGURE 71–8 The IAT sensor on this General Motors 3800 V-6 engine is in the air passage duct between the air cleaner housing and the throttle body.

INTAKE AIR TEMPERATURE SENSOR

PURPOSE AND FUNCTION The intake air temperature (IAT) sensor is a negative temperature coefficient (NTC) thermistor that decreases in resistance as the temperature of the sensor increases. The IAT sensor can be located in one of the following locations:

- In the air cleaner housing.
- In the air duct between the air filter and the throttle body, as shown in ● **FIGURE 71–8**.
- Built into the mass air flow (MAF) or airflow sensor. Most MAF sensors use three wires. If a MAF sensor has five wires, it also includes an IAT sensor built in as part of the assembly. If more than five wires, the MAF sensor may be equipped with a humidity sensor also.
- Screwed into the intake manifold where it senses the temperature of the air entering the cylinders.

NOTE: An IAT installed in the intake manifold is the most likely to suffer damage due to an engine backfire, which can often destroy the sensor.

TECH TIP

Quick and Easy ECT Test

To check that the wiring and the computer are functioning, regarding the ECT sensor, connect a scan tool and look at the ECT temperature display.

STEP 1 Unplug the connector from the ECT sensor. The temperature displayed on the scan tool should read about −40°C

NOTE: −40° Celsius is also −40° Fahrenheit. This is the point where both temperature scales meet.

STEP 2 With the connector still removed from the ECT sensor, use a fused jumper lead and connect the two terminals of the connector together. The scan tool should display about 285°F (140°C)

This same test procedure will work for the IAT and most other temperature sensors.

CASE STUDY

The Case of the Hot Audi

The owner of Audi A3 Quattro took the vehicle to a shop and mentioned that the engine temperature gauge was indicting that the engine was running hot. A check engine light was also on. A scan tool was used to retrieve a DTC P0116 (Engine Coolant Temperature (ECT) Sensor 1 Circuit Range/Performance). Another shop had replaced the thermostat, water pump, and ECT sensor (at the radiator outlet), which did not fix the overheat problem.

The service technician looked at the scan tool data and noticed that the ECT was showing a temperature of over 240° (112°C), yet the upper radiator hose was not hot. Checking service information, the technician discovered that this engine has two ECT sensors, one in the radiator outlet and another one located on the engine block. The DTC was referencing the ECT located on the engine block, designated G62 in service information. The technician checked the resistance of G62 and found it to be out of specifications. Replacing this ECT sensor resulted in both ECT sensors reading the same temperature with key on, engine off (KOEO). The DTC was cleared and the vehicle was driven, which confirmed that the root cause had been found.

Summary:

Complaint—The temperature gauge was showing that the engine was overheating and the check engine light was on.
Cause—One of the two ECT sensors was out of specification causing both the incorrect dash temperature reading and a stored diagnostic trouble code.
Correction—Replacing the ECT sensor located on the engine block (G62) corrected both issues.

The purpose and function of the intake air temperature sensor is to provide the engine computer (PCM) the temperature of the air entering the engine. The IAT sensor information is used for fuel control (adding or subtracting fuel) and spark timing, depending on the temperature of incoming air.

The IAT sensor is used as an input sensor by the PCM to control many functions including

- If the air temperature is low, the PCM will modify the amount of fuel delivery and add fuel.
- If the air temperature is high, the PCM will subtract the calculated amount of fuel.
- Spark timing is also changed, depending on the temperature of the air entering the engine. The timing is advanced if the temperature is cold and retarded from the base-programmed timing if the temperature is hot.
- Cold air is more dense, contains more oxygen, and therefore requires a richer mixture to achieve the proper air–fuel mixture. Air at 32°F (0°C) is 14% denser than air at 100°F (38°C).
- Hot air is less dense, contains less oxygen, and therefore requires less fuel to achieve the proper air–fuel mixture.

The IAT sensor is a low-authority sensor and is used by the computer to modify the amount of fuel and ignition timing as determined by the engine coolant temperature sensor.

The IAT sensor is used by the PCM as a backup in the event that the ECT sensor is determined to be inoperative.

NOTE: Some engines use a throttle-body temperature (TBT) sensor to sense the temperature of the air entering the engine, instead of an intake air temperature sensor.

Engine temperature is most accurately determined by looking at the engine coolant temperature sensor. In certain conditions, the IAT has an effect on performance and driveability. One such condition is a warm engine being stopped in very cold weather. In this case, when the engine is restarted, the ECT may be near normal operating temperature such as 200°F (93°C) yet the air temperature could be −20°F (−30°C) In this case, the engine requires a richer mixture due to the cold air than the ECT would seem to indicate.

TESTING THE INTAKE AIR TEMPERATURE SENSOR If the intake air temperature sensor circuit is damaged or faulty, a diagnostic trouble code is set and the malfunction indicator lamp (MIL) may or may not turn on depending on the condition and the type and model of the vehicle. To diagnose the IAT sensor follow these steps:

STEP 1 After the vehicle has been allowed to cool for several hours, using a scan tool, observe the IAT, and compare it to the engine coolant temperature. The two temperatures should be within 5°F of each other.

STEP 2 Perform a thorough visual inspection of the sensor and the wiring. If the IAT is screwed into the intake manifold, remove the sensor and check for damage.

STEP 3 Check the voltage.

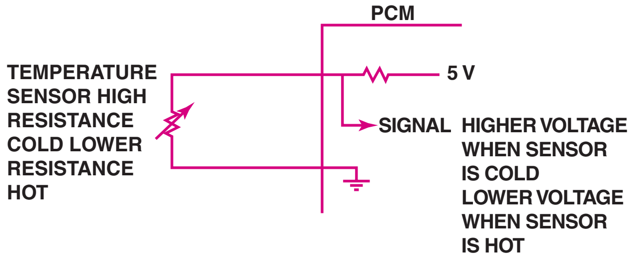

PCM
TEMPERATURE SENSOR HIGH RESISTANCE COLD LOWER RESISTANCE HOT
5 V
SIGNAL
HIGHER VOLTAGE WHEN SENSOR IS COLD LOWER VOLTAGE WHEN SENSOR IS HOT

FIGURE 71–9 A typical temperature sensor circuit.

FREQUENTLY ASKED QUESTION

What Exactly Is an NTC Sensor?

A negative temperature coefficient (NTC) thermistor is a semiconductor whose resistance decreases as the temperature increases. In other words, the sensor becomes more electrically conductive as the temperature increases. Therefore, when a voltage is applied, typically 5 volts, the signal voltage is high when the sensor is cold because the sensor has a high resistance and little current flows through to ground. ● **SEE FIGURE 71–9**.

However, when the temperature increases, the sensor becomes more electrically conductive and takes more of the 5 volts to ground, resulting in a lower signal voltage as the sensor warms.

OTHER TEMPERATURE SENSORS

AUTOMATIC TRANSMISSION FLUID TEMPERATURE SENSOR

The **transmission fluid temperature (TFT)**, also called *transmission oil temperature (TOT),* sensor is an important sensor for the proper operation of the automatic transmission. A TFT sensor is a NTC thermistor that decreases in resistance as the temperature of the sensor increases.

The transmission fluid temperature signal is used by the powertrain control module (PCM) to perform certain strategies based on the temperature of the automatic transmission fluid. For example:

- If the temperature of the automatic transmission fluid is low (typically below 32°F [0°C]), the shift points may be delayed and overdrive disabled. The torque converter clutch also may not be applied to assist in the heating of the fluid.
- If the temperature of the automatic transmission fluid is high (typically above 260°F [130°C]), the overdrive is disabled and the torque converter clutch is applied to help reduce the temperature of the fluid.

NOTE: Check service information for the exact shift strategy based on high and low transmission fluid temperatures for the vehicle being serviced.

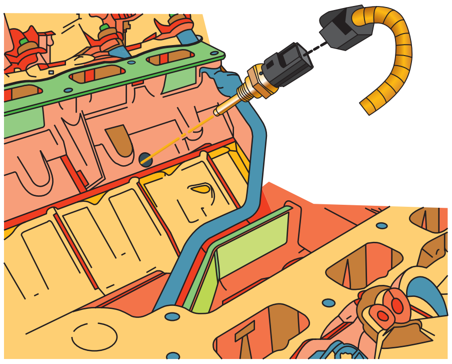


FIGURE 71–10 Some engines are equipped with a cylinder head temperature (CHT) sensor, which is used by the PCM along with the ECT to determine the temperature of the engine.

CYLINDER HEAD TEMPERATURE SENSOR Some vehicles are equipped with **cylinder head temperature (CHT)** sensors.

If the cylinder head temperature sensor is not providing the correct readings, the engine can have a variety of issues such as stalling, long cranking times, and hesitation while accelerating. ● **SEE FIGURE 71–10**.

ENGINE FUEL TEMPERATURE (EFT) SENSOR Some vehicles, such as many Ford vehicles that are equipped with an electronic returnless type of fuel injection, use an **engine fuel temperature (EFT)** sensor to give the PCM information regarding the temperature and, therefore, the density of the fuel. Check service information for the exact location, if equipped, and how to test and service the sensor.

EXHAUST GAS RECIRCULATION (EGR) TEMPERATURE SENSOR Some engines, such as Toyota, are equipped with exhaust gas recirculation (EGR) temperature sensors. EGR is a well-established method for reduction of NO_x emissions in internal combustion engines. The exhaust gas contains unburned hydrocarbons, which are recirculated in the combustion process. Recirculation is controlled by valves, which operate as a function of exhaust gas speed, load, and temperature. The gas reaches a temperature of about 850°F (450°C) for which a special heavy-duty glass-encapsulated NTC sensor is available.

The PCM monitors the temperature in the exhaust passage between the EGR valve and the intake manifold. If the temperature increases when the EGR is commanded on, the PCM can determine that the valve or related components are functioning.

ENGINE OIL TEMPERATURE SENSOR Engine oil temperature sensors are used on many General Motors vehicles and are used as an input to the oil life monitoring system. The computer program inside the PCM calculates engine oil life based on run time, engine RPM, and oil temperature.

TEMPERATURE SENSOR DIAGNOSTIC TROUBLE CODES The OBD-II diagnostic trouble codes that relate to temperature sensors include both high- and low-voltage codes, as well as intermittent codes. ● **SEE CHART 71–2**.

DIAGNOSTIC TROUBLE CODE	DESCRIPTION	POSSIBLE CAUSES
P0112	IAT sensor low voltage	■ IAT sensor internally shorted-to-ground ■ IAT sensor wiring shorted-to-ground ■ IAT sensor damaged by backfire (usually associated with IAT sensors that are mounted in the intake manifold) ■ Possible defective PCM
P0113	IAT sensor high voltage	■ IAT sensor internally (electrically) open ■ IAT sensor signal, circuit, or ground circuit open ■ Possible defective PCM
P0117	ECT sensor low voltage	■ ECT sensor internally shorted-to-ground ■ The ECT sensor circuit wiring shorted-to-ground ■ Possible defective PCM
P0118	ECT sensor high voltage	■ ECT sensor internally (electrically) open ■ ECT sensor signal, circuit, or ground circuit open ■ Engine operating in an overheated condition ■ Possible defective PCM

CHART 71–2

Selected temperature sensor-related diagnostic trouble codes.

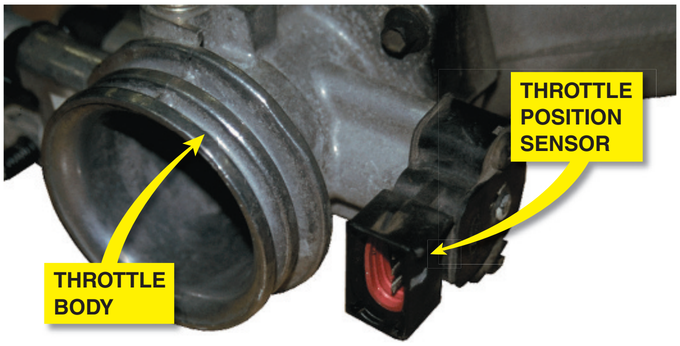


FIGURE 71–11 A typical TP sensor mounted on the throttle body of this port-injected engine.

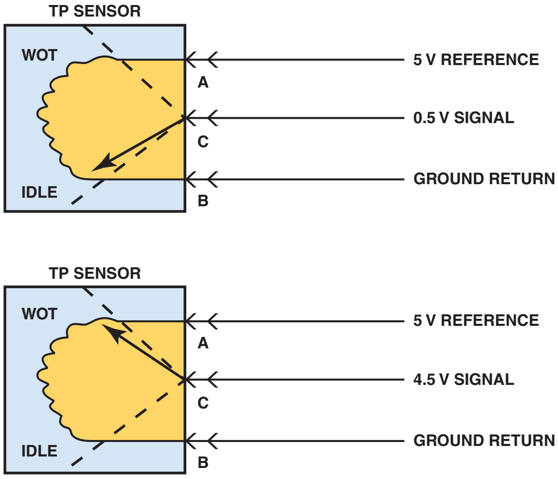


FIGURE 71–12 The signal voltage from a throttle position increases as the throttle is opened because the wiper arm is closer to the 5-volt reference. At idle, the resistance of the sensor winding effectively reduces the signal voltage output to the computer.

THROTTLE POSITION SENSOR CONSTRUCTION

PURPOSE AND FUNCTION Before the introduction of electronic throttle control (ECT) systems (throttle-by-wire), engines used a single **throttle position (TP) sensor** to signal to the powertrain control module (PCM) the position of the throttle.

POTENTIOMETERS A potentiometer is a variable-resistance sensor with three terminals. One end of the resistor receives reference voltage, while the other end is grounded. The third terminal is attached to a movable contact that slides across the resistor to vary its resistance. Depending on whether the contact is near the supply end or the ground end of the resistor, return voltage is high or low. ● **SEE FIGURES 71–11 AND 71–12.**

Throttle position (TP) sensors are among the most common potentiometer-type sensors. The computer uses their input to determine the amount of throttle opening and the rate of change.

A typical sensor has three wires:

- A 5-volt reference feed wire from the computer
- Signal return (a ground wire back to the computer)
- A voltage signal wire back to the computer; as the throttle is opened, the voltage to the computer changes

Normal throttle position voltage on most vehicles is about 0.5 volt at idle (closed throttle) and 4.5 volts at wide-open throttle (WOT).

NOTE: The TP sensor voltage at idle is usually about 10% of the TP sensor voltage when the throttle is wide open, but can vary from as low as 0.3 to 1.2 volts, depending on the make and model of vehicle.

TP SENSOR COMPUTER INPUT FUNCTIONS

- The computer senses any change in throttle position and changes the fuel mixture and ignition timing. The actual change in fuel mixture and ignition timing is also partly determined by the other sensors, such as the manifold pressure (engine vacuum), engine RPM, the coolant temperature, and oxygen sensor(s). Some throttle position sensors are adjustable and should be set according to the exact engine manufacturer's specifications.
- The throttle position sensor signals the PCM to pulse additional fuel from the injectors when the throttle is depressed. Because the air can quickly flow into the engine when the throttle is opened, additional fuel must be supplied to prevent the air–fuel mixture from going lean, causing the engine to hesitate when the throttle is depressed. If the TP sensor is unplugged or defective, the engine may still operate satisfactorily, but hesitate upon acceleration.
- The PCM supplies the TP sensor with a regulated voltage that ranges from 4.8 to 5.1 volts. This reference voltage is usually referred to as a 5-volt reference or "Vref." The TP output signal is an input to the PCM, and the TP sensor ground also flows through the PCM.

See the Ford throttle position sensor chart for an example of how sensor voltage changes with throttle angle.

FORD THROTTLE POSITION (TP) SENSOR CHART

THROTTLE ANGLE (DEGREES)	VOLTAGE (V)
0	0.50
10	0.97
20	1.44
30	1.90
40	2.37
50	2.84
60	3.31
70	3.78
80	4.24

NOTE: Generally, any reading higher than 80% represents wide-open throttle to the computer.

PCM USES FOR THE TP SENSOR

The TP sensor is used by the powertrain control module (PCM) for the following reasons:

- **Clear Flood Mode** If the throttle is depressed to the floor during engine cranking, the PCM will either greatly reduce or entirely eliminate any fuel-injector pulses to aid in clearing a flooded engine. If the throttle is depressed to the floor and the engine is not flooded with excessive fuel, the engine may not start.
- **Torque Converter Clutch Engagement and Release** The torque converter clutch will be released if the PCM detects rapid acceleration to help the transmission deliver maximum torque to the drive wheels. The torque converter clutch is applied when the vehicle is lightly accelerating and during cruise conditions to improve fuel economy.
- **Rationality Testing for MAP and MAF Sensors** As part of the rationality tests for the MAP and/or MAF sensor, the TP sensor signal is compared to the reading from other sensors to determine if they match. For example, if the throttle position sensor is showing wide-open throttle, the MAP and/or MAF reading should also indicate that this engine is under a heavy load. If not, a diagnostic trouble code could be set for the TP, as well as the MAP and/or MAF sensors.
- **Automatic Transmission Shift Points** The shift points are delayed if the throttle is opened wide to allow the engine speed to increase, thereby producing more power and aiding in the acceleration of the vehicle. If the throttle is barely open, the shift point occurs at the minimum speed designed for the vehicle.
- **Target Idle Speed (Idle Control Strategy)** When the TP sensor voltage is at idle, the PCM controls idle speed using the idle air control (IAC) and/ or spark timing variation to maintain the commanded idle speed. If the TP sensor indicates that the throttle has moved off idle, fuel delivery and spark timing are programmed for acceleration. Therefore, if the throttle linkage is stuck or binding, the idle speed may not be correct.
- **Air-Conditioning Compressor Operation** The TP sensor is also used as an input sensor for air-conditioning compressor operation. If the PCM detects that the throttle is at or close to wide open, the air-conditioning compressor is disengaged.
- **Backs Up Other Sensors** The TP sensor is used as a backup to the MAP sensor and/or MAF in the event the PCM detects that one or both are not functioning correctly. The PCM then calculates fuel needs and spark timing based on the engine speed (RPM) and throttle position.

TESTING THE THROTTLE POSITION SENSOR

A TP sensor can be tested using one or more of the following tools:

- A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or back probing using T-pins or other recommended tool that will not cause harm to the connector or wiring
- A scan tool or a specific tool recommended by the vehicle manufacturer
- An oscilloscope

Use jumper wires, T-pins to back-probe the wires, or a breakout box to gain electrical access to the wiring to the TP sensor. ● **SEE FIGURE 71–13**.

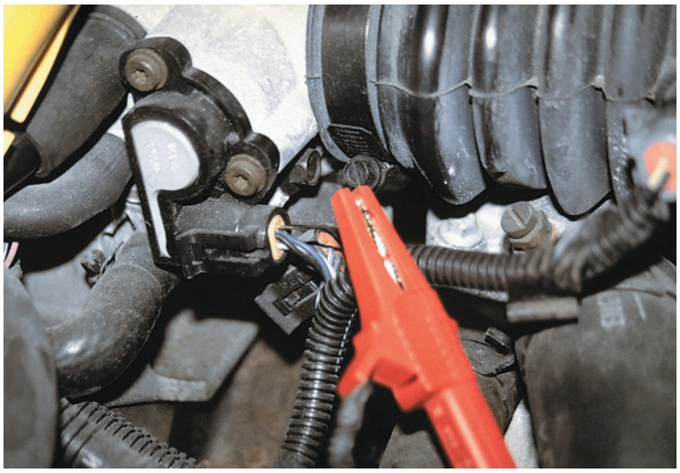


FIGURE 71–13 A meter lead connected to a T-pin that was gently pushed along the signal wire of the TP sensor until the point of the pin touched the metal terminal inside the plastic connector.

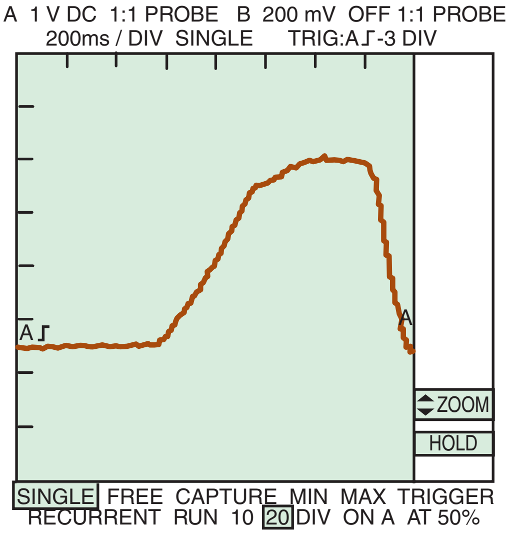


FIGURE 71–14 A typical waveform of a TP sensor signal as recorded on a DSO when the accelerator pedal was depressed with the ignition switch on (engine off). Clean transitions and the lack of any glitches in this waveform indicate a good sensor.

NOTE: The procedure that follows is the usual method used by many manufacturers. Always refer to service information for the exact recommended procedure and specifications for the vehicle being tested.

The procedure for testing the sensor using a digital multimeter is as follows:

1. Turn the ignition switch on (engine off).
2. Set the digital meter to read to DC volts and measure the voltage between the signal wire and ground (reference low) wire. The voltage should be about 0.5 volt.

NOTE: Consult the service information for exact wire colors or locations.

3. With the engine still not running (but with the ignition still on), slowly increase the throttle opening. The voltage signal from the TP sensor should also increase. Look for any "dead spots" or open circuit readings as the throttle is increased to the wide-open position. ● **SEE FIGURE 71–14** for an example of how a good TP sensor would look when tested with a digital storage oscilloscope (DSO).

NOTE: Use the accelerator pedal to depress the throttle because this applies the same forces on the TP sensor as the driver does during normal driving. Moving the throttle by hand under the hood may not accurately test the TP sensor.

4. With the voltmeter still connected, slowly return the throttle down to the idle position. The voltage from the TP sensor should also decrease evenly on the return to idle.

The TP sensor voltage at idle should be within the acceptable range as specified by the manufacturer. Some TP sensors can be adjusted by loosening their retaining screws and moving the sensor in relation to the throttle opening. This movement changes the output voltage of the sensor.

TECH TIP

Check Power and Ground before Condemning a Bad Sensor

Most engine sensors use a 5-volt reference and a ground. If the 5 volts to the sensor is too high (shorted to voltage) or too low (high resistance), the sensor output will be **skewed** or out of range. Before replacing the sensor that did not read correctly, measure both the 5-volt reference and ground. To measure the ground, simply turn the ignition on (engine off) and touch one test lead of a DMM set to read DC volts to the sensor ground and the other to the negative terminal of the battery. Any reading higher than 0.2 volt (200 mV) represents a poor ground. ● **SEE FIGURES 71–15 AND 71–16.**

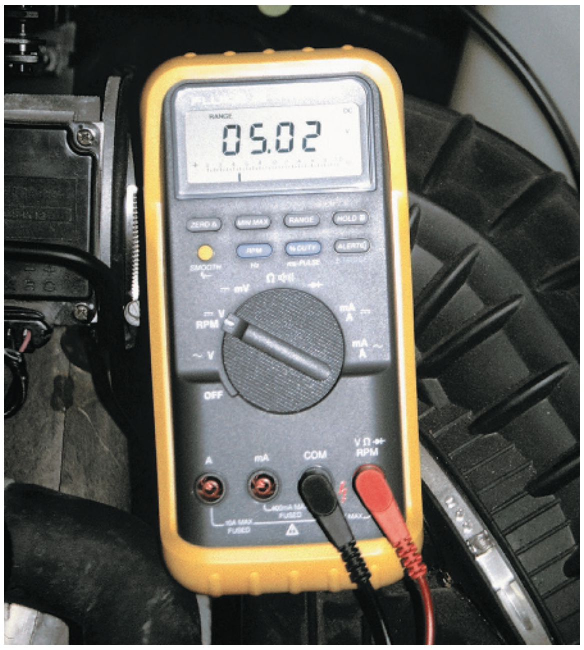


FIGURE 71–15 Checking the 5-volt reference from the computer being applied to the TP sensor with the ignition switch on (engine off).

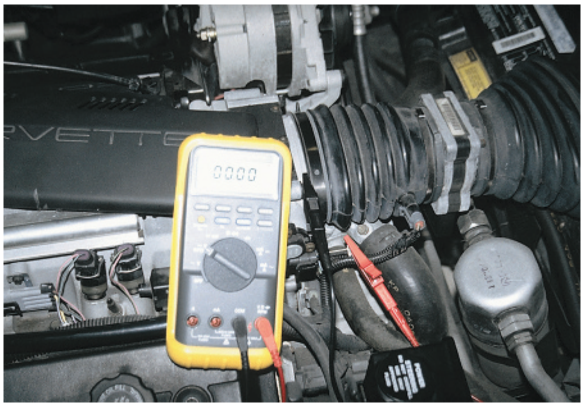


FIGURE 71–16 Checking the voltage drop between the TP sensor ground and a good engine ground with the ignition on (engine off). A reading of greater than 0.2 volt (200 mV) represents a bad computer ground.

All TP sensors should also provide a smooth transition voltage reading from idle to WOT and back to idle. Replace the TP sensor if erratic voltage readings are obtained or if the correct setting at idle cannot be obtained.

TESTING THE TP SENSOR USING A SCAN TOOL A scan tool can be used to check for proper operation of the throttle position sensor using the following steps:

STEP 1 With the key on, engine off, the TP sensor voltage display should be about 0.5 volt, but can vary from as low as 0.3 volt to as high as 1.2 volts.

STEP 2 Check the scan tool display for the percentage of throttle opening. The reading should be zero and gradually increase in percentage as the throttle is depressed.

STEP 3 The idle air control (IAC) counts should increase as the throttle is opened and decrease as the throttle is closed. Start the engine and observe the IAC counts as the throttle is depressed.

STEP 4 Start the engine and observe the TP sensor reading. Use a wedge or thin object to increase the throttle opening slightly. The throttle percentage reading should increase. Shut off and restart the engine. If the percentage of throttle opening returns to 0%, the PCM determines that the increased throttle opening is now the new minimum and resets the idle position of the TP sensor. Remove the wedge and cycle the ignition key. The throttle position sensor should again read zero percentage.

NOTE: Some engine computers are not capable of resetting the throttle position sensor.

TP SENSOR DIAGNOSTIC TROUBLE CODES The diagnostic trouble codes (DTCs) associated with the throttle position sensor include the following:

DIAGNOSTIC TROUBLE CODE	DESCRIPTION	POSSIBLE CAUSES
P0122	TP sensor low voltage	■ TP sensor internally shorted-to-ground ■ TP sensor wiring shorted-to-ground ■ TP sensor or wiring open
P0123	TP sensor high voltage	■ TP sensor internally shorted to 5-volt reference ■ TP sensor ground open ■ TP sensor wiring shorted-to-voltage
P0121	TP sensor signal does not agree with MAP	■ Defective TP sensor ■ Incorrect vehicle-speed (VS) sensor signal ■ MAP sensor out-of-calibration or defective

REVIEW QUESTIONS

1. How does a typical NTC temperature sensor work?
2. What is the difference between a stepped and a non-stepped ECT circuit?
3. What does the PCM do with the TP sensor signal voltage?
4. What is the procedure to follow when checking the 5-volt reference and TP sensor ground?
5. How can a TP sensor be diagnosed using a scan tool?

CHAPTER QUIZ

1. When checking the ECT sensor with a scan tool, about what temperature should be displayed if the connector is removed from the sensor with the key on, engine off?
   a. 284°F (140°C)
   b. 230°F (110°C)
   c. 120°F (50°C)
   d. −40°F (−40°C)
2. What happens to the voltage measured at the ECT sensor when the thermostat opens?
   a. Increases slightly
   b. Increases about 1 volt
   c. Decreases slightly
   d. Decreases about 1 volt

3. Two technicians are discussing a stepped ECT circuit. Technician A says that the sensor used for a stepped circuit is different than one used in a non-stepped circuit. Technician B says that a stepped ECT circuit uses different internal resistance inside the PCM. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. When testing an ECT sensor on a vehicle, a digital multimeter can be used and the signal wires back probed. What setting should the technician use to test the sensor?
   - **a.** AC volts
   - **b.** DC volts
   - **c.** Ohms
   - **d.** Hz (hertz)
5. A typical IAT or ECT sensor reads about 3,000 ohms when tested using a DMM. This resistance represents a temperature of about __________.
   - **a.** −40°F (−40°C)
   - **b.** 70°F (20°C)
   - **c.** 120°F (50°C)
   - **d.** 284°F (140°C)
6. Typical TP sensor voltage at idle is about __________.
   - **a.** 2.50 to 2.80 volts
   - **b.** 0.5 volt or 10% of WOT TP sensor voltage
   - **c.** 1.5 to 2.8 volts
   - **d.** 13.5 to 15.0 volts
7. A TP sensor is what type of sensor?
   - **a.** Rheostat
   - **b.** Voltage generating
   - **c.** Potentiometer
   - **d.** Piezoelectric
8. If the transmission fluid temperature (TFT) sensor indicates cold automatic transmission fluid temperature, what would the PCM do to the shifts?
   - **a.** Normal shifts and normal operation of the torque converter clutch
   - **b.** Disable torque converter clutch; normal shift points
   - **c.** Delayed shift points and torque converter clutch disabled
   - **d.** Normal shifts but overdrive will be disabled
9. Which sensor does the TP sensor back up if the PCM determines that a failure has occurred?
   - **a.** Oxygen sensor
   - **b.** MAF sensor
   - **c.** MAP sensor
   - **d.** Either b or c
10. Which wire on a TP sensor should be back-probed to check the voltage signal to the PCM?
    - **a.** 5-volt reference (Vref)
    - **b.** Signal
    - **c.** Ground
    - **d.** Meter should be connected between the 5-volt reference and the ground

Chapter

72

MAP AND MAF SENSORS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the variations in pressure that can occur within an engine.
- Describe principles of pressure sensors.
- Discuss how MAP sensors work.
- Discuss the PCM uses of the MAP sensor.
- Describe how the BARO sensor is used to test altitude.
- List the methods that can be used to test MAP sensors.
- Discuss MAF sensor types.
- Discuss the PCM uses for the MAF sensor.
- List the methods that can be used to test MAF sensors.
- List the methods that can be used to test MAF sensor contamination.

KEY TERMS:

Barometric manifold absolute pressure (BMAP) sensor 858 • Barometric pressure (BARO) sensor 858 • False air 862 • Manifold absolute pressure (MAP) sensor 855 • Mass airflow (MAF) sensor 860 • Piezoresistivity 856 • Pressure differential 854 • Speed density 857 • Tap test 862 • Vacuum 854

AIR PRESSURE

HIGH AND LOW PRESSURE Think of an internal combustion engine as a big air pump. As the pistons move up and down in the cylinders, they pump in air and fuel for combustion and pump out exhaust gases. They do this by creating a difference in air pressure. The air outside an engine has weight and exerts pressure, as does the air inside an engine.

As a piston moves down on an intake stroke with the intake valve open, it creates a larger area inside the cylinder for the air to fill. This lowers the air pressure within the engine. Because the pressure inside the engine is lower than the pressure outside, air flows into the engine to fill the low-pressure area and equalize the pressure.

The low pressure within the engine is called **vacuum** and is measured in inches of Mercury, abbreviated in. Hg. Vacuum causes the higher-pressure air on the outside to flow into the low-pressure area inside the cylinder. The difference in pressure between the two areas is called a **pressure differential**. ● **SEE FIGURE 72–1**.

PRESSURE SENSORS

PRINCIPLES Intake manifold pressure changes with changing throttle positions. At wide-open throttle, manifold pressure is almost the same as atmospheric pressure. On deceleration or at idle, manifold pressure is below atmospheric pressure, thus creating a vacuum. In cases where turbo- or supercharging is used, under part- or full-load condition, intake manifold pressure rises above atmospheric pressure. Also, oxygen content and barometric pressure change with differences in altitude, and the computer must be able to compensate by making changes in the flow of fuel entering the engine. To provide the computer with changing airflow information, a fuel-injection system may use the following:

- Manifold absolute pressure (MAP) sensor
- Manifold absolute pressure sensor plus barometric absolute pressure (BARO) sensor
- Barometric and manifold absolute pressure (BMAP) sensors combined

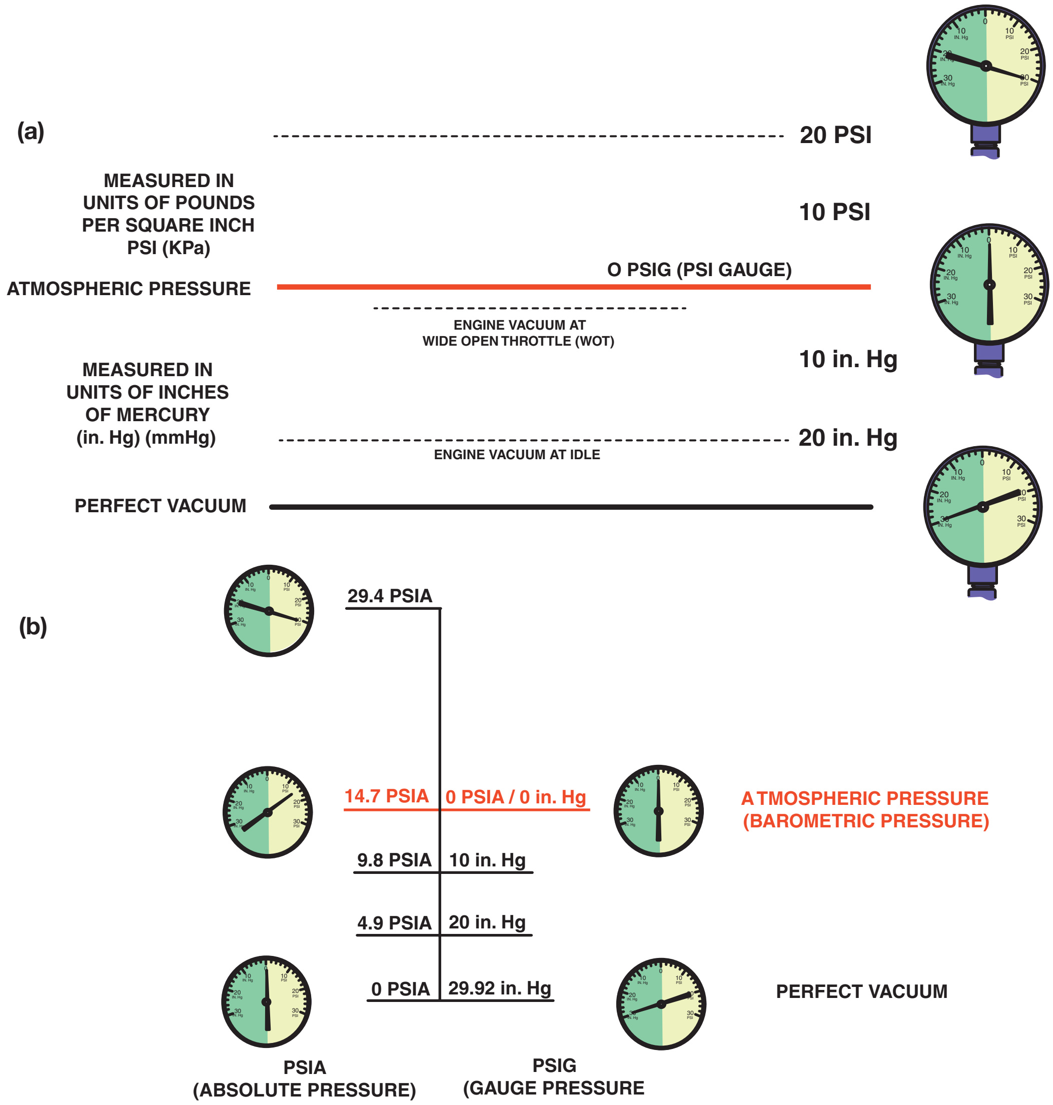

(a)
20 PSI
MEASURED IN UNITS OF POUNDS PER SQUARE INCH PSI (KPa)
10 PSI
O PSIG (PSI GAUGE)
ATMOSPHERIC PRESSURE
ENGINE VACUUM AT WIDE OPEN THROTTLE (WOT)
10 in. Hg
MEASURED IN UNITS OF INCHES OF MERCURY (in. Hg) (mmHg)
20 in. Hg
ENGINE VACUUM AT IDLE
PERFECT VACUUM
(b)
29.4 PSIA
14.7 PSIA
0 PSIA / 0 in. Hg
ATMOSPHERIC PRESSURE (BAROMETRIC PRESSURE)
9.8 PSIA
10 in. Hg
4.9 PSIA
20 in. Hg
0 PSIA
29.92 in. Hg
PERFECT VACUUM
PSIA (ABSOLUTE PRESSURE)
PSIG (GAUGE PRESSURE)

FIGURE 72–1 (a) As an engine is accelerated under a load, the engine vacuum drops. This drop in vacuum is actually an increase in absolute pressure in the intake manifold. A MAP sensor senses all pressures greater than that of a perfect vacuum. (b) The relationship between absolute pressure, vacuum, and gauge pressure.

The **manifold absolute pressure (MAP) sensor** may be a ceramic capacitor diaphragm, an aneroid bellows, or a piezoresistive crystal. It has a sealed vacuum reference input on one side; the other side is connected (vented) to the intake manifold. This sensor housing also contains signal conditioning circuitry. ● **SEE FIGURE 72–2**. Pressure changes in the manifold cause the sensor to deflect, varying its analog or digital return signal to the computer. As the air pressure increases, the MAP sensor generates a higher voltage or frequency return signal to the computer.

MANIFOLD ABSOLUTE PRESSURE SENSORS

CONSTRUCTION The manifold absolute pressure sensor is used by the engine computer to sense engine load. The typical MAP sensor consists of a ceramic or silicon wafer sealed on one side with a perfect vacuum and exposed to intake manifold vacuum on the other side. As the engine vacuum changes, the pressure difference on the wafer changes the output voltage or frequency of the MAP sensor.

A manifold absolute pressure sensor is used on many engines for the PCM to determine the load on the engine. The relationship among barometer pressure, engine vacuum, and MAP sensor voltage includes the following:

- Absolute pressure is equal to barometric pressure minus intake manifold vacuum.
- A decrease in manifold vacuum means an increase in manifold pressure.
- The MAP sensor compares manifold vacuum to a perfect vacuum.
- Barometric pressure minus MAP sensor reading equals intake manifold vacuum. Normal engine vacuum is 17–21 inch Hg.
- Supercharged and turbocharged engines require a MAP sensor that is calibrated for pressures above atmospheric, as well as for vacuum. ● **SEE FIGURE 72–3**.

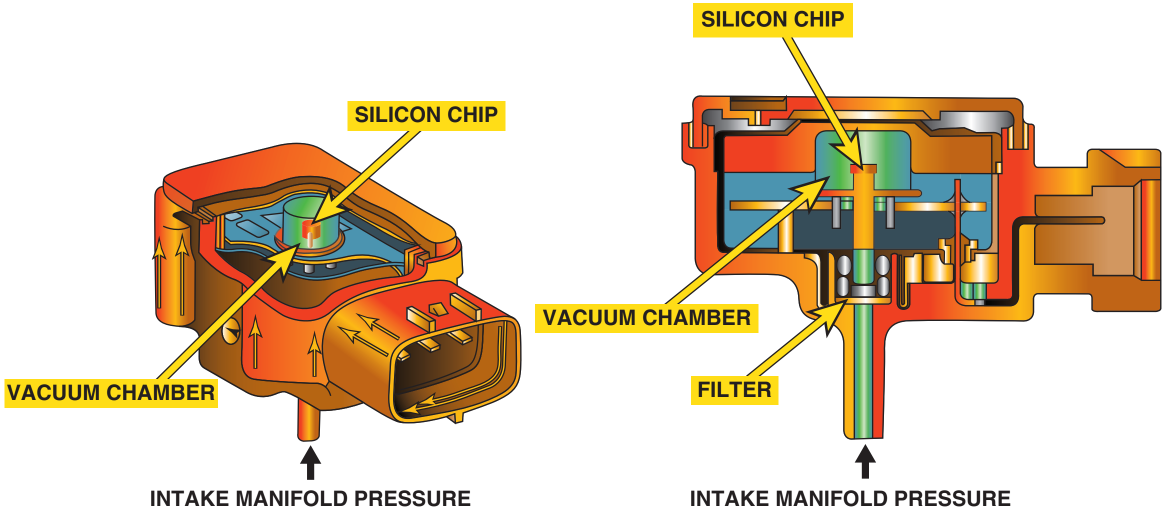


FIGURE 72–2 A MAP sensor compares the absolute pressure in the intake manifold to a perfect vacuum. The deflection of the silicon chip is converted to a an absolute pressure reading by the electronics in the sensor itself.

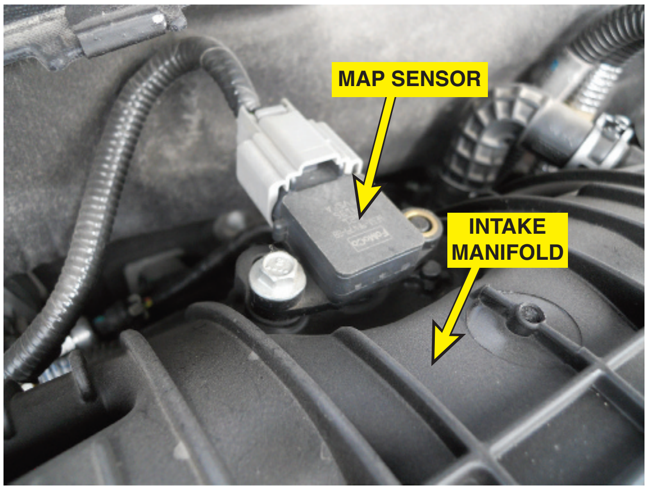


FIGURE 72–3 A typical MAP sensor installed in the intake manifold.

SILICON-DIAPHRAGM STRAIN GAUGE MAP SENSOR This is the most commonly used design for a MAP sensor and the output is a DC analog (variable) voltage. One side of a silicon wafer is exposed to engine vacuum and the other side is exposed to a perfect vacuum.

There are four resistors attached to the silicon wafer, which changes in resistance when strain is applied to the wafer. This change in resistance due to strain is called **piezoresistivity**. The resistors are electrically connected to a Wheatstone bridge circuit and then to a differential amplifier, which creates a voltage in proportion to the vacuum applied.

A typical General Motors MAP sensor voltage varies from 0.88 to 1.62 at engine idle.

- 17 inch Hg is equal to about 1.62 volts
- 21 inch Hg is equal to about 0.88 volts

Therefore, a good reading should be about 1.0 volt from the MAP sensor on a sound engine at idle speed. See the following chart that shows engine load, engine vacuum, and MAP. ● **SEE CHART 72–1**.

ENGINE LOAD	MANIFOLD VACUUM	MANIFOLD ABSOLUTE PRESSURE	MAP SENSOR VOLT SIGNAL
Heavy (WOT)	Low (almost 0 inch Hg)	High (almost atmospheric)	High (4.6–4.8 V)
Light (idle)	High (17–21 inch Hg)	Low (lower than atmospheric)	Low (0.8–1.6 V)

CHART 72–1

Engine load and how it is related to engine vacuum, and MAP sensor reading.

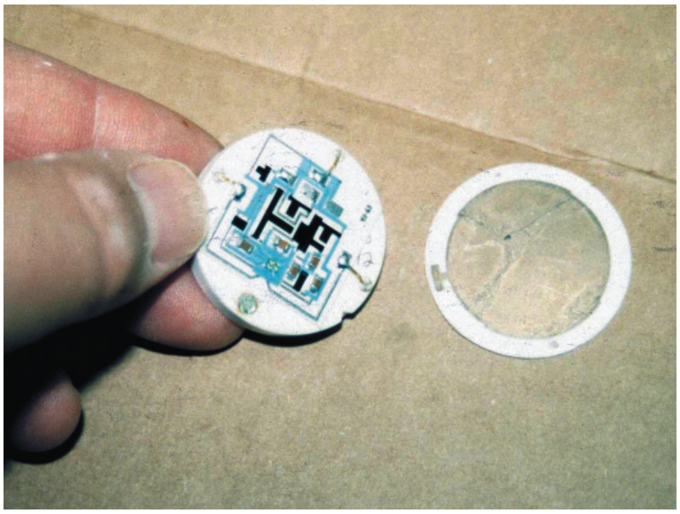


FIGURE 72–4 Shown is the electronic circuit inside a ceramic disc MAP sensor used on many Chrysler engines. The black areas are carbon resistors that are applied to the ceramic, and lasers are used to cut lines into these resistors during testing to achieve the proper operating calibration.

CERAMIC DISC MAP SENSOR The ceramic disc MAP sensor is used by Chrysler and it converts manifold pressure into a capacitance discharge. The discharge controls the amount of voltage delivered by the sensor to the PCM. The output is the same as the previously used strain gauge/Wheatstone bridge design and is interchangeable. ● **SEE FIGURE 72–4**. Also ● **SEE CHART 72–2**.

Chrysler MAP Sensor Chart

VACUUM (IN. HG)	MAP SENSOR SIGNAL VOLTAGE (V)
0.5	4.8
1.0	4.6
3.0	4.1
5.0	3.8
7.0	3.5
10.0	2.9
15.0	2.1
20.0	1.2
25.0	0.5

CHART 72–2

Chyrsler MAP sensor values compared to engine vacuum.

TECH TIP

If It's Green, It's a Signal Wire

Ford-built vehicles usually use a green wire as the signal wire back to the computer from the sensors. It may not be a solid green, but if there is green somewhere on the wire, then it is the signal wire. The other wires are the power and ground wires to the sensor.

PCM USES OF THE MAP SENSOR

SPEED DENSITY Engines that do not use an airflow meter or sensor rely on calculating the amount of air entering the engine by using the MAP sensor and engine speed as the major factors. The method of calculating the amount of fuel needed by the engine is called speed density.

The PCM uses the MAP sensor to determine the following:

- **The load on the engine.** The MAP sensor is used on a **speed density**–type fuel-injection system to determine the load on the engine, and therefore the amount of fuel needed. On engines equipped with a mass air flow (MAF) sensor, the MAP is used as a backup to the MAF, for diagnosis of other sensors, and systems such as the EGR system.
- **Altitude, fuel, and spark control calculations.** At key on, the MAP sensor determines the altitude (acts as a BARO sensor) and adjusts the fuel delivery and spark timing accordingly.
    - If the altitude is high, generally over 5,000 feet (1,500 meters), the PCM will reduce fuel delivery and advance the ignition timing.
    - The altitude is also reset when the engine is accelerated to wide-open throttle and the MAP sensor is used to reset the altitude reading. ● **SEE FIGURE 72–5.**

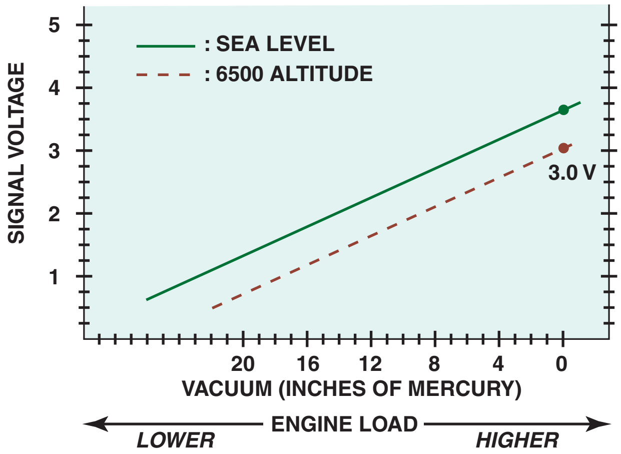


FIGURE 72–5 Altitude affects the MAP sensor voltage.

- **EGR system operation.** As part of the OBD-II standards, the exhaust gas recirculation (EGR) system must be checked for proper operation. One method used by many vehicle manufacturers is to command the EGR valve on and then watch the MAP sensor signal. The opening of the EGR pintle should decrease engine vacuum. If the MAP sensor does not react with the specified drop in manifold vacuum (increase in manifold pressure), an EGR flow rate problem diagnostic trouble code is set.
- **Detect deceleration (vacuum increases).** The engine vacuum rises when the accelerator is released, which changes the MAP sensor voltage. When deceleration is detected by the PCM, fuel is either stopped or greatly reduced to improve exhaust emissions.
- **Monitor engine condition.** As an engine wears, the intake manifold vacuum usually decreases. The PCM is programmed to detect the gradual change in vacuum and is able to keep the air–fuel mixture in the correct range. If the PCM were not capable of making adjustments for engine wear, the lower vacuum could be interpreted as increased load on the engine, resulting in too much fuel being injected, thereby reducing fuel economy and increasing exhaust emissions.
- **Load detection for returnless-type fuel injection.** On fuel delivery systems that do not use a return line back to the fuel tank, the engine load calculation for the fuel needed is determined by the signals from the MAP sensor.
- **Altitude and MAP sensor values.** On an engine equipped with a speed density–type fuel injection, the MAP sensor is the most important sensor needed to determine injection pulse width. Changes in altitude change the air density as well as weather conditions. Barometric pressure and altitude are inversely related:
    - As altitude increases—barometric pressure decreases
    - As altitude decreases—barometric pressure increases

  As the ignition switch is turned from off to the start position, the PCM reads the MAP sensor value to determine atmospheric and air pressure conditions. This barometric pressure reading is updated every time the engine is started and whenever wide-open throttle is detected. The barometric pressure reading at that time is updated. ● **SEE CHART 72–3.**

TECH TIP

Use the MAP Sensor as a Vacuum Gauge

A MAP sensor measures the pressure inside the intake manifold compared with absolute zero (perfect vacuum). For example, an idling engine that has 20 inches of mercury (inch Hg) of vacuum has a lower pressure inside the intake manifold than when the engine is under a load and the vacuum is at 10 inch Hg. A decrease in engine vacuum results in an increase in manifold pressure. A normal engine should produce between 17 and 21 inch Hg at idle. Comparing the vacuum reading with the voltage reading output of the MAP sensor indicates that the reading should be between 1.62 and 0.88 volt. Therefore, a digital multimeter (DMM), scan tool, or scope can be used to measure the MAP sensor voltage and be used instead of a vacuum gauge.

NOTE: This chart was developed by testing a MAP sensor at a location about 600 feet above sea level. For best results, a chart based on your altitude should be made by applying a known vacuum, and reading the voltage of a known-good MAP sensor. Vacuum usually drops about 1 inch per 1,000 feet of altitude.

Vacuum (in. Hg)	GM (DC volts)
0	4.80
1	4.52
2	4.46
3	4.26
4	4.06
5	3.88
6	3.66
7	3.50
8	3.30
9	3.10
10	2.94
11	2.76
12	2.54
13	2.36
14	2.20
15	2.00
16	1.80
17	1.62
18	1.42
19	1.20
20	1.10
21	0.88
22	0.66

Altitude and MAP Sensor Voltage

ALTITUDE	MAP SENSOR VOLTAGE (KEY ON, ENGINE OFF)
Sea level	4.6 – 4.8 V
2,500 ft (760 m)	4.0 V
5,000 ft (1,520 m)	3.7 V
7,500 ft (2,300 m)	3.35 V
10,000 ft (3,050 m)	3.05 V
12,500 ft (3,800 m)	2.80 V
15,000 ft (4,600 m)	2.45 V

CHART 72–3

Comparison between MAP sensor voltage and altitude.

BAROMETRIC PRESSURE SENSOR

TERMINOLOGY A **barometric pressure (BARO) sensor** is similar in design, but senses more subtle changes in barometric absolute pressure (atmospheric air pressure). It is vented directly to the atmosphere. The **barometric manifold absolute pressure (BMAP) sensor** is actually a combination of a BARO and MAP sensor in the same housing. The BMAP sensor has individual circuits to measure barometric and manifold pressure. This input not only allows the computer to adjust for changes in atmospheric pressure due to weather, but also is the primary sensor used to determine altitude.

NOTE: A MAP sensor and a BARO sensor are usually the same sensor, but the MAP sensor is connected to the manifold and a BARO sensor is open to the atmosphere. The MAP sensor is capable of reading barometric pressure just as the ignition switch is turned to the on position before the engine starts. See the Ford/BARO altitude chart for an example of how altitude affects intake manifold pressure. ● **SEE CHART 72–4**.

TESTING THE MAP SENSOR

Most pressure sensors operate on 5 volts from the computer and return a signal (voltage or frequency) based on the pressure (vacuum) applied to the sensor. If a MAP sensor is being tested, make certain that the vacuum hose and hose fittings are sound and making a good, tight connection to a manifold vacuum source on the engine.

Three different types of test instruments can be used to test a pressure sensor:

1. A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or back-probe the terminals.
2. A scope connected to the sensor output, power, and ground.
3. A scan tool or a specific tool recommended by the vehicle manufacturer.

Ford MAP/BARO Altitude Chart

ALTITUDE (FEET)	VOLTS (V)
0	1.59
1,000	1.56
2,000	1.53
3,000	1.50
4,000	1.47
5,000	1.44
6,000	1.41
7,000	1.39

CHART 72–4

Comparison between Ford MAP/BARO sensor voltage and altitude.

CASE STUDY

The Case of the No-Start Lexus

The owner of a Lexus IS250 had the car towed to a shop as a no-start. The technician discovered that the "check engine" light would not come on even with key on, engine off (KOEO). A scan tool would not communicate either. Checking the resources on www.iatn.net, the technician read of a similar case where the fuel pressure sensor was shorted, which disabled all serial data communications. The technician disconnected the fuel pressure sensor located on the backside of the engine and the communications were restored and the engine started. The fuel pressure sensor was replaced and returned to the happy owner.

Summary:

Complaint—The vehicle owner stated that the engine would not start.
Cause—A shorted fuel pressure sensor was found as per a previous similar case.
Correction—The fuel pressure sensor was replaced and this corrected the serial data fault that caused the no-start condition.

NOTE: Always check service information for the exact testing procedures and specifications for the vehicle being tested.

TESTING THE MAP SENSOR USING A DMM OR SCOPE Use jumper wires, T-pins to back-probe the connector, or a breakout box to gain electrical access to the wiring to the pressure sensor. Most pressure sensors use three wires:

1. A 5-volt wire from the computer
2. A variable-signal wire back to the computer
3. A ground or reference low wire

The procedure for testing the sensor is as follows:

1. Turn the ignition on (engine off)
2. Measure the voltage (or frequency) of the sensor output
3. Using a hand-operated vacuum pump (or other variable vacuum source), apply vacuum to the sensor

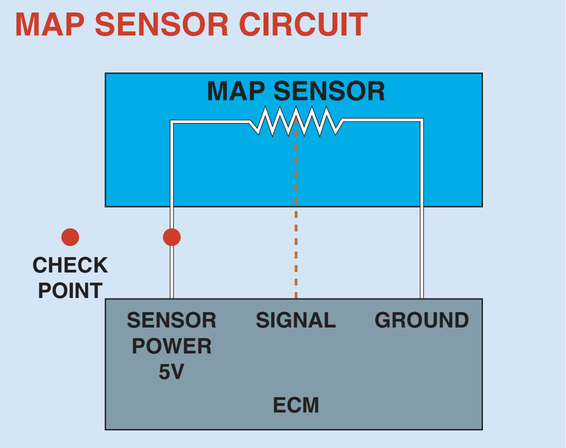


FIGURE 72–6 When checking a MAP sensor, first verify that the sensor is receiving a 5-volt reference voltage and then check for the output (signal) voltage.

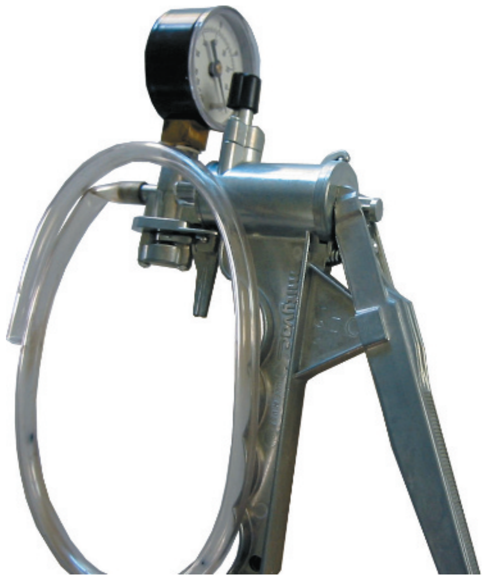


FIGURE 72–7 A typical hand-operated vacuum pump.

A good pressure sensor should change voltage in relation to the applied vacuum. If the signal does not change or the values are out of range according to the manufacturers' specifications, the sensor must be replaced. ● **SEE FIGURE 72–6**.

TESTING THE MAP SENSOR USING A SCAN TOOL A scan tool can be used to test a MAP sensor by monitoring the injector pulse width (in milliseconds) when vacuum is being applied to the MAP sensor using a hand-operated vacuum pump. ● **SEE FIGURE 72–7**.

STEP 1 Apply about 20 inch Hg of vacuum to the MAP sensor and start the engine.

STEP 2 Observe the injector pulse width. On a warm engine, the injector pulse width will normally be 1.5 to 3.5 milliseconds.

STEP 3 Slowly reduce the vacuum to the MAP sensor and observe the pulse width. A lower vacuum to the MAP sensor indicates a heavier load on the engine and the injector pulse width should increase.

NOTE: If 23 inch Hg or more vacuum is applied to the MAP sensor with the engine running, this high vacuum will often stall the engine. The engine stalls because the high vacuum is interpreted by the PCM to indicate that the engine is being

TECH TIP

Visual Check of the MAP Sensor

A defective vacuum hose to a MAP sensor can cause a variety of driveability problems including poor fuel economy, hesitation, stalling, and rough idle. A small air leak (vacuum leak) around the sensor can cause these symptoms and often set a trouble code in the vehicle computer.

When checking the MAP sensor, if anything comes out of the sensor itself, it should be replaced. This includes water, gasoline, or any other substance.

decelerated, which shuts off the fuel. During engine deceleration, the PCM shuts off the fuel injectors to reduce exhaust emissions and increase fuel economy.

MAP/BARO DIAGNOSTIC TROUBLE CODES The diagnostic trouble codes (DTCs) associated with the MAP and BARO sensors include

DIAGNOSTIC TROUBLE CODE	DESCRIPTION	POSSIBLE CAUSES
P0106	BARO sensor out-of-range at key on	■ MAP sensor fault ■ MAP sensor O-ring damaged or missing
P0107	MAP sensor low voltage	■ MAP sensor fault ■ MAP sensor signal circuit shorted-to-ground ■ MAP sensor 5-volt supply circuit open
P0108	Map sensor high voltage	■ MAP sensor fault ■ MAP sensor O-ring damaged or missing ■ MAP sensor signal circuit shorted-to-voltage

MASS AIRFLOW SENSOR TYPES

PURPOSE AND FUNCTION The purpose and function of mass air flow sensors is to measure the amount of air entering the engine.

There are several types of mass airflow sensors.

HOT FILM SENSOR The hot film sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the incoming air. Through the electronics within the sensor, a conductive film is kept at a temperature 70°C above the temperature of the incoming air. ● **SEE FIGURE 72–8.**

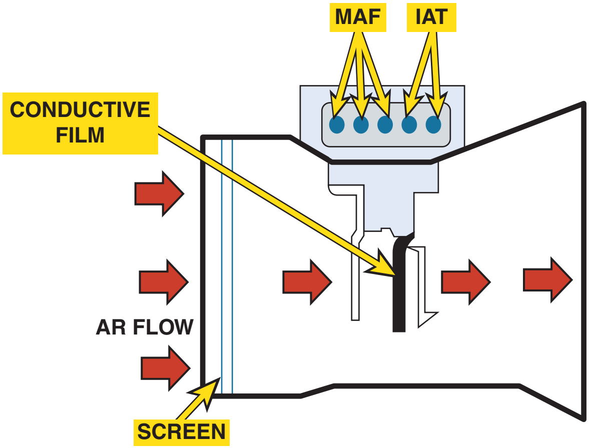


FIGURE 72–8 This five-wire mass air flow sensor consists of a metal foil sensing unit, an intake air temperature (IAT) sensor, and the electronic module.

Because the amount and density of the air both tend to contribute to the cooling effect as the air passes through the sensor, this type of sensor can actually produce an output based on the *mass* of the airflow. *Mass equals volume times density*. For example, cold air is denser than warm air so a small amount of cold air may have the same mass as a larger amount of warm air. Therefore, a mass airflow sensor is designed to measure the mass, not the volume, of the air entering the engine.

The output of this type of sensor is usually a frequency based on the amount of air entering the sensor. The more air that enters the sensor, the more the hot film is cooled. The electronics inside the sensor, therefore, increase the current flow through the hot film to maintain the 70°C temperature differential between the air temperature and the temperature of the hot film. This change in current flow is converted to a frequency output that the computer can use as a measurement of airflow. Most of these types of sensors are referred to as **mass airflow (MAF) sensors** because, unlike the air vane sensor, the MAF sensor takes into account relative humidity, altitude, and temperature of the air. The denser the air, the greater the cooling effect on the hot film sensor and the greater the amount of fuel required for proper combustion.

HOT WIRE SENSOR The hot wire sensor is similar to the hot film type, but uses a hot wire to sense the mass airflow instead of the hot film. Like the hot film sensor, the hot wire sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the air entering the sensor. ● **SEE FIGURE 72–9.** The electronic circuitry within the sensor keeps the temperature of the wire at 70°C above the temperature of the incoming air.

Both designs operate in essentially the same way. A resistor wire or screen installed in the path of intake airflow is heated to a constant temperature by electric current provided by the computer. Air flowing past the screen or wire cools it. The degree of cooling varies with air velocity, temperature, density, and humidity. These factors combine to indicate the mass of air entering the engine. As the screen or wire cools, more current is required to maintain the specified temperature. As the screen or wire heats up, less current is required. The operating principle can be summarized as follows:

- More intake air volume = cooler sensor, more current.
- Less intake air volume = warmer sensor, less current.

The computer constantly monitors the change in current and translates it into a voltage signal that is used to determine injector pulse width.

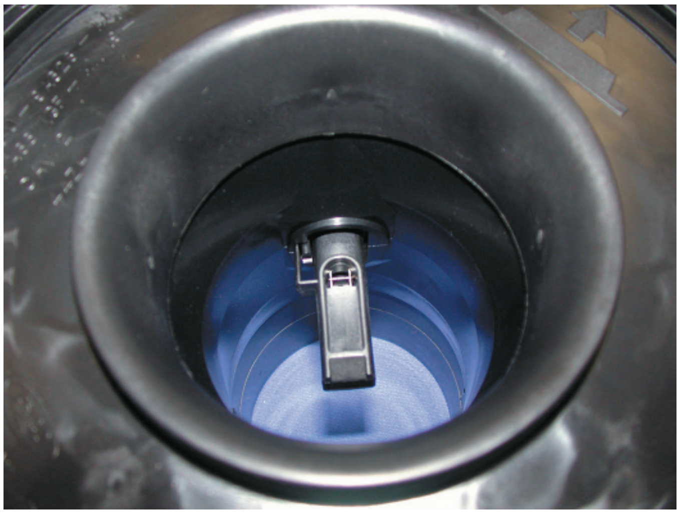


FIGURE 72–9 The sensing wire in a typical hot wire mass air flow sensor.

BURN-OFF CIRCUIT Some MAF sensors use a burn-off circuit to keep the sensing wire clean of dust and dirt. A high current is passed through the sensing wire for a short time, but long enough to cause the wire to glow due to the heat. The burn-off circuit is turned on when the ignition switch is switched off after the engine has been operating long enough to achieve normal operating temperature.

CASE STUDY

The Dirty MAF Sensor Story

The owner of a Buick Park Avenue equipped with a 3,800 V-6 engine complained that the engine would hesitate during acceleration, showed lack of power, and seemed to surge or miss at times. A visual inspection found everything to be like new, including a new air filter. There were no stored diagnostic trouble codes (DTCs). A look at the scan data showed airflow to be within the recommended 3 to 7 grams per second. A check of the frequency output showed the problem.

Idle frequency = 2.177 kHz (2,177 Hz)

Normal frequency at idle speed should be 2.37 to 2.52 kHz. Cleaning the hot wire of the MAF sensor restored proper operation. The sensor wire was covered with what looked like fine fibers, possibly from the replacement air filter.

Summary:

Complaint—Customer stated that the engine hesitated when accelerating.
Cause—Tests confirmed that the MAF sensor was operating correctly but the frequency output at idle was not within the normal range.
Correction—Cleaning the MAF sensor restored proper operation of the sensor and the engine now accelerates normally.

FREQUENTLY ASKED QUESTION

What Is Meant by a "High-Authority Sensor"?

A high-authority sensor is a sensor that has a major influence over the amount of fuel being delivered to the engine. For example, at engine start-up, the engine coolant temperature (ECT) sensor is a high-authority sensor and the oxygen sensor (O2S) is a low-authority sensor. However, as the engine reaches operating temperature, the oxygen sensor becomes a high-authority sensor and can greatly affect the amount of fuel being supplied to the engine. See the following chart:

High-Authority Sensors	Low-Authority Sensors
ECT (especially when the engine starts and is warming up)	IAT (intake air temperature) sensors modify and back up the ECT
O2S (after the engine reaches closed-loop operation)	TFT (transmission fluid temperature)
MAP	PRNDL (shift position sensor)
MAF	KS (knock sensor)
TP (high authority during acceleration and deceleration)	EFT (engine fuel temperature)

PCM USES FOR AIRFLOW SENSORS

The PCM uses the information from the airflow sensor for the following purposes:

- Airflow sensors are used mostly to determine the amount of fuel needed and base pulse-width numbers. The greater the mass of the incoming air, the longer the injectors are pulsed on.
- Airflow sensors back up the TP sensor in the event of a loss of signal or an inaccurate throttle position sensor signal. If the MAF sensor fails, then the PCM will calculate the fuel delivery needs of the engine based on throttle position and engine speed (RPM).

TESTING MASS AIRFLOW SENSORS

VISUAL INSPECTION Start the testing of a MAF sensor by performing a thorough visual inspection. Look at all the hoses that direct and send air, especially between the MAF sensor and the throttle body. Also check the electrical connector for the following:

- Corrosion
- Terminals that are bent or pushed out of the plastic connector
- Frayed wiring

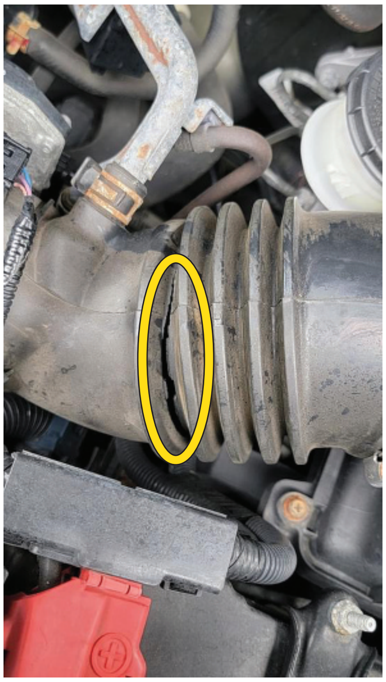


FIGURE 72–10 Carefully check the hose between the MAF sensor and the throttle plate for cracks or splits that could create extra (false) air into the engine that is not measured by the MAF sensor.

FREQUENTLY ASKED QUESTION

What Is False Air?

Airflow sensors and mass airflow (MAF) sensors are designed to measure *all* the air entering the engine. If an air inlet hose was loose or had a hole, extra air could enter the engine without being measured. This extra air is often called **false air**. ● **SEE FIGURE 72–10**.

NOTE: If the engine runs well in reverse, yet runs terrible in any forward gear, carefully look at the inlet hose for air leaks that would open when the engine torque moves the engine slightly on its mounts.

TAP TEST With the engine running at idle speed, *gently* tap the MAF sensor with the fingers of an open hand. If the engine stumbles or stalls, the MAF sensor is defective. This test is commonly called the **tap test**.

DMM AND DSO TEST OF A MAF SENSOR A digital multimeter can be used to measure the frequency (Hz) output of the sensor and compare the reading with specifications.

The frequency output and engine speed in RPM can also be plotted on a graph to check to see if the frequency and RPM are proportional, resulting in a straight line on the graph.

A digital storage oscilloscope (DSO) can be used to monitor the operation of a MAF sensor. Connect the test leads to the signal wire and the sensor ground and following the scope instructions look for a consistent pattern that changes in frequency as the engine speed is increased. ● **SEE FIGURE 72–11**.

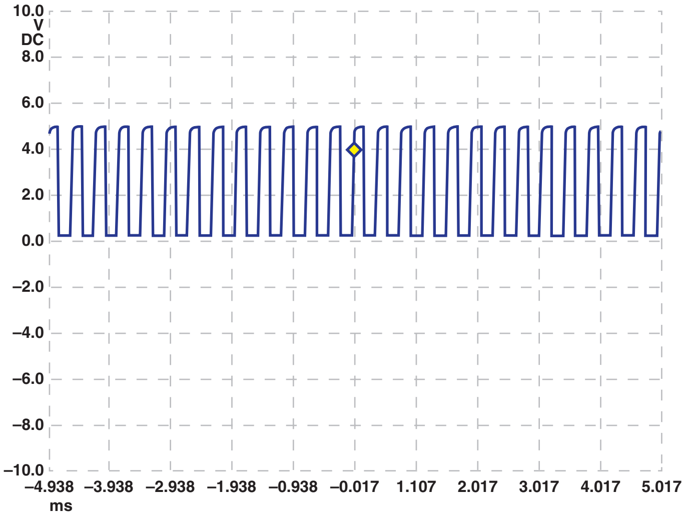


FIGURE 72–11 A scope display showing a normal Chevrolet Equinox MAF sensor at idle speed, the frequency is 2,600 hertz (2.6 kHz).

MAF SENSOR CONTAMINATION

Dirt, oil, silicon, or even spider webs can coat the sensing wire. Because it tends to insulate the sensing wire at low airflow rates, a contaminated sensor often overestimates the amount of air entering the engine at idle, and therefore causes the fuel system to go rich. At higher engine speeds near wide-open throttle (WOT), the contamination can cause the sensor to underestimate the amount of air entering the engine. As a result, the fuel system will go lean, causing spark knock and lack of power concerns. To check for contamination, check the fuel trim numbers.

If the fuel trim is negative (removing fuel) at idle, yet is positive (adding fuel) at higher engine speeds, a contaminated MAF sensor is a likely cause. Other tests for a contaminated MAF sensor are the following:

- At WOT, the grams per second, as read on a scan tool, should exceed 100.
- At WOT, the voltage, as read on a digital voltmeter, should exceed 4 volts for an analog sensor.
- At WOT, the frequency, as read on a meter or scan tool, should exceed 7 kHz for a digital sensor.

If the readings do not exceed these values, then the MAF sensor is contaminated.

MAF-RELATED DIAGNOSTIC TROUBLE CODES The diagnostic trouble codes (DTCs) associated with the mass airflow and air vane sensors are as follows:

DIAGNOSTIC TROUBLE CODE	DESCRIPTION	POSSIBLE CAUSES
P0100	Mass or volume airflow circuit problems	■ Open or short in mass airflow circuit ■ Defective MAF sensor
P0101	Mass airflow circuit range problems	■ Defective MAF sensor (check for false air)
P0102	Mass airflow circuit low output	■ Defective MAF sensor ■ MAF sensor circuit open or shorted-to-ground ■ Open 12-volt supply voltage circuit
P0103	Mass airflow circuit high output	■ Defective MAF sensor ■ MAF sensor circuit shorted-to-voltage

TECH TIP

The Unplug It Test

If a sensor is defective yet produces a signal to the computer, the computer will often accept the reading and make the required changes in fuel delivery and spark advance. If, however, the sensor is not reading correctly, the computer will process this wrong information and perform an action assuming that information being supplied is accurate. "If in doubt, take it out."

If the engine operates better with a sensor unplugged, then suspect that the sensor is defective. A sensor that is not supplying the correct information is said to be *skewed*. The computer will not set a diagnostic trouble code for this condition because the computer can often not detect that the sensor is supplying wrong information.

REVIEW QUESTIONS

1. What is the relationship between atmospheric pressure and engine vacuum?
2. What are three uses of a MAP sensor by the PCM?
3. What change in the signal will occur if engine speed is increased?
4. How is a MAF sensor tested?
5. What is the purpose of a MAF sensor?

CHAPTER QUIZ

1. As the load on an engine increases, the manifold vacuum decreases and the manifold absolute pressure ___________.
   - **a.** increases
   - **b.** decreases
   - **c.** changes with barometric pressure only (altitude or weather)
   - **d.** remains constant (absolute)
2. A typical MAP sensor compares the vacuum in the intake manifold to ___________.
   - **a.** atmospheric pressure
   - **b.** a perfect vacuum
   - **c.** barometric pressure
   - **d.** the value of the IAT sensor
3. Which statement is false?
   - **a.** Absolute pressure is equal to barometric pressure plus intake manifold vacuum.
   - **b.** A decrease in manifold vacuum means an increase in manifold pressure.
   - **c.** The MAP sensor compares manifold vacuum to a perfect vacuum.
   - **d.** Barometric pressure minus the MAP sensor reading equals intake manifold vacuum.
4. A MAP sensor can be tested using ___________.
   - **a.** a scope
   - **b.** a scan tool
   - **c.** a DMM
   - **d.** Any of these
5. Which is not a purpose or function of the MAP sensor?
   - **a.** Measures the load on the engine
   - **b.** Measures engine speed
   - **c.** Calculates fuel delivery based on altitude
   - **d.** Helps diagnose the EGR system
6. The MAF sensor is used mostly to determine the amount of what to deliver to the engine?
   - **a.** Vacuum correction
   - **b.** Idle air
   - **c.** Spark advance
   - **d.** Fuel
7. The typical MAF reading on a scan tool with the engine at idle speed and normal operating temperature is ___________.
   - **a.** 1 to 3 grams per second
   - **b.** 3 to 7 grams per second
   - **c.** 8 to 12 grams per second
   - **d.** 14 to 24 grams per second

8. Two technicians are diagnosing a poorly running engine. There are no diagnostic trouble codes. When the MAF sensor is unplugged, the engine runs better. Technician A says that this means that the MAF is supplying incorrect airflow information to the PCM. Technician B says that this indicates that the PCM is defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. If the MAF sensor fails, the PCM uses what to calculate fuel delivery needs?
   a. MAP and throttle position
   b. RPM and throttle position
   c. Throttle position and transmission RPM
   d. RPM alone

10. Air that enters the engine without passing through the airflow sensor is called ___________.
   a. bypass air
   b. dirty air
   c. false air
   d. measured air

Chapter 73

OXYGEN SENSORS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss how O2S sensors work.
- Discuss PCM uses of the oxygen sensor.
- Discuss oxygen sensor diagnosis.
- Discuss post-catalytic converter O2S testing.
- Explain the operation of wide-band oxygen sensors.
- Describe dual cell planar wide-band sensor operation.
- Discuss dual cell diagnosis.
- Describe single cell wide-band oxygen sensors.
- Interpret oxygen sensor-related diagnostic trouble codes.

KEY TERMS:

Air–fuel ratio sensor 878 • Ambient side electrode 866 • Closed loop 868 • Cup design 866 • Dual cell 875 • Exhaust side electrode 866 • False lean 870 • False rich 870 • Finger design 866 • Fuel trim 868 • HO2S 867 • Light-off time (LOT) 874 • Nernst cell 874 • Open loop 868 • Oxygen sensors (O2S) 865 • Planar 874 • Pump cell 875 • Reference 875 • Reference electrode 866 • RTV 873 • Signal electrode 866 • Single cell 878 • Thimble design 866 • Wide-band oxygen sensors 873 • Zirconia 865 • ZrO2 865

OXYGEN SENSORS

PURPOSE AND FUNCTION Automotive computer systems use a sensor in the exhaust system to measure the oxygen content of the exhaust. These sensors are called **oxygen sensors (O2S)**. The oxygen sensor is installed in the exhaust manifold or located downstream from the manifold in the exhaust pipe. ● **SEE FIGURE 73–1**.

The oxygen sensor is directly in the path of the exhaust gas stream where it monitors oxygen levels in both the exhaust stream and the ambient air. A **zirconia** oxygen sensor is made of **zirconium dioxide (ZrO2)**, an electrically conductive material capable of generating a small voltage in the presence of oxygen.

NARROW BAND A conventional zirconia oxygen sensor (O2S) is only able to detect if the exhaust is richer or leaner than 14.7:1. A conventional oxygen sensor is therefore referred to as the following:

- *Two-step sensor*, which is either rich or lean
- *Narrow-band sensor*, which informs the PCM whether the exhaust is rich or lean only

The voltage value where a zirconia oxygen sensor switches from rich to lean or from lean to rich is 0.45 V (450 mV).

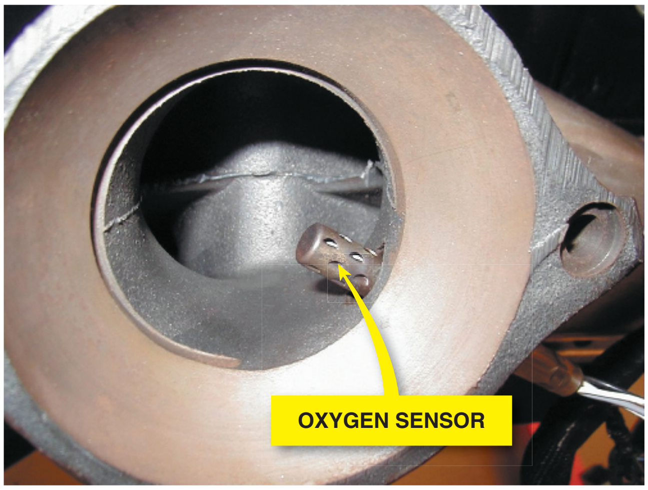
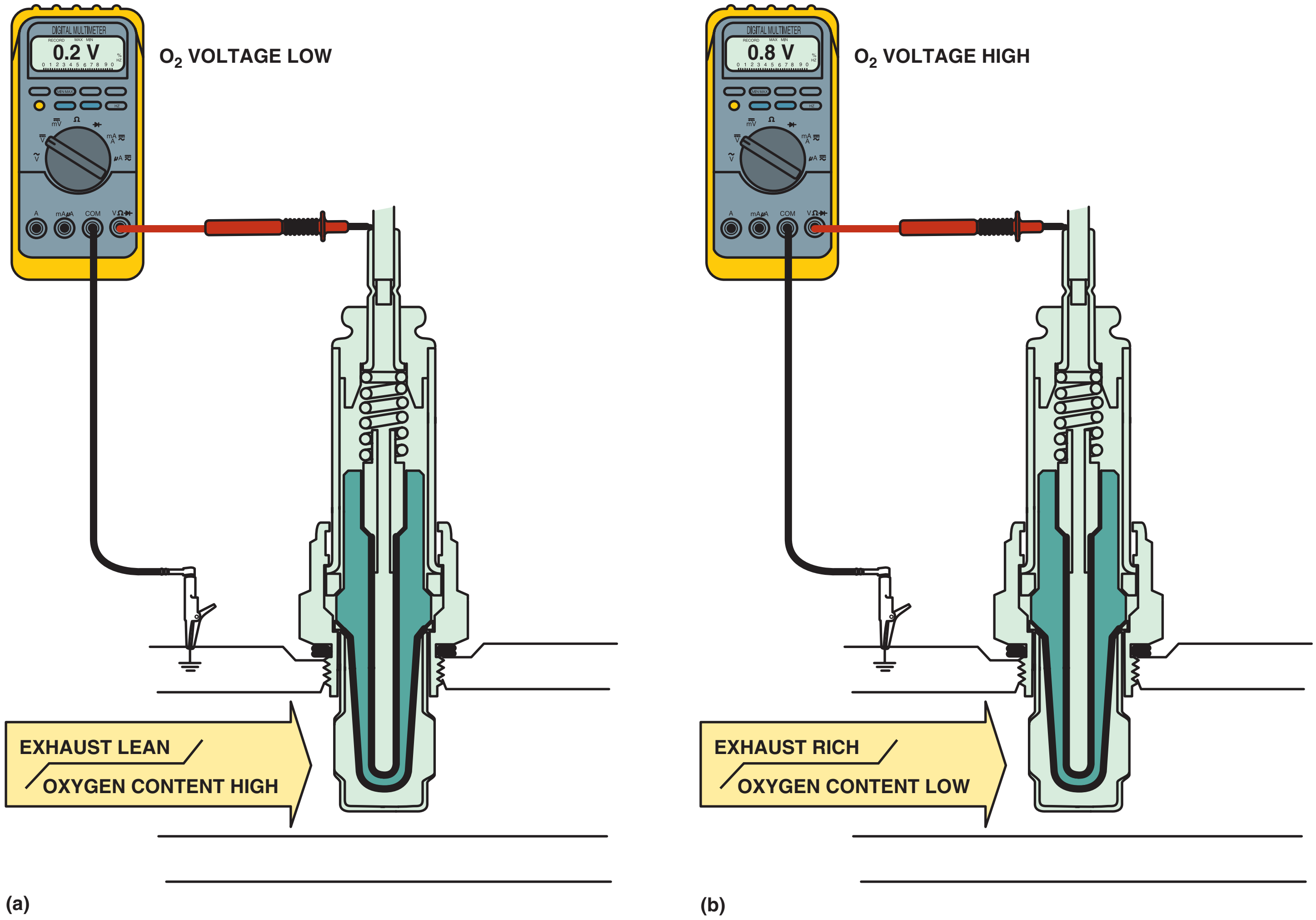


FIGURE 73–1 Many oxygen sensors are located in the exhaust manifold near its outlet so that the sensor can detect the air–fuel mixture in the exhaust stream for all cylinders that feed into the manifold.

- Above 0.45 V = rich
- Below 0.45 V = lean

● **SEE FIGURE 73–2**.


DIGITAL MULTIMETER
0.2 V
O_2 VOLTAGE LOW
EXHAUST LEAN
OXYGEN CONTENT HIGH
DIGITAL MULTIMETER
0.8 V
O_2 VOLTAGE HIGH
EXHAUST RICH
OXYGEN CONTENT LOW

(a) (b)

FIGURE 73–2 (a) When the exhaust is lean, the output of a zirconia oxygen sensor is below 450 mV. (b) When the exhaust is rich, the output of a zirconia oxygen sensor is above 450 mV.

CONSTRUCTION A typical zirconia oxygen sensor has the sensing element in the shape of a thimble; therefore, it is often referred to as one of the following:

- **Thimble design**
- **Cup design**
- **Finger design**
- ● **SEE FIGURE 73–3**.

A typical zirconia oxygen sensor has a heater inside the thimble and does not touch the inside of the sensor. The sensor is similar to a battery that has two electrodes and an electrolyte. The electrolyte is solid and is the zirconia (zirconium dioxide). There are also two porous platinum electrodes, which have the following functions:

- **Exhaust side electrode** is exposed to the exhaust stream.
- **Ambient side electrode** is exposed to outside (ambient) air and is the **signal electrode**, also called the **reference electrode**. ● **SEE FIGURE 73–4**.

The electrolyte (zirconia) is able to conduct electrons as follows:

- If the exhaust is rich, O_2 from the reference (inner) electrode wants to flow to the exhaust side electrode, which results in the generation of a voltage.
- If the exhaust is lean, O_2 flow is not needed. As a result, there is little if any electron movement and, therefore, no voltage is produced.

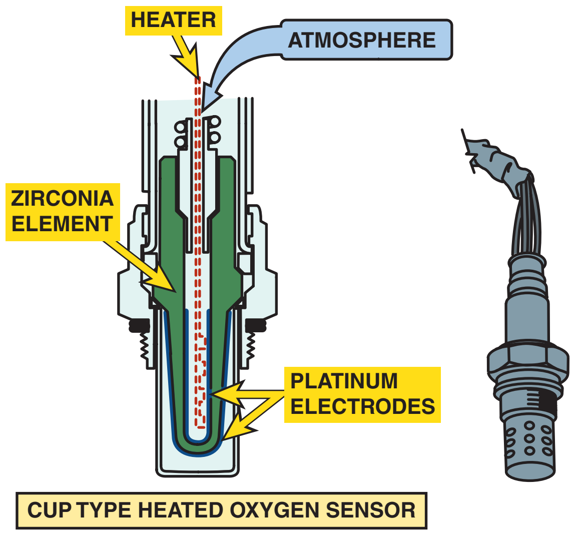

HEATER
ATMOSPHERE
ZIRCONIA ELEMENT
PLATINUM ELECTRODES
CUP TYPE HEATED OXYGEN SENSOR

FIGURE 73–3 Most conventional zirconia oxygen sensors and some wide-band oxygen sensors use the cup (finger) type of design.

OPERATION Exhaust from the engine passes through the end of the sensor where the gases contact the outer side of the thimble. Atmospheric air enters through the other end of the sensor or through the wire of the sensor and contacts the inner side of the thimble. The inner and outer surfaces of the thimble are plated with platinum. The inner surface becomes a negative

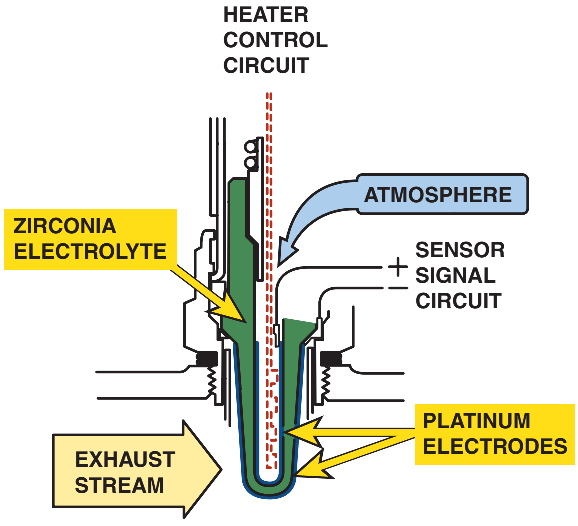


FIGURE 73–4 A typical heated zirconia oxygen sensor, showing the sensor signal circuit that uses the outer (exhaust) electrode as the negative and the ambient air side electrode as the positive.

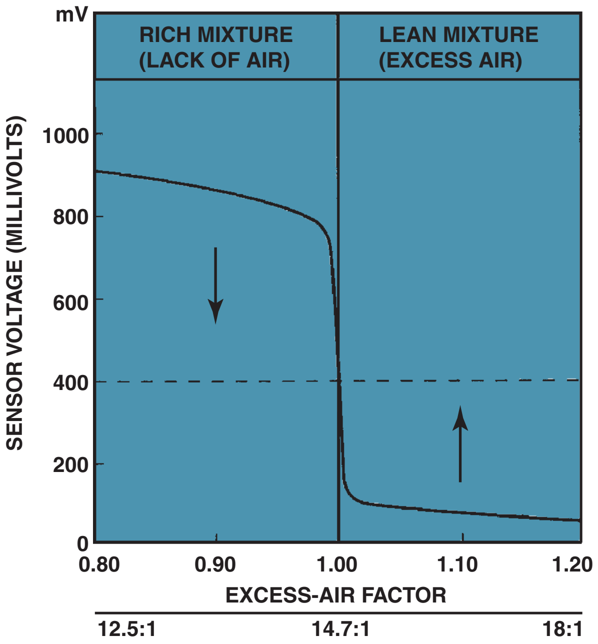


FIGURE 73–5 The oxygen sensor provides a quick response at the stoichiometric air–fuel ratio of 14.7:1.

electrode and the outer surface is a positive electrode. The atmosphere contains a relatively constant 21% of oxygen. Exhaust gases created by burning a rich air–fuel mixture contain little oxygen. Exhaust gases from burning a lean air–fuel mixture contain more oxygen.

Negatively charged oxygen ions are drawn to the thimble where they collect on both the inner and outer surfaces.

Because the oxygen present in the atmosphere exceeds that in the exhaust gases, the air side of the thimble draws more negative oxygen ions than the exhaust side. The difference between the two sides creates an electrical potential, or voltage. When the concentration of oxygen on the exhaust side of the thimble is low, a high voltage (0.60 to 1.0 V) is generated between the electrodes. As the oxygen concentration on the exhaust side increases, the voltage generated drops low (0.0 to 0.3 V).

An O2S does not send a voltage signal until its tip reaches a temperature of about 572°F (300°C). Also, oxygen sensors provide their fastest response to mixture changes at about 1,472°F (800°C). When the engine starts and the O2S is cold, the PCM operates the engine in the open-loop mode, drawing on prerecorded data in the PROM for fuel control on a cold engine, or when O2S output is not within certain limits.

If the exhaust contains very little oxygen, the PCM assumes that the intake charge is rich (too much fuel) and reduces fuel delivery. However, when the oxygen level is high, the PCM assumes that the intake charge is lean (not enough fuel) and increases fuel delivery. ● **SEE FIGURE 73–5.**

There are several different designs of oxygen sensors, including the following:

- **One-wire oxygen sensor.** The single wire of the one-wire oxygen sensor is the O2S signal wire. The ground for the O2S is through the shell and threads of the sensor and through the exhaust manifold.
- **Two-wire oxygen sensor.** The two-wire sensor has a signal wire and a ground wire for the O2S.
- **Three-wire oxygen sensor.** The three-wire sensor design uses an electric resistance heater to help get the O2S up to temperature more quickly and to help keep the sensor at operating temperature even at idle speeds. The three wires include the O2S signal, the power, and ground for the heater.
- **Four-wire oxygen sensor.** The four-wire sensor is a **heated O2S (HO2S)** that uses an O2S signal wire and signal ground. The other two wires are the power and ground for the heater.

HEATER CIRCUITS The heater circuit on conventional oxygen sensors requires 0.8 to 2.0 amperes and keeps the sensor at about 600°F (315°C).

A wide-band oxygen sensor operates at a higher temperature than a conventional HO2S, from 1,200°F to 1,400°F (650°C to 760°C). The amount of electrical current needed for a wide-band oxygen sensor is about 8 to 10 amperes.

CASE STUDY

The Chevrolet Pickup Truck Story

The owner of a Chevrolet pickup truck complained that the engine ran terribly. It would hesitate and surge, yet there were no diagnostic trouble codes (DTCs). After hours of troubleshooting, the technician discovered while talking to the owner that the problem started after the transmission had been repaired. However, the transmission shop said that the problem was an engine problem and not related to the transmission.

A thorough visual inspection revealed that the front and rear oxygen sensor connectors had been switched. The PCM was trying to compensate for an air-fuel mixture condition that did not exist. Reversing the O2S connectors restored proper operation of the truck.

Summary:

Complaint—Vehicle owner complained that the pickup truck ran terribly.
Cause—During a previous repair, the upstream and downstream oxygen sensor connectors were reversed.
Correction—The connectors were moved to their correct locations, which restored proper engine operation.

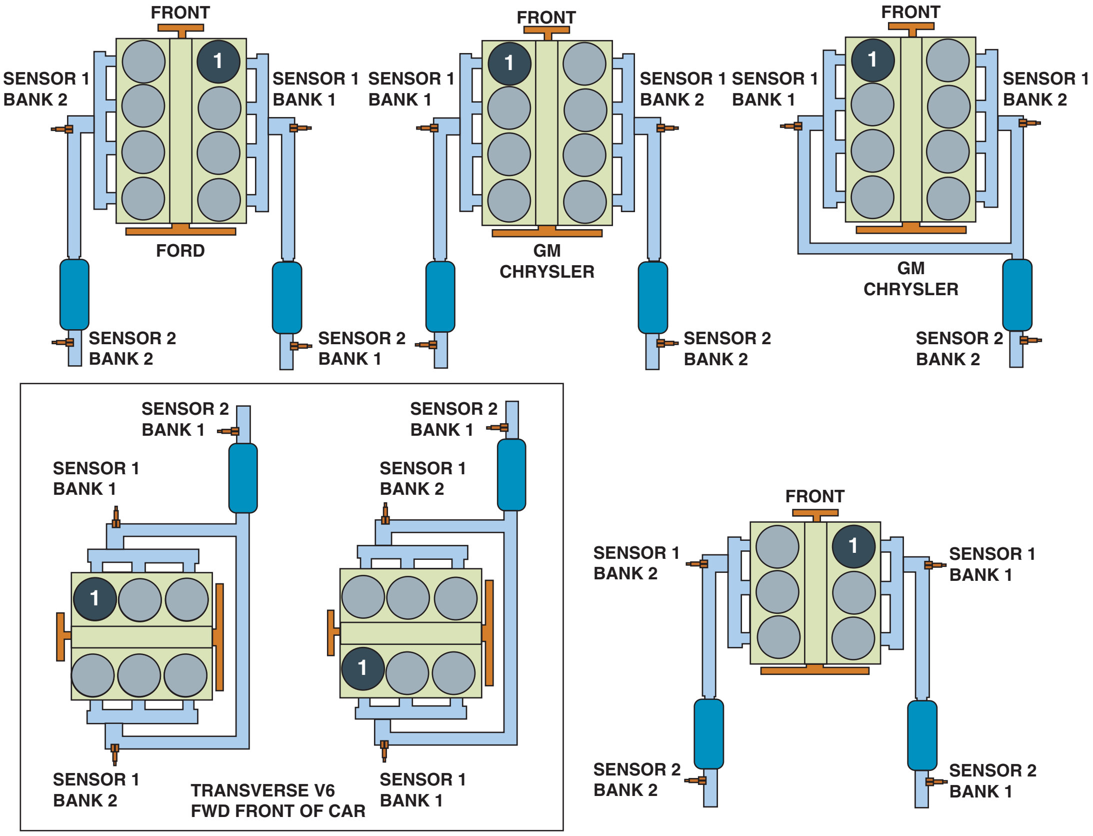

FRONT
SENSOR 1 BANK 2
1
SENSOR 1 BANK 1
FORD
SENSOR 2 BANK 2
SENSOR 2 BANK 1
FRONT
SENSOR 1 BANK 1
1
SENSOR 1 BANK 2
GM CHRYSLER
SENSOR 2 BANK 2
FRONT
SENSOR 1 BANK 1
1
SENSOR 1 BANK 2
GM CHRYSLER
SENSOR 2 BANK 2
SENSOR 2 BANK 1
SENSOR 1 BANK 1
1
SENSOR 1 BANK 2
TRANSVERSE V6 FWD FRONT OF CAR
SENSOR 2 BANK 1
SENSOR 1 BANK 2
1
SENSOR 1 BANK 1
FRONT
SENSOR 1 BANK 2
1
SENSOR 1 BANK 1
SENSOR 2 BANK 2
SENSOR 2 BANK 1

FIGURE 73–6 Number and label designations for oxygen sensors. Bank 1 is the bank where cylinder 1 is located.

FREQUENTLY ASKED QUESTION

Where Is HO2S1?

Oxygen sensors are numbered according to their location in the engine. On a V-type engine, heated oxygen sensor number 1 (HO2S1) is located in the exhaust system upstream of the catalytic converter on the side of the engine where cylinder 1 is located. ● **SEE FIGURE 73–6**.

PCM USES OF THE OXYGEN SENSOR

FUEL CONTROL The amount of fuel delivered to an engine is determined by the powertrain control module (PCM) based on inputs from the engine coolant temperature (ECT), throttle position (TP) sensor, and others until the oxygen sensor is capable of supplying a usable signal. When the PCM alone is determining the amount of fuel needed, it is called **open-loop** operation. As soon as the oxygen sensor (O2S) is capable of supplying rich and lean signals, PCM adjustments can be made to fine-tune the correct air–fuel mixture. This checking and adjusting of the PCM is called **closed-loop** operation.

The upstream oxygen sensors are among the high-authority sensors used for fuel control while operating in closed loop. Before the oxygen sensors are hot enough to give accurate exhaust oxygen information to the PCM, fuel control is determined by other sensors and the anticipated injector pulse width determined by those sensors. After the control system achieves closed-loop status, the oxygen sensor provides feedback to actual exhaust gas oxygen content.

FUEL TRIM The **fuel trim** numbers are determined from the signals by the oxygen sensor(s). If the engine has been operating too lean, short-term and long-term fuel time programming inside the PCM can cause an increase in the commanded injector pulse width to bring the air–fuel mixture back into the proper range. Fuel trim can be negative (subtracting fuel) or positive (adding fuel).

OXYGEN SENSOR DIAGNOSIS

PCM SYSTEM TESTS The oxygen sensors are used for diagnosis of other systems and components. For example, the exhaust gas recirculation (EGR) system is tested by the PCM, by commanding the EGR valve to open during the test. Some PCMs determine whether enough exhaust gas flows into the engine by looking at the oxygen sensor response (fuel trim numbers). The upstream and downstream oxygen sensors are also used to determine the efficiency of the catalytic converter. Therefore, if a fault occurs with an oxygen sensor, the PCM may not be able to test other systems. ● **SEE FIGURE 73–7**.

VISUAL INSPECTION Whenever an oxygen sensor is replaced, the old sensor should be carefully inspected to help determine the cause of the failure. This is an important step because if the

CASE STUDY

The Oxygen Sensor Is Lying to You

A technician was trying to solve a driveability problem with an older V-6 passenger car. The car idled roughly, hesitated, and accelerated poorly. A thorough visual inspection did not indicate problems and there were no diagnostic trouble codes stored.

The technician checked the oxygen sensor activity using a DMM. The voltage stayed above 600 mV most of the time. If the technician removed a large vacuum hose, the oxygen sensor voltage would temporarily drop to below 450 mV and then return to a reading of over 600 mV. Remember:

- High O2S readings = rich exhaust (low O_2 content in the exhaust)
- Low O2S readings = lean exhaust (high O_2 content in the exhaust)

As part of a thorough visual inspection, the technician removed and inspected the spark plugs. All the spark plugs were white, indicating a lean mixture, not the rich mixture that the oxygen sensor was indicating. The high O2S reading signaled the PCM to reduce the amount of fuel, resulting in an excessively lean operation.

After replacing the oxygen sensor, the engine ran great. But what killed the oxygen sensor? The technician finally learned from the owner that the head gasket had been replaced over a year ago. The silicate and phosphate additives in the antifreeze coolant had coated the oxygen sensor. Because the oxygen sensor was coated, the oxygen content of the exhaust could not be detected, resulting in a false rich signal from the oxygen sensor.

Summary:

Complaint—Vehicle owner complained that the car equipped with a V-6 engine ran terribly.
Cause—The oxygen sensor was contaminated by the additives in the coolant caused by a previously repaired head gasket failure.
Correction—Replacing the oxygen sensors restored proper engine operation.

cause of the failure is not discovered, it could lead to another sensor failure.

Inspection may reveal the following:

1. Black sooty deposits usually indicate a rich air–fuel mixture.
2. White chalky deposits are characteristic of silica contamination. Usual causes for this type of sensor failure include silica deposits in the fuel or a technician having used the wrong type of silicone sealant during the servicing of the engine.
3. White sandy or gritty deposits are characteristic of antifreeze (ethylene glycol) contamination. A defective cylinder head or intake manifold gasket could be the cause, or a cracked cylinder head or engine block. Antifreeze may also cause the oxygen sensor to become green as a result of the dye used in antifreeze.

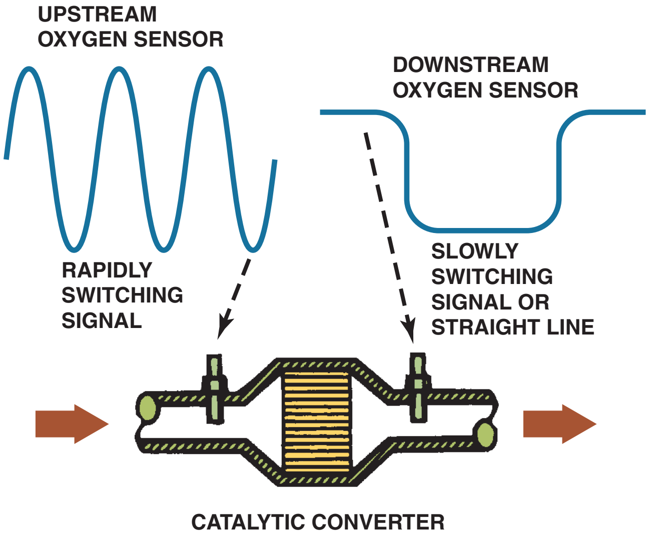


FIGURE 73–7 The OBD-II catalytic converter monitor compares the signals of the upstream and downstream oxygen sensor to determine converter efficiency.

4. Dark brown deposits indicate excessive oil consumption. Possible causes include a defective positive crankcase ventilation (PCV) system or a mechanical engine problem, such as defective valve stem seals or piston rings.

DIGITAL VOLTMETER TESTING The oxygen sensor can be checked for proper operation using a digital high-impedance voltmeter.

1. With the engine off, connect the red lead of the meter to the oxygen sensor signal wire and the black meter lead to a good engine ground. ● **SEE FIGURE 73–8**.
2. Start the engine and allow it to reach closed-loop operation.
3. In closed-loop operation, the oxygen sensor voltage should be constantly changing as the fuel mixture is being controlled.

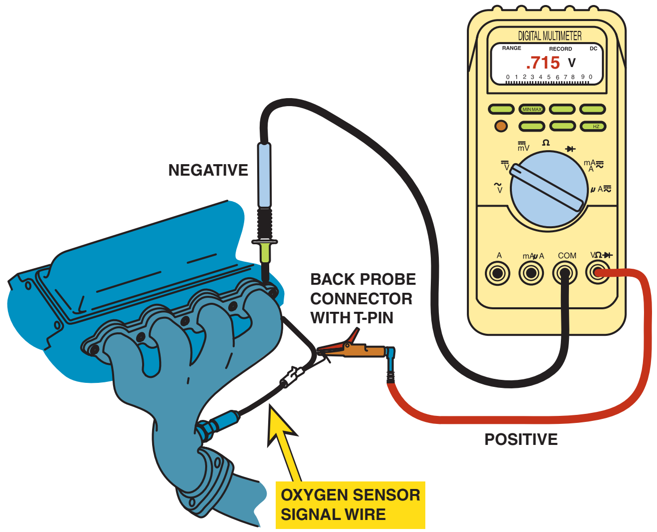


FIGURE 73–8 Testing an oxygen sensor using a DMM set on DC volts. With the engine operating in closed loop, the oxygen voltage should read over 800 mV and lower than 200 mV and be constantly fluctuating.

TECH TIP

Do Not Solder Oxygen Sensor Wires

Oxygen sensors must have outside oxygen to compare with the oxygen content in the exhaust. Most oxygen sensors breathe through the signal wire and, if soldered, would block the flow of outside air to the sensor. If a replacement oxygen sensor is used, always use the factory replacement, using the original connectors or a crimp-and-seal connector that will seal out any moisture and still allow air to flow through the connector.

The results should be interpreted as follows:

- If the oxygen sensor fails to respond, and its voltage remains at about 450 mV, the sensor may be defective and require replacement. Before replacing the oxygen sensor, check the manufacturer's recommended procedures.
- If the oxygen sensor reads high all the time (above 550 mV), the fuel system could be supplying too rich a fuel mixture or the oxygen sensor may be contaminated. An oxygen sensor reading that is high could be due to other things besides a rich air–fuel mixture. When the O2S reads temporarily drop to below 450 mV and besides a rich mixture, it is often called a **false rich** indication.

False rich indications (high O2S readings) can be attributed to the following:

- Contaminated O2S due to additives in the engine coolant or due to silicon poisoning
- A stuck open EGR valve (especially at idle)
- A spark plug wire too close to the oxygen sensor signal wire, which can induce a higher than normal voltage in the signal wire, thereby indicating to the PCM a false rich condition
- A loose oxygen sensor ground connection, which can cause a higher than normal voltage and a false rich signal
- A break or contamination of the wiring and its connectors, which could prevent reference oxygen from reaching the oxygen sensor, resulting in a false rich indication. (All oxygen sensors require an oxygen supply inside the sensor itself for reference to be able to sense exhaust gas oxygen.)

If the oxygen sensor voltage remains low (below 350 mV), the oxygen sensor itself could be bad or the fuel system could be supplying too lean a fuel mixture. Check for a vacuum leak or partially clogged fuel injector(s). Before replacing the oxygen sensor, check the manufacturer's recommended procedures. If an oxygen sensor reads low as a result of a factor besides a lean mixture, it is often called a **false lean** indication.

False lean indications (low O2S readings) can be attributed to the following:

1. **Ignition misfires.** An ignition misfire due to a defective spark plug wire, fouled spark plug, and so forth, causes no burned air and fuel to be exhausted past the O2S. The O2S "sees" the oxygen (not the unburned gasoline) and the O2S voltage is low.
2. **Exhaust leak in front of the O2S.** An exhaust leak between the engine and the oxygen sensor causes outside oxygen to be drawn into the exhaust and past the O2S. This oxygen is "read" by the O2S and produces a lower than normal voltage. The PCM interprets the lower than normal voltage signal from the O2S as meaning that the air–fuel mixture is lean. The PCM will cause the fuel system to deliver a richer air–fuel mixture.
3. **Spark plug misfire.** The PCM does not know that the extra oxygen going past the oxygen sensor is not due to a lean air–fuel mixture. The PCM commands a richer mixture, which could cause the spark plugs to foul, increasing the rate of misfiring.

MIN/MAX TESTING A digital meter set on DC volts can be used to record the minimum and maximum voltage with the engine running. A good oxygen sensor should be able to produce a value of less than 300 mV and a maximum voltage above 800 mV. ● **SEE FIGURE 73–9**.

Replace any oxygen sensor that fails to go above 700 mV or lower than 300 mV. ● **SEE CHART 73–1**.

FREQUENTLY ASKED QUESTION

Why Does the Oxygen Sensor Voltage Read 5 Volts on Many Chrysler Vehicles?

Many Chrysler vehicles apply a 5-volt reference to the signal wire of the oxygen sensor. The purpose of this voltage is to allow the PCM to detect if the oxygen sensor signal circuit is open or grounded.

- If the voltage on the signal wire is 4.5 volts or more, the PCM assumes that the sensor is open.
- If the voltage on the signal wire is zero, the PCM assumes that the sensor is shorted-to-ground.

If either condition exists, the PCM can set a diagnostic trouble code (DTC).

TECH TIP

The Key On, Engine Off Oxygen Sensor Test

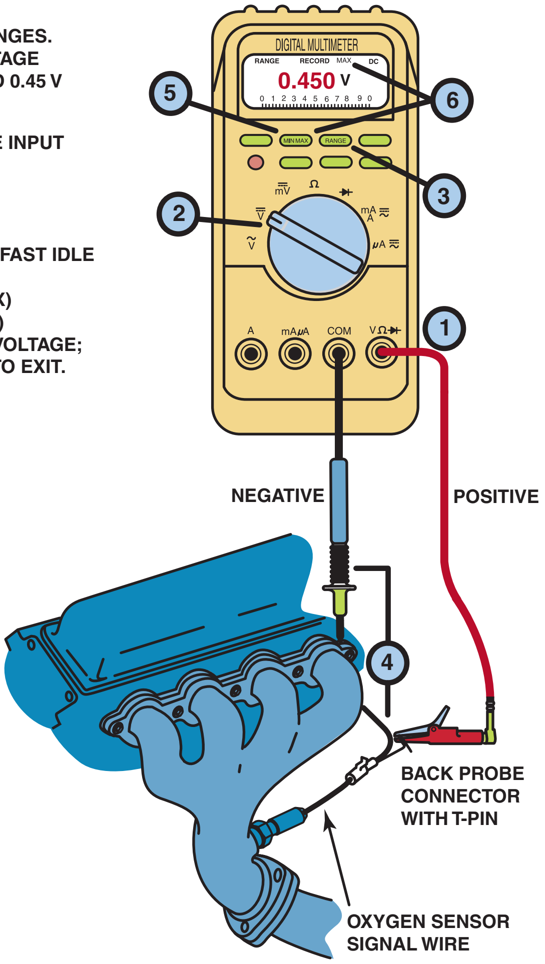
This test works on General Motors vehicles and may work on others if the PCM applies a bias voltage to the oxygen sensors. Zirconia oxygen sensors become more electrically conductive as they get hot. To perform this test, be sure that the vehicle has not run for several hours.

STEP 1 Connect a scan tool and get the display ready to show oxygen sensor data.

STEP 2 Key the engine on *without* starting the engine. The heater in the oxygen sensor will start heating the sensor.

STEP 3 Observe the voltage of the oxygen sensor. The applied bias voltage of 450 mV should slowly decrease for all oxygen sensors as they become more electrically conductive as the bias voltage is flowing to ground.

STEP 4 A good oxygen sensor should indicate a voltage of less than 100 mV after three minutes. Any sensor that displays a higher than usual voltage or seems to stay higher longer than the others could be defective or skewed high.



WATCH ANALOG POINTER SWEEP AS O2 VOLTAGE CHANGES. DEPENDING ON THE DRIVING CONDITIONS, THE O2 VOLTAGE RISES AND FALLS, BUT IT USUALLY AVERAGES AROUND 0.45 V

1. SHUT THE ENGINE OFF AND INSERT TEST LEAD IN THE INPUT TERMINALS SHOWN.
2. SET THE ROTARY SWITCH TO VOLTS DC.
3. MANUALLY SELECT THE 4 V RANGE
4. CONNECT THE TEST LEADS AS SHOWN.
5. START THE ENGINE. IF THE O2 SENSOR IS UNHEATED, FAST IDLE THE ENGINE FOR A FEW MINUTES.
6. PRESS MIN / MAX BUTTON TO DISPLAY MAXIMUM (MAX) 02 VOLTAGE; PRESS AGAIN TO DISPLAY MINIMUM (MIN) VOLTAGE; PRESS AGAIN TO DISPLAY AVERAGE (AVG) VOLTAGE; PRESS AND HOLD DOWN MIN / MAX FOR 2 SECONDS TO EXIT.

FIGURE 73–9 Using a digital multimeter to test an oxygen sensor using the MIN/MAX record function of the meter.

MIN/MAX OXYGEN SENSOR TEST CHART

MINIMUM VOLTAGE	MAXIMUM VOLTAGE	AVERAGE VOLTAGE	TEST RESULTS
Below 200 mV	Above 800 mV	400–500 mV	Oxygen sensor is okay.
Above 200 mV	Any reading	400–500 mV	Oxygen sensor is defective.
Any reading	Below 800 mV	400–500 mV	Oxygen sensor is defective.
Below 200 mV	Above 800 mV	Below 400 mV	System is operating lean.*
Below 200 mV	Below 800 mV	Below 400 mV	System is operating lean. (Add propane to the intake air to see if the oxygen sensor reacts. If not, the sensor is defective.)
Below 200 mV	Above 800 mV	Above 500 mV	System is operating rich.
Above 200 mV	Above 800 mV	Above 500 mV	System is operating rich. (Remove a vacuum hose to see if the oxygen sensor reacts. If not, the sensor is defective.)

CHART 73–1

The test results of using a digital meter set to read minimum and maximum values while testing a narrow-band oxygen sensor. *Check for an exhaust leak upstream from the O2S or ignition misfire that can cause a false lean indication before further diagnosis.

SCAN TOOL TESTING A good oxygen sensor should sense the oxygen content and change voltage outputs rapidly. How fast an oxygen sensor switches from high (above 450 mV) to low (below 350 mV) is measured as frequency, or the number of times the voltage switches per second.

NOTE: On a fuel-injected engine at 2000 engine RPM, 1 to 5 Hz (one to five switches per second) is normal.

Using a scan tool, observe the oxygen sensor voltages with the engine running at 2000 RPM. Look for numbers higher than 800 mV and lower than 200 mV.

If the frequency of switching is low, the oxygen sensor may be contaminated, or the fuel delivery system is delivering a constant rich or lean air–fuel mixture. If the frequency of switching is higher than 5 Hz, look for misfire conditions.

1. Connect the scan tool and start the engine.
2. Operate the engine at a fast idle (2,500 RPM) for two minutes to allow time for the oxygen sensor to warm to operating temperature.
3. Observe the oxygen sensor activity on the scan tool to verify closed-loop operation. Select the "snapshot" mode, hold the engine speed steady, and start recording.
4. Play back snapshot and place a mark beside each range of oxygen sensor voltage for each frame of the snapshot.

A good oxygen sensor and PCM should result in the most snapshot values at both ends (0 to 300 mV and 600 to 1,000 mV). If most of the readings are in the middle, the oxygen sensor is not working correctly.

SCOPE TESTING A scope can also be used to test an oxygen sensor. Connect the scope to the signal wire and ground for the sensor (if it is so equipped). ● **SEE FIGURE 73–10**.

With the engine operating in closed loop, the voltage signal of the sensor should be constantly changing. ● **SEE FIGURE 73–11**.

Check for rapid switching from rich to lean and lean to rich and change between once every two seconds and five times per second (0.5 to 5.0 Hz).

NOTE: General Motors warns not to base the diagnosis of an oxygen sensor problem solely on its scope pattern. The varying voltage output of an oxygen sensor can easily be mistaken for a fault in the sensor itself, rather than a fault in the fuel delivery system.

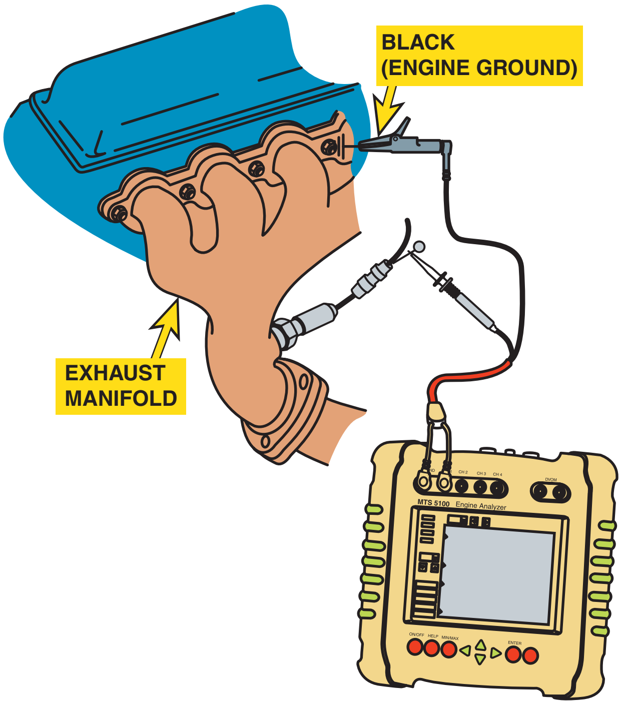


FIGURE 73–10 Connecting a handheld digital storage oscilloscope to an oxygen sensor signal wire. Check the instructions for the scope as some require the use of a filter to be installed in the test lead to reduce electromagnetic interference that can affect the oxygen sensor waveform.

POST-CATALYTIC CONVERTER OXYGEN SENSOR TESTING

The oxygen sensor located behind the catalytic converter is used on OBD-II vehicles to monitor converter efficiency. A changing air–fuel mixture is required for the most efficient operation of the converter. If the converter is working correctly, the oxygen content after the converter should be fairly constant. ● **SEE FIGURE 73–12**.

The post-catalytic converter oxygen sensor also is used to modify the amount of fuel delivered to the engine to allow the converter to work efficiently. If, for example, the rear oxygen sensor voltage stayed high, the PCM will try to increase the amount of oxygen entering the converter by leaning the air–fuel mixture

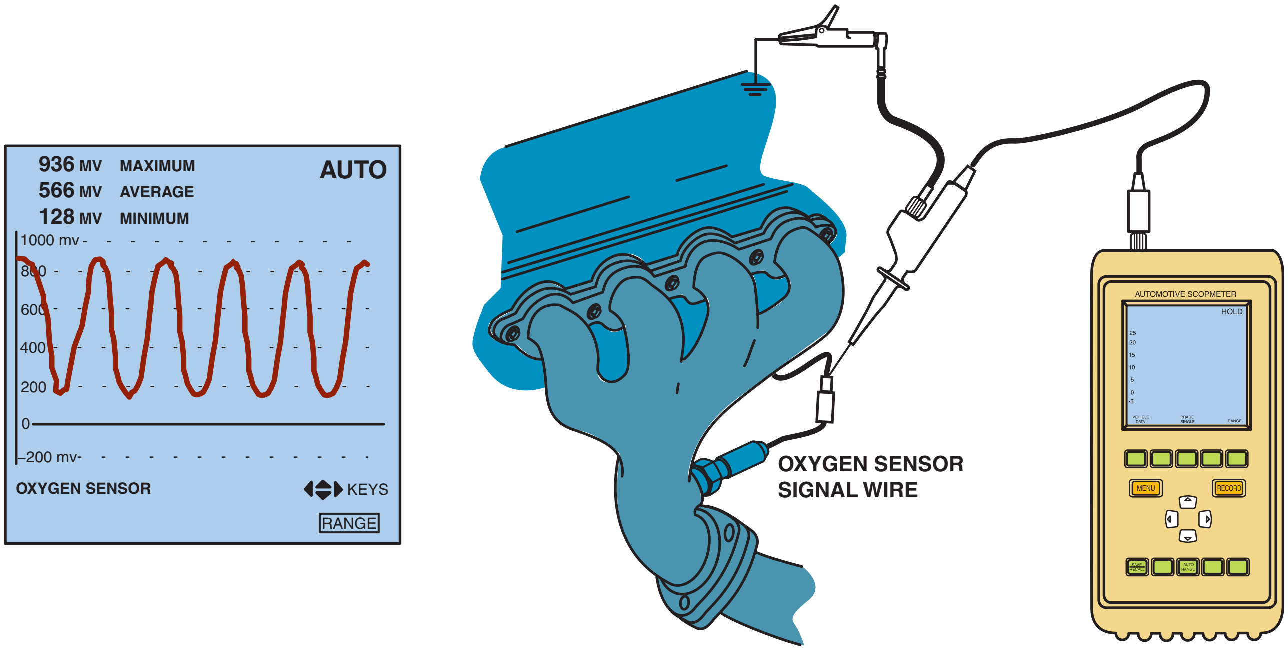


FIGURE 73–11 The waveform of a good oxygen sensor as displayed on a digital storage oscilloscope (DSO). Note that the maximum reading is above 800 mV and the minimum reading is less than 200 mV.

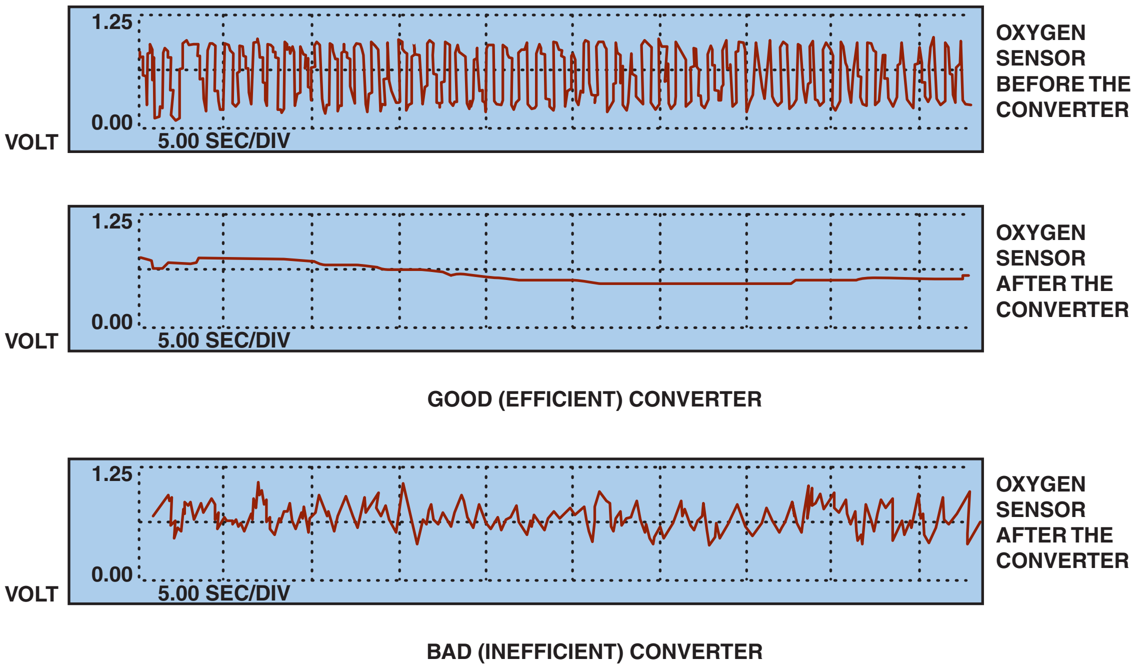


FIGURE 73–12 The post-catalytic converter oxygen sensor should display very little activity if the catalytic converter is efficient.

TECH TIP

The Propane Oxygen Sensor Test

Adding propane to the air inlet of a running engine is an excellent way to check if the oxygen sensor is able to react to changes in air–fuel mixture. Follow these steps in performing the propane trick:

1. Connect a digital storage oscilloscope to the oxygen sensor signal wire.
2. Start and operate the engine until it reaches operating temperature and is in closed-loop fuel control.
3. While watching the scope display, add some propane to the air inlet. The scope display should read full rich (over 800 mV).
4. Shut off the propane. The waveform should drop to less than 200 mV (0.2 V).
5. Quickly add some propane while the oxygen sensor is reading low and watch for a rapid transition to rich. The transition should occur in less than 100 milliseconds (ms).

FREQUENTLY ASKED QUESTION

How Could Using Silicone Sealer on a Valve Cover Gasket Affect the Oxygen Sensor?

The wrong type of silicone **room temperature vulcanization (RTV)** sealer on a valve cover gasket gives off harmful silica fumes during the curing process. These fumes enter the crankcase area by way of the oil drainback holes in the cylinder head, as well as through pushrod openings and other passages in the engine. During engine operation, these fumes are drawn into the intake manifold through the positive crankcase ventilation (PCV) system and are burned in the engine. The harmful silica then exits through the exhaust system, where the contamination affects the oxygen sensor.

NOTE: Be careful not to spray any silicone lubricant near the engine vacuum, which might draw the fumes into the engine and cause silica damage to the oxygen sensor.

to the engine. This process is often called the target upstream fuel trim. Therefore, instead of the PCM commanding a target air–fuel mixture of 14.7:1, the new target may specify an air–fuel ratio of 14.9:1 or slightly leaner than normal to help provide a little extra oxygen for use by the catalytic converter. This target air–fuel ratio or fuel trim is displayed on scan tools.

WIDE-BAND OXYGEN SENSORS

TERMINOLOGY **Wide-band oxygen sensors** have been used since 1992 on some Hondas. Today, they are used by most vehicle manufacturers to ensure that the exhaust emissions can meet the current standard. Wide-band oxygen sensors have various names, depending on the vehicle and/or oxygen sensor manufacturer, including the following:

- Wide-band oxygen sensor
- Broadband oxygen sensor
- Wide-range oxygen sensor
- Air–fuel ratio (AFR) sensor
- Wide-range air–fuel (WRAF) sensor
- Lean-air fuel (LAF) sensor
- Air–fuel (AF) sensor

Wide-band oxygen sensors are also manufactured in dual cell and single cell designs.

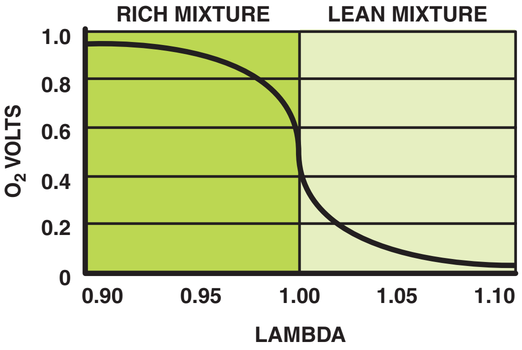


FIGURE 73–13 A conventional zirconia oxygen sensor can only reset to exhaust mixtures that are richer or leaner than 14.7:1 (lambda 1.00).

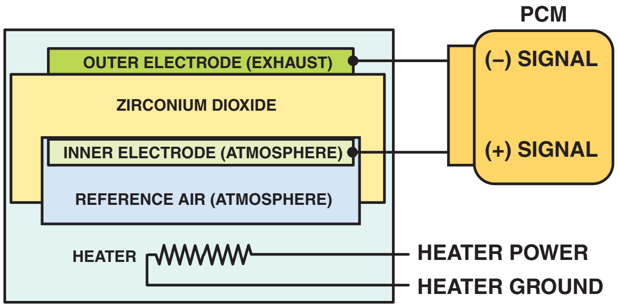

PCM
OUTER ELECTRODE (EXHAUST)
ZIRCONIUM DIOXIDE
INNER ELECTRODE (ATMOSPHERE)
REFERENCE AIR (ATMOSPHERE)
HEATER
(–) SIGNAL
(+) SIGNAL
HEATER POWER
HEATER GROUND

FIGURE 73–14 A planar design zirconia oxygen sensor places all of the elements together, which allows the sensor to reach operating temperature quickly.

INTRODUCTION A conventional zirconia oxygen sensor reacts to an air–fuel mixture that is either richer or leaner than 14.7:1. This means that the sensor cannot be used to detect the exact air–fuel mixture. ● **SEE FIGURE 73–13**.

The need for more stringent exhaust emission standards, such as the national low emission vehicle (NLEV), plus the ultra low emission vehicle (ULEV) and the super ultra low emission vehicle (SULEV) require more accurate fuel control than can be provided by a traditional oxygen sensor.

PURPOSE AND FUNCTION A wide-band oxygen sensor is capable of supplying air–fuel ratio information to the PCM over a much broader range. Compared with a conventional zirconia oxygen sensor, the wide-band oxygen sensor has the following features:

1. The ability to detect exhaust air–fuel ratio from as rich as 10:1 to as lean as 23:1 in some cases
2. Cold start activity within as little as 10 seconds

PLANAR DESIGN In 1998, Bosch introduced a wide-band oxygen sensor that is flat and thin (1.5 mm or 0.006 inch), known as a planar design and not in the shape of a thimble as previously constructed. Now several manufacturers produce a similar **planar** design wide-band oxygen sensor. Its thin design makes it easier to heat than older styles of oxygen sensors and, as a result, it can achieve closed loop in less than 10 seconds. This fast heating, called **light-off time (LOT)**, helps improve fuel economy and reduces cold-start exhaust emissions. The type of construction is not noticed by the technician, nor does it affect the testing procedures.

A conventional oxygen sensor can also be constructed using a planar design instead of the thimble-type design. A planar design has the following features:

- The elements including the zirconia electrolyte and the two electrodes and heater are stacked together in a flat-type design.
- It allows faster warm-up because the heater is in direct contact with the other elements.
- Planar oxygen sensors are the most commonly used. Some planar designs are used as a conventional narrow-band oxygen sensor.

The sandwich-type designs of the planar style of oxygen sensor have the same elements and operate the same, but are stacked in the following way from the exhaust side to the ambient air side:

Exhaust stream
Outer electrode
Zirconia (Zr_2) (electrolyte)
Inner electrode (reference or signal)
Outside (ambient) air
Heater

● **SEE FIGURE 73–14**.

Another name for a conventional oxygen sensor is a **Nernst cell**, named for Walther Nernst, 1864–1941, a German physicist known for his work in electrochemistry.

FREQUENTLY ASKED QUESTION

How Quickly Can a Wide-Band Oxygen Sensor Achieve Closed Loop?

In a Toyota Highlander hybrid electric vehicle, the operation of the gasoline engine is delayed for a short time when the vehicle is first driven. During this time of electric operation, the oxygen sensor heaters are turned on in readiness for the gasoline engine starting. The gasoline engine often achieves closed-loop operation during *cranking* because the oxygen sensors are fully warm and ready to go at the same time the engine is started. Having the gasoline engine achieve closed loop quickly, allows it to meet the stringent SULEV standards.

DUAL CELL PLANAR WIDE-BAND SENSOR OPERATION

CONSTRUCTION In a conventional zirconia oxygen sensor, a bias or reference voltage can be applied to the two platinum electrodes, and then oxygen ions can be forced (pumped) from the ambient reference air side to the exhaust side of the sensor.

If the polarity is reversed, the oxygen ion can be forced to travel in the opposite direction.

A **dual cell** planar-type wide-band oxygen sensor is made like a conventional planar O2S, or Nernst cell. Above the Nernst cell is another zirconia layer with two electrodes, called the **pump cell**. The two cells share a common ground, called the **reference**.

There are two internal chambers:

- The air reference chamber is exposed to ambient air.
- The diffusion chamber is exposed to the exhaust gases.

Platinum electrodes are on both sides of the zirconia electrolyte elements, which separate the air reference chamber and the exhaust exposed diffusion chamber.

OPERATION The basic principle of operation of a typical wide-band oxygen sensor is that it uses a positive or negative voltage signal to keep a balance between two sensors. Oxygen sensors do not measure the quantity of free oxygen in the exhaust. Instead, oxygen sensors produce a voltage that is based on the ion flow between the platinum electrodes of the sensor to maintain a stoichiometric balance.

For example,

- If there is a lean exhaust, there is oxygen in the exhaust and the ion flow from the ambient side to the exhaust side is low.
- If there is rich exhaust, the ion flow is increased to help maintain balance between the ambient air side and the exhaust side of the sensor.

The PCM can apply a small current to the pump cell electrodes, which causes oxygen ions through the zirconia into or out of the diffusion chamber. The PCM pumps O_2 ions in and out of the diffusion chamber to bring the voltage back to 0.45 V, using the pump cell.

The operation of a wide-band oxygen sensor is best described by looking at what occurs when the exhaust is stoichiometric, rich, and lean. ● **SEE FIGURE 73–15**.

STOICHIOMETRIC

- When the exhaust is at stoichiometric (14.7:1 air–fuel ratio), the voltage of the Nernst cell is 450 mV (0.45 V).
- The voltage between the diffusion chamber and the air reference chamber changes from 0.45 V. This voltage will be:
  - Higher if the exhaust is rich
  - Lower if the exhaust is lean

The reference voltage remains constant, usually at 2.5 V, but can vary depending on the year, make, and model of vehicle and the type of sensor. Typical reference voltages include the following:

- 2.2 V
- 2.5 V
- 2.7 V
- 3.3 V
- 3.6 V

RICH EXHAUST When the exhaust is rich, the voltage between the common (reference) electrode and the Nernst cell electrode that is exposed to ambient air is higher than 0.45 V. The PCM applies a negative current in milliamperes to the pump cell electrode to bring the circuit back into balance. ● **SEE FIGURE 73–16**.

LEAN EXHAUST When the exhaust is lean, the voltage between the common (reference) electrode and the Nernst cell electrode is lower than 0.45 V. The PCM applies a positive current in milliamperes to the pump cell to bring the circuit back into balance. ● **SEE FIGURE 73–17**.

DUAL CELL DIAGNOSIS

SCAN TOOL DIAGNOSIS Most service information specifies that a scan tool be used to check the wide-band oxygen sensor because the PCM performs tests of the unit and can identify faults. However, even wide-band oxygen sensors can be fooled if there is an exhaust manifold leak or other fault, which could lead to false or inaccurate readings. If the oxygen sensor reading is false, the PCM will command an incorrect

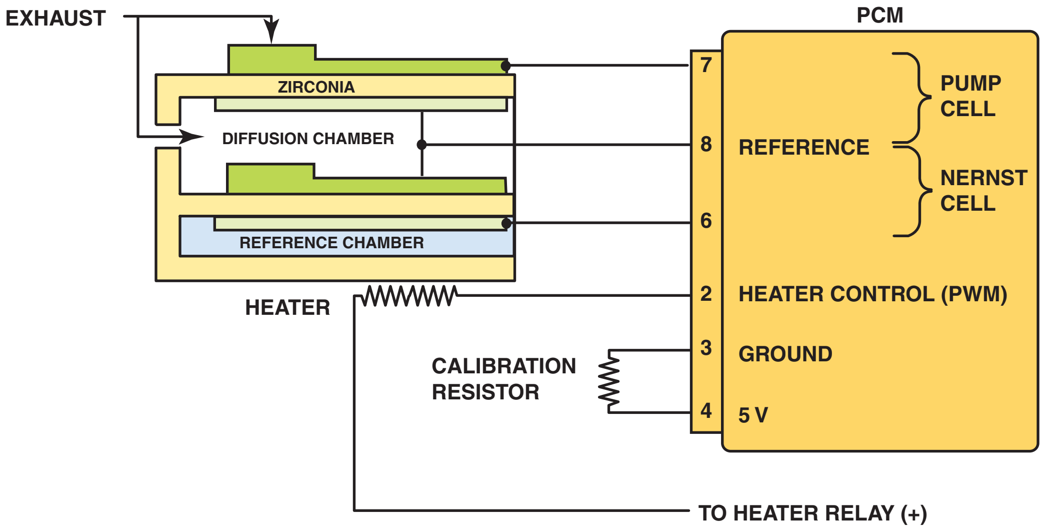


FIGURE 73–15 The reference electrodes are shared by the Nernst cell and the pump cell.

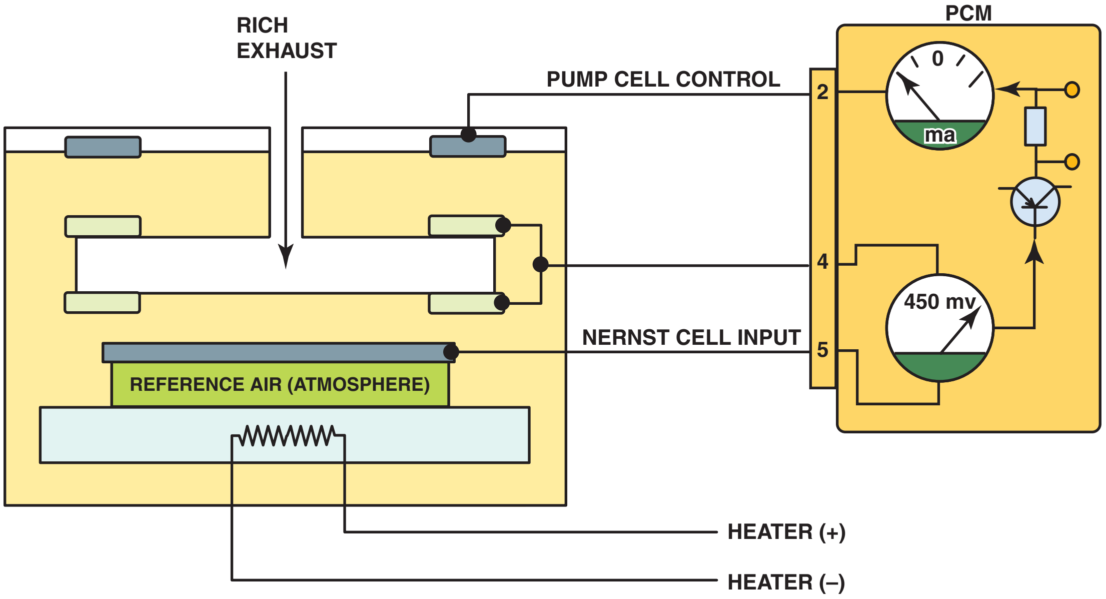

RICH
EXHAUST
PCM
PUMP CELL CONTROL
2
ma
0
4
450 mv
NERNST CELL INPUT
5
REFERENCE AIR (ATMOSPHERE)
HEATER (+)
HEATER (–)

FIGURE 73–16 When the exhaust is rich, the PCM applies a negative current into the pump cell.

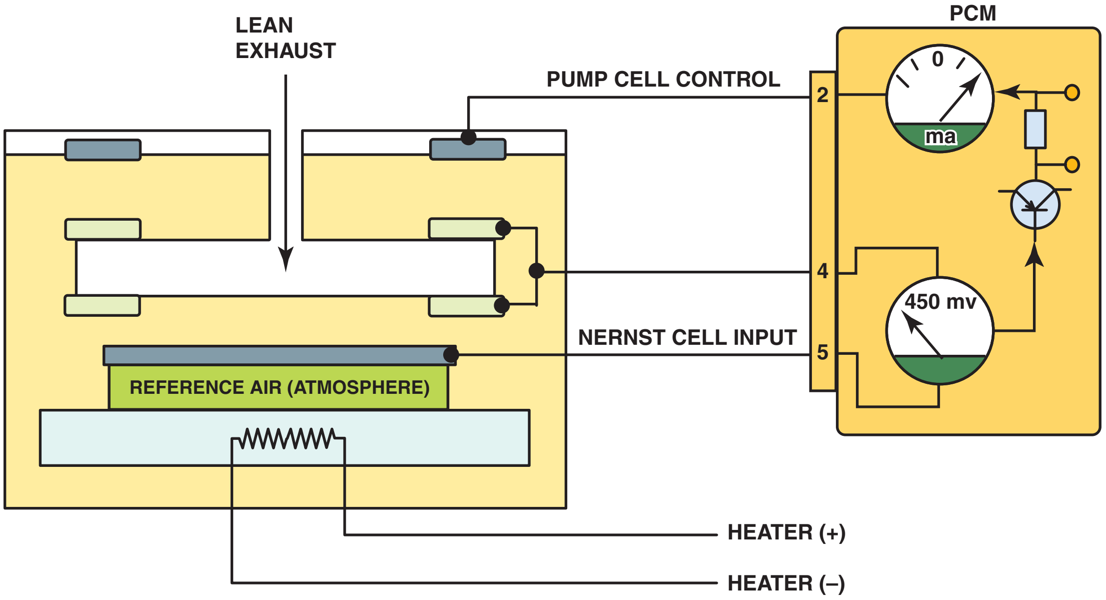

LEAN
EXHAUST
PCM
PUMP CELL CONTROL
2
ma
0
4
450 mv
NERNST CELL INPUT
5
REFERENCE AIR (ATMOSPHERE)
HEATER (+)
HEATER (–)

FIGURE 73–17 When the exhaust is lean, the PCM applies a positive current into the pump cell.

FACTORY SCAN TOOL	OBD II SCAN TOOL	AIR–FUEL RATIO
2.50 V	0.50 V	12.5:1
3.00 V	0.60 V	14.0:1
3.30 V	0.66 V	14.7:1
3.50 V	0.70 V	15.5:1
4.00 V	0.80 V	18.5:1

CHART 73–2

A comparison showing what a factory scan tool and a generic OBD-II scan tool might display at various air–fuel ratios.

amount of fuel. The scan data shown on a generic (global) OBD-II scan tool will often be different than the reading on the factory scan tool. ● **SEE CHART 73–2** for an example of a Toyota wide-band oxygen sensor being tested using a factory scan tool and a generic OBD-II scan tool.

SCAN TOOL DATA (PID) The following information will be displayed as a scan tool when looking at data for a wide-band oxygen sensor:

H02S1 = ______mA ÷	If the current is positive, this means that the PCM is pumping current in the diffusion gap due to a rich exhaust. If the current is negative, the PCM is pumping current out of the diffusion gap due to a lean exhaust.
Air–fuel ratio = ______	Usually expressed in lambda. One means that the exhaust is at stoichiometric (14.7:1 air–fuel ratio) and numbers higher than one indicate a lean exhaust and numbers lower than one indicate a rich exhaust.

DIGITAL METER TESTING When testing a wide-band oxygen sensor for proper operation, perform the following steps:

STEP 1 Check service information and determine the circuit and connector terminal identification.

STEP 2 Measure the calibration resistor. While the value of this resistor can vary widely depending on the type of sensor, the calibrating resistor should still be checked for opens and shorts.

NOTE: The calibration resistor is usually located within the connector itself.

- If open, the ohmmeter will read OL (infinity ohms).
- If shorted, the ohmmeter will read zero or close to zero.

STEP 3 Measure the heater circuit for proper resistance or current flow.

STEP 4 Measure the reference voltage relative to ground. This can vary but is generally 2.4 to 2.6 V.

STEP 5 Using jumper wires, connect an ammeter and measure the current in the pump cell control wire.

RICH EXHAUST When the exhaust is rich (lambda less than 1.00), the Nernst cell voltage will move higher than 0.45 V. The PCM will pump oxygen from the exhaust into the diffusion gap by applying a negative voltage to the pump cell.

LEAN EXHAUST When the exhaust is lean (lambda higher than 1.00), the Nernst cell voltage will move lower than 0.45 V. The PCM will pump oxygen out of the diffusion gap by applying a positive voltage to the pump cell.

Pump cell is used to pump oxygen into the diffusion gap when the exhaust is rich. The pump cell applies a negative voltage to do this.

- Positive current = lean exhaust
- Negative current = rich exhaust

● **SEE FIGURE 73–18.**

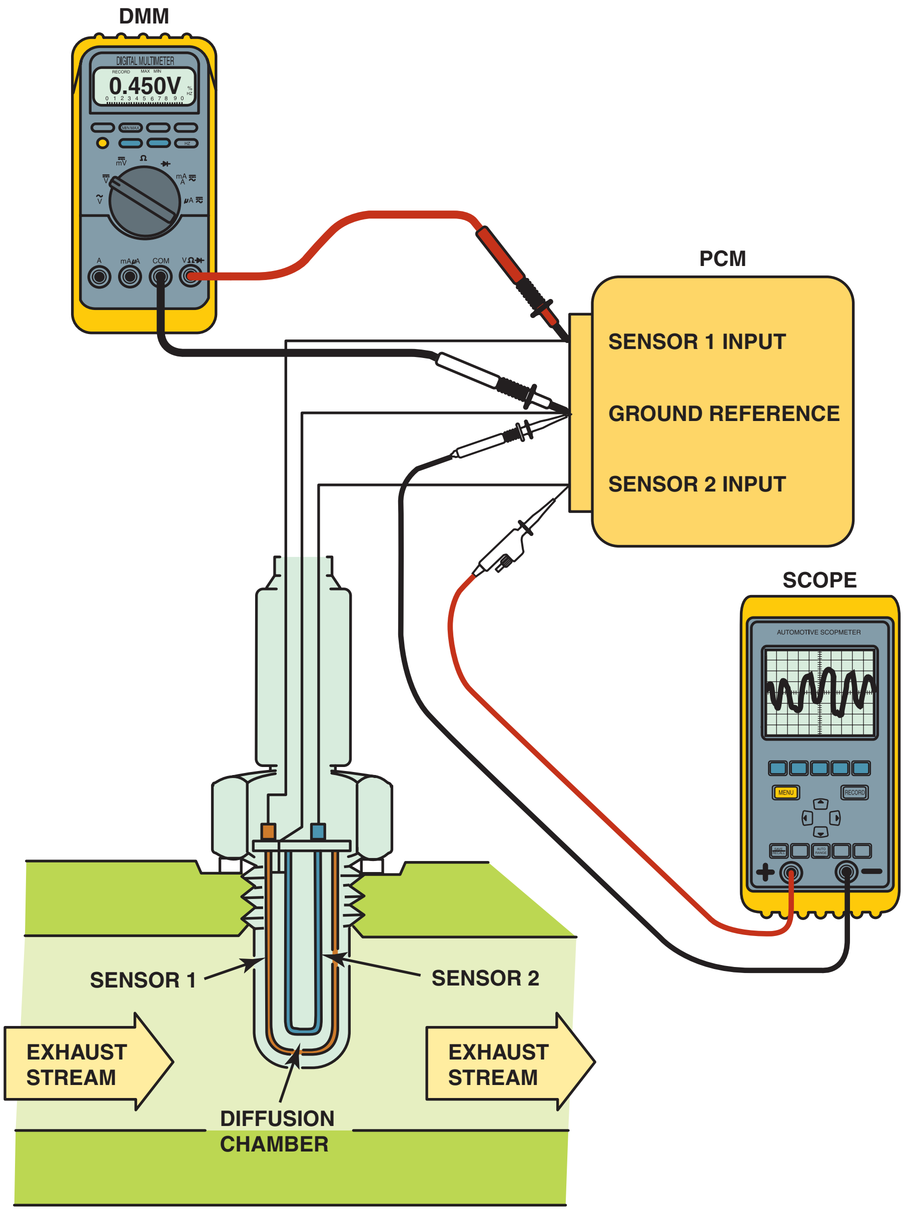


FIGURE 73–18 Testing a dual cell wide-band oxygen sensor can be done using a voltmeter or a scope. The meter reading is attached to the Nernst cell and should read stoichiometric (450 mV) at all times. The scope is showing activity to the pump cell with commands from the PCM to keep the Nernst cell at 14.7:1 air–fuel ratio.

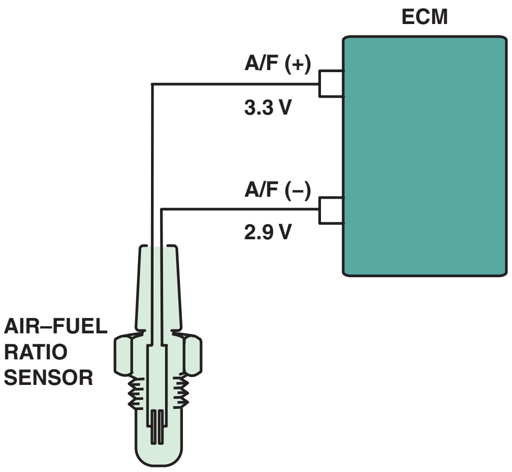


FIGURE 73–19 A single cell wide-band oxygen sensor has four wires with two for the heater and two for the sensor itself. The voltage applied to the sensor is 0.4 V (3.3 − 2.9 = 0.4) across the two leads of the sensor.

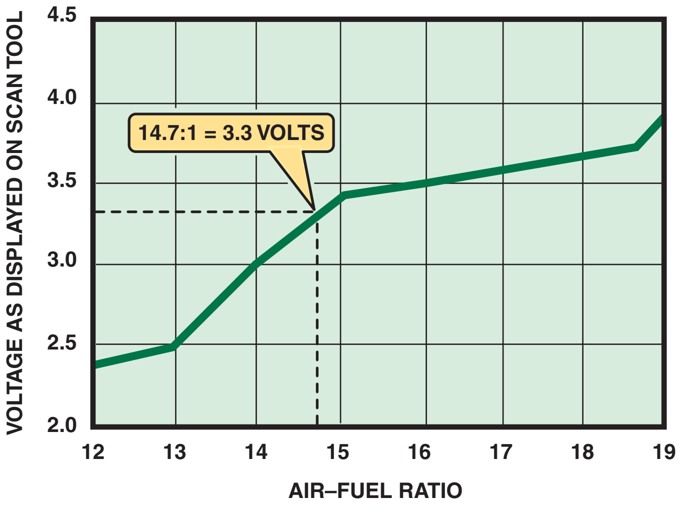


FIGURE 73–20 A scan tool can display various voltages but will often show 3.3 V because the PCM is controlling the sensor through applying a low current to the sensor to achieve balance.

SINGLE CELL WIDE-BAND OXYGEN SENSORS

CONSTRUCTION A typical **single cell** wide-band oxygen sensor looks similar to a conventional four-wire zirconia oxygen sensor. The typical single cell wide-band oxygen sensor, usually called an **air–fuel ratio sensor**, has the following construction features:

- It can be made using the cup or planar design.
- Oxygen (O_2) is pumped into the diffusion layer similar to the operation of a dual cell wide-band oxygen sensor. ● **SEE FIGURE 73–19**.
- Current flow reverses positive and negative.
- There are two cell wires and two heater wires (power and ground).
- The heater usually requires 6 amperes and the ground side is pulse-width modulated.

MILLIAMMETER TESTING The PCM controls the single cell wide-band oxygen sensor by maintaining a voltage difference of 300 mV (0.3 V) between the two sensor leads. The PCM keeps the voltage difference constant under all operating conditions by increasing or decreasing current between the element of the cell:

- Zero (0 mA) represents lambda or stoichiometric air–fuel ratio of 14.7:1
- +10 mA indicates a lean condition
- −10 mA indicates a rich condition

SCAN TOOL TESTING A scan tool will display a voltage reading but can vary depending on the type and maker of scan tool. ● **SEE FIGURE 73–20**.

OXYGEN SENSOR–RELATED DIAGNOSTIC TROUBLE CODES

Diagnostic trouble codes (DTCs) associated with the oxygen sensor include the following:

Diagnostic Trouble Codes	Description	Possible Causes
P0131	Upstream HO2S grounded	■ Exhaust leak upstream of HO2S (bank 1) ■ Extremely lean air–fuel mixture ■ HO2S defective or contaminated ■ HO2S signal wire shorted-to-ground
P0132	Upstream HO2S shorted	■ Upstream HO2S (bank 1) shorted ■ Defective HO2S ■ Fuel-contaminated HO2S
P0133	Upstream HO2S slow response	■ Open or short in heater circuit ■ Defective or fuel-contaminated HO2S ■ EGR or fuel system fault

REVIEW QUESTIONS

1. How does an oxygen sensor detect oxygen levels in the exhaust?
2. What is the difference between open-loop and closed-loop engine operation?
3. What are three ways oxygen sensors can be tested?
4. How can the oxygen sensor be fooled and provide the wrong information to the PCM?
5. What is the purpose of a wide-band oxygen sensor?

CHAPTER QUIZ

1. The voltage output of a zirconia oxygen sensor when the exhaust stream is lean (excess oxygen) is __________.
   a. relatively high (close to 1 volt)
   b. about in the middle of the voltage range
   c. relatively low (close to 0 volt)
   d. Either a or b, depending on atmospheric pressure
2. What does the PCM do with the input from the oxygen sensor(s)?
   a. Shifts the automatic transmission
   b. Controls fuel injector pulse width
   c. Helps determine the condition of the catalytic converter
   d. Both b and c
3. The post-catalytic converter oxygen sensor voltage is not going above 800 mV but instead is staying at a low voltage level. What is the most likely cause?
   a. Normal catalytic converter operation
   b. The catalytic converter is not working
   c. The catalytic converter is clogged
   d. The PCM has failed
4. A wide-band oxygen sensor can detect which of the following?
   a. The ability to detect exhaust air–fuel ratio from as rich as 10:1 to as lean as 23:1 in some cases
   b. Cold start activity within as little as 10 seconds
   c. Helps meet the national low emission vehicle (NLEV), ultra-low emission vehicle (ULEV) and the super ultra-low emission vehicle (SULEV)
   d. All of the above
5. A dual cell wide-band oxygen sensor uses __________.
   a. two internal chambers
   b. an air reference chamber
   c. a diffusion chamber
   d. All of the above
6. What is used to test a dual cell wide-band oxygen sensor?
   a. Scan tool
   b. Digital meter
   c. Either a or b
   d. Neither a nor b
7. A single cell wide-band oxygen sensor uses how many wires?
   a. One
   b. Two
   c. Three
   d. Four
8. A wide-band oxygen sensor is capable of detecting the air–fuel mixture in the exhaust from __________ (rich) to __________ (lean).
   a. 12:1; 15:1
   b. 13:1; 16.7:1
   c. 10:1; 23:1
   d. 8:1; 18:1
9. A wide-band oxygen sensor needs to be heated to what operating temperature?
   a. 600°F (315°C)
   b. 800°F (427°C)
   c. 1,400°F (760°C)
   d. 2,000°F (1,093°C)
10. A P0133 DTC is being discussed. Technician A says that a defective heater circuit could be the cause. Technician B says that a contaminated sensor could be the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

Chapter

74

FUEL PUMPS, LINES, AND FILTERS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the fuel delivery system, including fuel tanks and rollover leak protection.
- Discuss the different types of fuel lines.
- Explain the different types of electric fuel pumps.
- Describe fuel filters.
- Describe how to test fuel pumps.
- Describe how to replace fuel pumps.

KEY TERMS:

Accumulator 887 • Baffle 880 • Gerotor 885 • Hydrokinetic pump 885 • Inertia switch 882 • Onboard refueling vapor recovery (ORVR) 881 • Peripheral pump 885 • Residual or rest pressure 885 • Roller cell 885 • Rotary vane pump 885 • Side-channel pump 885 • Turbine pump 885 • Vapor lock 883 • Volatile organic compound (VOC) 884

FUEL DELIVERY SYSTEM

Creating and maintaining a correct air–fuel mixture requires a properly functioning fuel and air delivery system. Fuel delivery (and return) systems use many, if not all, of the following components to make certain that fuel is available under the right conditions to the fuel-injection system:

- Fuel storage tank, filler neck, and gas cap
- Fuel tank pressure sensor
- Fuel pump
- Fuel filter(s)
- Fuel delivery lines and fuel rail
- Fuel-pressure regulator
- Fuel return line (if equipped with a return-type fuel delivery system)

FUEL TANKS A vehicle fuel tank is made of corrosion-resistant steel or polyethylene plastic. Some models, such as sport utility vehicles (SUVs) and light trucks, may have an auxiliary fuel tank.

Tank design and capacity are a compromise between available space, filler location, fuel expansion room, and fuel movement. Some later-model tanks deliberately limit tank capacity by extending the filler tube neck into the tank low enough to prevent complete filling, or by providing for expansion room. ● **SEE FIGURE 74–1**. A vertical **baffle** in this same tank limits fuel sloshing as the vehicle moves.

Regardless of size and shape, all fuel tanks incorporate most if not all of the following features:

- Inlet or filler tube through which fuel enters the tank
- Filler cap with pressure holding and relief features
- An outlet to the fuel line leading to the fuel pump or fuel injector
- Fuel pump mounted within the tank
- Tank vent system
- Fuel pickup tube and fuel level sending unit

TANK LOCATION AND MOUNTING Most vehicles use a horizontally suspended fuel tank, usually mounted below the rear of the floor pan, just ahead of or behind the rear axle. Fuel tanks are located there so that frame rails and body components protect the tank in the event of a crash. To prevent squeaks, some models have insulated strips cemented on the top or sides of the tank wherever it contacts the underbody.

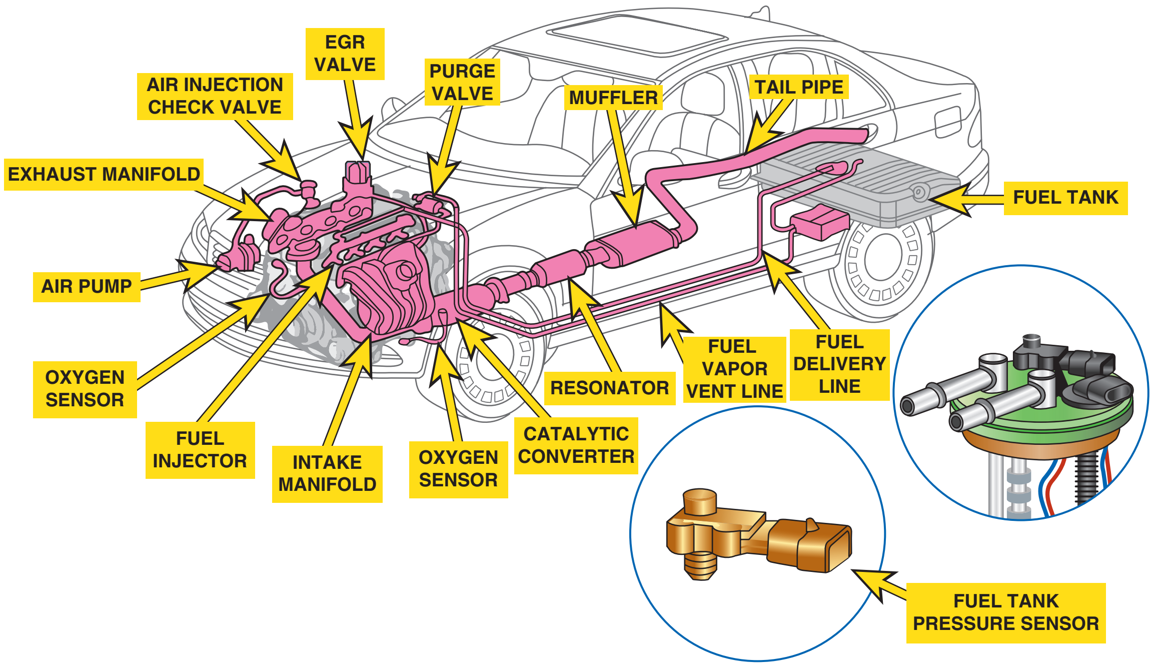

EGR VALVE
AIR INJECTION CHECK VALVE
PURGE VALVE
MUFFLER
TAIL PIPE
EXHAUST MANIFOLD
FUEL TANK
AIR PUMP
OXYGEN SENSOR
FUEL INJECTOR
INTAKE MANIFOLD
OXYGEN SENSOR
CATALYTIC CONVERTER
RESONATOR
FUEL VAPOR VENT LINE
FUEL DELIVERY LINE
FUEL TANK PRESSURE SENSOR

FIGURE 74–1 The fuel system includes many separate parts and components, including the fuel tank, fuel pump and lines, as well as the fuel tank pressure sensor used to measure the pressure inside the fuel tanks used by the evaporative fuel control system.

Fuel inlet location depends on the tank design and filler tube placement. It is located behind a filler cap and is often a hinged door in the outer side of either rear fender panel.

Generally, a pair of metal retaining straps holds a fuel tank in place. Underbody brackets or support panels hold the strap ends using bolts. The free ends are drawn underneath the tank to hold it in place and then bolted to other support brackets or to a frame member on the opposite side of the tank.

FILLER TUBES Fuel enters the tank through a large tube extending from the tank to an opening on the outside of the vehicle. ● **SEE FIGURE 74–2**.

Effective in 1993, federal regulations require manufacturers to install a device to prevent fuel from being siphoned through the filler neck. Federal authorities recognized methanol as a poison, and methanol used in gasoline is a definite health hazard. Additionally, gasoline is a suspected carcinogen (cancer-causing agent). To prevent siphoning, manufacturers welded a filler-neck check-ball tube in fuel tanks. To drain check ball-equipped fuel tanks, a technician must disconnect the check-ball tube at the tank and attach a siphon directly to the tank. ● **SEE FIGURE 74–3**.

Onboard refueling vapor recovery (ORVR) systems have been developed to reduce evaporative emissions during refueling. ● **SEE FIGURE 74–4**. These systems add components to the filler neck and the tank. One ORVR system utilizes a tapered filler neck with a smaller diameter tube and a check valve. When fuel flows down the neck, it opens the normally closed check valve. The vapor passage to the charcoal canister

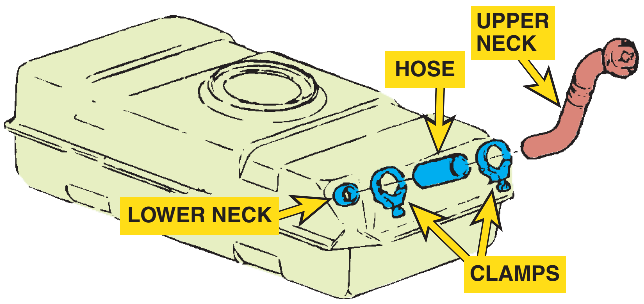

UPPER NECK
HOSE
LOWER NECK
CLAMPS

FIGURE 74–2 A three-piece filler tube assembly.

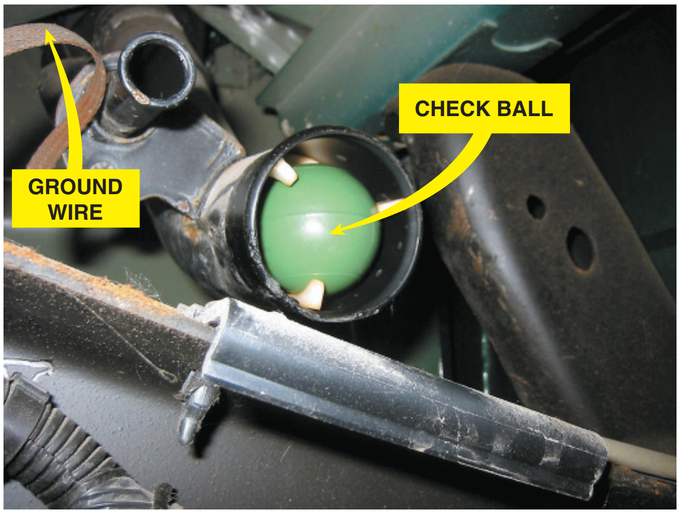

CHECK BALL
GROUND WIRE

FIGURE 74–3 A view of a typical filler tube with the fuel tank removed. Notice the ground strap used to help prevent the buildup of static electricity as the fuel flows into the plastic tank. The check ball looks like a ping-pong ball.

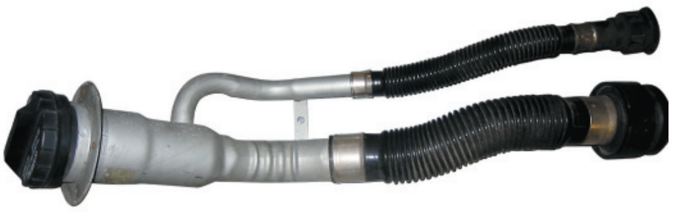


FIGURE 74–4 Vehicles equipped with onboard refueling vapor recovery usually have a reduced-size fill tube.

is opened. The decreased size neck and the opened air passage allow fuel and vapor to flow rapidly into the tank and the canister, respectively. When the fuel has reached a predetermined level, the check valve closes, and the fuel tank pressure increases. This forces the nozzle to shut off, thereby preventing the tank from being overfilled.

PRESSURE-VACUUM FILLER CAP Fuel and vapors are sealed in the tank by the safety filler cap. The safety cap must release excess pressure or excess vacuum. Either condition could cause fuel tank damage, fuel spills, and vapor escape. Typically, the cap will release if the pressure is over 1.5 to 2.0 PSI (10 to 14 kPa) or if the vacuum is 0.15 to 0.30 PSI (1 to 2 kPa).

FUEL PICKUP TUBE The fuel pickup tube is usually a part of the fuel sender assembly or the electric fuel pump assembly. Since dirt and sediment eventually gather on the bottom of a fuel tank, the fuel pickup tube is fitted with a filter sock or strainer to prevent contamination from entering the fuel lines. The woven plastic strainer also acts as a water separator by preventing water from being drawn up with the fuel. The filter sock usually is designed to filter out particles that are larger than 70 to 100 microns, or 30 microns if a gerotor-type fuel pump is used. One micron is 0.000039 inch. ● **SEE FIGURE 74–5**.

NOTE: The human eye cannot see anything smaller than about 40 microns.

The filter is made from woven Saran resin (copolymer of vinylidene chloride and vinyl chloride). The filter blocks any water that may be in the fuel tank, unless it is completely submerged in water. In that case, it will allow water through the filter. This filter should be replaced whenever the fuel pump is replaced.

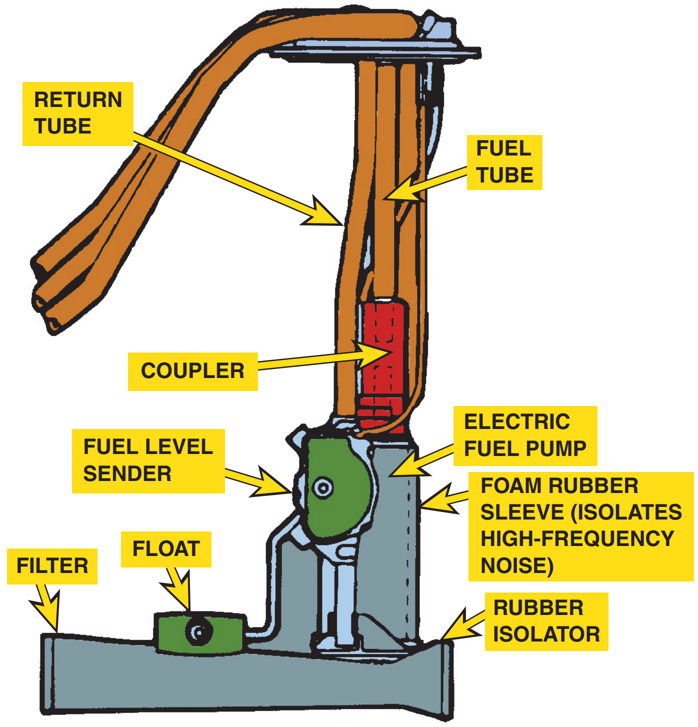


FIGURE 74–5 The fuel pickup tube is part of the fuel sender and pump assembly.

TANK VENTING REQUIREMENTS Fuel tanks must be vented to prevent a vacuum lock as fuel is drawn from the tank. As fuel is used and its level drops in the tank, the space above the fuel increases. As the air in the tank expands to fill this greater space, its pressure drops. Without a vent, the air pressure inside the tank would drop below atmospheric pressure, developing a vacuum, which prevents the flow of fuel. Under extreme pressure variance, the tank could collapse. Venting the tank allows outside air to enter as the fuel level drops, preventing a vacuum from developing.

An EVAP system vents gasoline vapors from the fuel tank directly to a charcoal-filled vapor storage canister, and uses an unvented filler cap. Many filler caps contain valves that open to relieve pressure or vacuum above specified safety levels. Systems that use completely sealed caps have separate pressure and vacuum relief valves for venting.

Because fuel tanks are not vented directly to the atmosphere, the tank must allow for fuel expansion, contraction, and overflow that can result from changes in temperature or overfilling. One way is to use a dome in the top of the tank. Many General Motors vehicles use a design that includes a vertical slosh baffle which reserves up to 12% of the total tank capacity for fuel expansion.

ROLLOVER LEAKAGE PROTECTION All vehicles have one or more devices to prevent fuel leaks in case of vehicle rollover or a collision in which fuel may spill.

Variations of the basic one-way check valve may be installed in any number of places between the fuel tank and the engine. The valve may be installed in the fuel return line, vapor vent line, or fuel tank filler cap.

In addition to the rollover protection devices, some vehicles use devices to ensure that the fuel pump shuts off when an accident occurs. Some pumps depend upon an oil pressure or an engine speed signal to continue operating; these pumps turn off whenever the engine dies.

Ford vehicles use an **inertia switch**. ● **SEE FIGURE 74–6**. The inertia switch is installed in the rear of the vehicle between the electric fuel pump and its power supply. With any sudden impact, such as a jolt from another vehicle in a parking lot, the inertia switch opens and shuts off power to the fuel pump. The switch must be reset manually by pushing a button to restore current to the pump.

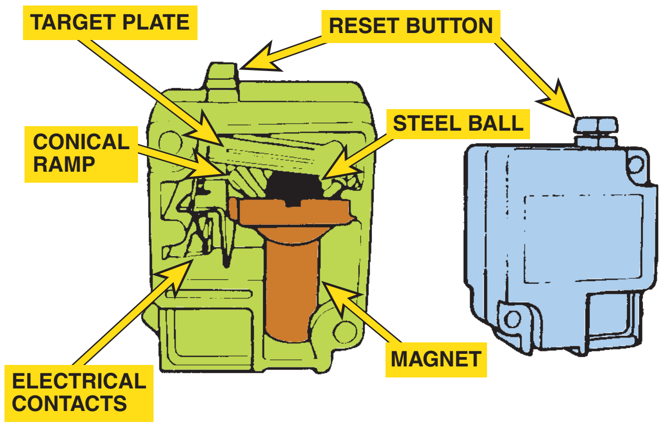


FIGURE 74–6 Ford uses an inertia switch to turn off the electric fuel pump in case of an accident.

FUEL LINES

PURPOSE AND FUNCTION Fuel and vapor lines made of steel, nylon tubing, or fuel-resistant rubber hoses connect the parts of the fuel system. Fuel lines supply fuel to the throttle body or fuel rail. They also return excess fuel and vapors to the tank. Depending on their function, fuel and vapor lines may be either rigid or flexible.

Fuel lines must remain as cool as possible. If any part of the line is located near too much heat, the gasoline passing through it vaporizes and **vapor lock** occurs. When this happens, the fuel pump supplies only vapor that passes into the injectors. Without liquid gasoline, the engine stalls and a hot restart problem develops.

The fuel delivery system supplies 10 to 15 PSI (69 to 103 kPa) or up to 35 PSI (241 kPa) to many throttle-body injection units and up to 50 PSI (345 kPa) for multiport fuel-injection systems. Fuel-injection systems retain residual or rest pressure in the lines for a half hour or longer when the engine is turned off to prevent hot engine restart problems. Higher-pressure systems such as these require special fuel lines.

RIGID LINES All fuel lines fastened to the body, frame, or engine are made of seamless steel tubing. Steel springs may be wound around the tubing at certain points to protect against impact damage.

Only steel tubing, or that recommended by the manufacturer, should be used when replacing rigid fuel lines. *Never substitute copper or aluminum tubing for steel tubing*. These materials do not withstand normal vehicle vibration and could combine with the fuel to cause a chemical reaction.

FLEXIBLE LINES Most fuel systems use synthetic rubber hose sections where flexibility is needed. Short hose sections often connect steel fuel lines to other system components. The fuel delivery hose inside diameter (ID) is generally larger (3/16 to 3/8 in. or 8 to 10 mm) than the fuel return hose ID (1/4 in. or 6 mm).

Fuel-injection systems require special-composition reinforced hoses specifically made for these higher-pressure systems. Similarly, vapor vent lines must be made of materials that resist fuel vapors. Replacement vent hoses are usually marked with the designation "EVAP" to indicate their intended use.

FUEL LINE MOUNTING Fuel supply lines from the tank to a throttle body or fuel rail are routed to follow the frame along the underbody of the vehicle. Vapor and return lines may be routed with the fuel supply line. All rigid lines are fastened to the frame rail or underbody with screws and clamps, or clips. ● **SEE FIGURE 74–7**.

FUEL-INJECTION LINES Hoses used for fuel-injection systems are made of materials with high resistance to oxidation and deterioration. Replacement hoses for injection systems should always be equivalent to original equipment manufacturer (OEM) hoses.

CAUTION: Do not use spring-type clamps on fuel-injected engines—they cannot withstand the fuel pressures involved.

FUEL-INJECTION FITTINGS AND NYLON LINES Because of their operating pressures, fuel-injection systems often use special kinds of fittings to ensure leakproof connections. Some high-pressure fittings on GM vehicles with port fuel-injection systems use O-ring seals instead of the traditional flare connections. When disconnecting such a fitting, inspect the O-ring for damage and replace it if necessary. *Always* tighten O-ring fittings to the specified torque value to prevent damage.

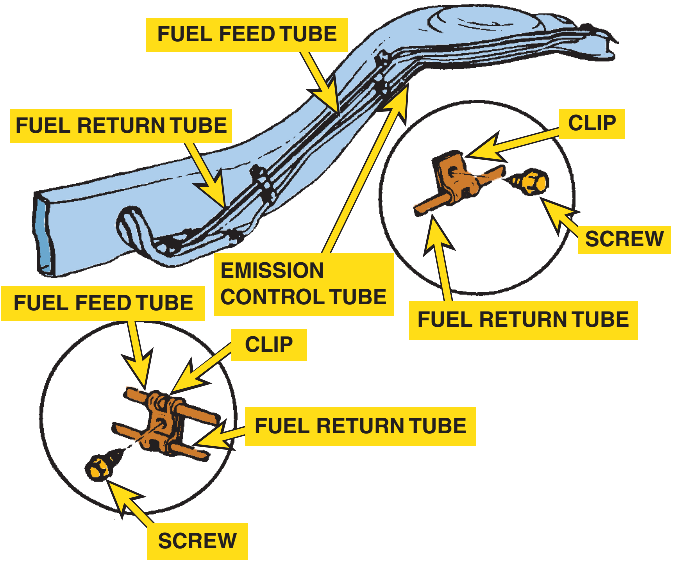


FIGURE 74–7 Fuel lines are routed along the frame or body and secured with clips.

Other manufacturers also use O-ring seals on fuel line connections. In all cases, the O-rings are made of special materials that withstand contact with gasoline and oxygenated fuel blends. Some manufacturers specify that the O-rings be replaced every time the fuel system connection is opened. When replacing one of these O-rings, a new part specifically designed for fuel system service must be used.

Ford also uses spring-lock connectors to join male and female ends of steel tubing. ● **SEE FIGURE 74–8**. The coupling is held together by a garter spring inside a circular cage. The flared end of the female fitting slips behind the spring to lock the coupling together.

General Motors has used nylon fuel lines with quick-connect fittings at the fuel tank and fuel filter since the early 1990s. Like the GM threaded couplings used with steel lines, nylon line couplings use internal O-ring seals. Unlocking the metal connectors

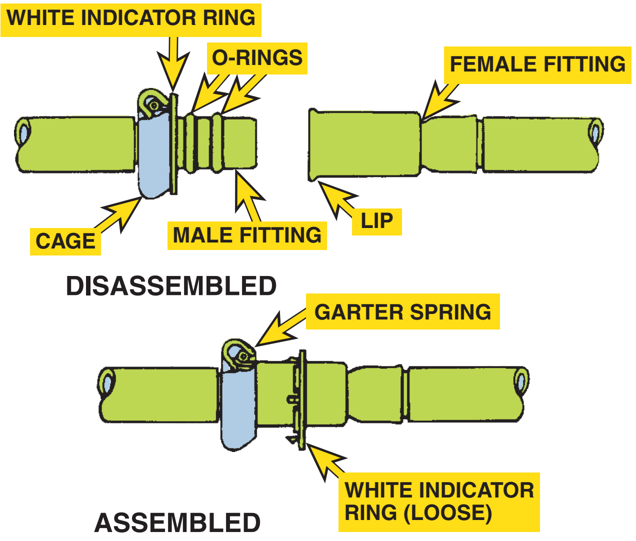


FIGURE 74–8 Some Ford metal line connections use springlocks and O-rings.

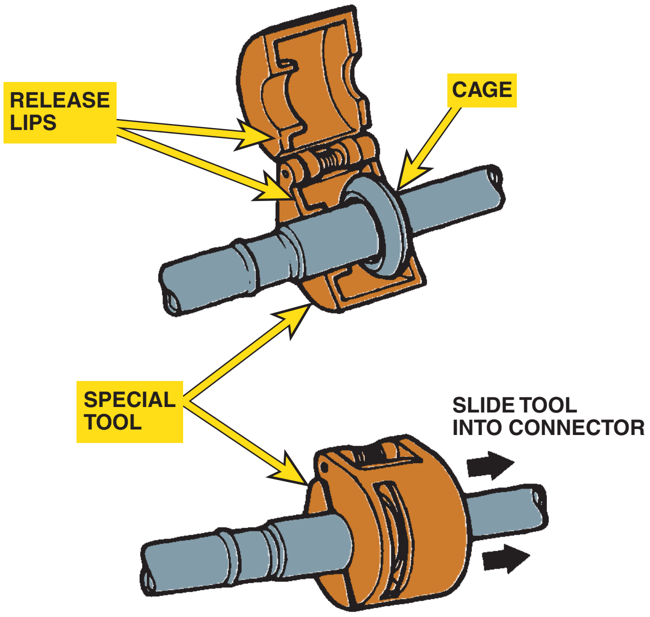


FIGURE 74–9 Ford spring-lock connectors require a special tool for disassembly.

requires a special quick-connector separator tool; plastic connectors can be released without the tool. ● **SEE FIGURES 74–9 AND 74–10.**

FREQUENTLY ASKED QUESTION

Just How Much Fuel Is Recirculated?

Approximately 80% of the available fuel-pump volume is released to the fuel tank through the fuel-pressure regulator at idle speed. For example, a passenger vehicle cruising down the road at 60 mph gets 30 mpg. With a typical return-style fuel system pumping about 30 gallons per hour from the tank, it would therefore burn 2 gallons per hour, and return about 28 gallons per hour to the tank!

FREQUENTLY ASKED QUESTION

How Can an Electric Pump Work Inside a Gas Tank and Not Cause a Fire?

Even though fuel fills the entire pump, no burnable mixture exists inside the pump because there is no air and no danger of commutator brush arcing, igniting the fuel.

FUEL LINE LAYOUT Fuel pressures have tended to become higher to prevent vapor lock, and a major portion of the fuel routed to the fuel-injection system returns to the tank by way of a fuel return line or return-type systems. This allows better control, within limits, of heat absorbed by the gasoline as it is routed through the engine compartment. Throttle-body and multiport injection systems have typically used a pressure regulator to control fuel pressure in the throttle body or fuel rail, and also allow excess fuel not used by the injectors to return to the tank. However, the warmer fuel in the tank may create problems, such as an excessive rise in fuel vapor pressures in the tank.

With late-model vehicles, there has been some concern about too much heat being sent back to the fuel tank, causing rising in-tank temperatures and increases in fuel vaporization and **volatile organic compound (VOC)** (hydrocarbon) emissions. To combat this problem, manufacturers have placed the pressure regulator back by the tank instead of under the hood on mechanical returnless systems. In this way, returned fuel is not subjected to the heat generated by the engine and the underhood environment. To prevent vapor lock in these systems, pressures have

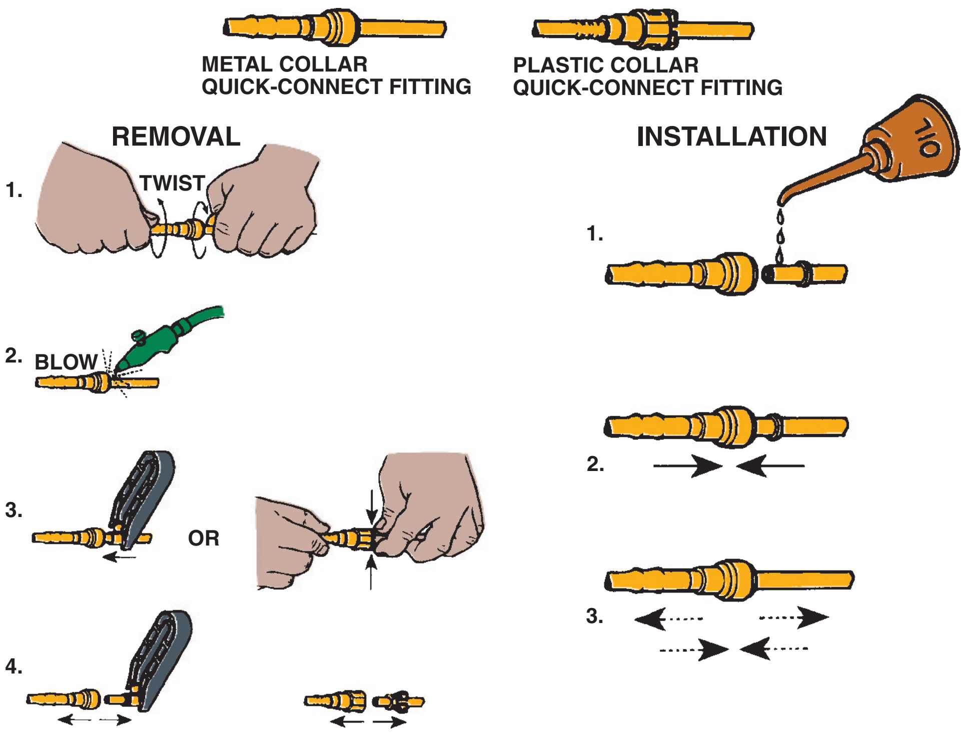

METAL COLLAR QUICK-CONNECT FITTING
PLASTIC COLLAR QUICK-CONNECT FITTING
REMOVAL
1.
TWIST
2.
BLOW
3.
OR
4.
INSTALLATION
OIL
1.
2.
3.

FIGURE 74–10 Typical quick-connect steps.

been raised in the fuel rail, and injectors tend to have smaller openings to maintain control of the fuel spray under pressure.

Not only must the fuel be filtered and supplied under adequate pressure, but there must also be a consistent *volume* of fuel to assure smooth engine performance even under the heaviest of loads.

ELECTRIC FUEL PUMPS

LOCATION The electric fuel pump is a pusher unit. When the pump is mounted in the tank, the entire fuel supply line to the engine can be pressurized. Because the fuel, when pressurized, has a higher boiling point, it is unlikely that vapor will form to interfere with fuel flow.

Most vehicles use the impeller or turbine pumps. ● **SEE FIGURE 74–11**. All electrical pumps are driven by a small electric motor, but the turbine pump turns at higher speeds and is quieter than the others.

POSITIVE DISPLACEMENT PUMP A positive displacement pump is a design that forces everything that enters the pump to leave the pump.

In the **roller cell** or vane pump, the impeller draws fuel into the pump, and then pushes it out through the fuel line to the injection system. All designs of pumps use a variable-sized chamber to draw in fuel. When the maximum volume has been reached, the supply port closes and the discharge opens. Fuel is forced out the discharge as this volume decreases. The chambers are formed by rollers or gears in a rotor plate. Since this type of pump uses no valves to move the fuel, the fuel flows steadily through the pump housing. Since fuel flows steadily through the entire pump, including the electrical portion, the pump stays cool. Usually, only when a vehicle runs out of fuel is there a risk of pump damage.

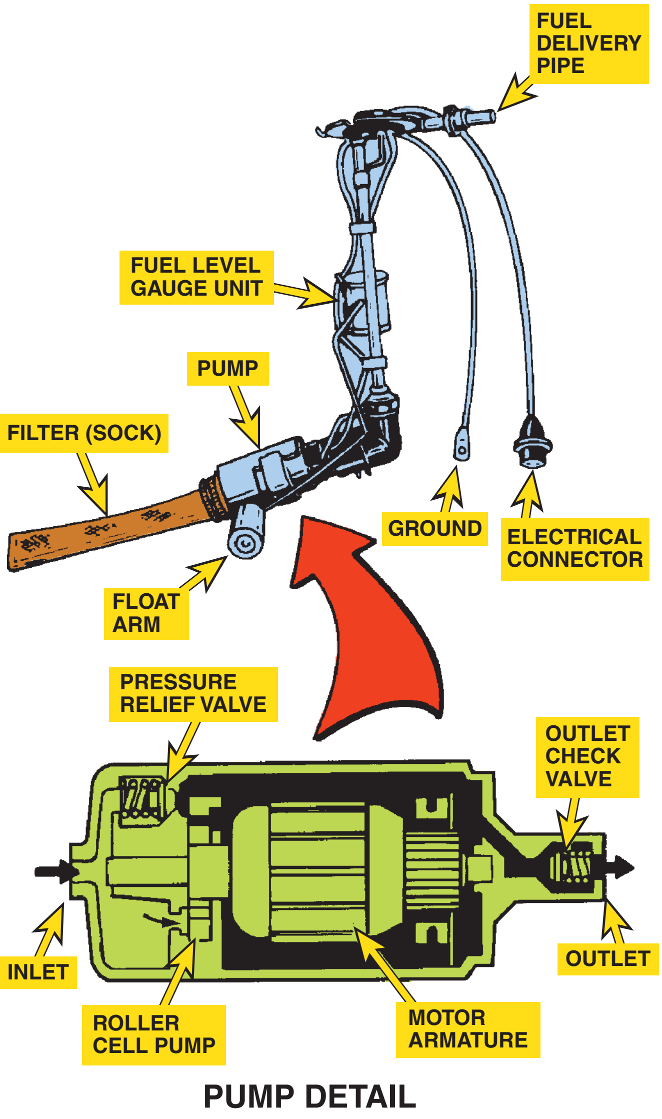


FIGURE 74–11 A roller cell-type electric fuel pump.

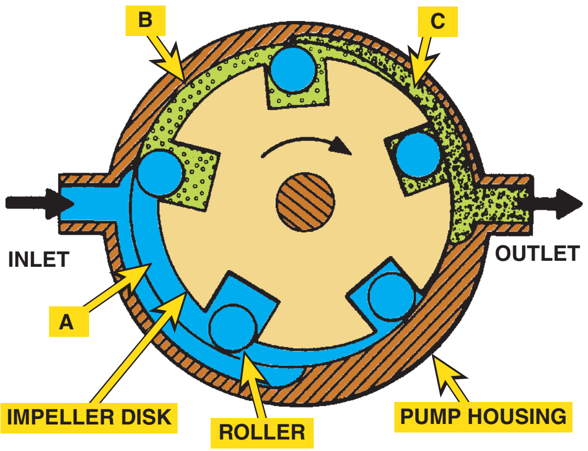


FIGURE 74–12 The pumping action of an impeller or rotary vane pump.

Most electric fuel pumps are equipped with a fuel outlet check valve that closes to maintain fuel pressure when the pump shuts off. **Residual or rest pressure** prevents vapor lock and hot-start problems on these systems.

● **FIGURE 74–12** shows the pumping action of a **rotary vane pump**. The pump consists of a central impeller disk, several rollers or vanes that ride in notches in the impeller, and a pump housing that is offset from the impeller centerline. The impeller is mounted on the end of the motor armature and spins whenever the motor is running. The rollers are free to slide in and out within the notches in the impeller to maintain sealing contact. Unpressurized fuel enters the pump, fills the spaces between the rollers, and is trapped between the impeller, the housing, and two rollers. An internal gear pump, called a **gerotor**, is another type of positive displacement pump that is often used in engine oil pumps. It uses the meshing of internal and external gear teeth to pressurize the fuel. ● **SEE FIGURE 74–13** for an example of a gerotor-type fuel pump that uses an impeller as the first stage and is used to move the fuel gerotor section where it is pressurized.

HYDROKINETIC FLOW PUMP DESIGN The word *hydro* means liquid and the term *kinetic* refers to motion, so the term **hydrokinetic pump** means that this design of pump rapidly moves the fuel to create pressure. This design of pump is a nonpositive displacement pump design.

A **turbine pump** is the most common because it tends to be less noisy. Sometimes called turbine, **peripheral**, and **side-channel**, these units use an impeller that accelerates the fuel particles before actually discharging them into a tract where they generate pressure via pulse exchange. Actual pump volume is controlled by using a different number of impeller blades, and in some cases a higher number of impellers, or different shapes along the side discharge channels. These units are fitted more toward lower operating pressures of less than 60 PSI. ● **SEE FIGURE 74–14** for an example of a two-stage turbine pump.

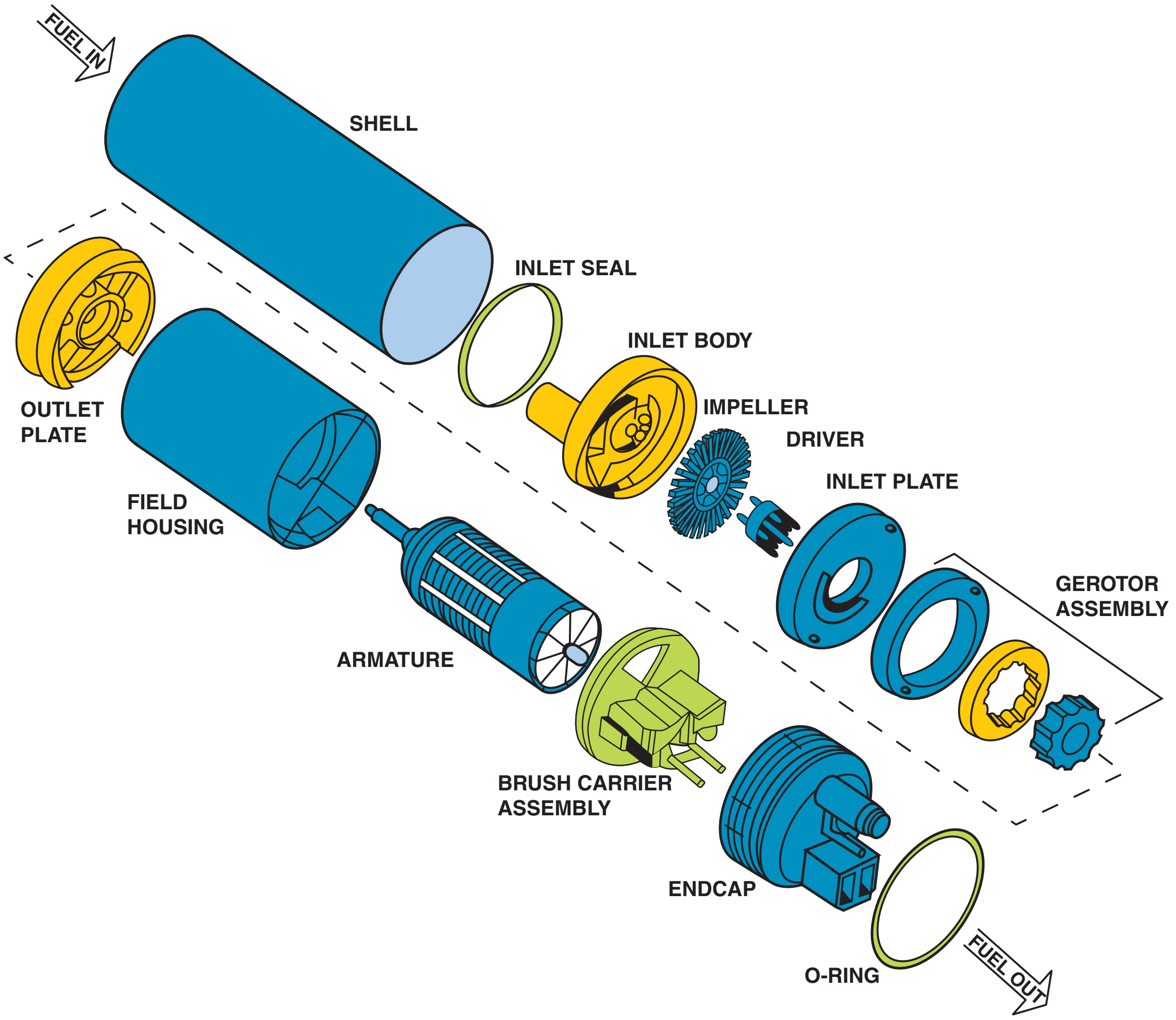

FUEL IN
SHELL
INLET SEAL
INLET BODY
IMPELLER
DRIVER
INLET PLATE
GEROTOR ASSEMBLY
OUTLET PLATE
FIELD HOUSING
ARMATURE
BRUSH CARRIER ASSEMBLY
ENDCAP
O-RING
FUEL OUT

FIGURE 74–13 An exploded view of a gerotor electric fuel pump.

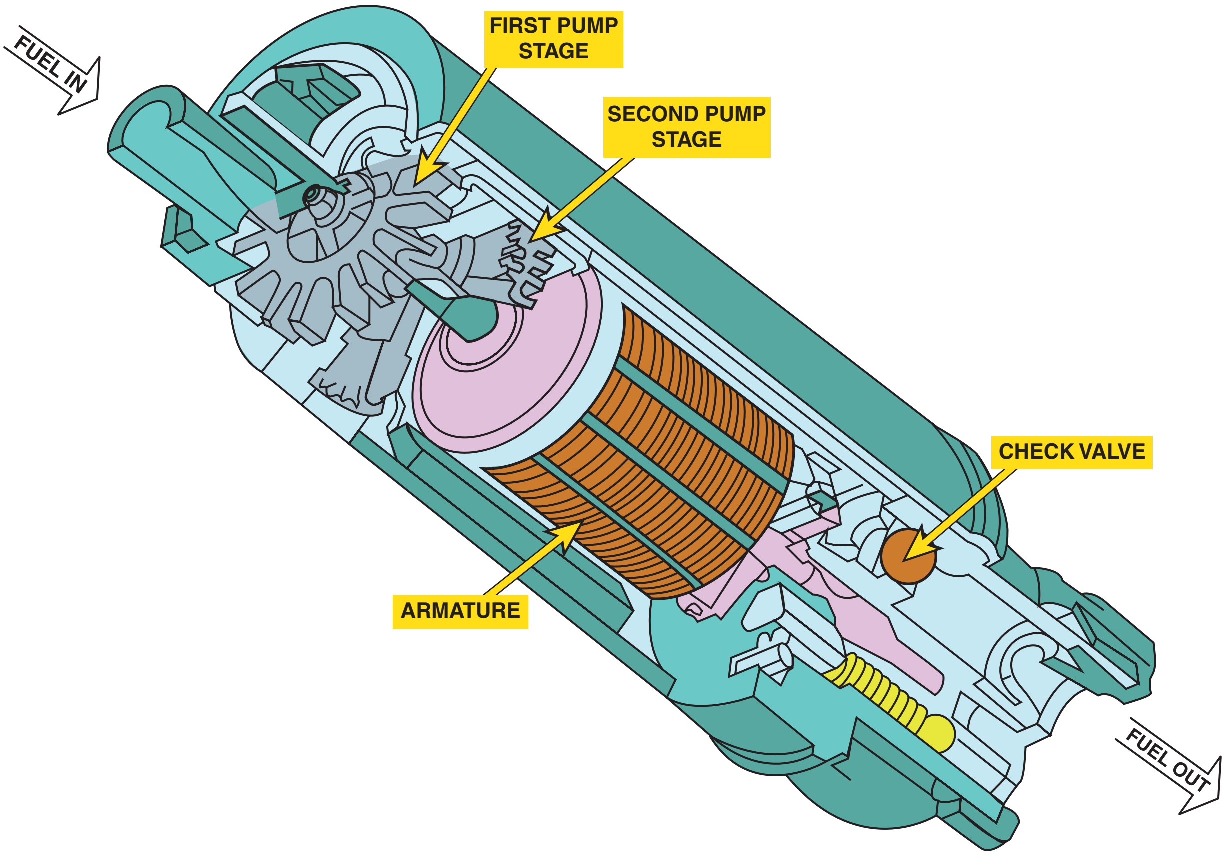

FUEL IN
FIRST PUMP STAGE
SECOND PUMP STAGE
CHECK VALVE
ARMATURE
FUEL OUT

FIGURE 74–14 A cutaway view of a typical two-stage turbine electric fuel pump.

The turbine impeller has a staggered blade design to minimize pump harmonic noise and to separate vapor from the liquid fuel. The end cap assembly contains a pressure relief valve and a radio-frequency interference (RFI) suppression module. The check valve is usually located in the upper fuel pipe connector assembly.

After it passes through the strainer, fuel is drawn into the lower housing inlet port by the impellers. It is pressurized and delivered to the convoluted fuel tube for transfer through a check valve into the fuel feed pipe. A typical electric fuel pump used on a fuel-injection system delivers about 40 to 50 gallons per hour or 0.6 to 0.8 gallons per minute at a pressure of 70 to 90 PSI.

MODULAR FUEL SENDER ASSEMBLY The modular fuel sender consists of a fuel level sensor, a turbine pump, and a jet pump. The reservoir housing is attached to the cover containing fuel pipes and the electrical connector. Fuel is transferred from the pump to the fuel pipe through a convoluted (flexible) fuel pipe. The convoluted fuel pipe eliminates the need for rubber hoses, nylon pipes, and clamps. The reservoir dampens fuel slosh to maintain a constant fuel level available to the roller vane pump; it also reduces noise.

Some of the flow, however, is returned to the jet pump for recirculation. Excess fuel is returned to the reservoir through one of the three hollow support pipes. The hot fuel quickly mixes with the cooler fuel in the reservoir; this minimizes the possibility of vapor lock. In these modules, the reservoir is filled by the jet pump. Some of the fuel from the pump is sent through the jet pump to lift fuel from the tank into the reservoir.

ELECTRIC PUMP CONTROL CIRCUITS Fuel-pump circuits are controlled by the fuel-pump relay. Fuel-pump relays are activated initially by turning the ignition key to on, which allows the pump to pressurize the fuel system. As a safety precaution, the relay de-energizes after a few seconds unless the key is moved to the crank position. On some systems, once an ignition coil signal, or “tach” signal, is received by the engine control computer, indicating the engine is rotating, the relay remains energized even with the key released to the run position.

CHRYSLER On older Chrysler vehicles, the PCM must receive an engine speed (RPM) signal during cranking before it can energize a circuit driver inside the power module to activate an automatic shutdown (ASD) relay to power the fuel pump, ignition coil, and injectors. As a safety precaution, if the RPM signal to the logic module is interrupted, the logic module signals the power module to deactivate the ASD, turning off the pump, coil, and injectors. In some vehicles, the oil pressure switch circuit may be used as a safety circuit to activate the pump in the ignition switch run position.

FREQUENTLY ASKED QUESTION

Why Are Many Fuel-Pump Modules Spring-Loaded?

Fuel modules that contain the fuel pickup sock, fuel pump, and fuel level sensor are often spring-loaded when fitted to a plastic fuel tank. The plastic material shrinks when cold and expands when hot, so having the fuel module spring-loaded ensures that the fuel pickup sock will always be the same distance from the bottom of the tank. ● **SEE FIGURE 74–15**.

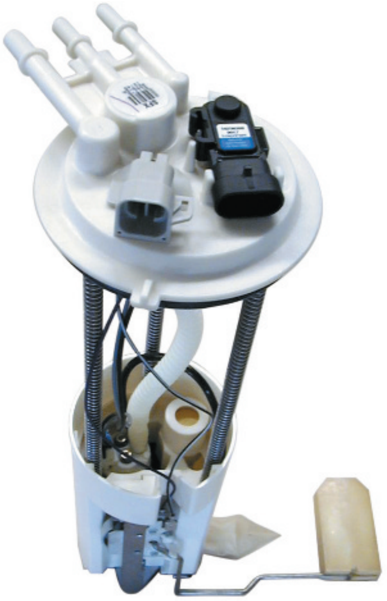


FIGURE 74–15 A typical fuel-pump module assembly, which includes the pickup strainer and fuel pump, as well as the fuel pressure sensor and fuel level sensing unit.

GENERAL MOTORS General Motors systems energize the pump with the ignition switch to initially pressurize the fuel lines, but then deactivate the pump if an RPM signal is not received within one or two seconds. The pump is reactivated as soon as engine cranking is detected. The oil pressure sending unit serves as a backup to the fuel-pump relay on some vehicles. In case of pump relay failure, the oil pressure switch will operate the fuel pump once oil pressure reaches about 4 PSI (28 kPa).

FORD Older fuel-injected Fords used an inertia switch between the fuel pump relay and fuel pump.

The inertia switch opens under a specified impact, such as a collision. When the switch opens, current to the pump shuts off because the fuel-pump relay will not energize. The switch must be reset manually by opening the trunk and depressing the reset button before current flow to the pump can be restored. ● **SEE FIGURE 74–16** for a schematic of a typical fuel system that uses an inertia switch in the power feed circuit to the electric fuel pump.

Since about 2008, the inertial switch has been replaced with a signal input from the airbag module. If the airbag is deployed, the circuit to the fuel pump is opened and the fuel pump stops.

PUMP PULSATION DAMPENING Some manufacturers use an **accumulator** in the system to reduce pressure pulses and noise. Others use a pulsator located at the outlet of the fuel pump to absorb pressure pulsations that are created by the pump. These pulsators are usually used on roller vane pumps and are a source of many internal fuel leaks. ● **SEE FIGURE 74–17**.

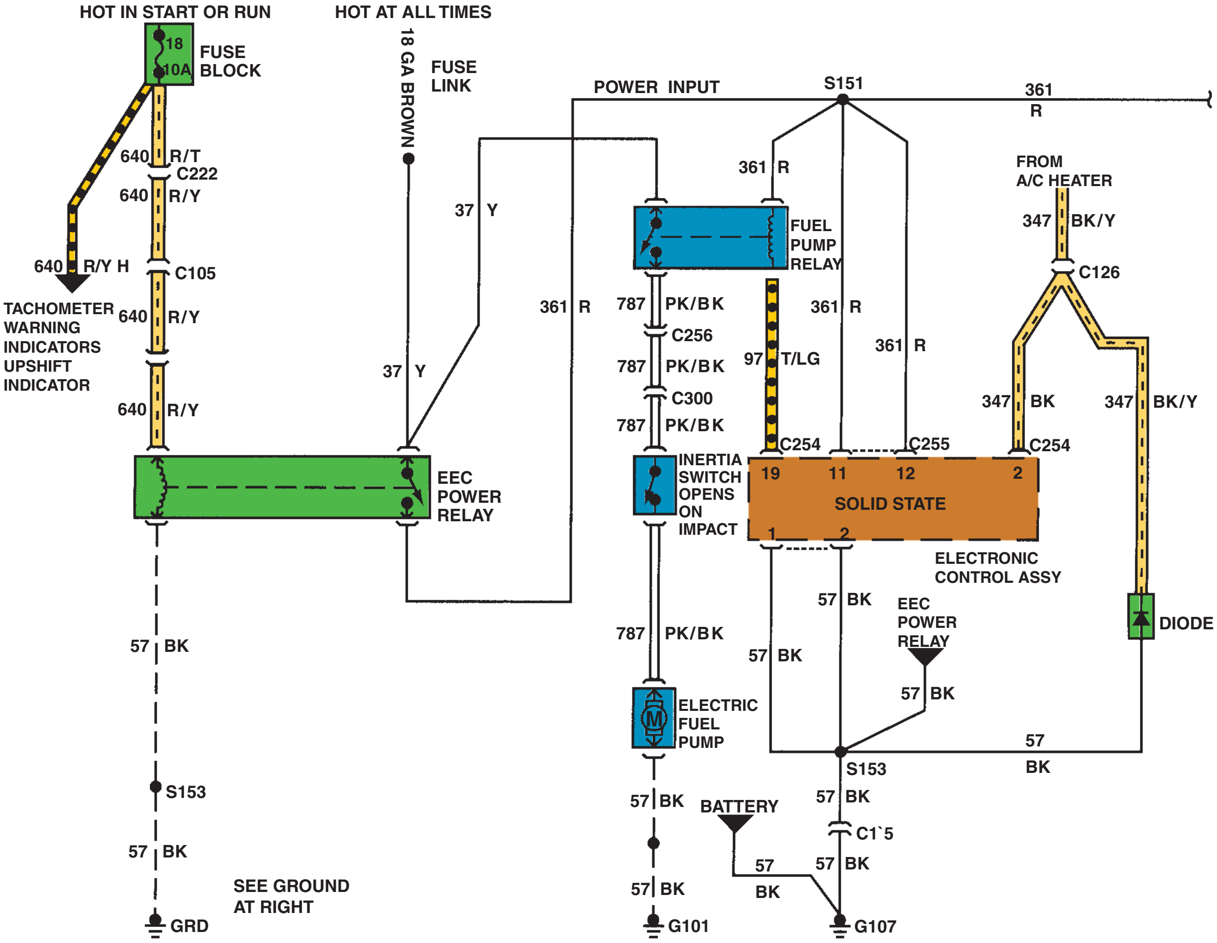

HOT IN START OR RUN
HOT AT ALL TIMES
18
10A
FUSE BLOCK
18 GA BROWN
FUSE LINK
POWER INPUT
S151
361 R
640 R/T
C222
640 R/Y
640 R/Y H
C105
TACHOMETER WARNING INDICATORS UPSHIFT INDICATOR
640 R/Y
640 R/Y
37 Y
37 Y
361 R
361 R
FUEL PUMP RELAY
787 PK/BK
C256
787 PK/BK
C300
787 PK/BK
97 T/LG
361 R
361 R
FROM A/C HEATER
347 BK/Y
C126
347 BK
347 BK/Y
C254
C255
C254
EEC POWER RELAY
INERTIA SWITCH OPENS ON IMPACT
19
11
12
2
SOLID STATE
1
2
ELECTRONIC CONTROL ASSY
57 BK
EEC POWER RELAY
DIODE
57 BK
787 PK/BK
57 BK
57 BK
ELECTRIC FUEL PUMP
M
57 BK
S153
S153
57 BK
BATTERY
57 BK
C1`5
57 BK
57 BK
57 BK
SEE GROUND AT RIGHT
57 BK
57 BK
GRD
G101
G107

FIGURE 74–16 A schematic showing that an inertia switch is connected in series between the fuel-pump relay and the fuel pump.

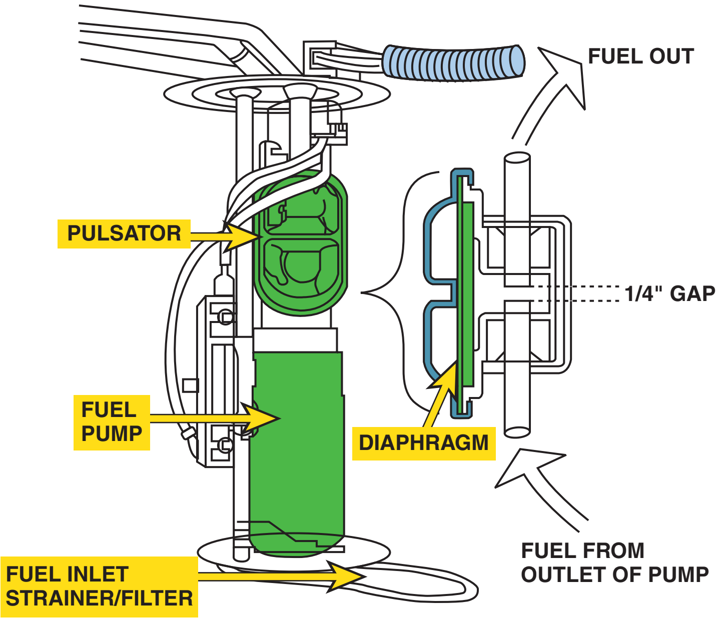

FUEL OUT
PULSATOR
1/4" GAP
FUEL PUMP
DIAPHRAGM
FUEL INLET STRAINER/FILTER
FUEL FROM OUTLET OF PUMP

FIGURE 74–17 A typical fuel pulsator used mostly with roller vane-type pumps to help even out the pulsation in pressure that can cause noise.

NOTE: Some experts suggest that the pulsator be removed and replaced with a standard section of fuel line to prevent the loss of fuel pressure that results when the connections on the pulsator loosen and leak fuel back into the tank.

VARIABLE SPEED PUMPS Another way to help reduce noise, current draw, and pump wear is to reduce the speed of the pump when less than maximum output is required. Pump speed and pressure can be regulated by controlling the voltage supplied to the pump with a resistor switched into the circuit, or by using a separate fuel pump driver module to supply a pulse-width modulated (PWM) voltage to the pump. With slower pump speed and pressure, less noise is produced.

FUEL FILTERS

PURPOSE AND FUNCTIONS Despite the care generally taken in refining, storing, and delivering gasoline, some impurities get into the automotive fuel system. Fuel filters remove dirt, rust, water, and other contamination from the gasoline before it can reach the fuel injectors. Most fuel filters are designed to filter particles that are 10 to 20 microns or larger in size.

The useful life of many filters is limited, but vehicles that use a returnless-type fuel-injection system usually use filters that are part of the fuel pump assembly and do not have any specified interval. This means they should last the life of the vehicle. If fuel filters are not replaced according to the manufacturer's recommendations, they can become clogged and restrict fuel flow.

In addition to using several different types of fuel filters, a single fuel system may contain two or more filters. The inline filter is located in the line between the fuel pump and the throttle body or fuel rail. ● **SEE FIGURE 74–18**. This filter protects the system from contamination, but does not protect the fuel pump. The

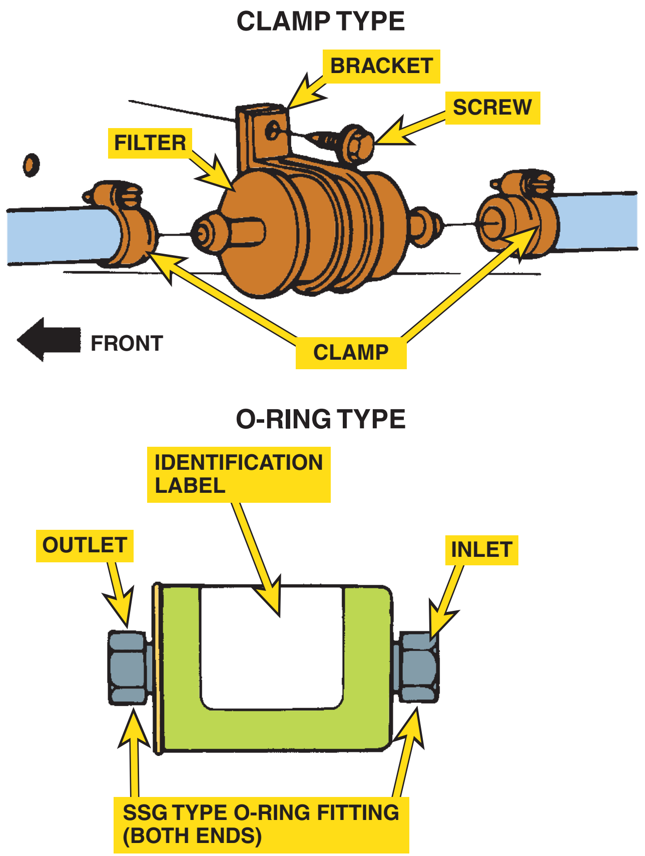


FIGURE 74–18 Inline fuel filters are usually attached to the fuel line with screw clamps or threaded connections. The fuel filter must be installed in the proper direction or a restricted fuel flow can result.

TECH TIP

Use a Headlight to Test for Power and Ground

When replacing a fuel pump, always check for proper power and ground. If the supply voltage is low due to resistance in the circuit or the ground connection is poor, the lower available voltage to the pump will result in lower pump output and could also reduce the life of the pump. While a voltage drop test can be preformed, a quick and easy test is to use a headlight connected to the circuit. If the headlight is bright, then both the power side and the ground side of the pump circuit are normal. If the headlight is dim, then more testing will be needed to find the source of the resistance in the circuit(s). ● **SEE FIGURE 74–19**.

TECH TIP

The Ear Test

No, this is not a test of your hearing, but rather using your ear to check that the electric fuel pump is operating. The electric fuel pump inside the fuel tank is often difficult to hear running, especially in a noisy shop environment. A commonly used trick to better hear the pump is to use a funnel in the fuel filter neck. ● **SEE FIGURE 74–20**.

FIGURE 74–19 A dim headlight indicates excessive resistance in fuel pump circuit.

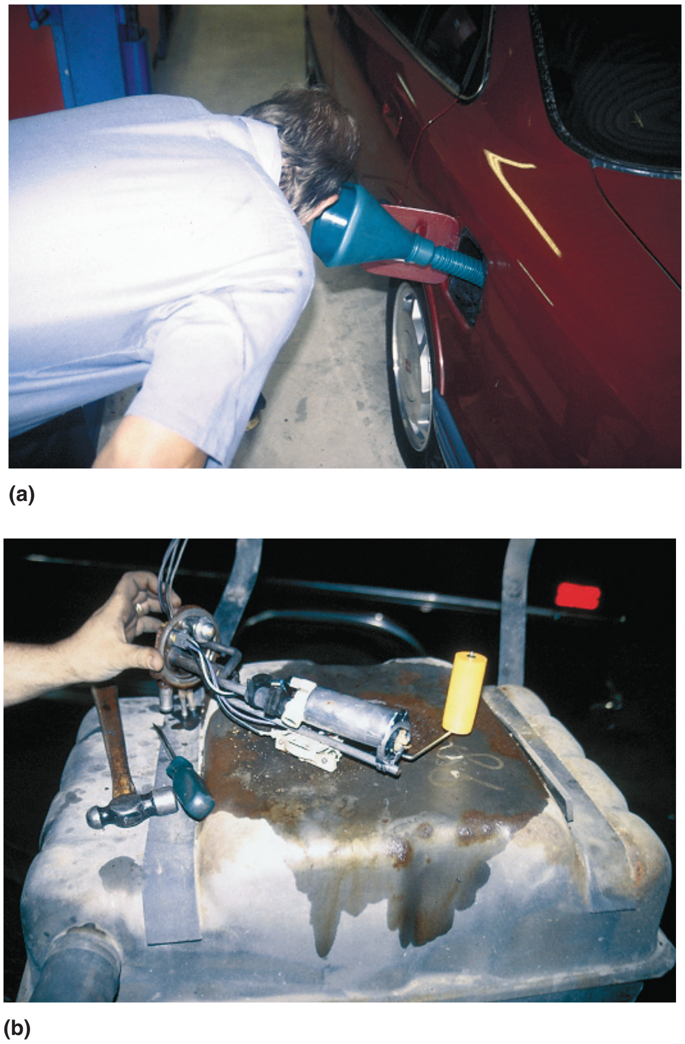


FIGURE 74–20 (a) A funnel helps in hearing if the electric fuel pump inside the gas tank is working. (b) If the pump is not running, check the wiring and current flow before going through the process of dropping the fuel tank to remove the pump.

inline filter usually is a metal or plastic container with a pleated paper element sealed inside.

Fuel filters may be mounted on a bracket on the fender panel, a shock tower, or another convenient place in the engine compartment. They may also be installed under the vehicle near the fuel tank. Fuel filters should be replaced according to the vehicle manufacturer's recommendations, which range from every 30,000 miles (48,000 km) to 100,000 miles (160,000 km) or longer. Fuel filters that are part of the fuel-pump module assemblies usually do not have any specified service interval.

FUEL-PUMP TESTING

Fuel-pump testing includes many different tests and procedures. Even though a fuel pump can pass one test, it does not mean that there is not a fuel-pump problem. For example, if the pump motor is rotating slower than normal, it may be able to produce the specified pressure, but not enough volume to meet the needs of the engine while operating under a heavy load.

TESTING FUEL-PUMP VOLUME Fuel pressure alone is not enough for proper engine operation. Sufficient fuel capacity (flow) should be at least 2 pints (1 L) every 30 seconds or 1 pint in 15 seconds. Fuel flow specifications are usually expressed in gallons per minute. A typical specification would be 0.5 gallons per minute or more. Volume testing is shown in ● **FIGURE 74–21**.

All fuel must be filtered to prevent dirt and impurities from damaging the fuel system components and/or engine. The first filter is inside the gas tank and is usually not replaceable separately but is attached to the fuel pump (if the pump is electric) and/or fuel gauge sending unit. The replaceable fuel filter is usually located between the fuel tank and the fuel rail or inlet to the fuel-injection system. Most vehicle manufacturers state in service information when to replace the fuel filter. Most newer vehicles, that use returnless-type fuel-injection systems, do not have replaceable filters as they are built into the fuel pump module assembly. (Check the vehicle manufacturers' recommendations for exact time and mileage intervals.)

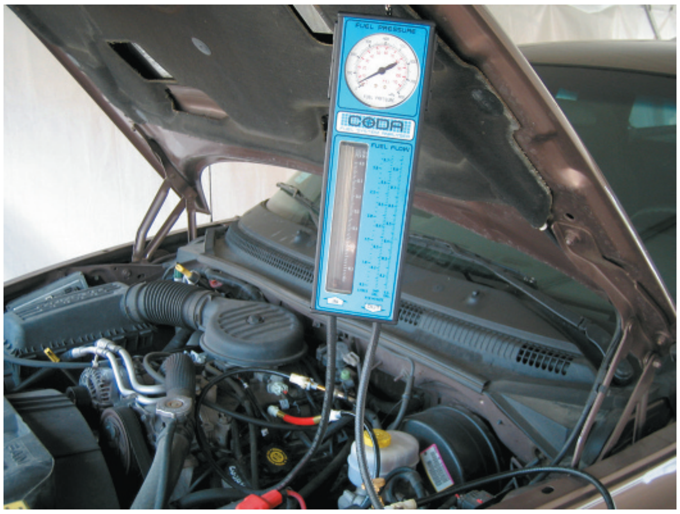


FIGURE 74–21 A fuel system tester connected in series in the fuel system so all of the fuel used flows through the meter, which displays the rate of flow and the fuel pressure.

TECH TIP

Remove the Bed to Save Time?

The electric fuel pump is easier to replace on many General Motors pickup trucks if the bed is removed. Access to the top of the fuel tank, where the access hole is located, for the removal of the fuel tank sender unit and pump is restricted by the bottom of the pickup truck bed. It would take several people (usually other technicians in the shop) to lift the truck bed from the frame after removing only a few fasteners. ● **SEE FIGURE 74–22**.

CAUTION: Be sure to clean around the fuel pump opening so that dirt or debris does not enter the tank when the fuel pump is removed.

FUEL-PUMP CURRENT DRAW TEST Another test that can and should be performed on a fuel pump is to measure the current draw in amperes. This test is most often performed by connecting a digital multimeter set to read DC amperes and test the current draw. ● **SEE FIGURE 74–23** for the hookup for vehicles equipped with a fuel-pump relay. Compare the reading to factory specifications.

FUEL-PUMP REPLACEMENT

The following recommendations should be followed whenever replacing an electric fuel pump:

- The fuel-pump strainer (sock) should be replaced with the new pump.
- If the original pump had a deflector shield, it should always be used to prevent fuel return bubbles from blocking the inlet to the pump.

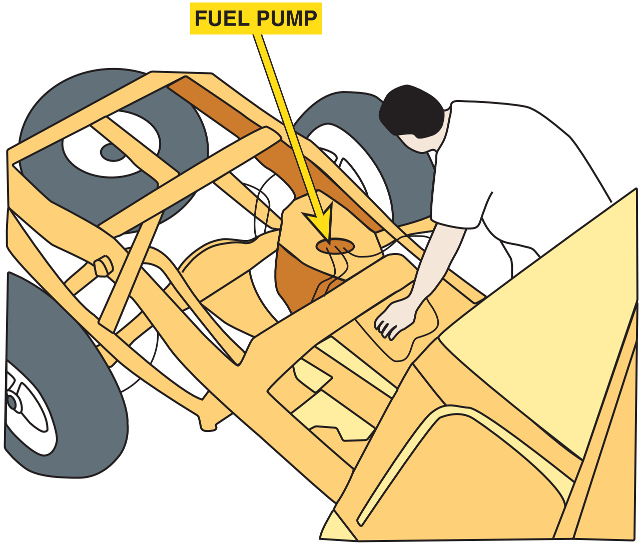


FIGURE 74–22 Removing the bed from a pickup truck makes gaining access to the fuel pump a lot easier.

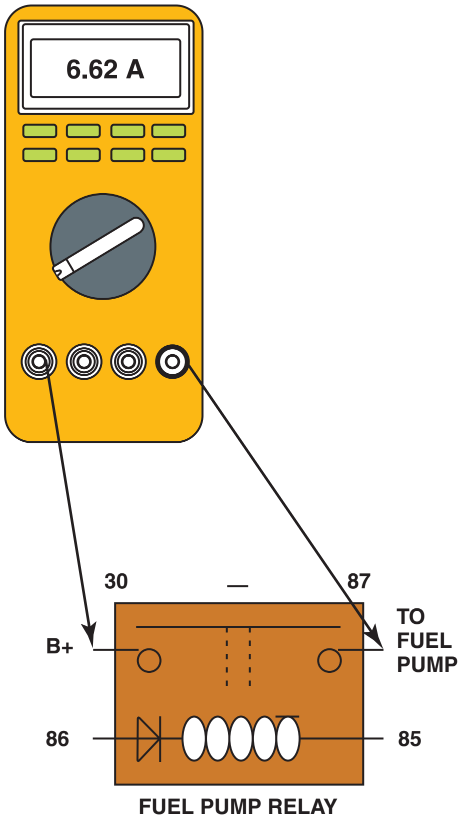


FIGURE 74–23 Hookup for testing fuel-pump current draw on any vehicle equipped with a fuel-pump relay.

- Always check the interior of the fuel tank for evidence of contamination or dirt.
- Double-check that the replacement pump is correct for the application.
- Check that the wiring and electrical connectors are clean and tight.

FUEL SUPPLY-RELATED SYMPTOM GUIDE

PROBLEM	POSSIBLE CAUSES
Pressure too high after engine start-up.	1. Defective fuel-pressure regulator
	2. Restricted fuel return line
	3. Excessive system voltage
	4. Restricted return line
	5. Wrong fuel pump
Pressure too low after engine start-up.	1. Stuck-open pressure regulator
	2. Low voltage
	3. Poor ground
	4. Plugged fuel filter
	5. Faulty inline fuel pump
	6. Faulty in-tank fuel pump
	7. Partially clogged filter sock
	8. Faulty hose coupling
	9. Leaking fuel line
	10. Wrong fuel pump
	11. Leaking pulsator
	12. Restricted accumulator
	13. Faulty pump check valves
	14. Faulty pump installation
Pressure drops off with key on/ engine off. With key off, the pressure does not hold.	1. Leaky pulsator
	2. Leaking fuel-pump coupling hose
	3. Faulty fuel pump (check valves)
	4. Faulty pressure regulator
	5. Leaking fuel injector
	6. Leaking cold-start fuel injector
	7. Faulty installation
	8. Lines leaking

REVIEW QUESTIONS

1. What are the three most commonly used pump designs?

2. What is the proper way to disconnect and connect plastic fuel line connections?

3. Where are the fuel filters located in the fuel system?

4. What accident and rollover devices are installed in a fuel delivery system?

5. What methods can be used to test a fuel pump?

CHAPTER QUIZ

1. The first fuel filter in the sock inside the fuel tank normally filters particles larger than ___________.
a. 0.001 to 0.003 inch
b. 0.010 to 0.030 inch
c. 10 to 20 microns
d. 70 to 100 microns

2. If it is tripped, which type of safety device will keep the electric fuel pump from operating?
a. Rollover valve
b. Inertia switch
c. Anti-siphoning valve
d. Check valve

3. Fuel lines are constructed from ___________.
   a. seamless steel tubing
   b. nylon plastic
   c. copper and/or aluminum tubing
   d. both a and b
4. What prevents the fuel pump inside the fuel tank from catching the gasoline on fire?
   a. Electricity is not used to power the pump
   b. No air is around the motor brushes
   c. Gasoline is hard to ignite in a closed space
   d. All of the above
5. A good fuel pump should be able to supply how much fuel per minute?
   a. 1/4 pint
   b. 1/2 pint
   c. 1 pint
   d. 0.6 to 0.8 gallons
6. Technician A says that fuel pump modules are spring-loaded so that they can be compressed to fit into the opening. Technician B says that they are spring-loaded to allow for expansion and contraction of plastic fuel tanks. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Most fuel filters are designed to remove particles larger than ___________.
   a. 10 microns
   b. 20 microns
   c. 70 microns
   d. 100 microns
8. The fuel pressure is lower than specified. All of the following are possible causes *except* ___________
   a. poor ground
   b. plugged fuel filter
   c. restriction in the return line
   d. defective fuel pump
9. A fuel pump is being replaced for the third time. Technician A says that the gasoline could be contaminated. Technician B says that wiring to the pump could be corroded. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. After starting the engine, the fuel pressure is too high. What is the most likely cause?
    a. Poor ground
    b. Restricted accumulator
    c. Restricted return line
    d. Stuck-open pressure regulator

Chapter

75

FUEL-INJECTION PARTS AND OPERATION

LEARNING OBJECTIVES:

After studying this chapter, the reader will be able to:

- Describe how electronic fuel injection works.
- Describe types of fuel injection.
- Explain the different methods used to regulate fuel pressure.
- Discuss fuel injectors.
- Discuss fuel-injection modes of operation.
- Describe idle control systems.

KEY TERMS:

Demand delivery system (DDS) 898 • Electronic air control (EAC) 900 • Electronic returnless fuel system (ERFS) 897 • Flare 900 • Fuel rail 898 • Mechanical returnless fuel system (MRFS) 897 • Port fuel-injection 893 • Pressure control valve (PCV) 898 • Pressure vent valve (PVV) 897

ELECTRONIC FUEL INJECTION

OPERATION Electronic fuel-injection systems use the computer to control the following operation of fuel injectors and other functions based on information sent to the computer from the various sensors. Most electronic fuel-injection systems share the following:

1. Electric fuel pump (usually located inside the fuel tank)
2. Fuel-pump relay (controlled by the computer)
3. Fuel-pressure regulator (mechanically operated spring-loaded rubber diaphragm maintains proper fuel pressure)
4. Fuel-injector nozzle or nozzles which are basically 12-volt solenoids

● **SEE FIGURE 75–1**. Most electronic fuel-injection systems use the computer to control the following aspects of their operation:

1. **Pulsing the fuel injectors on and off.** The longer the injectors are held open, the greater the amount of fuel injected into the intake manifold near the intake valve.
2. **Operating the fuel-pump relay circuit.** The computer usually controls the operation of the electric fuel pump located inside (or near) the fuel tank. The computer uses signals from the ignition switch and RPM signals from the ignition module or system to energize the fuel-pump relay circuit.

NOTE: This is a safety feature, because if the engine stalls and the tachometer (engine speed) signal is lost, the computer will shut off (de-energize) the fuel-pump relay and stop the fuel pump.

A **port fuel-injection** design uses a nozzle for each cylinder and the fuel is squirted into the intake manifold about 2 to 3 inches (70 to 100 mm) from the intake valve. ● **SEE FIGURE 75–2**.

TYPES OF FUEL INJECTION

Fuel-injection computer systems require a method for measuring the amount of air the engine is breathing in, in order to match the correct fuel delivery. There are two basic methods used:

1. Speed density
2. Mass airflow

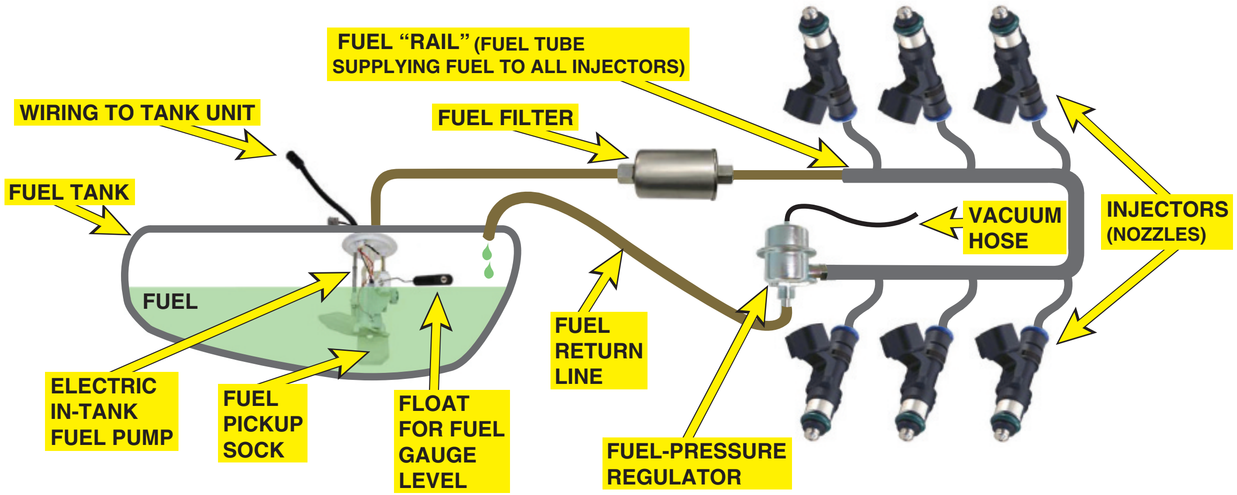

FUEL "RAIL" (FUEL TUBE SUPPLYING FUEL TO ALL INJECTORS)
WIRING TO TANK UNIT
FUEL FILTER
FUEL TANK
FUEL
VACUUM HOSE
INJECTORS (NOZZLES)
ELECTRIC IN-TANK FUEL PUMP
FUEL PICKUP SOCK
FLOAT FOR FUEL GAUGE LEVEL
FUEL RETURN LINE
FUEL-PRESSURE REGULATOR

FIGURE 75–1 Typical port fuel-injection system, indicating the location of various components. Notice that the fuel-pressure regulator is located on the fuel return side of the system. The computer does not control fuel pressure, but does control the operation of the electric fuel pump (on most systems) and the pulsing on and off of the injectors.

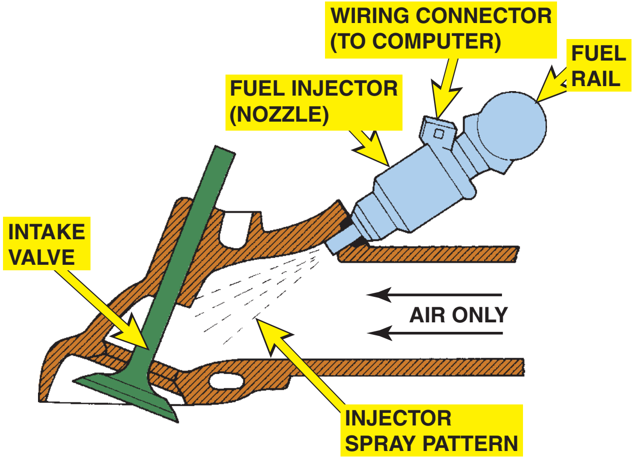

WIRING CONNECTOR (TO COMPUTER)
FUEL RAIL
FUEL INJECTOR (NOZZLE)
INTAKE VALVE
AIR ONLY
INJECTOR SPRAY PATTERN

FIGURE 75–2 A typical port fuel-injection system squirts fuel into the low pressure (vacuum) of the intake manifold, about 3 inch (70 to 100 mm) from the intake valve.

SPEED-DENSITY The speed-density method does not use an air quantity sensor, but rather calculates the amount of fuel required by the engine. The computer uses information from sensors such as the MAP and TP to calculate the needed amount of fuel.

- **MAP sensor.** The value of the intake (inlet) manifold pressure (vacuum) is a direct indication of engine load.
- **TP sensor.** The position of the throttle plate and its rate of change are used as part of the equation to calculate the proper amount of fuel to inject.
- **Temperature sensors.** Both engine coolant temperature (ECT) and intake air temperature (IAT) are used to calculate the density of the air and the need of the engine for fuel. A cold engine (low-coolant temperature) requires a richer air–fuel mixture than a warm engine.

On speed-density systems, the computer calculates the amount of air in each cylinder by using manifold pressure and engine RPM. The amount of air in each cylinder is the major factor in determining the amount of fuel needed. Other sensors provide information to modify the fuel requirements. The formula used to determine the injector pulse width (PW) in milliseconds (ms) is the following:

Injector pulse width = MAP/BARO × RPM/maximum RPM

The formula is modified by values from other sensors, including the following:

- Throttle position (TP)
- Engine coolant temperature (ECT)
- Intake air temperature (IAT)
- Oxygen sensor voltage (O2S)
- Adaptive memory

A fuel injector delivers atomized fuel into the airstream where it is instantly vaporized. All throttle body injection (TBI) systems and early multipoint (port) injection systems used the speed-density method of fuel calculation.

MASS AIRFLOW The formula used by fuel-injection systems that use a mass airflow (MAF) sensor to calculate the injection base pulse width is the following:

Injector pulse width = airflow/RPM

The formula is modified by other sensor values such as the following:

- Throttle position
- Engine coolant temperature
- Barometric pressure
- Adaptive memory

Electronic fuel-injection systems use a solenoid operated injector to spray atomized fuel in timed pulses into the manifold or near the intake valve. Injectors are sequenced and fired by the PCM and their pulse width is determined and controlled by the engine computer. ● **SEE FIGURES 75–3, 75–4, AND 75–5.**

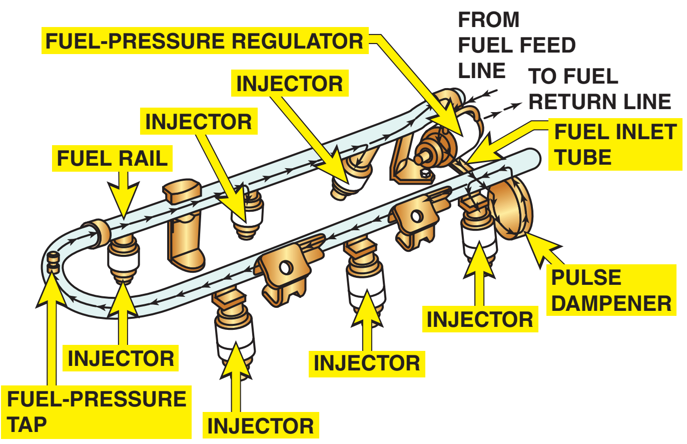

FUEL-PRESSURE REGULATOR
FROM FUEL FEED LINE
TO FUEL RETURN LINE
INJECTOR
INJECTOR
FUEL RAIL
FUEL INLET TUBE
PULSE DAMPENER
INJECTOR
INJECTOR
INJECTOR
FUEL-PRESSURE TAP
INJECTOR

FIGURE 75–3 The injectors receive fuel and are supported by the fuel rail.

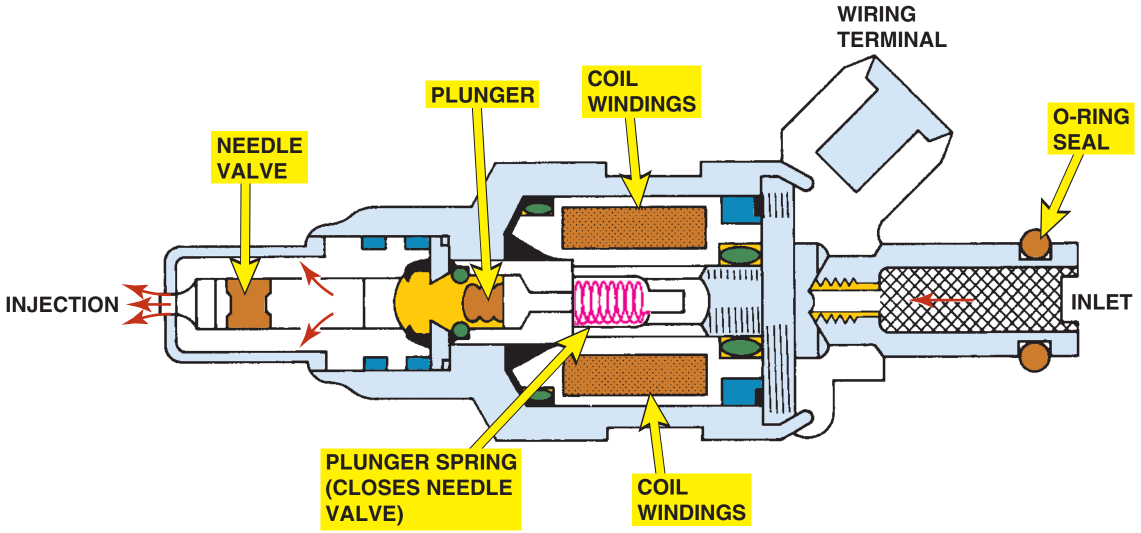

WIRING TERMINAL
COIL WINDINGS
PLUNGER
NEEDLE VALVE
O-RING SEAL
INJECTION
INLET
PLUNGER SPRING (CLOSES NEEDLE VALVE)
COIL WINDINGS

FIGURE 75–4 Cross section of a typical port fuel-injection nozzle assembly. These injectors are serviced as an assembly only; no part replacement or service is possible except for replacement of external O-ring seals.

FREQUENTLY ASKED QUESTION

How Do the Sensors Affect the Pulse Width?

The base pulse width of a fuel-injection system is primarily determined by the value of the MAF or MAP sensor and engine speed (RPM). However, the PCM relies on the input from many other sensors, such as the following, to modify the base pulse width as needed:

- **TP Sensor.** This sensor causes the PCM to command up to 500% (five times) the base pulse width if the accelerator pedal is depressed rapidly to the floor. It can also reduce the pulse width by about 70% if the throttle is rapidly closed.
- **ECT.** The value of this sensor determines the temperature of the engine coolant, helps determine the base pulse width, and can account for up to 60% of the determining factors.
- **BARO.** The BARO sensor compensates for altitude and adds up to about 10% under high-pressure conditions and subtracts as much as 50% from the base pulse width at high altitudes.
- **IAT.** The intake air temperature is used to modify the base pulse width based on the temperature of the air entering the engine. It is usually capable of adding as much as 20% if very cold air is entering the engine or reducing the pulse width by up to 20% if very hot air is entering the engine.
- **O2S.** This is one of the main modifiers to the base pulse width and can add or subtract up to about 20% to 25% or more, depending on the oxygen sensor activity.

FUEL-PRESSURE REGULATOR

PURPOSE AND FUNCTION The pressure regulator and fuel pump work together to maintain the required pressure drop at the injector tips. The fuel-pressure regulator typically consists of a spring-loaded, diaphragm-operated valve in a metal housing.

Fuel-pressure regulators on fuel-return-type fuel-injection systems are installed on the return (downstream) side of the injectors at the end of the fuel rail, or are built into or mounted upon the throttle-body housing. Downstream regulation minimizes fuel-pressure pulsations caused by pressure drop across the injectors as the nozzles open. It also ensures positive fuel pressure at the injectors at all times and holds residual pressure in the lines when the engine is off. On

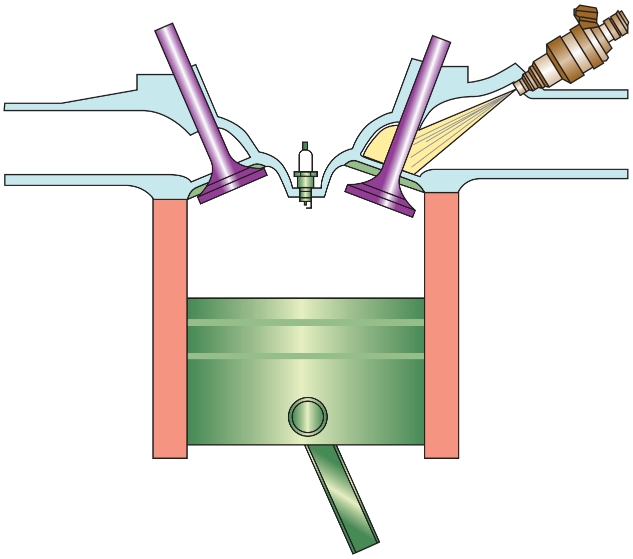


FIGURE 75–5 Port fuel injectors spray atomized fuel into the intake manifold about 3 inches (75 mm) from the intake valve.

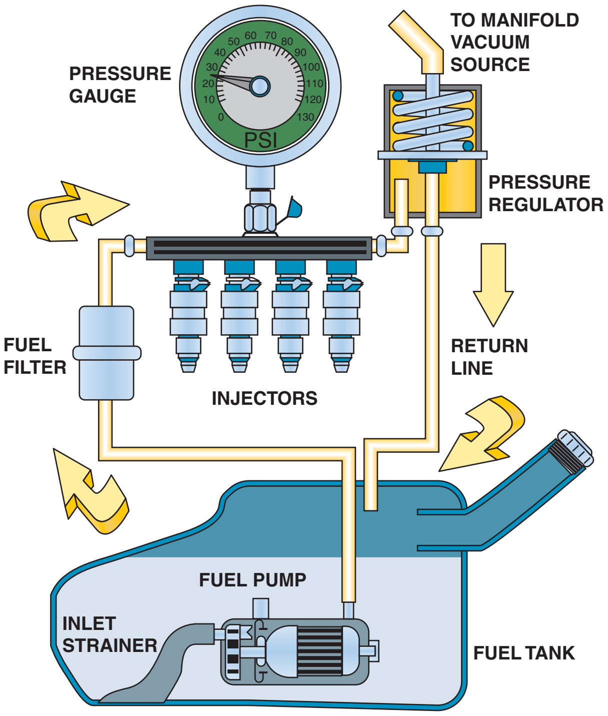


FIGURE 75–6 A typical port fuel-injected system showing a vacuum-controlled fuel-pressure regulator.

mechanical returnless systems, the regulator is located back at the tank with the fuel filter.

OPERATION In order for excess fuel (about 80% to 90% of the fuel delivered) to return to the tank, fuel pressure must overcome spring pressure on the spring-loaded diaphragm to uncover the return line to the tank. This happens when system pressure exceeds operating requirements. With TBI, the regulator is close to the injector tip, so the regulator senses essentially the same air pressure as the injector.

The pressure regulator used in a port fuel-injection system has an intake-manifold vacuum line connection on the regulator vacuum chamber. This allows fuel pressure to be modulated by a combination of spring pressure and manifold vacuum acting on the diaphragm. ● **SEE FIGURES 75–6 AND 75–7.**

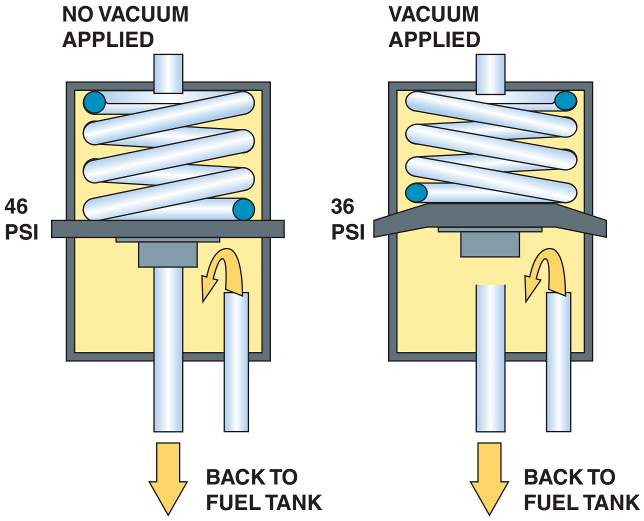


FIGURE 75–7 A typical fuel-pressure regulator that has a spring that exerts 46 pounds of force against the fuel. If 20 inches of vacuum are applied above the spring, the vacuum reduces the force exerted by the spring on the fuel, allowing the fuel to return to the tank at a lower pressure.

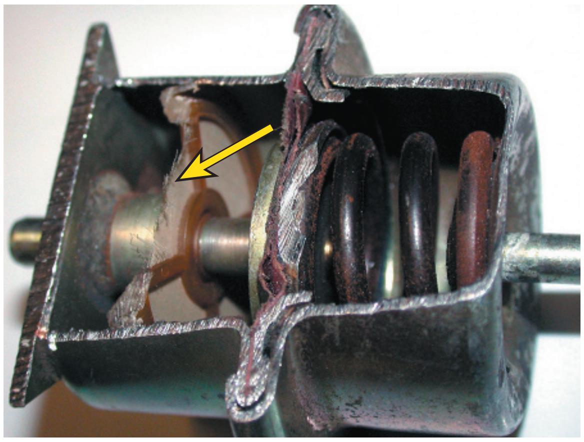


FIGURE 75–8 A lack of fuel flow could be due to a restricted fuel-pressure regulator. Notice the fine screen filter. If this filter were to become clogged, higher than normal fuel pressure would occur.

TECH TIP

Don't Forget the Regulator

Some fuel-pressure regulators contain a 10 micron filter. If this filter becomes clogged, a lack of fuel flow would result. ● **SEE FIGURE 75–8.**

In both TBI and port fuel-injection systems, the regulator shuts off the return line when the fuel pump is not running. This maintains pressure at the injectors for easy restarting after hot soak as well as reducing vapor lock.

Port fuel-injection systems generally operate with pressures at the injector of about 30 to 55 PSI (207 to 379 kPa).

VACUUM-BIASED FUEL-PRESSURE REGULATOR The primary reason why many port fuel-injected systems use a vacuum-controlled fuel-pressure regulator is to ensure that there is a constant pressure drop across the injectors. In a throttle-body fuel-injection system, the injector squirts into the atmospheric pressure regardless of the load on the engine. In a port fuel-injected engine, however, the pressure inside the intake manifold changes as the load on the engine increases.

ENGINE OPERATING CONDITION	INTAKE-MANIFOLD VACUUM	FUEL PRESSURE
Idle or cruise	High	Lower
Heavy load	Low	Higher

The computer can best calculate injector pulse width based on all sensors if the pressure drop across the injector is the same under all operating conditions. A vacuum-controlled fuel-pressure regulator allows the equal pressure drop by reducing the force exerted by the regulator spring at high vacuum (low-load condition), yet allowing the full force of the regulator spring to be exerted when the vacuum is low (high-engine-load condition).

ELECTRONIC RETURNLESS FUEL SYSTEM This system is unique because it does not use a mechanical valve to regulate rail pressure. Fuel pressure at the rail is sensed by a pressure transducer, which sends a low-level signal to a controller. The controller contains logic to calculate a signal to the pump power driver. The power driver contains a high-current transistor that controls the pump speed using pulse width modulation (PWM). This system is called the **electronic returnless fuel system (ERFS)**. ● **SEE FIGURE 75–9**. This transducer can be differentially referenced to manifold pressure for closed-loop feedback, correcting and maintaining the output of the pump to a desired rail setting. This system is capable of continuously varying rail pressure as a result of engine vacuum, engine fuel demand, and fuel temperature (as sensed by an external temperature transducer, if necessary). A **pressure vent valve (PVV)** is employed at the tank to relieve overpressure due to thermal expansion of fuel. In addition, a supply-side bleed, by means of an in-tank reservoir using a supply-side jet pump, is necessary for proper pump operation.

MECHANICAL RETURNLESS FUEL SYSTEM The first production returnless systems employed the **mechanical returnless fuel system (MRFS)** approach. This system has a bypass regulator to control rail pressure that is located in close proximity to the fuel tank. Fuel is sent by the in-tank pump to a chassis-mounted inline filter with excess fuel returning to the tank through a short return line. ● **SEE FIGURE 75–10**. The inline filter may be mounted directly to the tank, thereby eliminating the shortened return line. Supply pressure is regulated on the downstream side of the inline filter to accommodate changing restrictions throughout the filter's service life. This system is limited to constant rail pressure (*CRP) system calibrations, whereas with ERFS, the pressure transducer can be referenced to atmospheric pressure for CRP systems or differentially referenced to intake-manifold pressure for constant differential injector pressure (**CIP) systems.

NOTE: *CRP is referenced to atmospheric pressure, has lower operating pressure, and is desirable for calibrations using speed/air density sensing. **CIP is referenced to manifold pressure, varies rail pressure, and is desirable in engines that use mass airflow sensing.

DEMAND DELIVERY SYSTEM (DDS) Given the experience with both ERFS and MRFS, a need was recognized to develop new returnless technologies that could combine the speed control and constant injector pressure attributes of ERFS together with the cost savings, simplicity, and reliability of MRFS. This

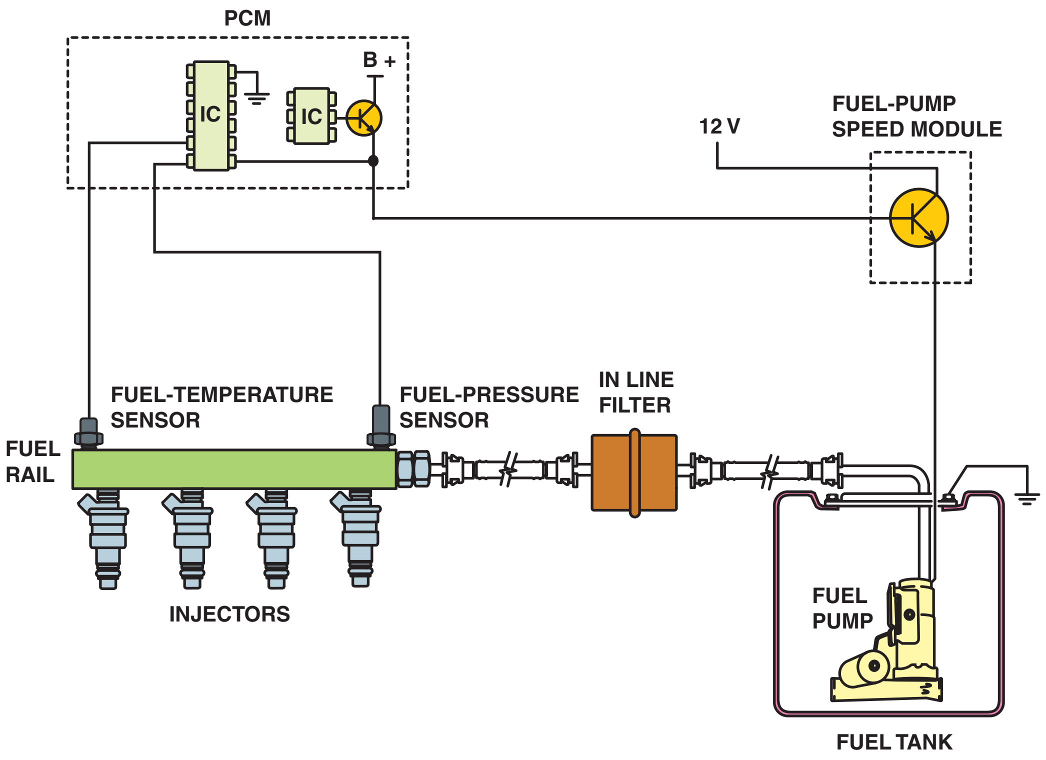


FIGURE 75–9 The fuel-pressure sensor and fuel-temperature sensor are often constructed together in one assembly to help give the PCM the needed data to control the fuel-pump speed.

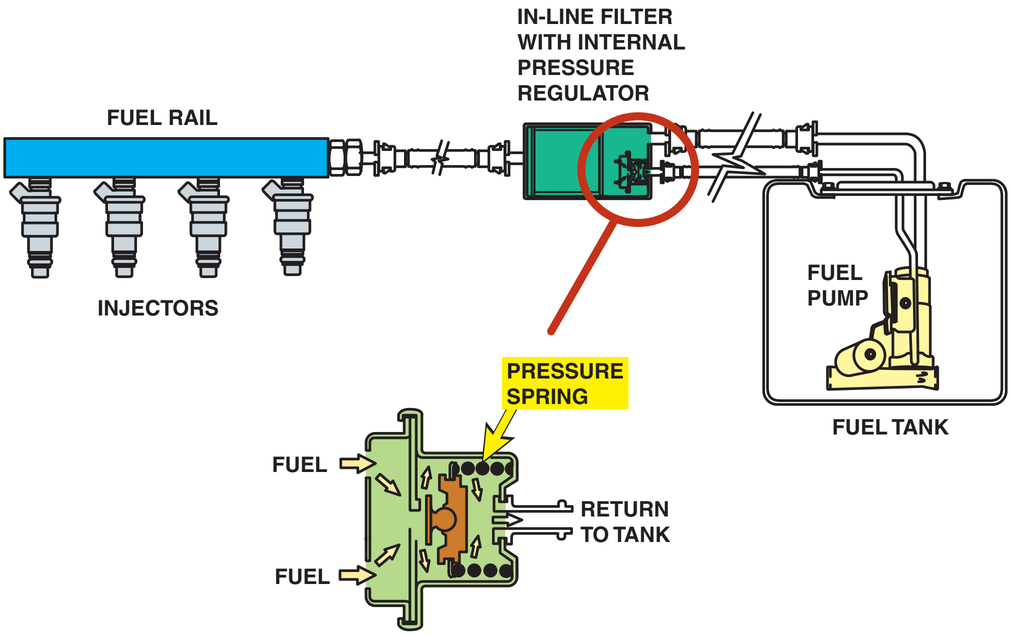

IN-LINE FILTER
WITH INTERNAL
PRESSURE
REGULATOR
FUEL RAIL
INJECTORS
FUEL
PUMP
FUEL TANK
PRESSURE
SPRING
FUEL
FUEL
RETURN
TO TANK

FIGURE 75–10 A mechanical returnless fuel system. The bypass regulator in the fuel tank controls fuel line pressure.

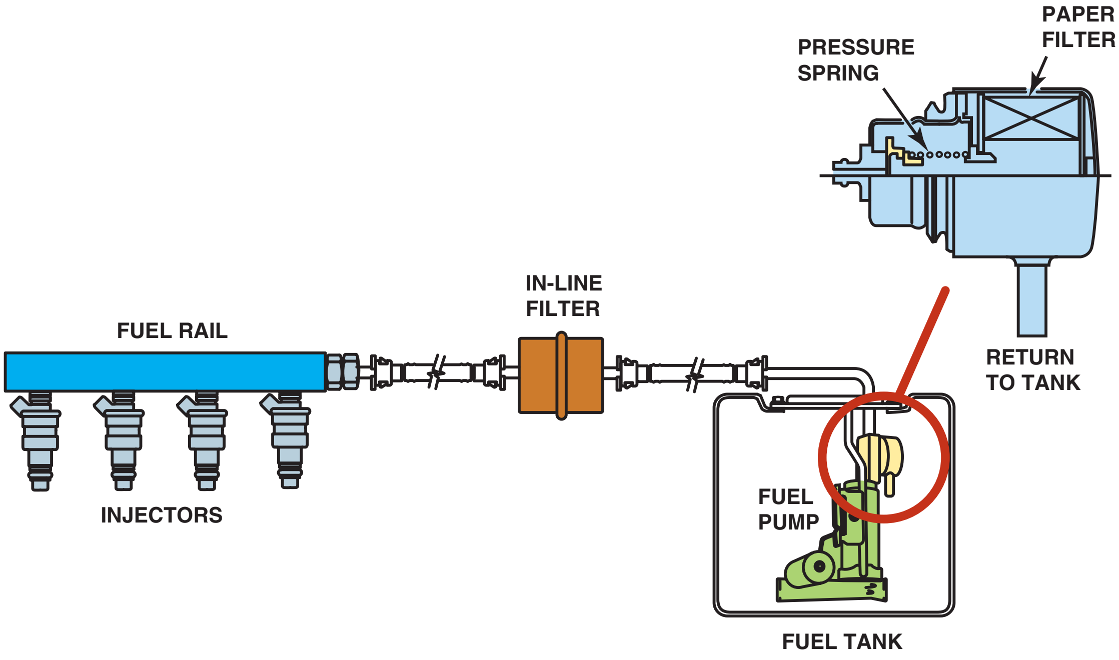

PAPER
FILTER
PRESSURE
SPRING
IN-LINE
FILTER
FUEL RAIL
RETURN
TO TANK
INJECTORS
FUEL
PUMP
FUEL TANK

FIGURE 75–11 A demand delivery system uses a fuel-pressure regulator attached to the fuel pump assembly inside the fuel tank.

new technology also needed to address pulsation dampening/hammering and fuel transient response. Therefore, the **demand delivery system (DDS)** technology was developed. A different form of demand pressure regulator has been applied to the fuel rail. It mounts at the head or port entry and regulates the pressure downstream at the injectors by admitting the precise quantity of fuel into the rail as consumed by the engine. Having demand regulation at the rail improves pressure response to flow transients and provides rail pulsation dampening. A fuel pump and a low-cost, high-performance bypass regulator are used within the appropriate fuel sender. ● **SEE FIGURE 75–11**. They supply a pressure somewhat higher than the required rail set pressure to accommodate dynamic line and filter pressure losses. Electronic pump speed control is accomplished using a smart regulator as an integral flow sensor. A **pressure control valve (PCV)** may also be used and can readily reconfigure an existing design fuel sender into a returnless sender.

FREQUENTLY ASKED QUESTION

Why Are Some Fuel Rails Rectangular Shaped?

A port fuel-injection system uses a pipe or tubes to deliver fuel from the fuel line to the intended fuel injectors. This pipe or tube is called the **fuel rail**. Some vehicle manufacturers construct the fuel rail in a rectangular cross section. ● **SEE FIGURE 75–12**. The sides of the fuel rail are able to move in and out slightly, thereby acting as a fuel pulsator evening out the pressure pulses created by the opening and closing of the injectors to reduce underhood noise. A round cross-sectional fuel rail is not able to deform and, as a result, some manufacturers have had to use a separate dampener.

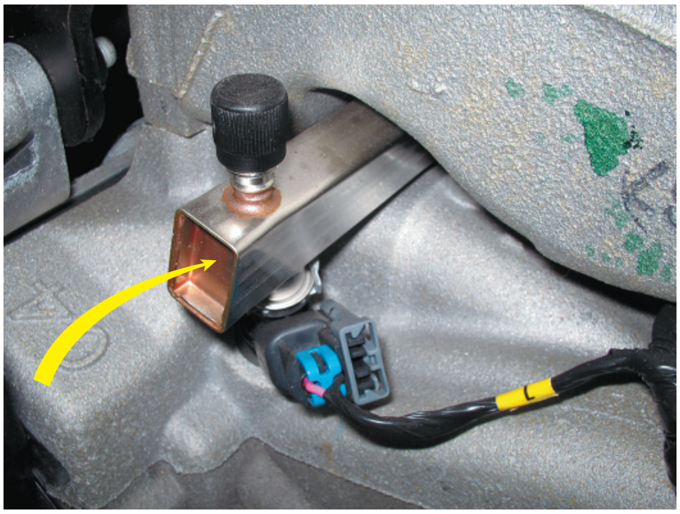


FIGURE 75–12 A rectangular-shaped fuel rail is used to help dampen fuel system pulsations and noise caused by the injectors opening and closing.

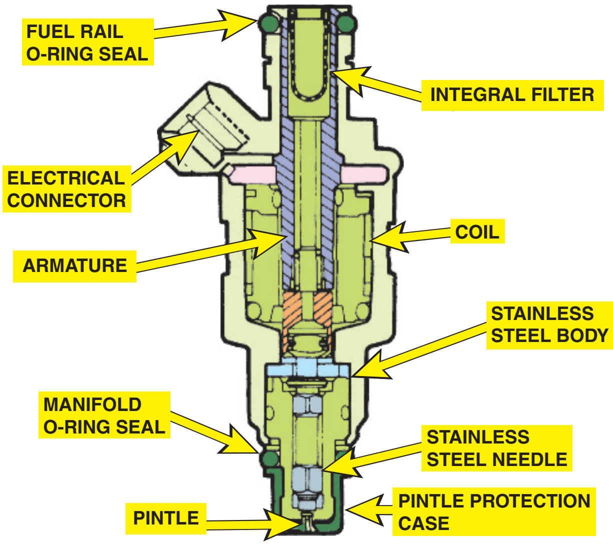


FIGURE 75–13 A multiport fuel injector. Notice that the fuel flows straight through and does not come in contact with the coil windings.

FUEL INJECTORS

EFI systems use 12-volt solenoid-operated injectors. ● **SEE FIGURE 75–13**. This electromagnetic device contains an armature and a spring-loaded needle valve or ball valve assembly. When the computer energizes the solenoid, voltage is applied to the solenoid coil until the current reaches a specified level. This permits a quick pull-in of the armature during turn-on. The armature is pulled off of its seat against spring force, allowing fuel to flow through the inlet filter screen to the spray nozzle, where it is sprayed in a pattern that varies with application. ● **SEE FIGURE 75–14**. The injector opens the same amount each time it is energized, so the amount of fuel injected depends on the length of time the injector remains open. By angling the director hole plates, the injector sprays fuel more directly at the intake valves, which further atomizes and vaporizes the fuel before it enters the combustion chamber. PFI injectors typically are a top-feed design in which fuel enters the top of the injector and passes through its entire length to keep it cool before being injected.

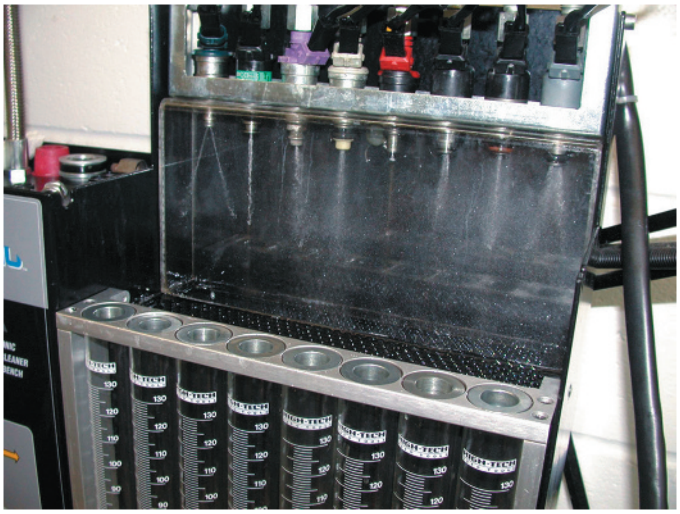


FIGURE 75–14 Each of the eight injectors shown are producing a correct spray pattern for the applications. While all throttle-body injectors spray a conical pattern, most port fuel injections do not.

FUEL-INJECTION MODES OF OPERATION

STARTING MODE When the ignition is turned to the start (on) position, the engine cranks and the PCM energizes the fuel-pump relay. The PCM also pulses the injectors on, basing the pulse width on engine speed and engine coolant temperature. The colder the engine is, the greater the pulse width. Cranking mode air–fuel ratio varies from about 1.5:1 at −40°F (−40°C) to 14.7:1 at 200°F (93°C).

CLEAR FLOOD MODE If the engine becomes flooded with too much fuel, the driver can depress the accelerator pedal to greater than 80% to enter the clear flood mode. When the PCM detects that the engine speed is low (usually below 600 RPM) and the throttle-position (TP) sensor voltage is high (WOT), the injector pulse width is greatly reduced or even shut off entirely, depending on the vehicle.

OPEN-LOOP MODE Open-loop operation occurs during warm-up before the oxygen sensor can supply accurate information to the PCM. The PCM determines injector pulse width based on values from the MAF, MAP, TP, ECT, and IAT sensors.

CLOSED-LOOP MODE Closed-loop operation is used to modify the base injector pulse width as determined by feedback from the oxygen sensor to achieve proper fuel control.

ACCELERATION ENRICHMENT MODE During acceleration, the throttle-position (TP) voltage increases, indicating that a richer air–fuel mixture is required. The PCM then supplies a longer injector pulse width and may even supply extra pulses to supply the needed fuel for acceleration.

DECELERATION ENLEANMENT MODE When the engine decelerates, a leaner air–fuel mixture is required to help reduce emissions and to prevent deceleration backfire. If the deceleration is rapid, the injector may be shut off entirely for a short time and then pulsed on enough to keep the engine running.

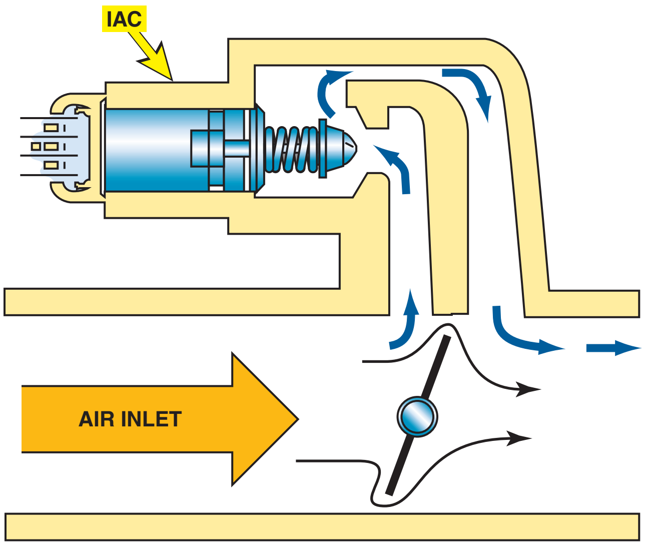


FIGURE 75–15 The small arrows indicate the air bypassing the throttle plate in the closed throttle position. This air is called minimum air. The air flowing through the IAC is the airflow that determines the idle speed.

FUEL SHUTOFF MODE Besides shutting off fuel entirely during periods of rapid deceleration, PCM also shuts off the injector when the ignition is turned off to prevent the engine from continuing to run.

IDLE CONTROL

PURPOSE AND FUNCTION Before electronic throttle control (ETC) systems, the idle speed was controlled by using an air bypass control unit. ● **SEE FIGURE 75–15**. This air bypass or regulator provides needed additional airflow, and thus more fuel. The engine needs more power when cold to maintain its normal idle speed to overcome the increased friction from cold lubricating oil. It does this by opening an intake air passage to let more air into the engine just as depressing the accelerator pedal would open the throttle valve, allowing more air into the engine. The system is calibrated to maintain engine idle speed at a specified value regardless of engine temperature.

Most PFI systems use an idle air control (IAC) motor to regulate idle bypass air. The IAC is computer-controlled, and is either a solenoid-operated valve or a stepper motor that regulates the airflow around the throttle. The idle air control valve is also called an **electronic air control (EAC)** valve.

When the engine stops, most IAC units will retract outward to get ready for the next engine start. When the engine starts, the engine speed is high to provide for proper operation when the engine is cold. Then, as the engine gets warmer, the computer reduces engine idle speed gradually by reducing the number of counts or steps commanded by the IAC.

When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine **flare**. If the engine speed does not flare, then the IAC may not be working (it may be stuck in one position).

STEPPER MOTOR OPERATION A digital output is used to control stepper motors. Stepper motors are direct-current motors that move in fixed steps or increments from de-energized (no voltage) to fully energized (full voltage). A stepper motor often has as many as 120 steps of motion.

A common use for stepper motors is as an idle air control (IAC) valve, which controls engine idle speeds and prevents stalls due to changes in engine load. When used as an IAC, the stepper motor is usually a reversible DC motor that moves in increments, or steps. The motor moves a shaft back and forth to operate a conical valve. When the conical valve is moved back, more air bypasses the throttle plates and enters the engine, increasing idle speed. As the conical valve moves inward, the idle speed decreases.

When using a stepper motor that is controlled by the PCM, it is very easy for the PCM to keep track of the position of the stepper motor. By counting the number of steps that have been sent to the stepper motor, the PCM can determine the relative position of the stepper motor. While the PCM does not actually receive a feedback signal from the stepper motor, it does know how many steps forward or backward the motor should have moved.

A typical stepper motor uses a permanent magnet and two electromagnets. Each of the two electromagnetic windings is controlled by the computer. The computer pulses the windings and changes the polarity of the windings to cause the armature of the stepper motor to rotate 90 degrees at a time. Each 90-degree pulse is recorded by the computer as a "count" or "step"; therefore, the name given to this type of motor. ● **SEE FIGURE 75–16**.

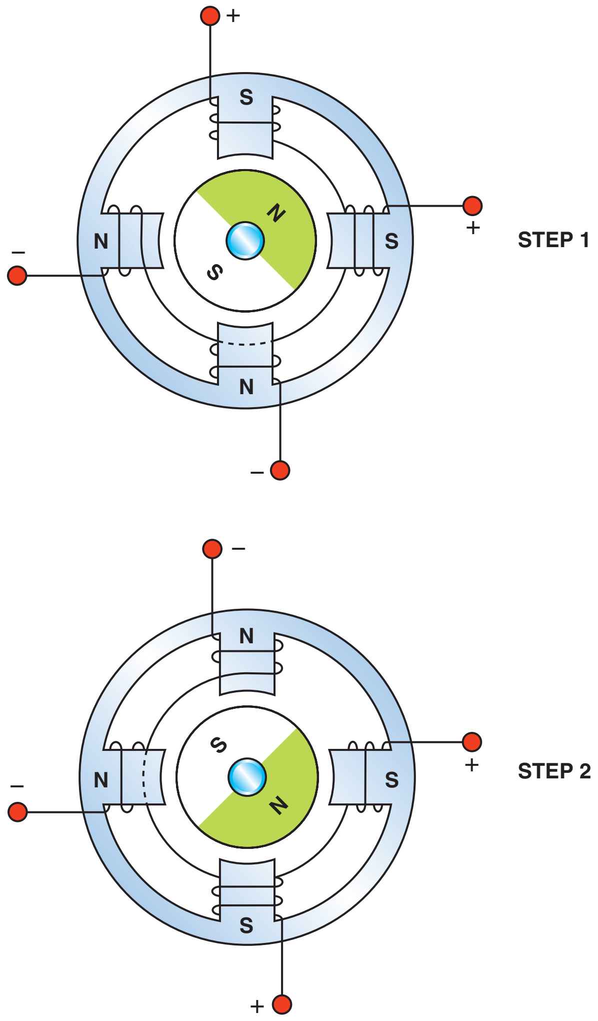


FIGURE 75–16 Most stepper motors use four wires, which are pulsed by the computer to rotate the armature in steps.

ELECTRONIC THROTTLE CONTROL SYSTEM The idle speed on newer vehicles is controlled by the electric throttle control (ETC) system. Using an ETC system on an engine has many advantages over a conventional method that uses a mechanical cable between the accelerator pedal and the throttle valve.

The major components of an ETC system include the following:

- Accelerator pedal position (APP) sensor
- ETC actuator motor and spring
- Throttle position (TP) sensor
- Electronic control unit

See Chapter 77 for more details on ETC systems.

REVIEW QUESTIONS

1. What are the two basic methods used for measuring the amount of air the engine is breathing in, in order to match the correct fuel delivery?
2. What is the purpose of the vacuum-controlled (biased) fuel-pressure regulator?
3. How many sensors are used to determine the base pulse width on a speed-density system?
4. How many sensors are used to determine the base pulse width on a mass airflow system?
5. What are the three types of returnless fuel-injection systems?

CHAPTER QUIZ

1. Technician A says that the fuel-pump relay is usually controlled by the PCM. Technician B says that the injector sprays fuel above the throttle plate. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Why are some fuel rails rectangular in shape?
   a. Increases fuel pressure
   b. Helps keep air out of the injectors
   c. Reduces noise
   d. Increases the speed of the fuel through the fuel rail
3. Which fuel-injection system uses the MAP sensor as the primary sensor to determine the base pulse width?
   a. Speed density
   b. Mass airflow
   c. Demand delivery
   d. Mechanical returnless
4. Why is a vacuum line attached to a fuel-pressure regulator on many fuel-injected engines?
   a. To draw fuel back into the intake manifold through the vacuum hose
   b. To create an equal pressure drop across the injectors
   c. To raise the fuel pressure at idle
   d. To lower the fuel pressure under heavy engine load conditions to help improve fuel economy
5. Which sensor has the greatest influence on injector pulse width besides the MAF sensor?
   a. IAT
   b. BARO
   c. ECT
   d. TP
6. Technician A says that the port fuel-injection injectors operate using 5 volts from the computer. Technician B says that electronic fuel injectors use 12 volts to operate. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Which type of electronic fuel-injection system uses a fuel-temperature and/or fuel-pressure sensor?
   a. All port fuel-injected engines
   b. TBI units only
   c. Electronic returnless systems
   d. Demand delivery systems
8. Which of these is NOT a mode of operation for electronic fuel injection?
   a. Clear flood
   b. Open loop
   c. Closed loop
   d. Mid loop
9. Where is the fuel-pressure regulator located on a vacuum biased port fuel-injection system?
   a. In the tank
   b. At the inlet of the fuel rail
   c. At the outlet of the fuel rail
   d. Near or on the fuel filter
10. What type of device is used to control idle speed?
   a. ETC system
   b. Stepper motor
   c. Either a or b
   d. Neither a nor b

Chapter

76

GASOLINE DIRECT-INJECTION SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain how a direct fuel-injection system works.
- Describe the direct-injection fuel delivery system.
- Describe modes of operation.
- Discuss GDI piston designs.
- Discuss port/direct injection systems.
- Discuss engine start systems.
- Discuss GDI service issues.

KEY TERMS:

Gasoline direct-injection (GDI) 902 • Homogeneous mode 904 • Spark ignition direct injection (SIDI) 902 • Stratified mode 904

DIRECT FUEL INJECTION

PORT INJECTION VS. DIRECT INJECTION Unlike a port fuel-injection system, a GDI system varies the fuel pressure to achieve greater fuel delivery using a very short pulse time, which is usually less than one millisecond.

- Port Fuel Injection–Constant fuel pressure but variable injector pulse-width.
- GDI–Almost constant injector pulse-width with varying fuel pressure.

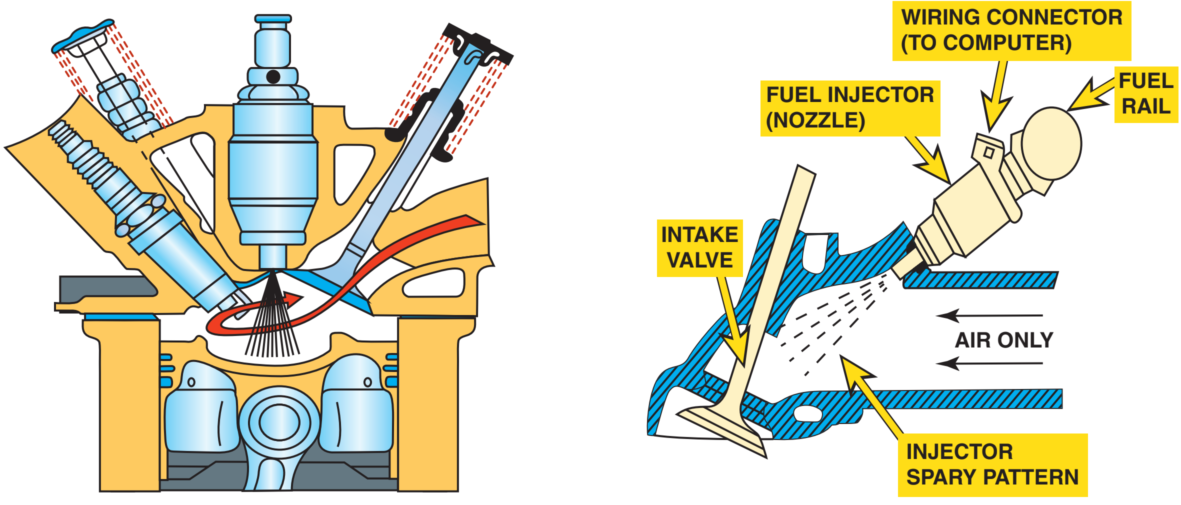
In a port fuel injection system, the fuel is squirted into the intake manifold or in the intake port upstream from the intake valve. The atomized fuel then mixes with the air entering the cylinder on the way to the combustion chamber.

In a **gasoline direct-injection (GDI)** system the fuel is squirted directly into the combustion chamber. ● **SEE FIGURE 76–1**. General Motors refers to GDI as a **spark ignition direct injection (SIDI)** system.

PARTS AND OPERATION A direct-injection system sprays high-pressure fuel, up to 2,900 PSI, into the combustion chamber as the piston approaches the top of the compression stroke. With the combination of high-pressure swirl injectors and modified combustion chamber, almost instantaneous vaporization occurs. This combined with a higher compression ratio allows a direct-injected engine to operate using a leaner-than-normal air–fuel ratio, which results in improved fuel economy with higher power output and reduced exhaust emissions. ● **SEE FIGURE 76–2**.

ADVANTAGES OF GASOLINE DIRECT INJECTION The use of direct injection compared with port fuel injection has many advantages including the following:

- Improved fuel economy due to reduced pumping losses and heat loss
- Allows a higher compression ratio for higher engine efficiency
- Allows the use of lower-octane gasoline
- The volumetric efficiency is higher
- Less need for extra fuel for acceleration
- Improved cold starting and throttle response
- Allows the use of greater percentage of EGR to reduce exhaust emissions
- Up to 25% improvement in fuel economy
- 12% to 15% reduction in exhaust emissions



Direct injection into cylinder

Injection upstream near the valve

FIGURE 76–1 A comparison of a port fuel injection system (right) to a gasoline direct injection (GDI) system on the left.

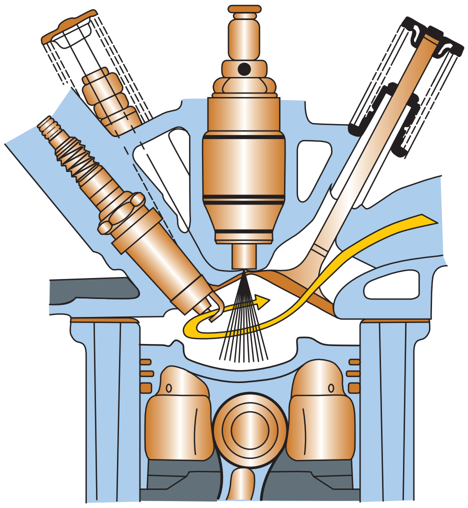


FIGURE 76–2 A gasoline direct-injection system injects fuel under high pressure directly into the combustion chamber.

DISADVANTAGES OF GASOLINE DIRECT INJECTION

- Higher cost due to high-pressure pump and injectors
- More components compared with port fuel injection
- Due to the high compression, a NO$_x$ storage catalyst is sometimes required to meet emission standards, especially in Europe. ● **SEE FIGURE 76–3**.
- Uses up to six operating modes depending on engine load and speed, which requires more calculations to be performed by the Powertrain Control module (PCM).

DIRECT-INJECTION FUEL DELIVERY SYSTEM

LOW-PRESSURE SUPPLY PUMP The fuel pump in the fuel tank supplies fuel to the high-pressure fuel pump at a pressure of approximately 60 PSI. The fuel filter is located in the fuel tank and is part of the fuel pump assembly. It is not usually serviceable as a separate component; the engine control module (ECM) controls the output of the high-pressure pump, which has a range between 500 PSI (3,440 kPa) and 2,900 PSI (15,200 kPa) during engine operation. ● **SEE FIGURES 76–3 AND 76–4**.

HIGH-PRESSURE PUMP In a General Motors system, the engine control module (ECM) controls the output of the high-pressure pump, which has a range between 500 PSI (3,440 kPa) and 2,900 PSI (15,200 kPa) during engine operation. The high-pressure fuel pump connects to the pump in the fuel tank through the low-pressure fuel line. The pump consists of a single-barrel piston pump, which is driven by the engine camshaft. The pump plunger rides on a three-lobed cam on the camshaft. The high-pressure pump is cooled and lubricated by the fuel itself. ● **SEE FIGURE 76–5**.

FUEL RAIL The fuel rail stores the fuel from the high-pressure pump and stores high-pressure fuel for use to each injector. All injectors get the same pressure fuel from the fuel rail.

FUEL PRESSURE REGULATOR An electric pressure-control valve is installed between the pump inlet and outlet valves. The fuel rail pressure sensor connects to the PCM with three wires:

- 5-volt reference
- ground
- signal

The sensor signal provides an analog signal to the PCM that varies in voltage as fuel rail pressure changes. Low pressure results in a low-voltage signal and high pressure results in a high-voltage signal.

The PCM uses internal drivers to control the power feed and ground for the pressure control valve. When both PCM drivers are deactivated, the inlet valve is held open by spring pressure. This causes the high-pressure fuel pump to default to low-pressure mode. The fuel from the high-pressure fuel pump flows through a line to the fuel rail and injectors. The actual operating pressure can vary from as low as 500 PSI (3,440 kPa) at idle to over 2,000 PSI (13,800 kPa) during high speed or heavy load conditions. ● **SEE FIGURE 76–6**.

GDI FUEL INJECTORS Each high-pressure fuel injector assembly is an electrically magnetic injector mounted in the cylinder head. In the GDI system, the PCM controls each fuel injector with 50 to 90 volts (usually 60 to 70 volts), depending on the system, which is created by a boost capacitor in the PCM. During the high-voltage boost phase, the capacitor is discharged through an injector, allowing for initial injector opening. The injector is then held open with 12 volts. The high-pressure fuel injector has a small slit or six precision-machined holes that generate the desired spray

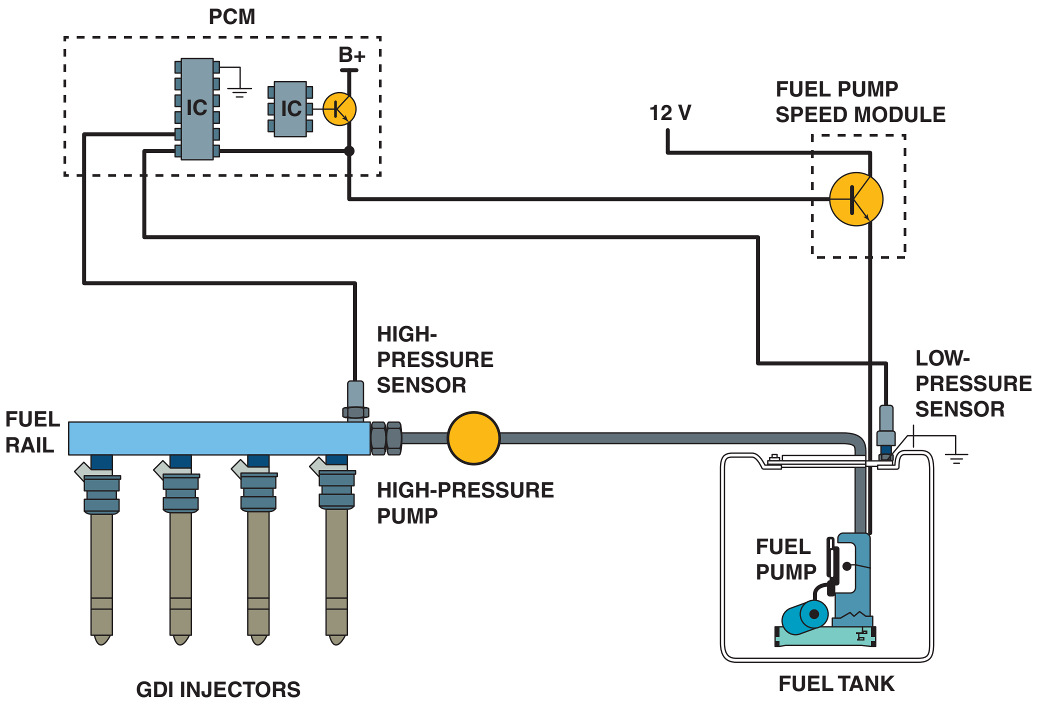

PCM
B+
IC
IC
12 V
FUEL PUMP SPEED MODULE
HIGH-PRESSURE SENSOR
LOW-PRESSURE SENSOR
FUEL RAIL
HIGH-PRESSURE PUMP
FUEL PUMP
GDI INJECTORS
FUEL TANK

FIGURE 76–3 A GDI system uses a low-pressure pump in the gas tank similar to other types of fuel-injection systems. The PCM controls the pressure of the high-pressure pump using sensor inputs.

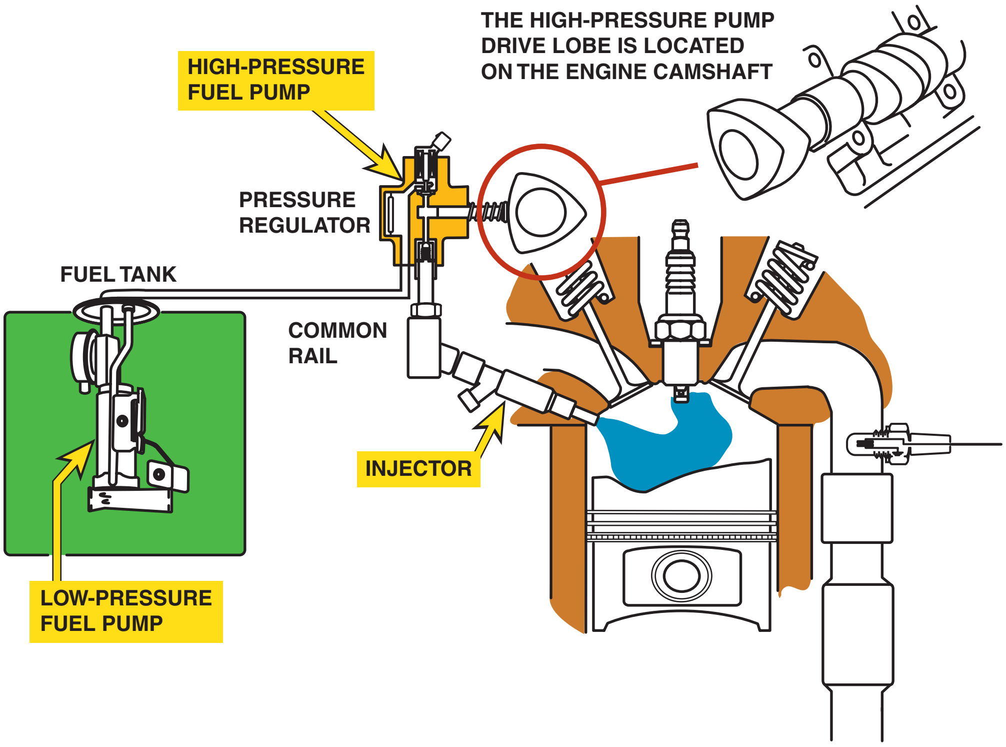

THE HIGH-PRESSURE PUMP DRIVE LOBE IS LOCATED ON THE ENGINE CAMSHAFT
HIGH-PRESSURE FUEL PUMP
PRESSURE REGULATOR
FUEL TANK
COMMON RAIL
INJECTOR
LOW-PRESSURE FUEL PUMP

FIGURE 76–4 A typical direct-injection system uses two pumps-one low-pressure electric pump in the fuel tank and the other a high-pressure pump driven by the camshaft. The high-pressure fuel system operates at a pressure as low as 500 PSI during light load conditions and as high as 2,900 PSI under heavy loads.

pattern. The injector also has an extended tip to allow for cooling from a water jacket in the cylinder head.

● **SEE CHART 76–1** for an overview of the differences between a port fuel-injection system and a GDI system.

MODES OF OPERATION

The two basic modes of operation include the following:

1. **Stratified mode**. In this mode of operation, the air–fuel mixture is richer around the spark plug than it is in the rest of the cylinder.
2. **Homogeneous mode**. In this mode of operation, the air–fuel mixture is the same throughout the cylinder.

There are variations of these modes that can be used to fine-tune the air–fuel mixture inside the cylinder. For example, Bosch, a supplier to many vehicle manufacturers, uses the following six modes of operation:

- **Homogeneous mode.** In this mode, the injector is pulsed one time to create an even air–fuel mixture in the cylinder. The injection occurs during the intake stroke. This mode is used during high-speed and/or high-torque conditions.
- **Homogeneous lean mode.** Similar to the homogeneous mode except that the overall air–fuel mixture is slightly lean

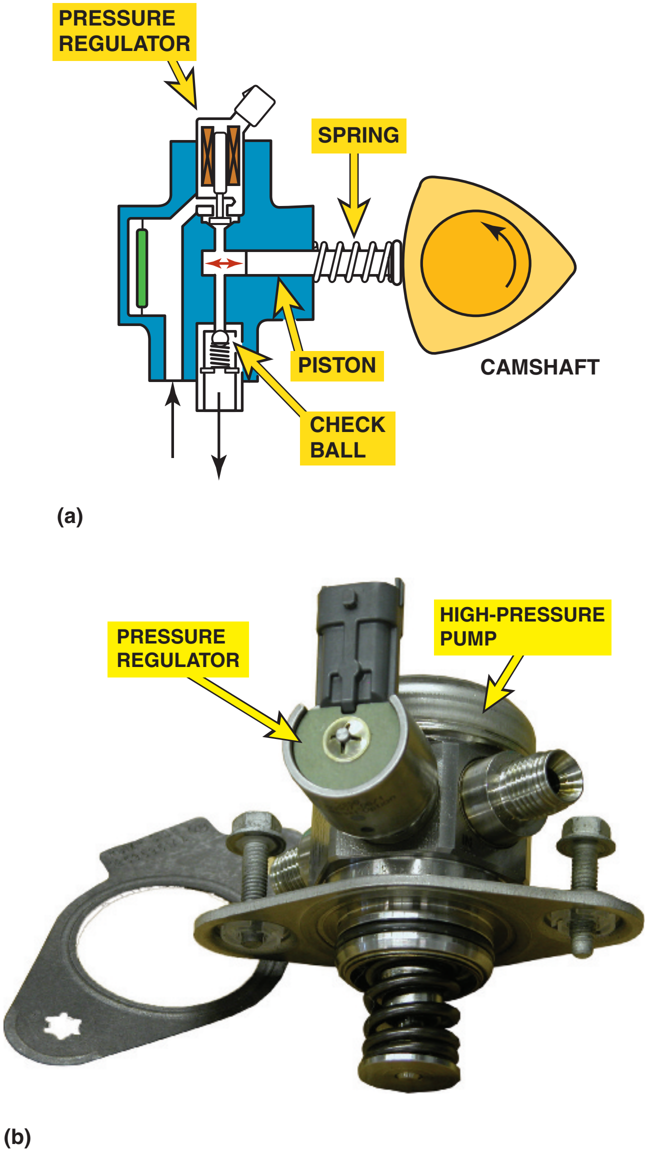


FIGURE 76–5 (a) A typical camshaft-driven high-pressure pump used to increase fuel pressure to 2,000 PSI or higher. (b) The high-pressure pump assembly removed from the engine. Many GDI engines use a roller where the high-pressure pump rides against the cam lobes to help reduce friction and wear.

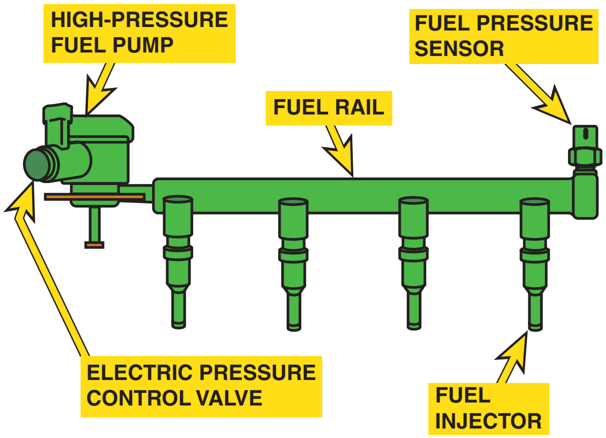


FIGURE 76–6 A GDI fuel rail and pump assembly with the electric pressure control valve.

PORT FUEL-INJECTION SYSTEM COMPARED WITH GDI SYSTEM

	PORT FUEL INJECTION	GASOLINE DIRECT INJECTION
Fuel pressure	35–60 PSI	Lift pump—50 to 60 PSI High-pressure pump—500 to 2,900 PSI
Injection pulse width at idle	1.5–3.5 ms	About 0.4 ms (400 µs)
Injector resistance	12–16 ohms	1–3 ohms
Injector voltage	6 V for low-resistance injectors, 12 V for most injectors	50–90 V
Number of injections per event	One	1–3
Engine compression ratio	8:1–11:1	11:1–13:1

CHART 76–1

A comparison chart showing the major differences between a port fuel-injection system and a GDI system.

for better fuel economy. The injection occurs during the intake stroke. This mode is used under steady, light-load conditions.

- **Stratified mode.** In this mode of operation, the injection occurs just before the spark occurs resulting in lean combustion, reducing fuel consumption.
- **Homogeneous stratified mode.** In this mode, there are two injections of fuel:
  - The first injection is during the intake stroke.
  - The second injection is during the compression stroke.

  As a result of these double injections, the rich air–fuel mixture around the spark plug is ignited first. Then, the rich mixture ignites the leaner mixture. The advantages of this mode include lower exhaust emissions than the stratified mode and less fuel consumption than the homogeneous lean mode.
- **Homogeneous knock protection mode.** The purpose of this mode is to reduce the possibility of spark knock from occurring under heavy loads at low engine speeds. There are two injections of fuel:
  - The first injection occurs on the intake stroke.
  - The second injection occurs during the compression stroke with the overall mixture being stoichiometric.

  As a result of this mode, the PCM does not need to retard ignition timing as much to operate knock-free.
- **Stratified catalyst heating mode.** In this mode, there are two injections:
  - The first injection is on the compression stroke just before combustion.

- The second injection is after combustion occurs to heat the exhaust. This mode is used to quickly warm the catalytic converter and to burn the sulfur from the NO_x catalyst.

PISTON TOP DESIGNS

GDI systems use a variety of shapes of piston and injector locations, depending on make and model of engine. Three of the most locations, used designs include the following:

- **Spray-guided combustion.** In this design, the injector is placed in the center of the combustion chamber and injects fuel into the dished-out portion of the piston. The shape of the piston helps guide and direct the mist of fuel in the combustion chamber. ● **SEE FIGURE 76–7**.
- **Swirl combustion.** This design uses the shape of the piston and the position of the injector at the side of the combustion chamber to create turbulence and swirl of the air–fuel mixture. ● **SEE FIGURE 76–8**.

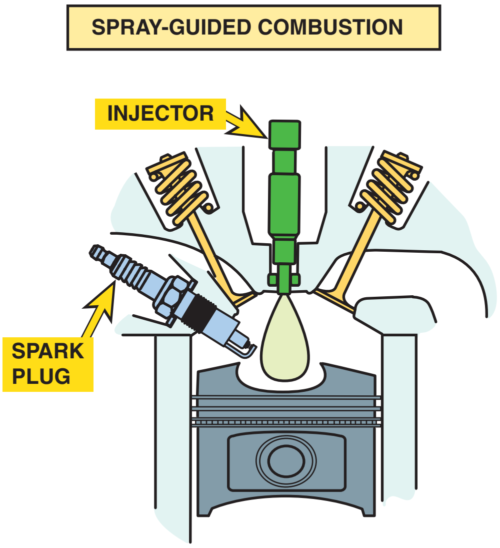


FIGURE 76–7 In this design, the fuel injector is at the top of the cylinder and sprays fuel into the cavity of the piston.

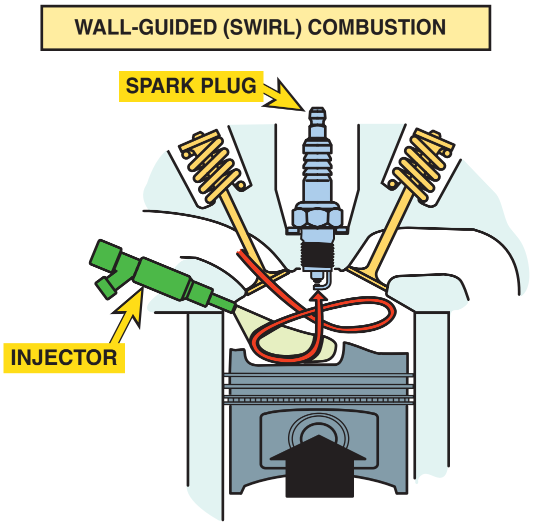


FIGURE 76–8 The side injector combines with the shape of the piston to create a swirl as the piston moves up on the compression stroke.

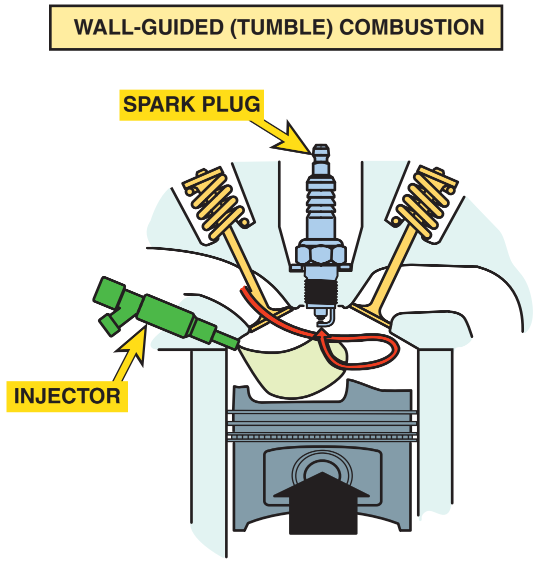


FIGURE 76–9 The piston creates a tumbling force as it moves upward.

- **Tumble combustion.** Depending on when the fuel is injected into the combustion chamber helps determine how the air–fuel mixture is moved or tumbled. ● **SEE FIGURE 76–9**.

PORT- AND DIRECT-INJECTION SYSTEMS

OVERVIEW Many vehicles use gasoline direct injection and in some engines they also use a conventional port fuel injection system. The system combines direct-injection injectors located in the combustion chamber with port fuel injectors in the intake manifold near the intake valve. The two injection systems work together to supply the fuel needed by the engine. ● **SEE FIGURE 76–10**. for how the two systems are used throughout the various stages of engine operation.

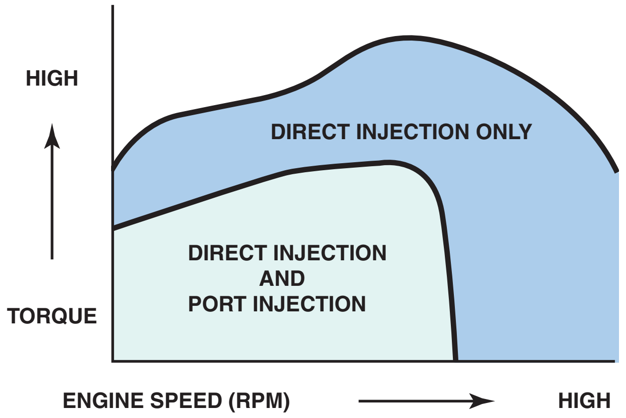


FIGURE 76–10 Notice that there are conditions when the port fuel injector, located in the intake manifold, and the gasoline direct injector, located in the cylinder, both operate to provide the proper air–fuel mixture.

COLD-START WARM-UP To help reduce exhaust emissions after a cold start, the fuel system uses a stratified charge mode. This results in a richer air–fuel mixture near the spark plug and allows for the spark to be retarded to increase the temperature of the exhaust. As a result of the increased exhaust temperature, the catalytic converter rapidly reaches operating temperature, which reduces exhaust emissions.

ENGINE START SYSTEM

An engine equipped with gasoline direct injection could use the system to start the engine. This is most useful during idle stop mode when the engine is stopped while the vehicle is at a traffic light to save fuel. The steps used in the Mazda start-stop system, called the *smart idle stop system (SISS)*, allow the engine to be started without a starter motor and include the following steps:

STEP 1 The engine is stopped. The normal stopping position of an engine when it stops is 70 degrees before top dead center, plus or minus 20 degrees. This is because the engine stops with one cylinder on the compression stroke and the PCM can determine the cylinder position, using the crankshaft and camshaft position sensors.

STEP 2 When a command is made to start the engine by the PCM, fuel is injected into the cylinder that is on the compression stroke and ignited by the spark plug.

STEP 3 The piston on the compression stroke is forced downward forcing the crankshaft to rotate counterclockwise or in the opposite direction to normal operation.

STEP 4 The rotation of the crankshaft forces the companion cylinder toward the top of the cylinder.

STEP 5 Fuel is injected and the spark plug is fired, forcing the piston down, causing the crankshaft to rotate in the normal (clockwise) direction. Normal combustion events continue allowing the engine to keep running.

GDI ISSUES

NOISE ISSUES GDI systems operate at high pressure and the injectors can often be heard with the engine running and the hood open. This noise can be a customer concern because the clicking sound is similar to noisy valves. If a noise issue is the customer concern, check the following:

- Check a similar vehicle to determine if the sound is louder or more noticeable than normal.
- Check that nothing under the hood is touching the fuel rail. If another line or hose is in contact with the fuel rail, the sound of the injectors clicking can be transmitted throughout the engine, making the sound more noticeable.
- Check for any technical service bulletins (TSBs) that may include new clips or sound insulators to help reduce the noise.

CARBON ISSUES Carbon is often an issue in engines equipped with GDI systems. Carbon can affect engine operation by accumulating in two places:

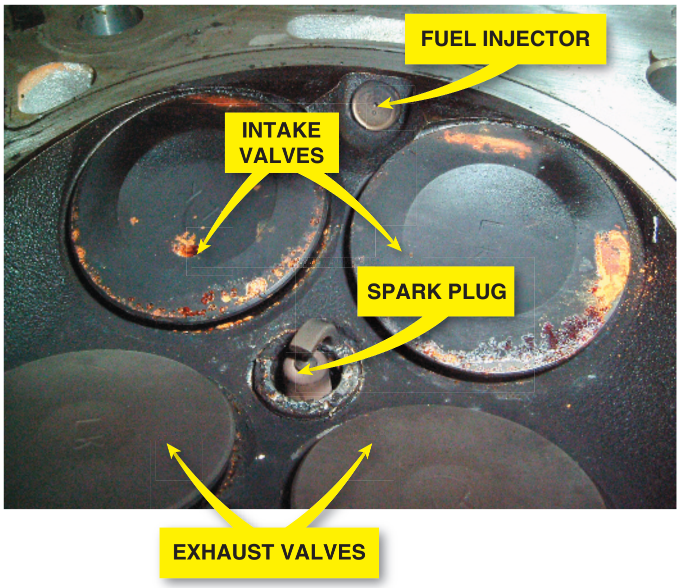


FIGURE 76–11 There may become a driveability issue because the GDI injector is exposed to combustion carbon and fuel residue.

- **On the injector itself.** Because the injector tip is in the combustion chamber, fuel residue can accumulate on the injector, reducing its ability to provide the proper spray pattern and amount of fuel. Some injector designs are more likely to be affected by carbon than others. For example, if the injector uses small holes, these tend to become clogged more than an injector that uses a single slit opening where the fuel being sprayed out tends to blast away any carbon. ● **SEE FIGURE 76–11**.
- **The backside of the intake valve.** This is a common place for fuel residue and carbon to accumulate on engines equipped with gasoline direct injection. The accumulation of carbon on the intake valve can become so severe that the engine will start and idle, but lack power to accelerate the vehicle. The carbon deposits restrict the airflow into the cylinder enough to decrease engine power.

NOTE: Engines that use both port fuel and GDI injectors do not show intake valve deposits. It is thought that the fuel being sprayed onto the intake valve from the port fuel injector helps keep the intake valve clean.

CARBON PREVENTION Most experts recommend the use of Techron®, a fuel system dispersant, to help keep carbon from accumulating. The use of a dispersant every six months or every 6,000 miles has proven to help prevent injector and intake valve deposits.

If the lack of power is discovered and there are no stored diagnostic trouble codes, a conventional carbon cleaning procedure will likely restore power if the intake valves are coated.

SERVICING PRECAUTIONS Because of the high pressures involved, it is important to adhere to safety precautions when working on GDI system which include the following:

- Don't reuse high-pressure lines. The ball-ends deform when tightened and will not seal if reused. ● **SEE FIGURE 76–12**.

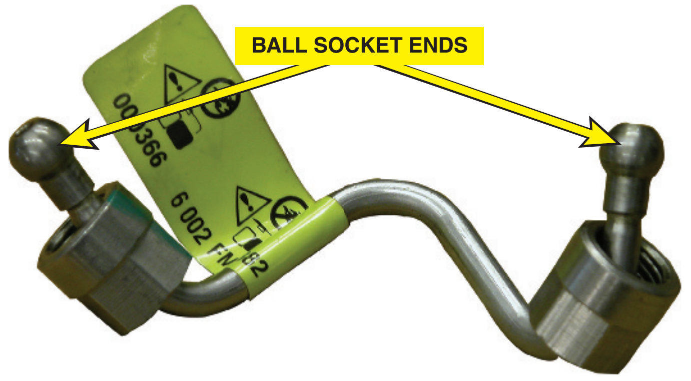


FIGURE 76–12 The high-pressure lines use a ball and socket connection. The ball end deforms when the line is tightened and must be replaced with a new part whenever it is removed.

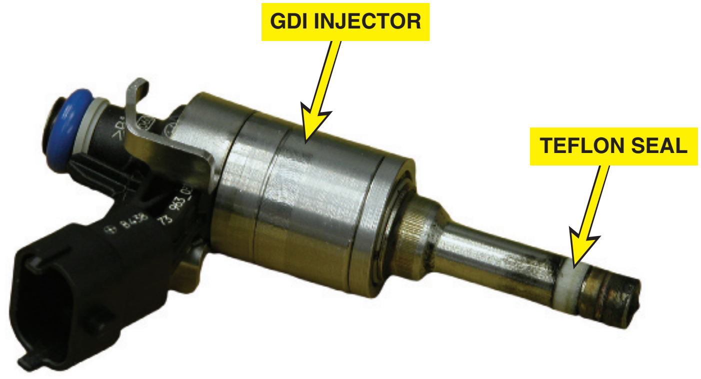


FIGURE 76–13 Whenever a GDI fuel injector is removed, a new Teflon seal must be installed to ensure a leak-free connection in the combustion chamber.

- Always use a torque wrench when tightening fuel line fittings.
- Do not loosen any fuel fittings with the engine cranking or running.
- Always replace the Teflon seal whenever replacing or reinstalling an GDI injector. ● **SEE FIGURE 76–13**.

Always check service information for the exact procedures to follow when working on a GDI system.

REVIEW QUESTIONS

1. What are two advantages of gasoline direct injection compared with port fuel injection?
2. What are two disadvantages of gasoline direct injection compared with port fuel injection?
3. How is the fuel delivery system different from a port fuel-injection system?
4. What are the basic modes of operation of a GDI system?
5. What should be replaced anytime it is removed from the high-pressure GDI fuel system?

CHAPTER QUIZ

1. Where is the fuel injected in an engine equipped with gasoline direct injection?
   - **a.** Into the intake manifold near the intake valve
   - **b.** Directly into the combustion chamber
   - **c.** Above the intake port
   - **d.** In the exhaust port
2. The fuel pump inside the fuel tank on a vehicle equipped with gasoline direct injection produces about what fuel pressure?
   - **a.** 5 to 10 PSI
   - **b.** 10 to 20 PSI
   - **c.** 20 to 40 PSI
   - **d.** 50 to 60 PSI
3. The high-pressure fuel pumps used in GDI systems are powered by _________.
   - **a.** electricity (DC motor)
   - **b.** electricity (AC motor)
   - **c.** the camshaft
   - **d.** the crankshaft
4. The high-pressure fuel pump pressure is regulated by using _________.
   - **a.** an electric pressure-control valve
   - **b.** a vacuum-biased regulator
   - **c.** a mechanical regulator at the inlet to the fuel rail
   - **d.** a non-vacuum biased regulator
5. A GDI equipped engine can _________.
   - **a.** be used to start the engine
   - **b.** be used without an ignition system
   - **c.** meet emissions standards without a catalytic converter
   - **d.** All of the above
6. The fuel injectors used on a GDI system are pulsed on using what voltage?
   - **a.** 12 to 14 volt
   - **b.** 50 to 90 volt
   - **c.** 100 to 110 volt
   - **d.** 200 to 220 volt
7. Which mode of operation results in a richer air–fuel mixture near the spark plug?
   - **a.** Stoichiometric
   - **b.** Homogeneous
   - **c.** Stratified
   - **d.** Knock protection
8. Some engines that use a GDI system have carbon issues _________.
   - **a.** on the intake valves
   - **b.** on the exhaust valves
   - **c.** on the fuel injectors
   - **d.** Both a and c
9. Why should any high-pressure line removed be replaced with a new part on a GDI system?
   - **a.** The ball-ends deform when tightened and will not seal if reused
   - **b.** The high-pressure lines are part of the high-pressure pump and must be replaced as an assembly
   - **c.** The torque needed to remove the lines causes the lines to be damaged
   - **d.** All of the above
10. A GDI-equipped engine may have specially shaped _________.
    - **a.** head bolts
    - **b.** pistons
    - **c.** valve guides
    - **d.** engine mounts

Chapter

77

ELECTRONIC THROTTLE CONTROL SYSTEM

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe electronic throttle control systems.
- Explain how an electronic throttle control system works.
- Describe the APP sensor.
- Describe the throttle body assembly.
- Describe TP sensors.
- Describe how to diagnose faults in an electronic throttle control system.
- Explain how to service an electronic throttle system.

KEY TERMS:

Accelerator pedal position (APP) sensor 909 • Coast-down stall 915 • Default position 911 • Drive-by-wire 909 • Electronic throttle control (ETC) 909 • Fail safe position 911 • Neutral position 911 • Servomotor 911 • Throttle position (TP) sensor 909

ELECTRONIC THROTTLE CONTROL (ETC) SYSTEM

ADVANTAGES OF ETC The absence of any mechanical linkage between the throttle pedal and the throttle body requires the use of an electric actuator motor. The electronic throttle system has the following advantages over the conventional cable:

- Eliminates the mechanical throttle cable, thereby reducing the number of moving parts.
- Eliminates the need for cruise control actuators and controllers.
- Helps reduce engine power for traction control (TC) and electronic stability control (ESC) systems.
- Used to delay rapid applications of torque to the transmission/transaxle to help improve driveability and to smooth shifts.
- Helps reduce pumping losses by causing the electronic throttle to open at highway speeds with greater fuel economy. The ETC opens the throttle to maintain engine and vehicle speed as the powertrain control module (PCM) leans the air–fuel ratio, retards ignition timing, and introduces additional exhaust gas recirculation (EGR) to reducing pumping losses.
- Used to provide smooth engine operation, especially during rapid acceleration.
- Eliminates the need for an idle air control valve.

The electronic throttle can be called **drive-by-wire**, but most vehicle manufacturers use the term **electronic throttle control (ETC)** to describe the system that opens the throttle valve electrically.

PARTS INVOLVED The typical ETC system includes the following components:

1. **Accelerator pedal position (APP) sensor,** also called *accelerator pedal sensor (APS)*
2. The electronic throttle actuator (servomotor), which is part of the electronic throttle body
3. A **throttle position (TP) sensor**
4. An electronic control unit, which is usually the PCM

● **SEE FIGURE 77–1**.

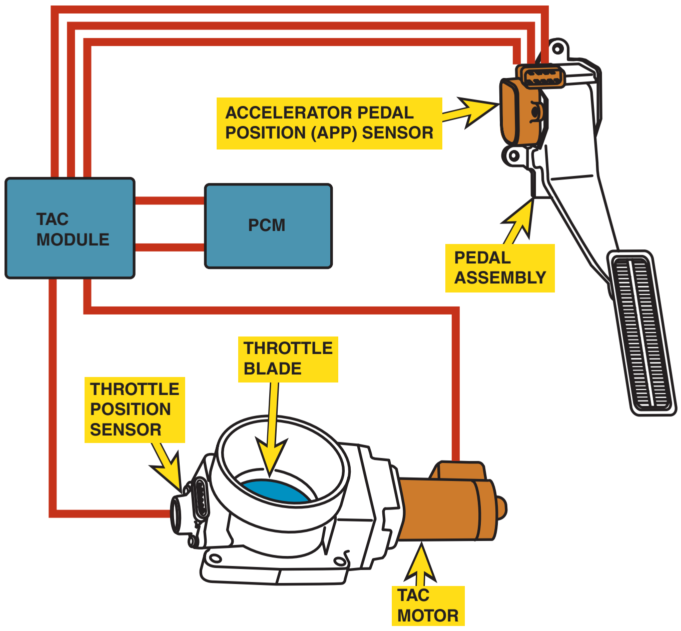


FIGURE 77–1 The throttle pedal is connected to the APP sensor. The electronic throttle body includes a throttle position sensor to provide throttle angle feedback to the vehicle computer. Some systems use a throttle actuator control (TAC) module to operate the throttle blade (plate).

NORMAL OPERATION OF THE ETC SYSTEM

Driving a vehicle equipped with an ETC system is about the same as driving a vehicle with a conventional mechanical throttle cable and throttle valve. However, the driver may notice some differences, which are to be considered normal. These normal conditions include the following:

- The engine may not increase above idle speed when depressing the accelerator pedal when the gear selector is in PARK.
- If the engine speed does increase when the accelerator is depressed with the transmission in PARK or NEUTRAL, the engine speed will likely be limited to less than 2,000 RPM.
- While accelerating rapidly, there is often a slight delay before the engine responds. ● **SEE FIGURE 77–2**.
- While at cruise speed, the accelerator pedal may or may not cause the engine speed to increase if the accelerator pedal is moved slightly.

APP SENSOR

CABLE-OPERATED SYSTEM Honda Accords until the 2008 model year used a cable attached to the accelerator pedal to operate the APP sensor located under the hood. A similar arrangement was used in Dodge RAM trucks in 2003. In both of these applications, the throttle cable was simply moving the APP sensor and not moving the throttle plate. The throttle plate is controlled by the PCM and moved by the ETC motor.

TWO SENSORS The APP sensor uses two and sometimes three separate sensors, which act together to give accurate accelerator pedal position information to the controller, but also are used to check that the sensor is working properly. The APP sensor uses two different signals. Both signals increase, but at different rates. The controller compares the signals with a look-up table to determine the pedal position. Using two or three signals improves redundancy should one sensor fail, and allows the PCM to quickly detect a malfunction. When three sensors are used, the third signal can either decrease or increase with pedal position, but its voltage range will still be different from the other two. ● **SEE FIGURE 77–3**.

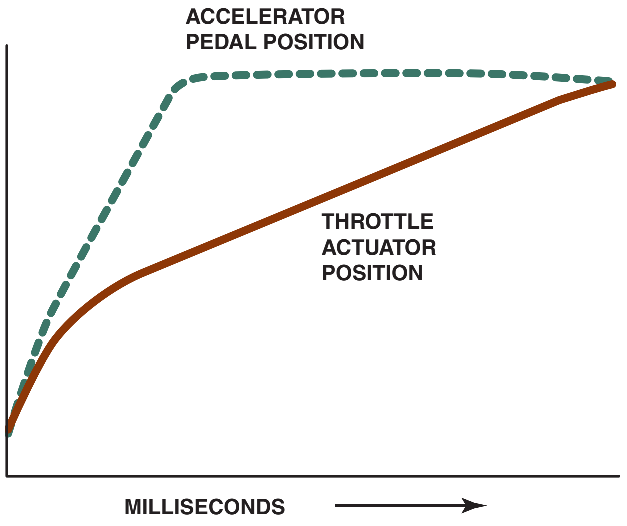


FIGURE 77–2 The opening of the throttle plate can be delayed as long as 30 milliseconds (0.030 sec) to allow time for the amount of fuel needed to catch up to the opening of the throttle plate.

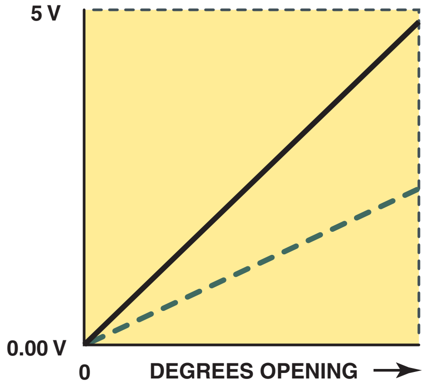


FIGURE 77–3 A typical APP sensor, showing two different output voltage signals that are used by the PCM to determine accelerator pedal position. Two (or three in some applications) are used as a double check because this is a safety-related sensor.

THROTTLE BODY ASSEMBLY

PARTS INCLUDED The throttle body assembly contains the following components:

- Throttle plate
- Electric actuator DC motor
- Dual TP sensors

- Gears used to multiply the torque of the DC motor
- Springs used to hold the throttle plate in the default location

THROTTLE PLATE AND SPRING The throttle plate is held slightly open by a concentric clock spring. The spring applies a force that will close the throttle plate if power is lost to the actuator motor. The spring is also used to open the throttle plate slightly from the fully closed position.

ELECTRONIC THROTTLE BODY MOTOR The actuator is a DC electric motor and is often called a **servomotor**. The throttle plate is held in a **default position** by a spring inside the throttle body assembly. This partially open position, also called the **neutral position** or the **fail safe position**, is about 16% to 20% open. This default position varies, depending on the vehicle and usually results in an engine speed of 1,200 to 1,500 RPM.

- The throttle plate is driven closed to achieve speeds lower than the default position, such as idle speed.
- The throttle plate is driven open to achieve speeds higher than the default position, such as during acceleration. ● **SEE FIGURE 77–4**.

FREQUENTLY ASKED QUESTION

What Is the "Spring Test"?

The spring test is a self-test performed by the PCM whenever the engine is started. The PCM operates the throttle to check if it can react to the command and return to the default (home) position. This self-test is used by the PCM to determine that the spring and motor are working correctly and may be noticed by some vehicle owners by the following factors:

- A slight delay in the operation of the starter motor. It is when the ignition is turned to the on position that the PCM performs the test. While it takes just a short time to perform the test, it can be sensed by the driver that there could be a fault in the ignition switch or starter motor circuits.
- A slight "clicking" sound may also be heard coming from under the hood when the ignition is turned on. This is normal and is related to the self-test on the throttle as it opens and closes.

FREQUENTLY ASKED QUESTION

Why Not Use a Stepper Motor for ETC?

A stepper motor is a type of motor that has multiple windings and is pulsed by a computer to rotate a certain number of degrees when pulsed. The disadvantage is that a stepper motor is too slow to react compared with a conventional DC electric motor and is the reason a stepper motor is not used in ETC systems.

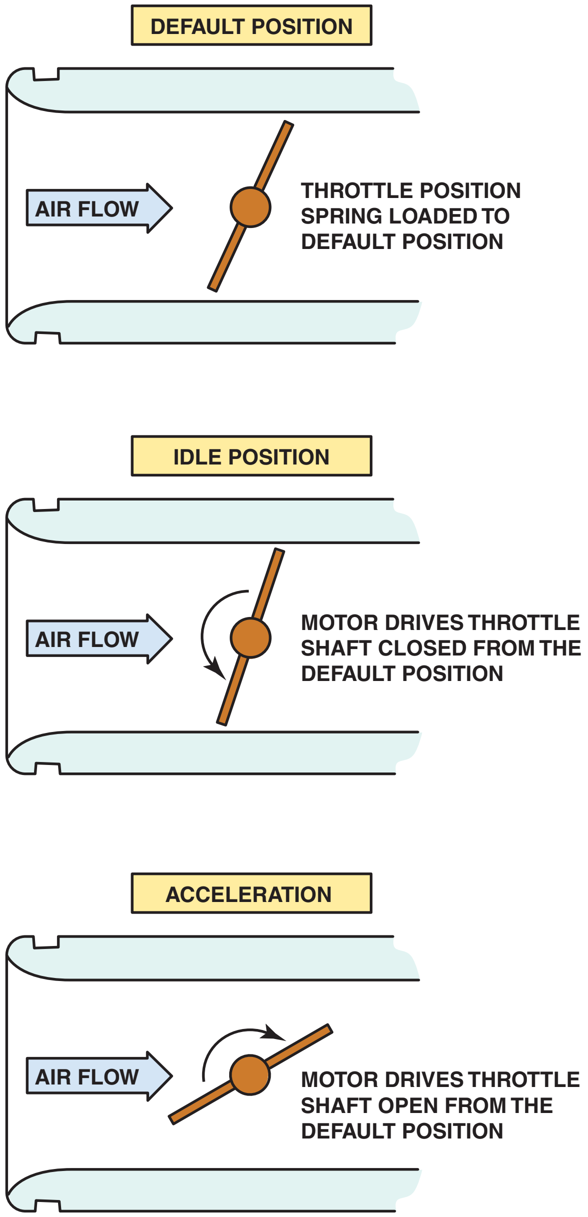

DEFAULT POSITION
AIR FLOW
THROTTLE POSITION SPRING LOADED TO DEFAULT POSITION
IDLE POSITION
AIR FLOW
MOTOR DRIVES THROTTLE SHAFT CLOSED FROM THE DEFAULT POSITION
ACCELERATION
AIR FLOW
MOTOR DRIVES THROTTLE SHAFT OPEN FROM THE DEFAULT POSITION

FIGURE 77–4 The default position for the throttle plate is in slightly open position. The servomotor then is used to close it for idle and open it during acceleration.

The throttle plate motor is driven by a bidirectional pulse-width modulated (PWM) signal from the PCM or ETC module using an H-bridge circuit. ● **SEE FIGURE 77–5**.

The H-bridge circuit is controlled by the PMC by the following:

- Reversing the polarity of power and ground brushes to the DC motor
- Pulse-width modulating the current through the motor

The PCM monitors the position of the throttle from the two TP sensors. The PCM then commands the throttle plate to the desired position. ● **SEE FIGURE 77–6**.

THROTTLE POSITION (TP) SENSOR

PURPOSE AND FUNCTION Two throttle position sensors are used in the throttle body assembly to provide throttle position signals to the PCM. Two sensors are used as a fail-safe measure

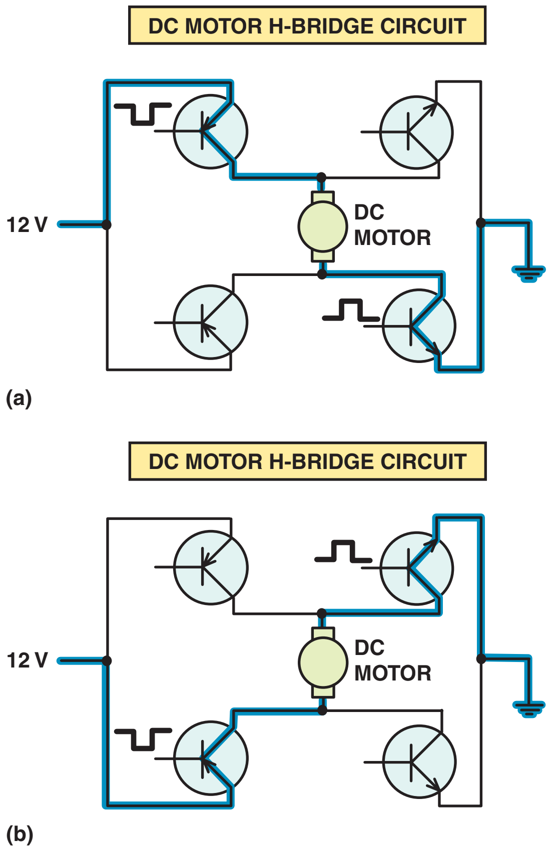


FIGURE 77–5 (a) An H-bridge circuit is used to control the direction of the DC electric motor of the ETC unit. (b) To reverse the direction of operation, the polarity of the current through the motor is reversed.

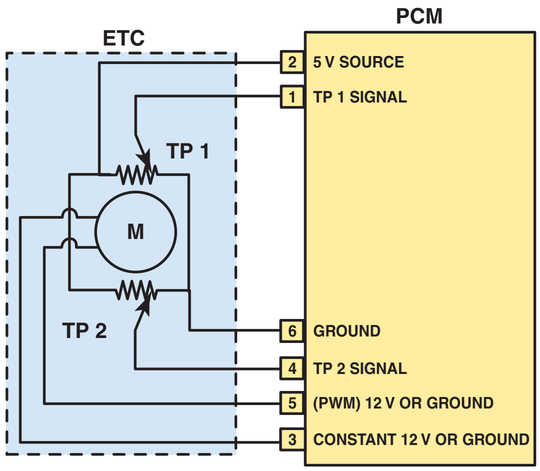


FIGURE 77–6 Schematic of a typical ETC system. Note that terminal #5 is always PWM and that terminal #3 is always constant, but both power and ground are switched to change the direction of the motor.

and for diagnosis. There are two types of TP sensors used in ETC systems: potentiometers and Hall-effect.

THREE-WIRE POTENTIOMETER SENSORS These sensors use a 5-volt reference from the PCM and produce an analog (variable) voltage signal that is proportional to the throttle plate position. The two sensors produce opposite signals as the throttle plate opens:

- One sensor starts at low voltage (about 0.5 volt) and increases as the throttle plate is opened.

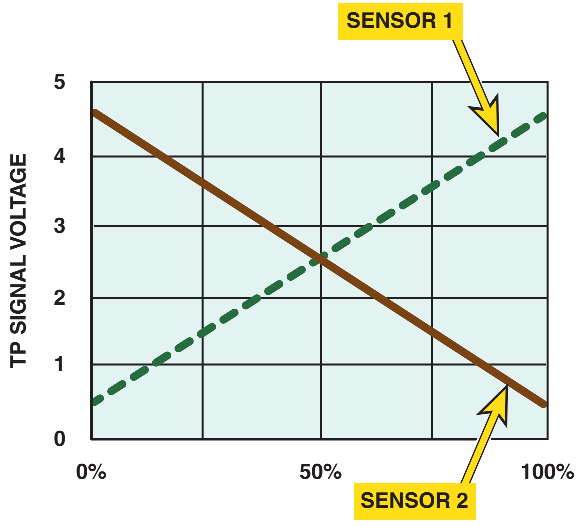


FIGURE 77–7 The two TP sensors used on the throttle body of an electronic throttle body assembly produce opposite voltage signals as the throttle is opened. The total voltage of both combined at any throttle plate position is 5 volts.

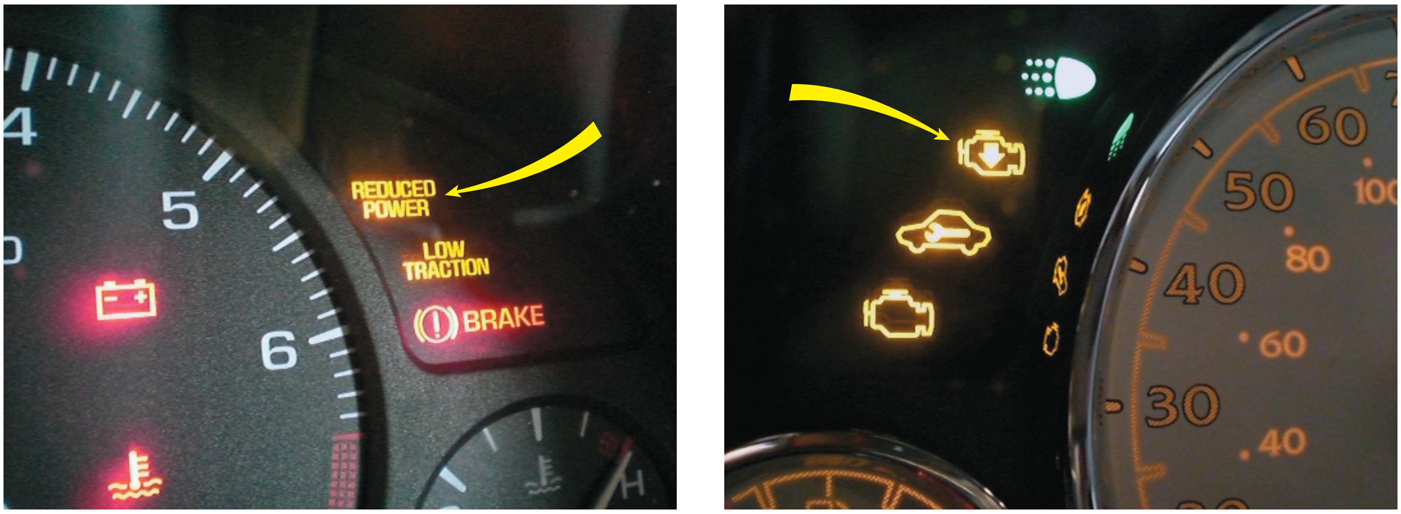
- The second sensor starts at a higher voltage (about 4.5 volt) and produces a lower voltage as the throttle plate is opened. ● **SEE FIGURE 77–7**.

HALL-EFFECT TP SENSORS Some vehicle manufacturers, such as Honda use a noncontact Hall-effect TP sensor. Because there is no physical contact, this type of sensor is less likely to fail due to wear.

DIAGNOSIS OF ETC SYSTEMS

FAULT MODE ETC systems can have faults like any other automatic system. Due to the redundant sensors in APP sensors and throttle position sensor, many faults result in a "limp home" situation instead of a total failure. The limp home mode is also called the "fail-safe mode" and indicates the following actions performed by the PCM:

- Engine speed is limited to the default speed (about 1,200 to 1,600 RPM).
- There is slow or no response when the accelerator pedal is depressed.
- The cruise control system is disabled.
- A diagnostic trouble code (DTC) is set.
- An ETC warning lamp on the dash will light. The warning lamp may be labeled differently, depending on the vehicle manufacturer. For example,
  - **General Motors vehicle**—Reduced power lamp (● **SEE FIGURE 77–8)**
  - **Ford**—Wrench symbol (amber or green) (● **SEE FIGURE 77–9)**
  - **Chrysler**—Red lightning bolt symbol (● **SEE FIGURE 77–10)**
- The engine will run and can be driven slowly. This limp-in mode operation allows the vehicle to be driven off of the road and to a safe location.



(a) (b)

FIGURE 77–8 (a) A "reduced power" warning light indicates a fault with the ETC system on some General Motors vehicles. (b) A symbol showing an engine with an arrow pointing down is used on some General Motors vehicles to indicate a fault with the ETC system.

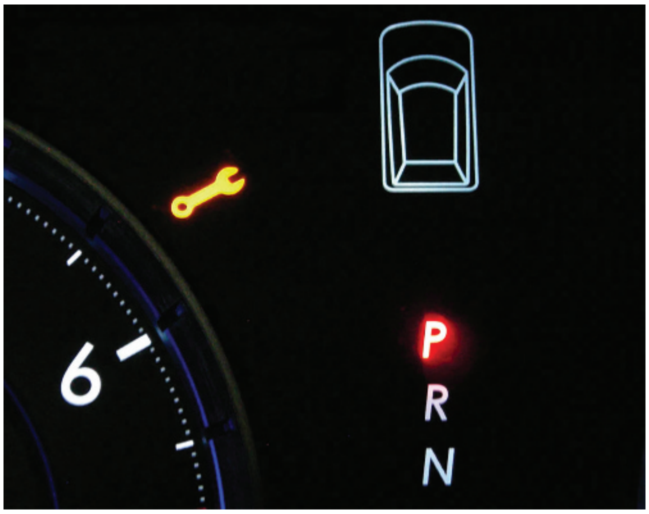


FIGURE 77–9 A wrench symbol warning lamp on a Ford vehicle. The symbol can also be green.

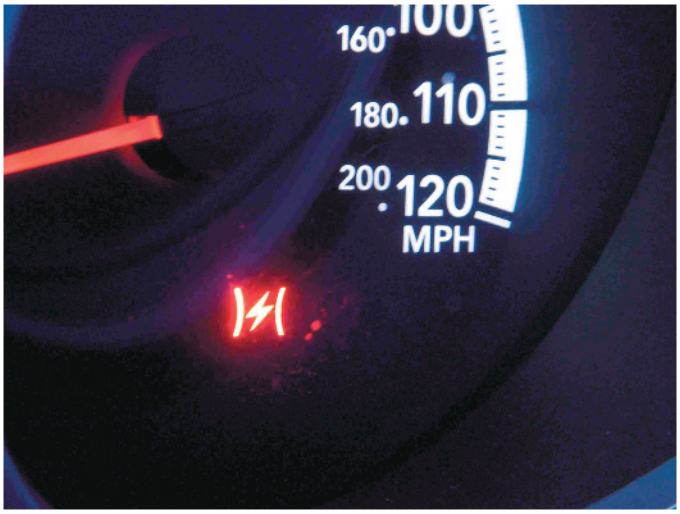


FIGURE 77–10 A symbol used on a Chrysler vehicle indicating a fault with the ETC.

FREQUENTLY ASKED QUESTION

How Do You Calibrate a New APP Sensor?

Whenever an APP sensor is replaced, it should be calibrated before it will work correctly. Always check service information for the exact procedure to follow after APP sensor replacement. Here is a typical example of the procedure:

STEP 1 Make sure the accelerator pedal is fully released.

STEP 2 Turn the ignition switch on (engine off) and wait at least 2 seconds.

STEP 3 Turn the ignition switch off and wait at least 10 seconds.

STEP 4 Turn the ignition switch on (engine on) and wait at least 2 seconds.

STEP 5 Turn the ignition switch off and wait at least 10 seconds.

The ETC may enter the limp-in mode if any of the following has occurred:

- Low battery voltage has been detected
- PCM failure
- One TP and the MAP sensors have failed
- Both TP sensors have failed
- The ETC actuator motor has failed
- The ETC throttle spring has failed

VACUUM LEAKS The ETC system is able to compensate for many vacuum leaks. A vacuum leak at the intake manifold, for example, will allow air into the engine that is not measured by the mass airflow sensor. The ETC system will simply move the throttle as needed to achieve the proper idle speed to compensate for the leak.

DIAGNOSTIC PROCEDURE If a fault occurs in the ETC system, check service information for the specified procedure to follow for the vehicle being checked. Most vehicle service information includes the following steps:

STEP 1 Verify the customer concern.

STEP 2 Use a factory scan tool or an aftermarket scan tool with original equipment capability and check for DTCs.

STEP 3 If there are stored ETCs, follow service information instructions for diagnosing the system.

STEP 4 If there are no stored ETCs, check scan tool data for possible fault areas in the system.

SCAN TOOL DATA Scan data related to the ETC system can be confusing. Typical data and the meaning include the following:

- **APP indicated angle.** The scan tool will display a percentage ranging from 0% to 100%. When the throttle is released, the indicated angle should be 0%. When the throttle is depressed to wide open, the reading should indicate 100%.

CASE STUDY

The High Idle Toyota

The owner of a Toyota Camry complained that the engine would idle at over 1,200 RPM compared with a normal 600 to 700 RPM. The vehicle would also not accelerate. Using a scan tool, a check for DTCs showed one code: P2101—"TAC motor circuit low."

Checking service information led to the inspection of the ETC throttle body assembly. With the ignition key out of the ignition and the inlet air duct off the throttle body, the technician used a screwdriver to see if the throttle plate worked.

Normal operation—The throttle plate should move and then spring back quickly to the default position.

Abnormal operation—If the throttle plate stays where it is moved or does not return to the default position, there is a fault with the throttle body assembly. ● **SEE FIGURE 77–11**.

The technician replaced the throttle body assembly with an updated version and proper engine operation was restored. The technician disassembled the old throttle body and found it was corroded inside due to moisture entering the unit through the vent hose. ● **SEE FIGURE 77–12**.

Summary:

Complaint—Customer stated that the engine would idle at over 2,000 RPM.

Cause—A stored P2101 DTC was stored indicating a fault with the throttle body assembly.

Correction—The throttle body was replaced with an improved version that placed the vent tube in a different position to help avoid water getting into the assembly.

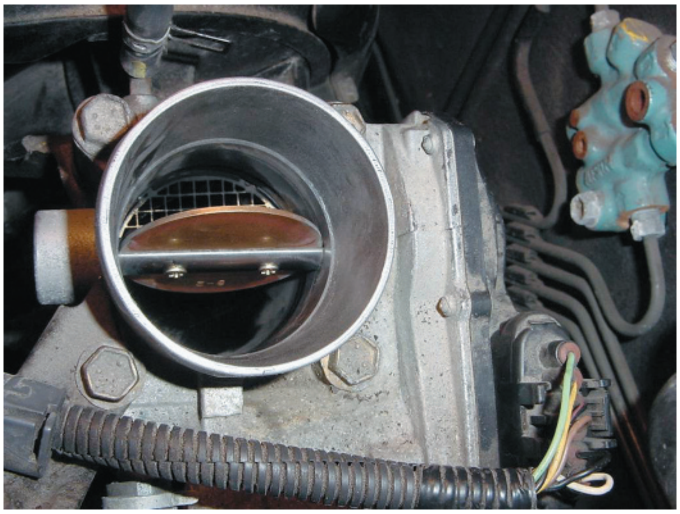


FIGURE 77–11 The throttle plate stayed where it was moved, which indicates that there is a problem with the electronic throttle body control assembly.

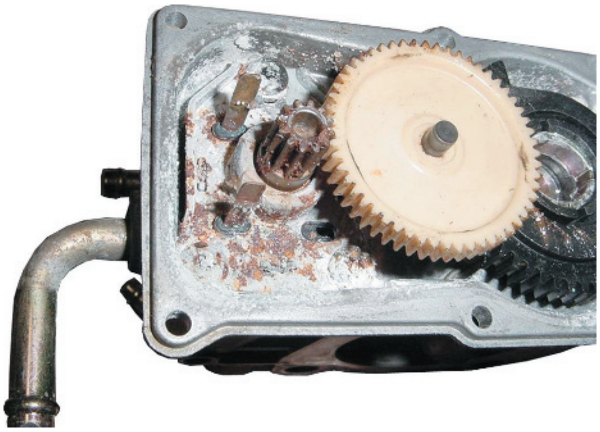


FIGURE 77–12 A corroded ETC assembly shown with the cover removed.

- **TP desired angle.** The scan tool will display a percentage ranging from 0% to 100%. This represents the desired throttle angle as commanded by the driver of the vehicle.
- **TP indicated angle.** The TP indicated angle is the angle of the measured throttle opening and it should agree with the TP desired angle.
- **TP sensors 1 and 2.** The scan tool will display "agree" or "disagree." If the PCM or TAC module receives a voltage signal from one of the TP sensors that is not in the proper relationship to the other TP sensor, the scan tool will display *disagree*.

ETC THROTTLE FOLLOWER TEST On some vehicles, such as many Chrysler vehicles, the operation of the ETC can be tested using a factory or factory-level scan tool. To perform this test, use the "throttle follower test" procedure as shown on the scan tool. An assistant is needed to check that the throttle plate is moving as the accelerator pedal is depressed. This test cannot be done normally because the PCM does not normally allow the throttle plate to be moved unless the engine is running.

SERVICING ELECTRONIC THROTTLE SYSTEMS

ETC-RELATED PERFORMANCE ISSUES The only service that an ETC system may require is a cleaning of the throttle body. Throttle body cleaning is a routine service procedure on port fuel-injected engines and is still needed when the throttle is being opened by an electric motor rather than a throttle cable tied to a mechanical accelerator pedal. The throttle body may need cleaning if one or more of the following symptoms are present:

- Lower than normal idle speed
- Rough idle
- Engine stalls when coming to a stop (called a **coast-down stall**)

If any of the above conditions exists, a throttle body cleaning will often correct these faults.

CAUTION: Some vehicle manufacturers add a nonstick coating to the throttle assembly and warn that cleaning could remove this protective coating. Always follow the vehicle manufacturer's recommended procedures.

THROTTLE BODY CLEANING PROCEDURE Before attempting to clean a throttle body on an engine equipped with an ETC system, be sure that the ignition key is out of the vehicle and the ready light is off if working on a Toyota/Lexus hybrid electric vehicle to avoid the possibility of personal injury.

To clean the throttle, perform the following steps:

STEP 1 With the ignition off and the key removed from the ignition, remove the air inlet hose from the throttle body.

STEP 2 Spray throttle body cleaner onto a shop cloth.

STEP 3 Open the throttle body and use the shop cloth to remove the varnish and carbon deposits from the throttle body housing and throttle plate.

CAUTION: Do not spray cleaner into the throttle body assembly. The liquid cleaner could flow into and damage the TP sensors.

WARNING

The electric motor that operates the throttle plate is strong enough to cut off a finger. ● **SEE FIGURE 77–13**.

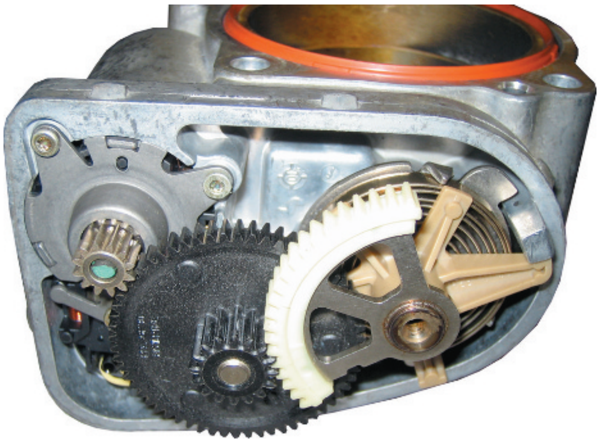


FIGURE 77–13 Notice the small motor gear on the left drives a larger plastic gear (black), which then drives the small gear in mesh with the section of a gear attached to the throttle plate. This results in a huge torque increase from the small motor and helps explain why it could be dangerous to insert a finger into the throttle body assembly.

STEP 4 Reinstall the inlet hose being sure that there are no air leaks between the hose and the throttle body assembly.

STEP 5 Start the engine and allow the PCM to learn the correct idle. If the idle is not correct, check service information for the specified procedures to follow to perform a throttle relearn.

THROTTLE BODY RELEARN PROCEDURE When installing a new throttle body or PCM or sometimes after cleaning the throttle body, the throttle position has to be learned by the PCM. After the following conditions have been met, a typical throttle body relearn procedure for a General Motors vehicle includes the following:

- Accelerator pedal released
- Battery voltage higher than 8 volts
- Vehicle speed must be zero
- Engine coolant temperature (ECT) higher than 40°F (5°C) and lower than 212°F (100°C)
- Intake air temperature (IAT) higher than 40°F (5°C)
- No throttle DTCs set

If all of the above conditions are met, perform the following steps:

STEP 1 Turn the ignition on (engine off) for 30 seconds.

STEP 2 Turn the ignition off and wait 30 seconds.

Start the engine and the idle learn procedure should cause the engine to idle at the correct speed.

REVIEW QUESTIONS

1. What parts can be deleted if an engine uses an ETC system instead of a conventional accelerator pedal and cable to operate the throttle valve?
2. How can the use of an ETC system improve fuel economy?
3. How is the operation of the throttle different on a system that uses an ETC system compared with a conventional mechanical system?
4. What component parts are included in an ETC system?
5. What is the default or limp-in position of the throttle plate?

CHAPTER QUIZ

1. The use of an ETC system allows the elimination of all *except* __________.
   - a. accelerator pedal
   - b. mechanical throttle cable (most systems)
   - c. cruise control actuator
   - d. idle air control
2. To what extent is the throttle plate spring loaded to hold the throttle slightly open?
   - a. 3% to 5%
   - b. 8% to 10%
   - c. 16% to 20%
   - d. 22% to 28%
3. What type of electric motor is the throttle plate actuator motor?
   - a. Stepper motor
   - b. DC motor
   - c. AC motor
   - d. Brushless motor
4. The actuator motor is controlled by the PCM through what type of circuit?
   - a. Series
   - b. Parallel
   - c. H-bridge
   - d. Series-parallel
5. When does the PCM perform a self-test of the ETC system?
   - a. During cruise speed when the throttle is steady
   - b. During deceleration
   - c. During acceleration
   - d. When the ignition switch is first rotated to the on position before the engine starts
6. What type is the throttle position sensor used in the throttle body assembly of an ETC system?
   - a. A single potentiometer
   - b. Two potentiometers that read in the opposite direction
   - c. A Hall-effect sensor
   - d. Either b or c
7. A green wrench symbol is displayed on the dash. What does this mean?
   - a. A fault in the ETC in a Ford vehicle has been detected
   - b. A fault in the ETC in a Honda vehicle has been detected
   - c. A fault in the ETC in a Chrysler vehicle has been detected
   - d. A fault in the ETC in a General Motors vehicle has been detected
8. A technician is checking the operation of the ETC system by depressing the accelerator pedal with the ignition in the on (run) position (engine off). What is the most likely result if the system is functioning correctly?
   - a. The throttle goes to wide open when the accelerator pedal is depressed all the way
   - b. No throttle movement
   - c. The throttle will open partially but not all of the way
   - d. The throttle will perform a self-test by closing and then opening to the default position
9. With the ignition off and the key out of the ignition, what should happen if a technician uses a screwdriver and pushes on the throttle plate in an attempt to open the valve?
   - a. Nothing. The throttle should be kept from moving by the motor, which is not energized with the key off.
   - b. The throttle should move and stay where it is moved and not go back unless moved back.
   - c. The throttle should move, and spring back to the home position when released.
   - d. The throttle should move closed, but not open further than the default position.
10. The throttle body may be cleaned (if recommended by the vehicle manufacturer) if what conditions are occurring?
    - a. Coast-down stall
    - b. Rough idle
    - c. Lower-than-normal idle speed
    - d. Any of the above

Chapter 78

FUEL-INJECTION SYSTEM DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader will be able to:

- Explain fuel-injection system diagnosis including scan tool diagnosis.
- Describe how to test for an injector pulse.
- Describe how to check fuel-injection resistance.
- Describe the pressure-drop balance test.
- Describe injection voltage-drop tests.
- Describe scope-testing fuel injectors.
- Describe how to service the fuel-injection system.

KEY TERMS:

Noid light 918 • Peak-and-hold injector 921 • Saturation 921

FUEL-INJECTION SYSTEM DIAGNOSIS

VISUAL INSPECTION All fuel-injection systems require the proper amount of clean fuel delivered to the system at the proper pressure and the correct amount of filtered air. The following items should be carefully inspected before proceeding to more detailed tests:

- Check the air filter and replace as needed.
- Check the air induction system for obstructions.
- Check the conditions of all vacuum hoses. Replace any hose that is split, soft (mushy), or brittle.

DIAGNOSTIC STEPS To determine if a port fuel-injection system—including the fuel pump, injectors, and fuel-pressure regulator—is operating correctly, take the following steps:

1. Attach a fuel-pressure gauge to the Schrader valve on the fuel rail. ● **SEE FIGURE 78–1**.
2. Turn the ignition key on or start the engine to build up the fuel-pump pressure (to about 35 to 45 PSI).

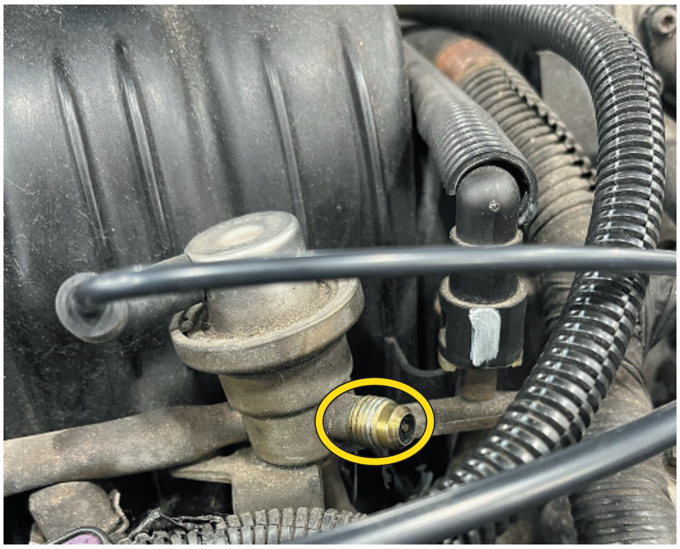


FIGURE 78–1 A fuel pressure gauge can be connected to many older fuel injection systems at the threaded port on the fuel rail.

3. Wait 20 minutes and observe the fuel pressure retained in the fuel rail and note the PSI reading. The fuel pressure should not drop more than 20 PSI (140 kPa) in 20 minutes. If the drop is less than 20 PSI in 20 minutes, everything is

okay; if the drop is *greater,* there is a possible problem with the following:

- The check valve in the fuel pump
- Injectors, lines, or fittings
- A fuel-pressure regulator

To determine which unit is defective, perform the following:

- Reenergize the electric fuel pump.
- Clamp the fuel *supply* line, and wait 10 minutes (see CAUTION). If the pressure drop does not occur, replace the fuel pump. If the pressure drop still occurs, continue with the next step.
- Repeat the pressure buildup of the electric pump and clamp the fuel return line. If the pressure drop time is now okay, replace the fuel-pressure regulator.
- If the pressure drop still occurs, one or more of the injectors is leaking. Remove the injectors with the fuel rail and hold over paper. Replace those injectors that drip one or more drops after 10 minutes with pressurized fuel.

CAUTION: Do not clamp plastic fuel lines. Connect shutoff valves to the fuel system to shut off supply and return lines. ● **SEE FIGURE 78–2**.

FUEL-SYSTEM SCAN TOOL DIAGNOSTICS Diagnosing a faulty fuel system can be a difficult task. However, it can be made easier by utilizing the information available via the serial data stream. By observing the long-term fuel trim and the short-term fuel trim, a determination can be made on how the fuel system is performing. Short-term fuel trim and long-term fuel trim can help zero in on specific areas of trouble. Readings should be taken at idle and at 3,000 RPM. **SEE CHART 78–1**.

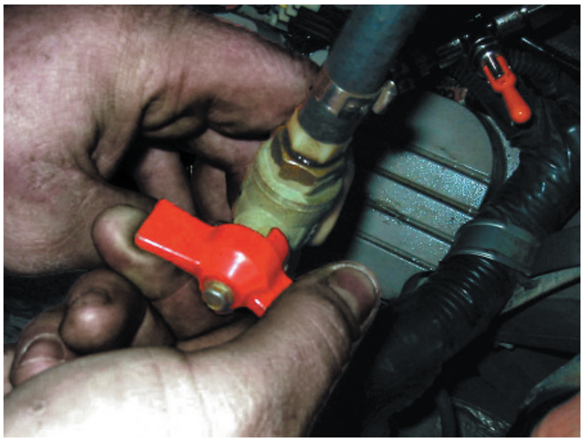


FIGURE 78–2 Shutoff valves must be used on vehicles equipped with plastic fuel lines to isolate the cause of a pressure drop in the fuel system.

Condition	Long-Term Fuel Trim at Idle	Long-Term Fuel Trim at 3000 RPM
System normal	0% ± 10%	0% ± 10%
Vacuum leak	HIGH	OK
Fuel flow problem	OK	HIGH
Low fuel pressure	HIGH	HIGH
High fuel pressure	*OK or LOW	*OK or LOW

*High fuel pressure will affect trim at idle, at 3000 RPM, or both.

CHART 78–1

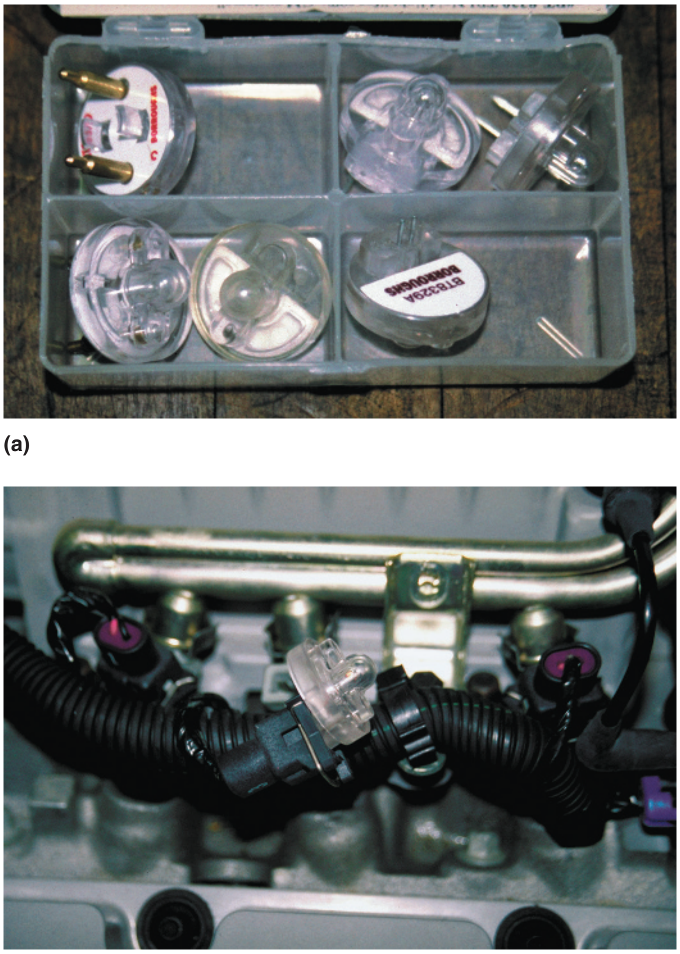
Fuel trim levels and possible causes if not within 10%.

TESTING FOR AN INJECTOR PULSE

One of the first checks that should be performed when diagnosing a no-start condition is whether the fuel injectors are being pulsed by the computer. Checking for proper pulsing of the injector is also important in diagnosing a weak or dead cylinder.

A **noid light** is designed to electrically replace the injector in the circuit and to flash if the injector circuit is working correctly. ● **SEE FIGURE 78–3**. To use a noid light, disconnect the electrical connector at the fuel injector and plug the noid light into the injector harness connections. Crank or start the engine. The noid light should flash regularly.

NOTE: The term *noid* is simply an abbreviation of the word *solenoid*. Injectors use a movable iron core and are therefore solenoids. Therefore, a noid light is a replacement for the solenoid (injector).



(a)

(b)

FIGURE 78–3 (a) Noid lights are usually purchased as an assortment so that one is available for any type or size of injector wiring connector. (b) The connector is unplugged from the injector and a noid light is plugged into the injector connector. The noid light should flash when the engine is being cranked if the power circuit and the pulsing to ground by the computer are functioning okay.

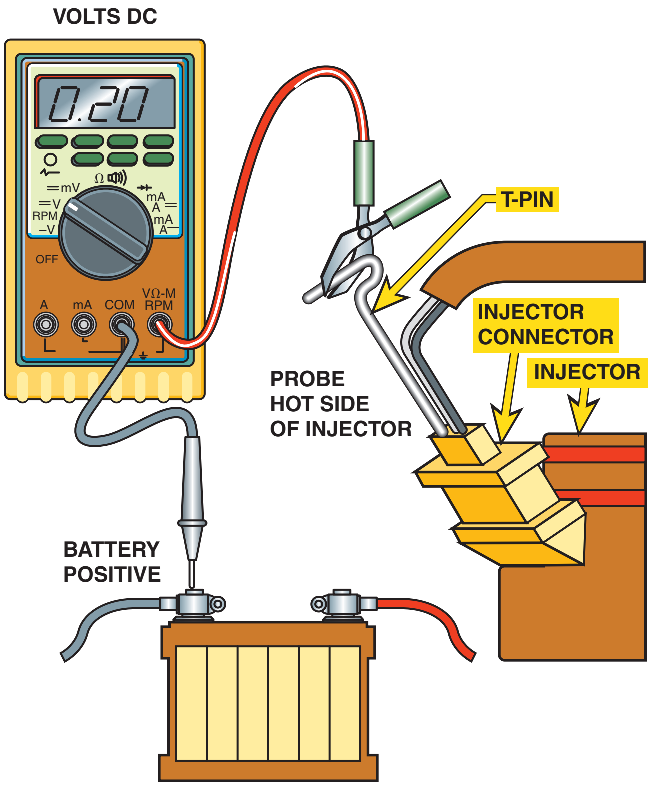


FIGURE 78–4 Use a DMM set to read DC volts to check the voltage drop of the positive circuit to the fuel injector. A reading of 0.5 volt or less is generally considered to be acceptable.

Possible noid light problems and causes include the following:

1. **The light is off and does not flash.** The problem is an open in either the power side or ground side (or both) of the injector circuit.
2. **The noid light flashes dimly.** A dim noid light indicates excessive resistance or low voltage available to the injector. Both the power and ground side must be checked.
3. **The noid light is on and does not flash.** If the noid light is on, both a power and a ground are present. Because the light does not flash (blink) when the engine is being cranked or started, a short-to-ground fault exists either in the computer itself or in the wiring between the injector and the computer.

CAUTION: A noid lamp must be used with caution. The computer may show a good noid light operation and have low supply voltage. ● **SEE FIGURE 78–4.**

CHECKING FUEL-INJECTOR RESISTANCE

Each port fuel injector must deliver an equal amount of fuel or the engine will idle roughly or perform poorly.

The electrical balance test involves measuring the injector coil-winding resistance. For best engine operation, all injectors should have the same electrical resistance. To measure the resistance, carefully release the locking feature of the connector and remove the connector from the injector.

NOTE: Some engines require specific procedures to gain access to the injectors. Always follow the manufacturers' recommended procedures.

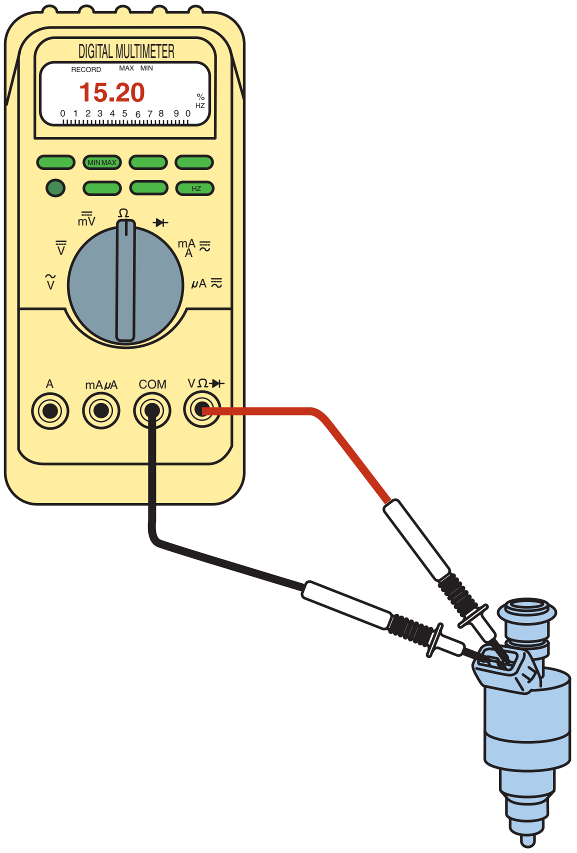


FIGURE 78–5 Connections and settings necessary to measure fuel-injector resistance.

With an ohmmeter, measure the resistance across the injector terminals. Be sure to lowest ohmmeter setting of the digital ohmmeter to read in tenths (0.1) of an ohm. ● **SEE FIGURES 78–5 AND 78–6.** Check service information for the resistance specification of the injectors. Measure the resistance of all of the injectors. Replace any injector that does not fall within the resistance range of the specification. The resistance of the injectors should be measured twice—once when the engine (and injectors) are cold and once after the engine has reached normal operating temperature. If any injector measures close to specification, make certain that the terminals of the injector are electrically sound, and perform other tests to confirm an injector problem before replacement.

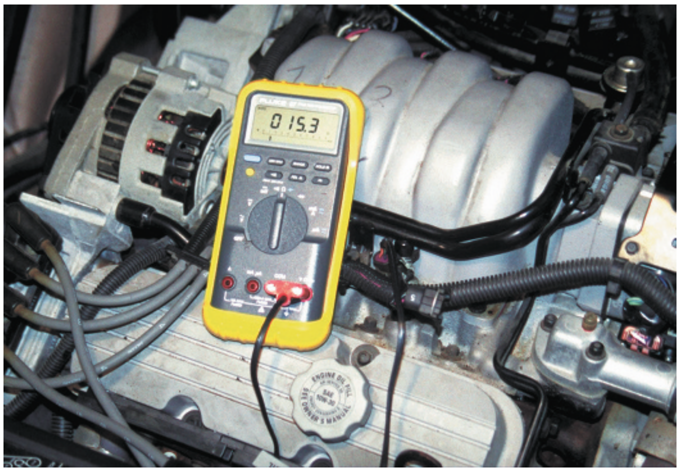


FIGURE 78–6 To measure fuel-injector resistance, a technician constructed a short wiring harness with a double banana plug that fits into the V and COM terminals of the meter and an injector connector at the other end. This setup makes checking resistance of fuel injectors quick and easy.

TYPICAL RESISTANCE VALUES There are two basic types of injectors, which have an effect on their resistance, including the following:

1. **Low-resistance injectors.** The features of a low-resistance injectors include the following:
    - Uses a "peak and hold" type firing where a high current, usually about 4 amperes, is used to open the injector, then it is held open by using a lower current, which is usually about 1 ampere.
    - All throttle body injection (TBI) injectors and some port fuel injectors are low-resistance injectors and are fired using a peak-and-hold circuit by the PCM.
    - The resistance value of a peak-and-hold-type injector is usually 1.5 to 4.0 ohms.
2. **Higher-resistance injectors.** The features of a higher-resistance injectors include the following:
    - Uses a constant low current, usually 1 ampere, to open the injector.
    - Is called a "saturated" type of injector because the current flows until the magnetic field is strong enough to open the injector.
    - Most port fuel injectors are of the saturated type.
    - The resistance value of a saturated injector is usually 12 to 16 ohms.

PRESSURE-DROP BALANCE TEST

The pressure balance test involves using an electrical timing device to pulse the fuel injectors on for a given amount of time, usually 500 milliseconds or 0.5 seconds, and observing the drop in pressure that accompanies the pulse. If the *fuel flow* through each injector is equal, the drop in pressure in the system will be equal. Most manufacturers recommend that the pressures be within about 1.5 PSI (10 kPa) of each other for satisfactory engine performance. This test method not only tests the electrical functioning of the injector (for definite time and current pulse), but also tests for mechanical defects that could affect fuel flow amounts.

The purpose of running this injector balance test is to determine which injector is restricted, inoperative, or delivering fuel differently than the other injectors. Replacing a complete set of injectors can be expensive. The basic tools needed are the following:

- Accurate pressure gauge with pressure relief
- Injector pulser with time control
- Necessary injector connection adapters
- Safe receptacle for catching and disposing of any fuel released

STEP 1 Attach the pressure gauge to the fuel delivery rail on the supply side. Make sure the connections are safe and leakproof.

STEP 2 Attach the injector pulser to the first injector to be tested.

STEP 3 Turn the ignition key to the on position to prime the fuel rail. Note the static fuel-pressure reading. ● **SEE FIGURE 78–8.**

STEP 4 Activate the pulser for the timed firing pulses.

STEP 5 Note and record the new static rail pressure after the injector has been pulsed.

STEP 6 Reenergize the fuel pump and repeat this procedure for all of the engine injectors.

STEP 7 Compare the two pressure readings and compute the pressure drop for each injector. Compare the pressure drops of the injectors to each other. Any variation in pressure drops will indicate an uneven fuel delivery rate between the injectors.

For example,

Injector	1	2	3	4	5	6
Initial pressure	40	40	40	40	40	40
Second pressure	30	30	35	30	20	30
Pressure drop	10	10	5	10	20	10
Possible problem	OK	OK	Restriction	OK	Leak	OK

TECH TIP

Equal Resistance Test

All fuel injectors should measure the specified resistance. However, the specification often indicates the temperature of the injectors be at room temperature and of course will vary according to the temperature. Rather than waiting for all of the injectors to achieve room temperature, measure the resistance and check that they are all within 0.4 ohm of each other. To determine the difference, record the resistance of each injector and subtract the lowest resistance reading from the highest resistance reading to get the difference. If more than 0.4 ohm, then further testing will be needed to verify defective injector(s). ● **SEE FIGURE 78–7.**

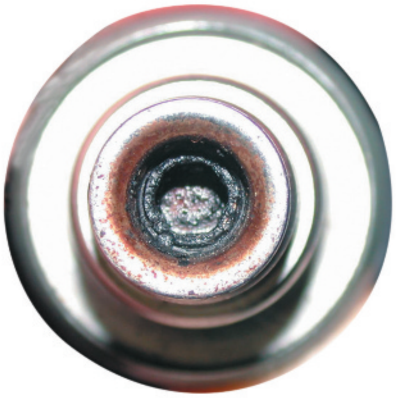


FIGURE 78–7 If an injector has the specified resistance, this does not mean that it is okay. This injector had the specified resistance, yet it did not deliver the correct amount of fuel because it was clogged.

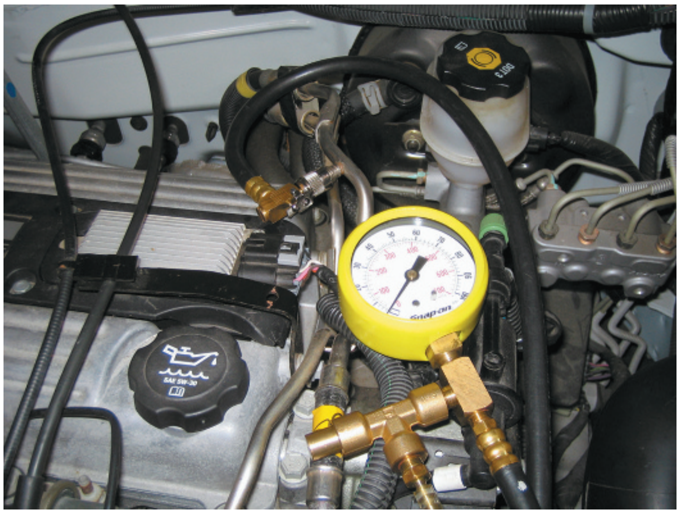


FIGURE 78–8 Connect a fuel-pressure gauge to the fuel rail at the Schrader valve.

INJECTOR VOLTAGE-DROP TESTS

Another test of injectors involves pulsing the injector and measuring the voltage drop across the windings as current is flowing. A typical voltage-drop tester is shown in ● **FIGURE 78–9**. The tester, which is recommended for use by General Motors Corporation, pulses the injector while a digital multimeter is connected to the unit, which will display the voltage drop as the current flows through the winding.

CAUTION: Do not test an injector using a pulse-type tester more than one time without starting the engine to help avoid a hydrostatic lock caused by the flow of fuel into the cylinder during the pulse test.

Record the highest voltage drop observed on the meter display during the test. Repeat the voltage-drop test for all of the injectors. The voltage drop across each injector should be within 0.1 volt of each other. If an injector has a higher-than-normal voltage drop, the injector windings have higher-than-normal resistance.

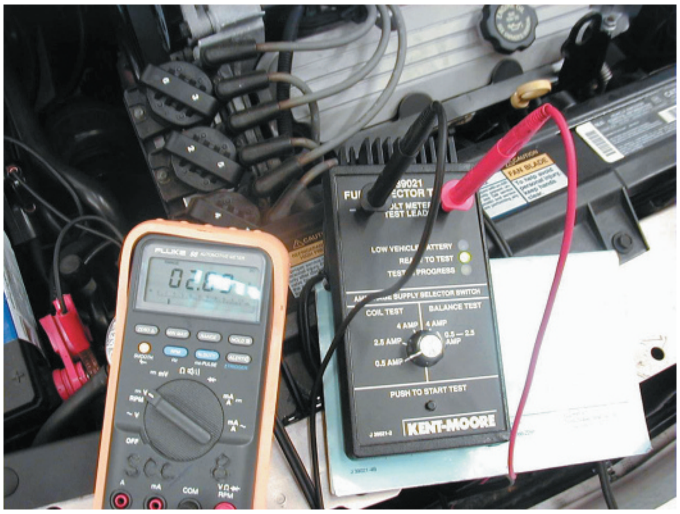


FIGURE 78–9 An injector tester being used to check the voltage drop through the injector while the tester is sending current through the injectors. This test is used to check the coil inside the injector. This same tester can be used to check for equal pressure drop of each injector by pulsing the injector on for 500 ms.

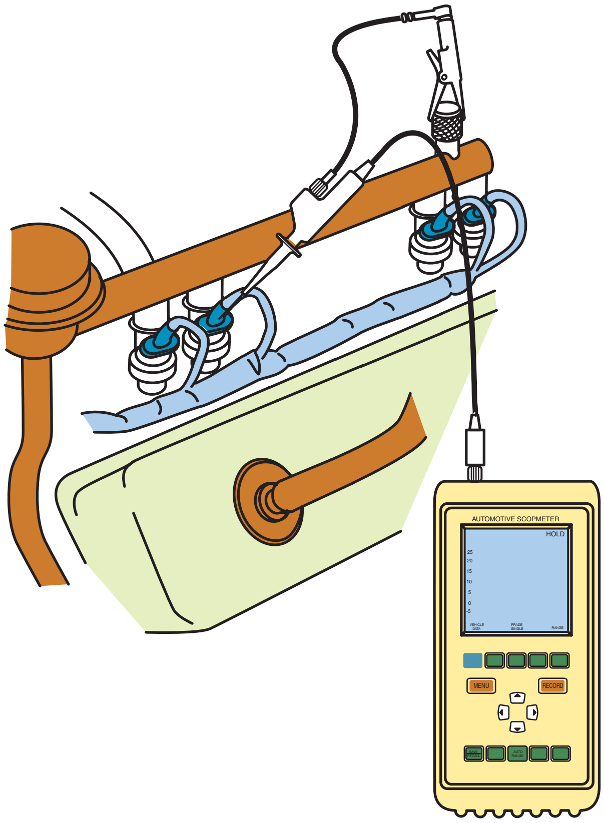


FIGURE 78–10 A DSO can be easily connected to an injector by carefully back-probing the electrical connector.

SCOPE-TESTING FUEL INJECTORS

A scope (analog or digital storage) can be connected into each injector circuit. There are three types of injector drive circuits and each type of circuit has its own characteristic pattern. ● **SEE FIGURE 78–10** for an example of how to connect a scope to read a fuel-injector waveform.

SATURATED SWITCH TYPE In a saturated switch-type injector-driven circuit, voltage (usually a full 12 volts) is applied to the injector. The ground for the injector is provided by the vehicle computer. When the ground connection is completed, current flows through the injector windings. Due to the resistance and inductive reactance of the coil itself, it requires a fraction of a second (about 3 milliseconds or 0.003 seconds) for the coil to reach **saturation** or maximum current flow. Most saturated switch-type fuel injectors have 12 to 16 ohms of resistance. This resistance, as well as the computer switching circuit, control and limit the current flow through the injector. A voltage spike occurs when the computer shuts off (opens the injector ground-side circuit) the injectors. ● **SEE FIGURE 78–11**.

PEAK-AND-HOLD TYPE A **peak-and-hold** type is typically used for TBI and some port low-resistance injectors. Full battery voltage is applied to the injector and the ground side is controlled through the computer. The computer provides a high initial current flow (about 4 amperes) to flow through the injector windings to open the injector core. Then the computer reduces the current to a lower level (about 1 ampere). The hold current is enough to keep the injector open, yet conserves energy and reduces the heat buildup that would occur if the full current flow

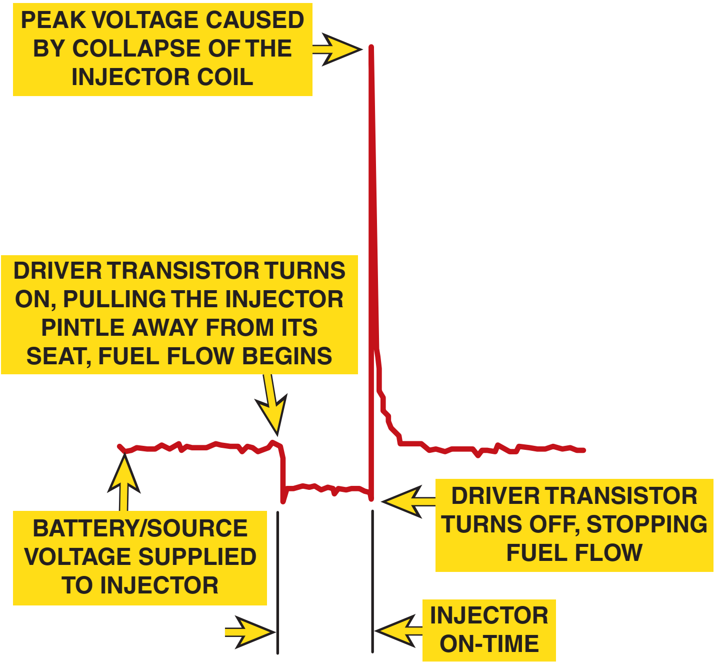

PEAK VOLTAGE CAUSED BY COLLAPSE OF THE INJECTOR COIL
DRIVER TRANSISTOR TURNS ON, PULLING THE INJECTOR PINTLE AWAY FROM ITS SEAT, FUEL FLOW BEGINS
BATTERY/SOURCE VOLTAGE SUPPLIED TO INJECTOR
DRIVER TRANSISTOR TURNS OFF, STOPPING FUEL FLOW
INJECTOR ON-TIME

FIGURE 78–11 The injector on-time is called the pulse width.

remains on as long as the injector is commanded on. Typical peak-and-hold-type injector resistance ranges from 2 to 4 ohms.

The scope pattern of a typical peak-and-hold-type injector shows the initial closing of the ground circuit, then a voltage spike as the current flow is reduced. Another voltage spike occurs when the lower level current is turned off (opened) by the computer. ● **SEE FIGURE 78–12**.

PULSE-WIDTH MODULATED TYPE A pulse-width modulated type of injector drive circuit uses lower-resistance coil injectors. Battery voltage is available at the positive terminal of the injector and the computer provides a variable-duration connection to ground on the negative side of the injector. The computer can vary the time intervals that the injector is grounded for very precise fuel control.

Each time the injector circuit is turned off (ground circuit opened), a small voltage spike occurs. It is normal to see multiple voltage spikes on a scope connected to a pulse-width modulated type of fuel injector. ● **SEE FIGURE 78–13**.

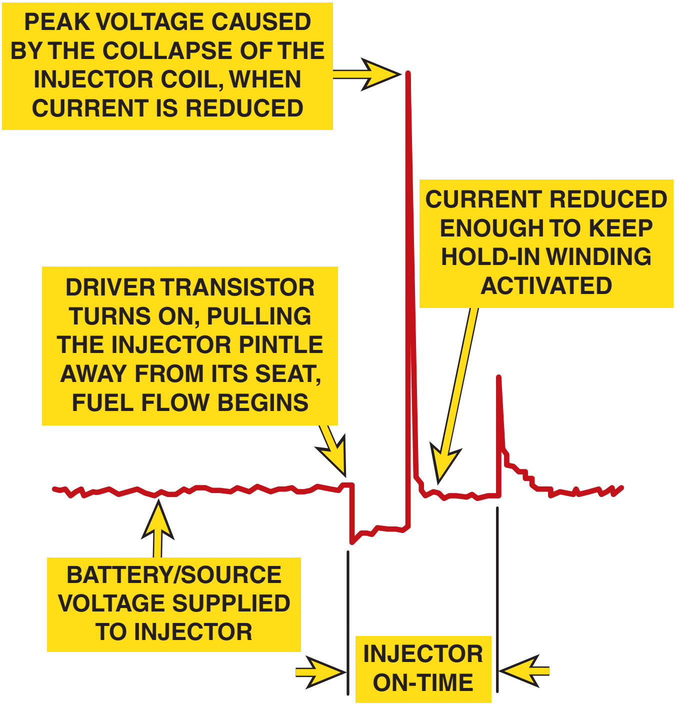

PEAK VOLTAGE CAUSED BY THE COLLAPSE OF THE INJECTOR COIL, WHEN CURRENT IS REDUCED
CURRENT REDUCED ENOUGH TO KEEP HOLD-IN WINDING ACTIVATED
DRIVER TRANSISTOR TURNS ON, PULLING THE INJECTOR PINTLE AWAY FROM ITS SEAT, FUEL FLOW BEGINS
BATTERY/SOURCE VOLTAGE SUPPLIED TO INJECTOR
INJECTOR ON-TIME

FIGURE 78–12 A typical peak-and-hold fuel-injector wave form. Most fuel injectors that measure less than 6 ohms will usually display a similar waveform.

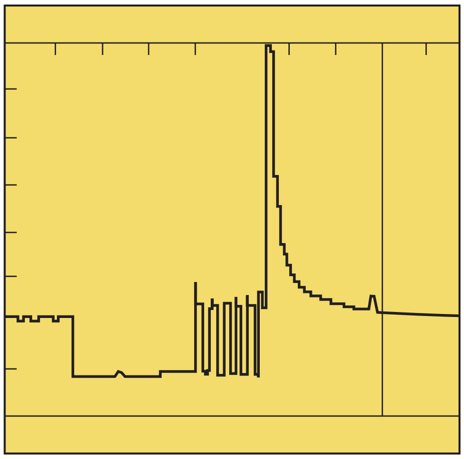


FIGURE 78–13 A waveform of a pulse-width modulated fuel injector. At the end, when the voltage is removed, there is an inductive spike created similar to the spike created but other types of injectors.

FUEL-INJECTION SERVICE

NEED FOR SERVICE All engines using fuel injection do require some type of fuel-system maintenance. Normal wear and tear with today's underhood temperatures and changes in gasoline quality contribute to the buildup of olefin wax, dirt, water, and many other additives. Unique to each engine is an air-control design that also may contribute different levels of carbon deposits, such as oil control.

FREQUENTLY ASKED QUESTION

If Three of Six Injectors Are Defective, Should I Also Replace the Other Three?

This is a good question. Many service technicians "recommend" that the three good injectors be replaced along with the other three that tested as being defective. The reasons given by these technicians include the following:

- All six injectors have been operating under the same fuel, engine, and weather conditions.
- The labor required to replace all six is just about the same as replacing only the three defective injectors.
- Replacing all six at the same time helps ensure that all of the injectors are flowing the same amount of fuel so that the engine is operating most efficiently.

With these ideas in mind, the customer should be informed and offered the choice. Complete sets of injectors, such as those in ● **FIGURE 78–14** can be purchased at a reasonable cost.

FIGURE 78–14 A set of six reconditioned injectors. The sixth injector is barely visible at the far right.

CASE STUDY

There Is No Substitute for a Thorough Visual Inspection

An intermittent "check engine" light and a random-misfire diagnostic trouble code (DTC) P0300 was being diagnosed. A scan tool did not provide any help because all systems seemed to be functioning normally. Finally, the technician removed the engine cover and discovered a mouse nest. ● **SEE FIGURE 78–15**.

Summary:

Complaint—Customer stated that the "Check Engine" light was on.
Cause—A stored P0300 DTC was stored indicating a random misfire had been detected caused by an animal that had partially eaten some fuel-injector wires.
Correction—The mouse nest was removed and the wiring was repaired.

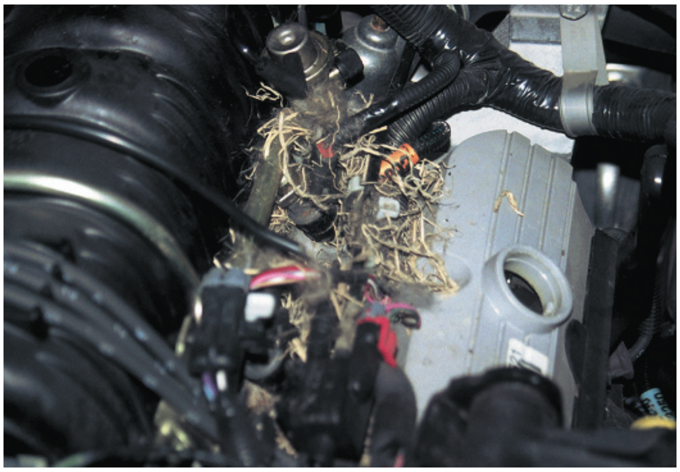


FIGURE 78–15 When the cover is removed from the top of the engine, a mouse or some other animal nest is visible. The animal had already eaten through a couple of injector wires. At least the cause of the intermittent misfire was discovered.

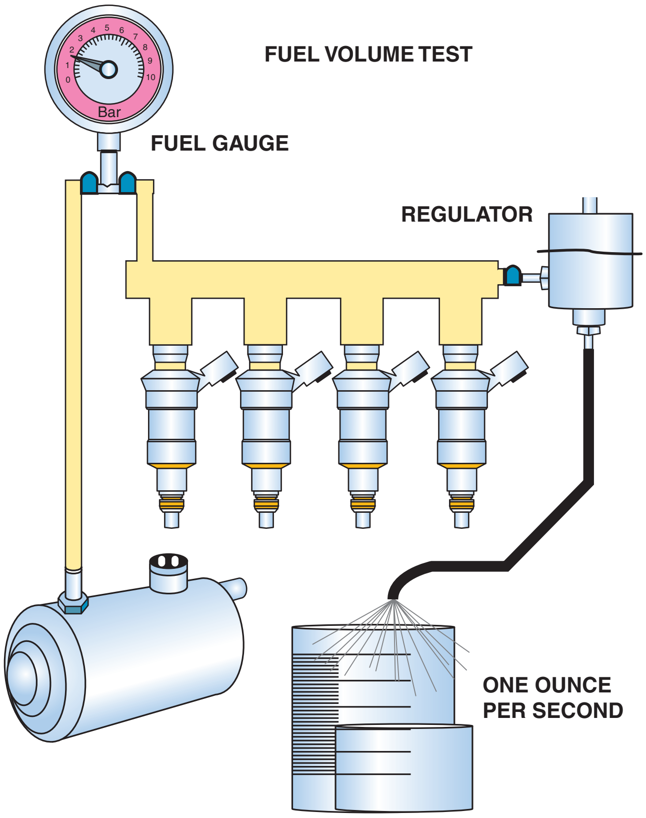


FIGURE 78–16 Checking fuel-pump volume using a hose from the outlet of the fuel-pressure regulator into a calibrated container.

FUEL-INJECTION SERVICE Fuel-injection system service should include the following operations:

1. **Check fuel-pump operating pressure and volume.** The missing link here is volume. Most working technicians assume that if the pressure is correct, the volume is also okay. Hook up a fuel-pressure tester to the fuel rail inlet to quickly test the fuel pressure with the engine running. At the same time, test the volume of the pump by sending fuel into the holding tank. (One ounce per second is the usual specification.) ● **SEE FIGURE 78–16**. A two-line system tester is the recommended procedure to use and is attached to the fuel inlet and the return on the fuel rail. The vehicle onboard system is looped and returns fuel to the tank.
2. **Test the fuel-pressure regulator for operation and leakage.** At this time, the fuel-pressure regulator would be tested for operational pressure and proper regulation, including leakage. (This works well as the operator has total control of rail pressure with a unit control valve.) Below are some points to consider:
   - Good pressure does not mean proper volume. For example, a clogged filter may test okay on pressure, but the restriction may not allow proper volume under load. ● **SEE FIGURE 78–17**.
   - It is a good idea to use the vehicle's own gasoline to service the system versus a can of shop gasoline that has been sitting around for some time.
   - Pressure regulators do fail and a lot more do not properly shut off fuel, causing higher-than-normal pump wear and shorter service life.

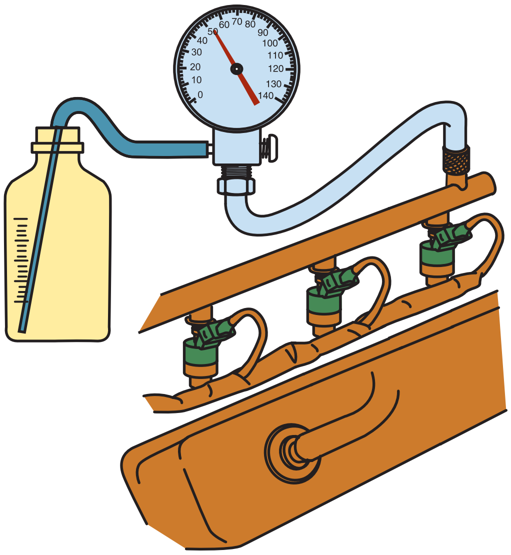


FIGURE 78–17 Testing fuel-pump volume using a fuel-pressure gauge with a bleed hose inserted into a suitable container. The engine is running during this test.

3. **Flush the entire fuel rail and upper fuel-injector screens including the fuel-pressure regulator.** Raise the input pressure to a point above regulator setting to allow a constant flow of fuel through the inlet pressure side of the system, through the fuel rail, and out the open fuel-pressure regulator. In most cases the applied pressure is 75 to 90 PSI (517 to 620 kPa), but will be maintained by the presence of a regulator. At this point, cleaning chemical is added to the fuel at a 5:1 mixture and allowed to flow through the system for 15 to 30 minutes. ● **SEE FIGURE 78–18**. Results are best on a hot engine with the fuel supply looped and the engine not running.
4. **Decarbon the engine assembly.** On most vehicles, the injector spray will help the decarboning process. On others, you may need to enhance the operation with external addition of a mixture through the PCV hose, throttle plates, or idle air controls.
5. **Clean the throttle plate and idle air control passages.** Doing this service alone on most late-model engines will show a manifold vacuum increase of up to 2 inches Hg. ● **SEE FIGURE 78–19**. This works well as air is drawn into IAC passages on a running engine and will clean the passages without IAC removal.
6. **Relearn the onboard computer.** Some vehicles may have been running in such a poor state of operation that the onboard computer may need to be relearned. Consult service information for the suggested relearn procedures for each particular vehicle.

All of the previously listed steps may be performed using a two-line fuel-injector service unit such as Carbon Clean, Auto Care, Injector Test, DeCarbon, or Motor-Vac.

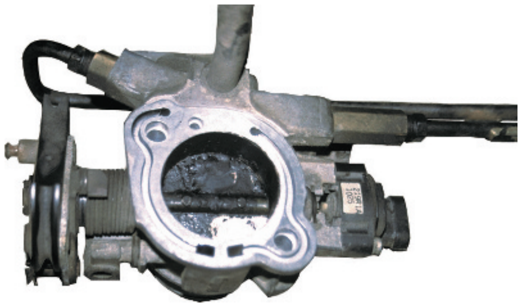


FIGURE 78–19 To thoroughly clean a throttle body, it is sometimes best to remove it from the vehicle. The throttle plate may need to be cleaned if the engine tends to stall, hesitate or has a rough idle.

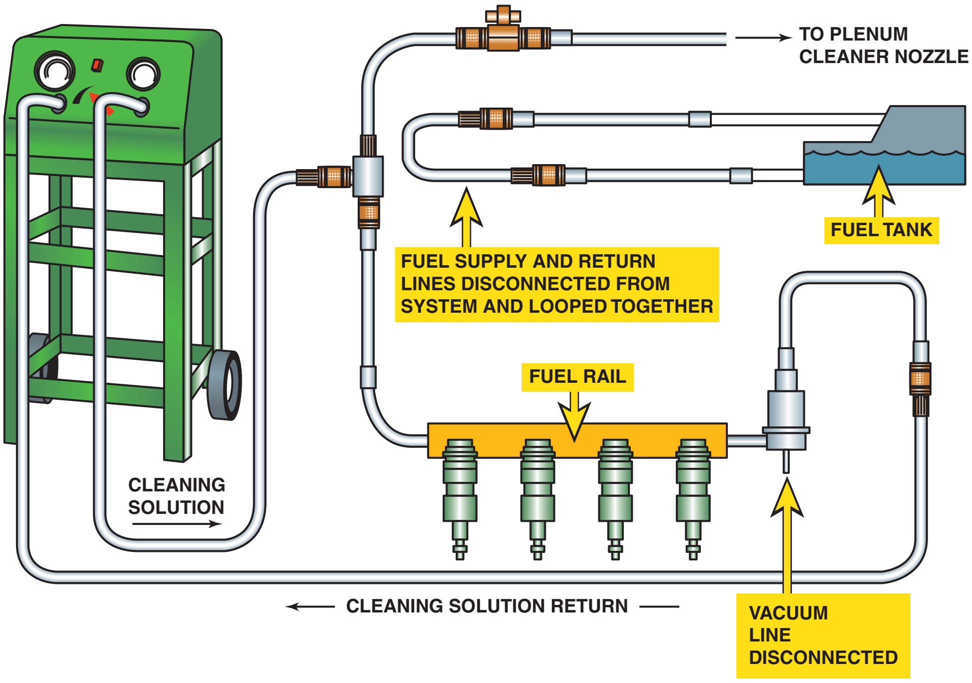


FIGURE 78–18 A typical two-line cleaning machine hookup, showing an extension hose that can be used to squirt a cleaning solution into the throttle body while the engine is running on the cleaning solution and gasoline mixture.

FUEL-INJECTION SYMPTOM CHART

Symptom	Possible Causes
Hard cold starts	• Low fuel pressure • Leaking fuel injectors • Contaminated fuel • Low-volatility fuel • Dirty throttle plate
Garage stalls	• Low fuel pressure • Insufficient fuel volume • Restricted fuel injector • Contaminated fuel • Low-volatility fuel
Poor cold performance	• Low fuel pressure • Insufficient fuel volume • Contaminated fuel • Low-volatility fuel
Tip-in hesitation (hesitation just as the accelerator pedal is depressed)	• Low fuel pressure • Insufficient fuel volume • Intake valve deposits • Contaminated fuel • Low-volatility fuel

TECH TIP

Check the Injectors at the "Bends and the Ends"

Injectors that are most likely to become restricted due to clogging of the filter basket screen are the injectors at the ends of the rail, especially on returnless systems where dirt can accumulate. Also the injectors that are located at the bends of the fuel rail are also subject to possible clogging due to the dirt being deposited where the fuel makes a turn in the rail.

TECH TIP

Use an Injector Tester

The best way to check injectors is to remove them all from the engine and test them using an injector tester. A typical injector tester uses a special nonflammable test fluid that has the same viscosity as gasoline. The tester pulses the injectors, and the amount of fuel delivered, as well as the spray pattern can be seen. Many testers are capable of varying the frequency of the pulse, as well as the duration that helps find intermittent injector faults. ● **SEE FIGURE 78–20**.

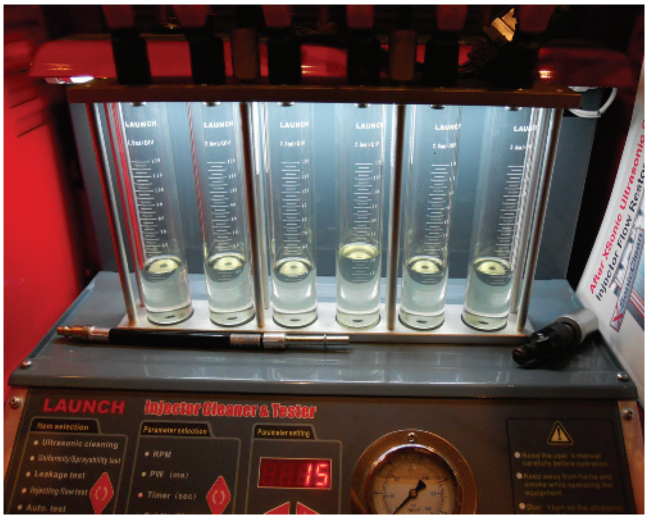


FIGURE 78–20 The amount each injector is able to flow is displayed in glass cylinders are each injector for a quick visual check.

WARNING

Before opening any part of the high-pressure section of a gasoline direct injection (GDI) system, the pressure must be bled off. The high pressures of this fuel system can cause injury or death. If any of the high-pressure lines are removed, even temporarily, they MUST be replaced because the ends use a ball-fitting that deforms to create the high-pressure seal. Once this seal has been opened, a new ball end must be used to insure a proper seal. ● **SEE FIGURE 78–21**.

Always check service information for the exact procedures to follow for the vehicle being serviced.

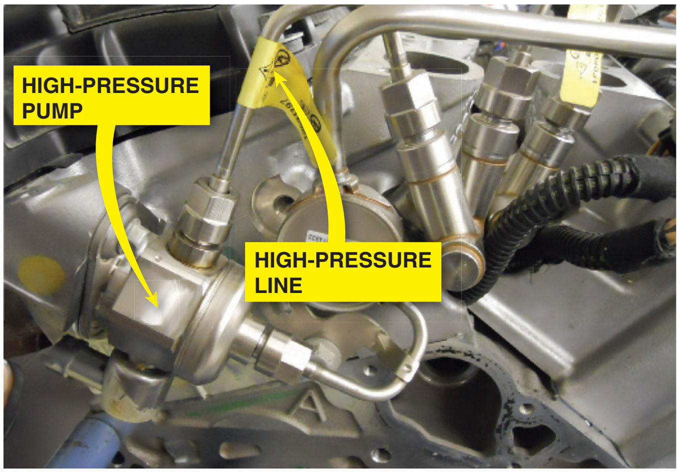


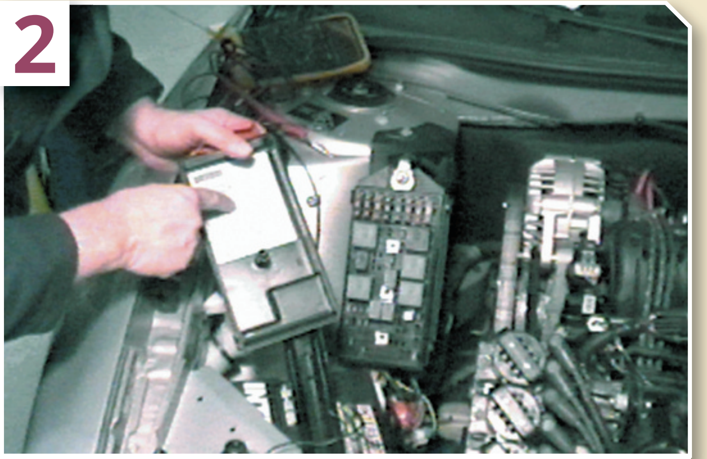
FIGURE 78–21 The line that has the yellow tag is a high-pressure line and this line must be replaced with a new part if removed even for a few minutes to gain access to another part.

FUEL-PUMP RELAY CIRCUIT DIAGNOSIS

1

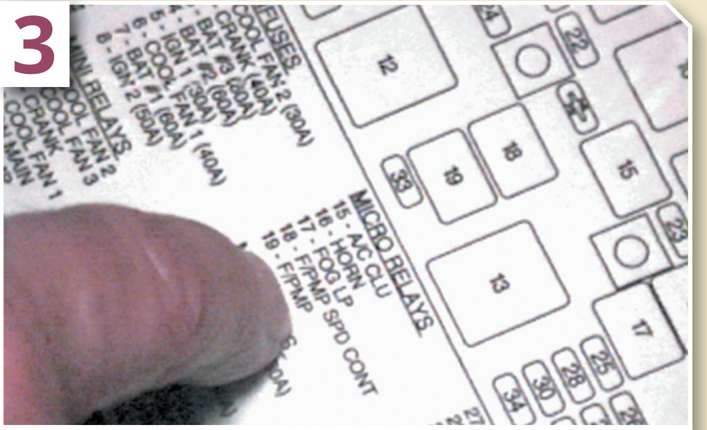
The tools needed to diagnose a circuit containing a relay include a digital multimeter (DMM), a fused jumper wire, and an assortment of wiring terminals.

2



Start the diagnosis by locating the relay center. It is under the hood on this General Motors vehicle, so access is easy. Not all vehicles are this easy.

3

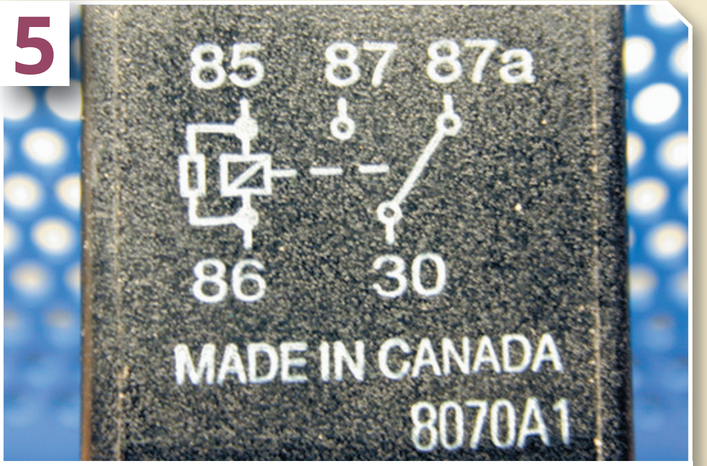

FUSES
MINI RELAYS
COOL FAN 2
COOL FAN 3
CRANK
COOL FAN 1
MICRO RELAYS
15 - AC CLU
16 - HORN
17 - FOG LP
18 - F/PMP SPD CONT
19 - F/PMP

The chart under the cover for the relay center indicates the location of the relay that controls the electric fuel pump.

4

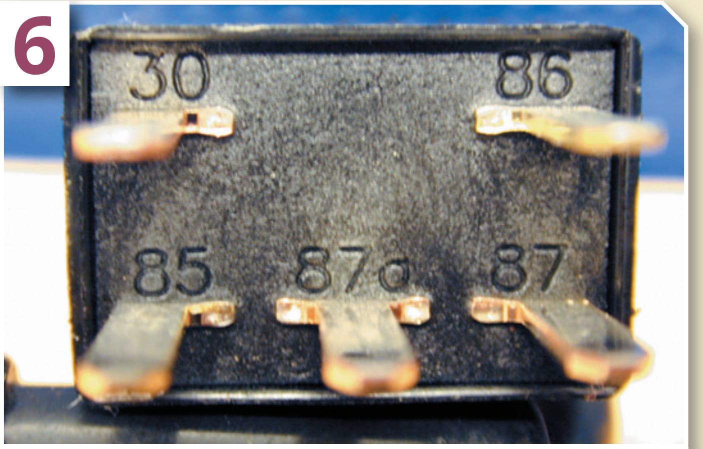
Locate the fuel-pump relay and remove it by using a puller if necessary. Try to avoid rocking or twisting the relay to prevent causing damage to the relay terminals or the relay itself.

5


85
87
87a
86
30
MADE IN CANADA
8070A1

Terminals 85 and 86 represent the coil inside the relay. Terminal 30 is the power terminal, 87a is the normally closed contact, and 87 is the normally open contact.

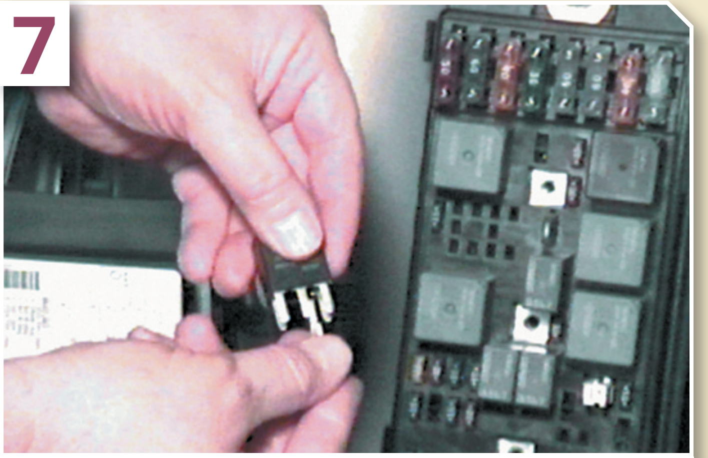
6


30
86
85
87a
87

The terminals are also labeled on most relays.

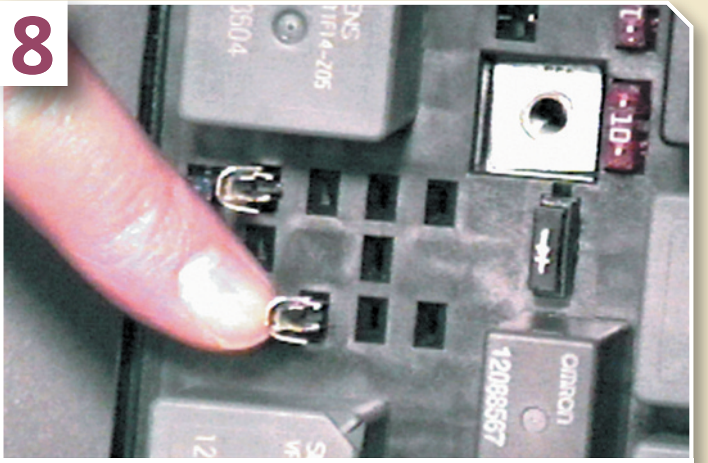
STEP BY STEP

7



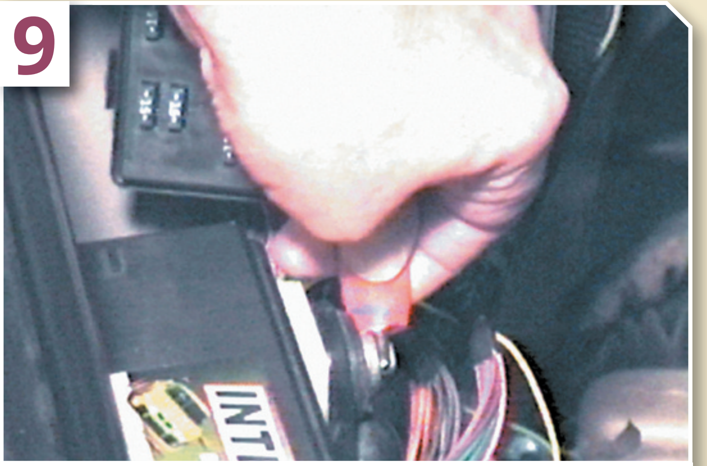
To help make good electrical contact with the terminals without doing any harm, select the proper-size terminal from the terminal assortment.

8



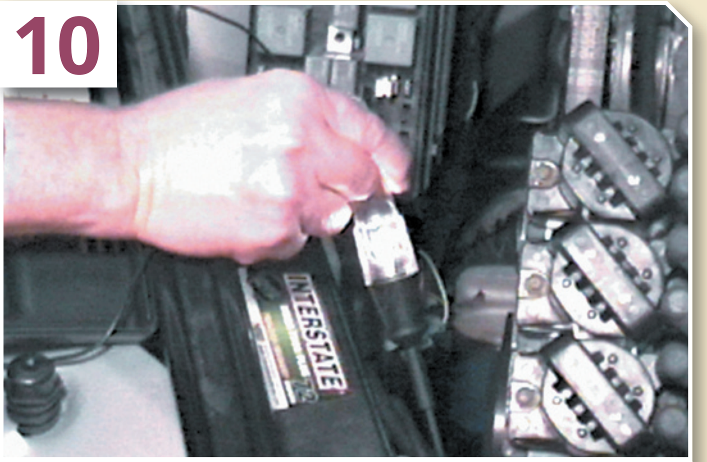
Insert the terminals into the relay socket in 30 and 87.

9



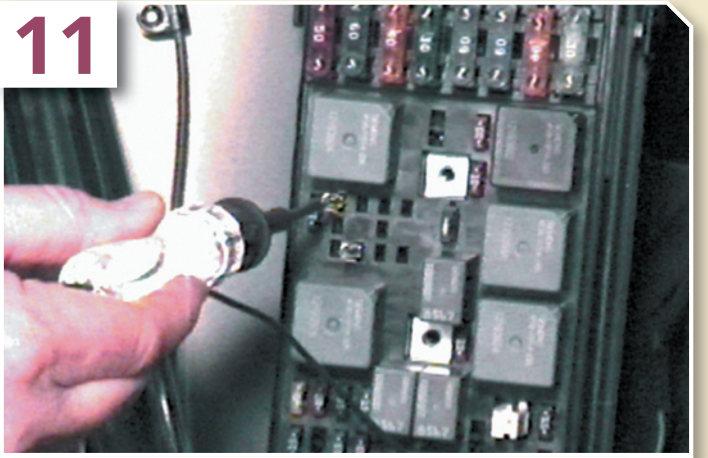
To check for voltage at terminal 30, use a test light or a voltmeter. Start by connecting the alligator clip of the test light to the positive (1) terminal of the battery.

10



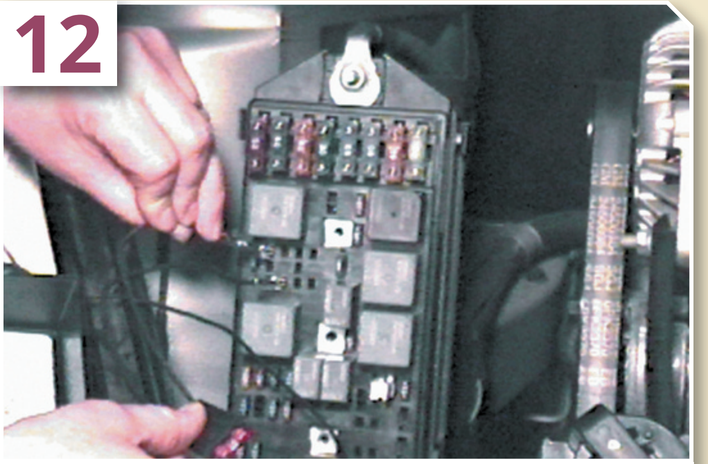
Touch the test light to the negative (–) terminal of the battery or a good engine ground to check the test light.

11



Use the test light to check for voltage at terminal 30 of the relay. The ignition may have to be in the on (run) position.

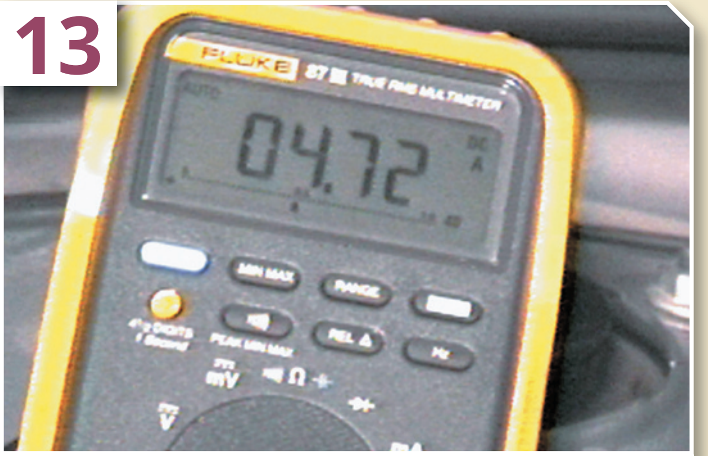
12



To check to see if the electric fuel pump can be operated from the relay contacts, use a fused jumper wire and touch the relay contacts that correspond to terminals 30 and 87 of the relay.

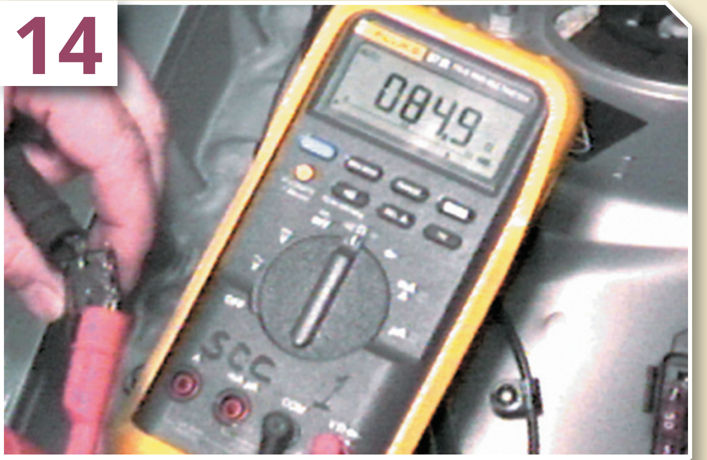
FUEL-PUMP RELAY CIRCUIT DIAGNOSIS

13



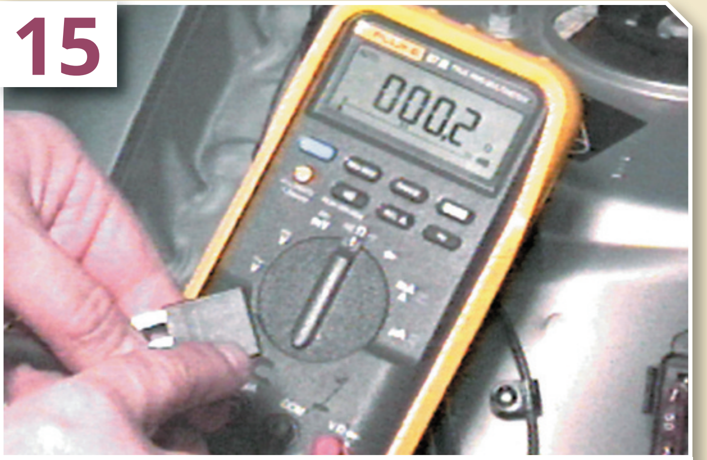
Connect the leads of the meter to contacts 30 and 87 of the relay socket. The reading of 4.7 amperes is okay because the specification is 4 to 8 amperes.

14



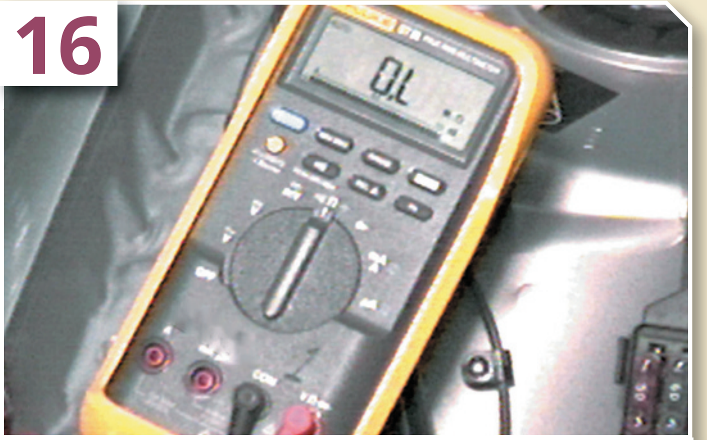
Set the meter to read ohms (Ω) and measure the resistance of the relay coil. The usual reading for most relays is between 60 and 100 ohms.

15



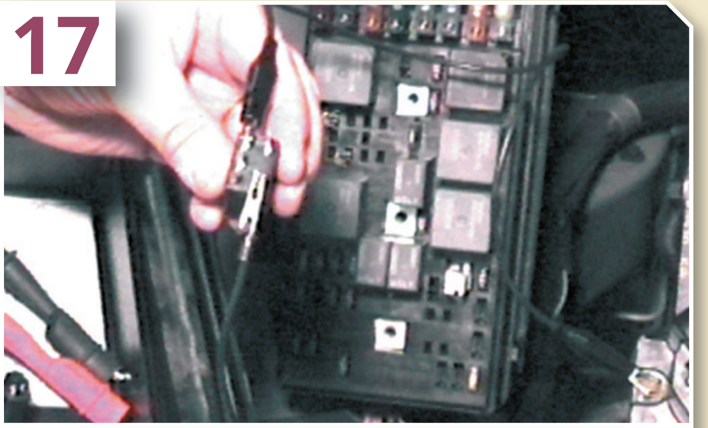
Measure between terminal 30 and 87a. Terminal 87a is the normally closed contact, and there should be little, if any, resistance between these two terminals, as shown.

16



To test the normally open contacts, connect one meter lead to terminal 30 and the other lead to terminal 87. The ohmmeter should show an open circuit by displaying OL.

17



Connect a fused jumper wire to supply 12 volts to terminal 86 and a ground to terminal 85 of the relay. If the relay clicks, then the relay coil is able to move the armature (movable arm) of the relay.

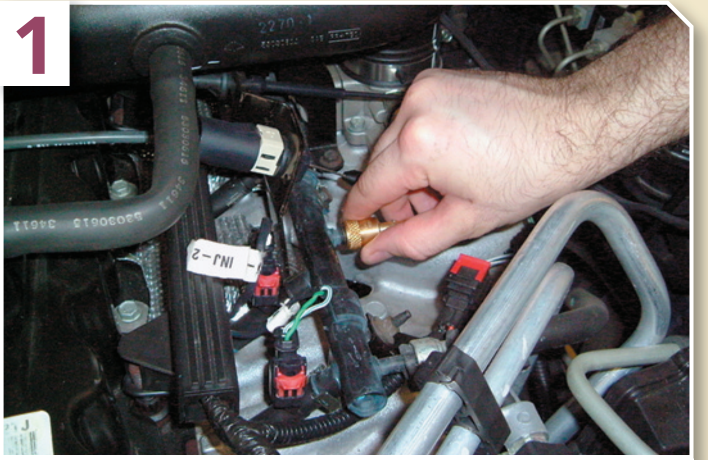
18

After testing, be sure to reinstall the relay and the relay cover.

FUEL INJECTOR CLEANING

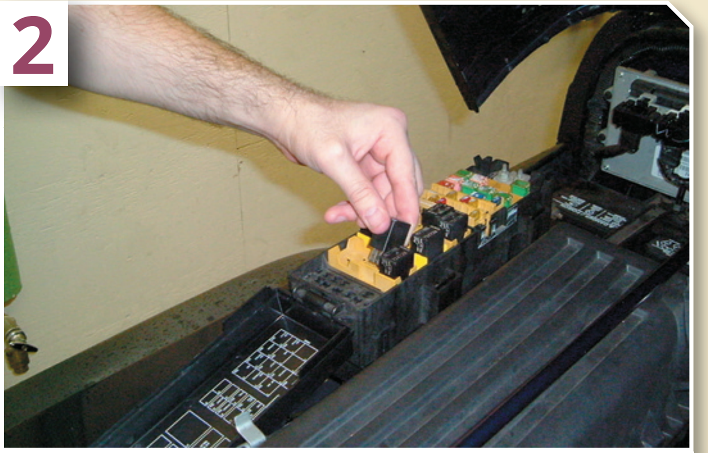
STEP BY STEP

1



Start the fuel injector cleaning process by bringing the vehicle's engine up to operating temperature. Shut off the engine, remove the cap from the fuel rail test port, and install the appropriate adapter.

2



The vehicle's fuel pump is disabled by removing its relay or fuse. In some cases, it may be necessary to disconnect the fuel pump at the tank if the relay or fuse powers more than just the pump.

3

UAS
Automotive

Turn the outlet valve of the canister to the OFF or CLOSED position.

4

OTC
7448
Fuel Injection
Cleaner

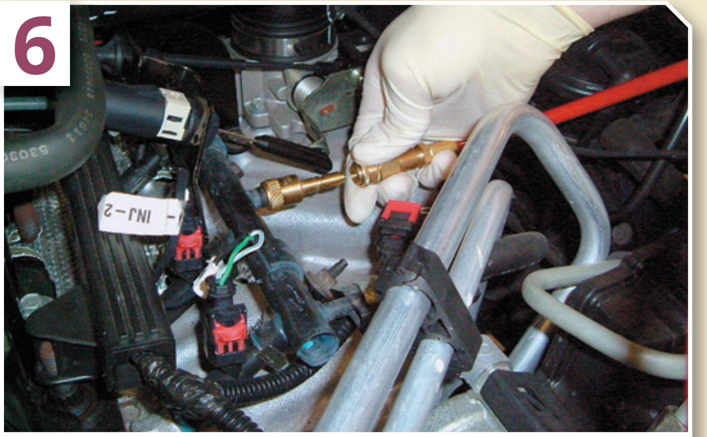
Remove the fuel injector cleaning canister's top and regulator assembly. Note that there is an O-ring seal located here that must be in place for the canister's top to seal properly.

5

OTC
7448
Fuel Injection
Cleaner
UAS
Automotive
OTC

Pour the injection system cleaning fluid into the open canister. Rubber gloves are highly recommended for this step as the fluid is toxic.

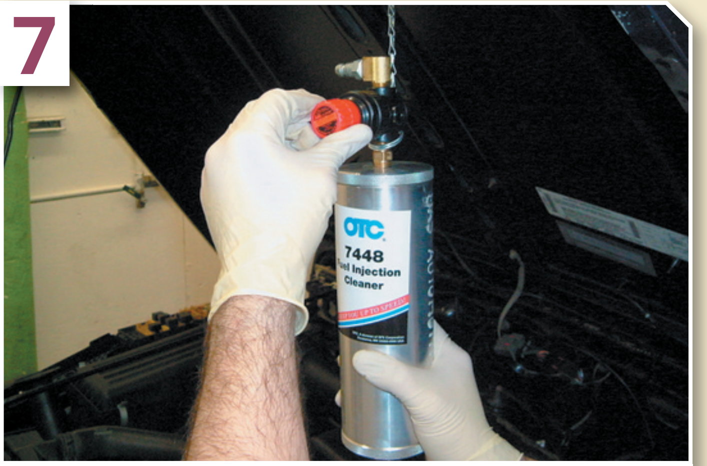
6



Replace the canister's top (making sure it is tight) and connect its hose to the fuel rail adapter. Be sure that the hose is routed away from exhaust manifolds and other hazards.

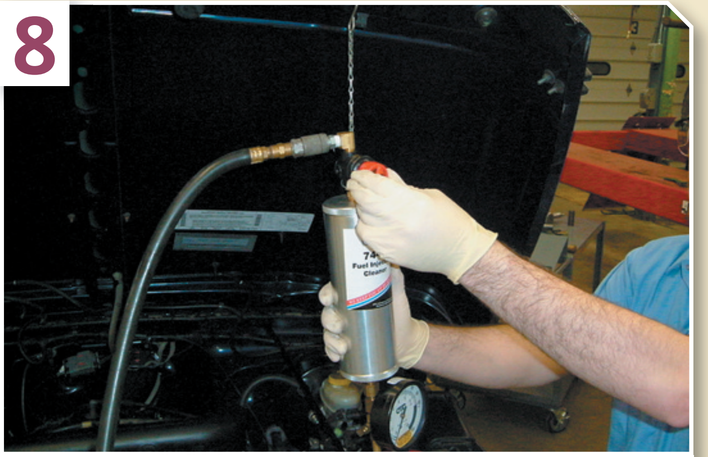
FUEL INJECTOR CLEANING

7


OTC
7448
Fuel Injection Cleaner

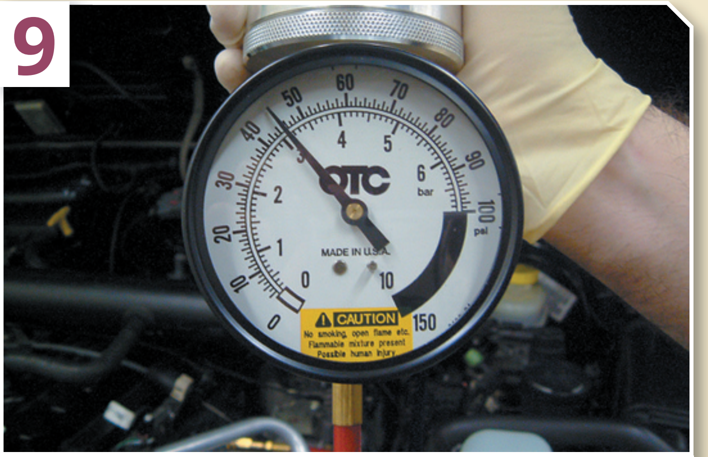
Hang the canister from the vehicle's hood and adjust the air pressure regulator to full OPEN position (CCW).

8



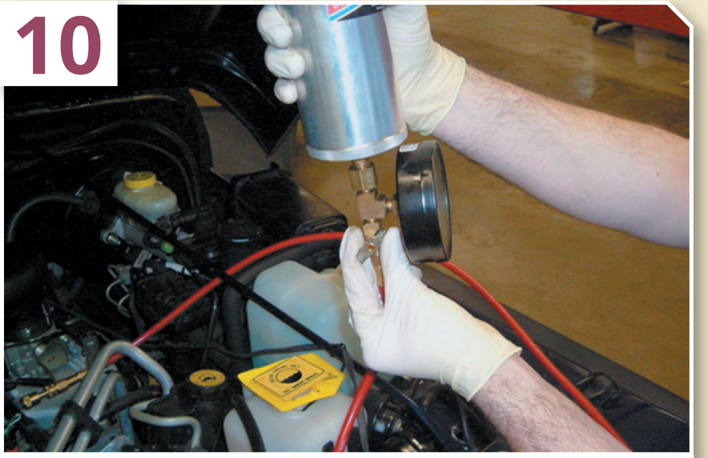
Connect shop air to the canister and adjust the air pressure regulator to the desired setting. Canister pressure can be read directly from the gauge.

9


OTC
bar
psi
MADE IN U.S.A.
0
10
20
30
40
50
60
70
80
90
100
150
0
1
2
4
5
6
10
CAUTION
No smoking, open flame etc.
Flammable mixture present
Possible human injury

Canister pressure should be adjusted to 5 PSI below system fuel pressure. An alternative for return-type systems is to block the fuel return line to the tank.

10

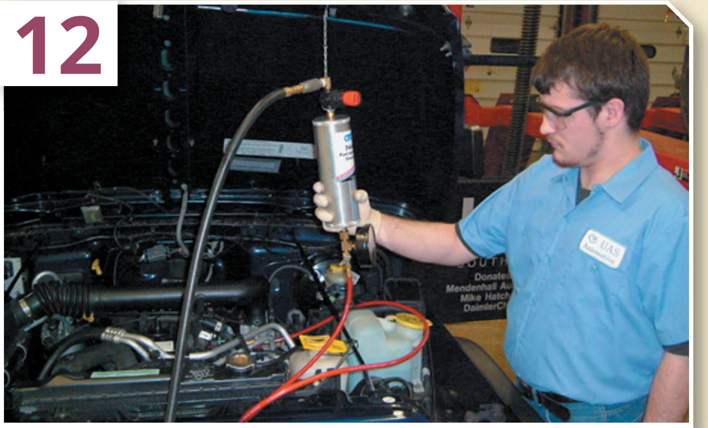


Open the outlet valve on the canister.

11

Start the vehicle's engine and let run at 1000–1500 RPM. The engine is now running on fuel injector cleaning fluid provided by the canister.

12



Continue the process until the canister is empty and the engine stalls. Remove the cleaning equipment, enable the vehicle's fuel pump, and run the engine to check for leaks.

REVIEW QUESTIONS

1. In what ways can fuel injectors be tested?
2. What are the characteristics of a saturated switch-type fuel injector?
3. What is the purpose of the injector pressure-drop balance test?
4. Why would fuel injectors at the bends and ends of the fuel rail tend to become clogged?
5. What does an injector voltage drop test indicate?

CHAPTER QUIZ

1. Most port fuel-injected engines operate on how much fuel pressure?
   - **a.** 3 to 5 PSI (21 to 35 kPa)
   - **b.** 9 to 13 PSI (62 to 90 kPa)
   - **c.** 35 to 45 PSI (240 to 310 kPa)
   - **d.** 55 to 65 PSI (380 to 450 kPa)
2. Fuel injectors can be tested using ______________.
   - **a.** an ohmmeter
   - **b.** an injector pulser
   - **c.** a scope
   - **d.** Any of the above
3. Which injector test is used to find a clogged injector?
   - **a.** Voltage drop test
   - **b.** Scope test
   - **c.** Pressure drop test
   - **d.** None of these
4. Port fuel-injection systems generally use what type of injector driver?
   - **a.** Peak and hold
   - **b.** Saturated switch
   - **c.** Pulse-width modulated
   - **d.** Pulsed
5. Fuel-injector resistance is being discussed. Technician A says that some injectors have a normal resistance of 1.5 to 4 ohms. Technician B says that some injectors have a normal resistance of 12 to 16 ohms. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. The fuel pressure drops rapidly when the engine is turned off. Technician A says that one or more injectors could be leaking. Technician B says that a defective check valve in the fuel pump could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. In a typical port fuel-injection system, which injectors are most subject to becoming restricted?
   - **a.** Any of them equally
   - **b.** The injectors at the end of the rail on a returnless system
   - **c.** The injectors at the bends in the rail
   - **d.** Either b or c
8. What component pulses the fuel injector on most vehicles?
   - **a.** Electronic control unit (computer)
   - **b.** Ignition module
   - **c.** Crankshaft sensor
   - **d.** Both b and c
9. Fuel-injection service is being discussed. Technician A says that the throttle plate(s) should be cleaned. Technician B says that the fuel rail should be cleaned. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. If the throttle plate needs to be cleaned, what symptoms will be present regarding the operation of the engine?
    - **a.** Stalls
    - **b.** Rough idle
    - **c.** Hesitation on acceleration
    - **d.** Any of the above

Chapter

79

VEHICLE EMISSIONS STANDARDS AND TESTING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss normal engine combustion.
- Discuss exhaust analysis and combustion efficiency.
- Discuss the catalytic converter.
- Explain diagnosis using exhaust analysis.
- Explain engine fault possibilities.
- Discuss US and European emission standards.
- Explain vehicle emission testing.

KEY TERMS:

Carbon dioxide (CO_2) 932 • Carbon monoxide (CO) 932 • Federal Test Procedure (FTP) 939 • Hydrocarbons (HC) 932 • Lean indicator 935 • Nitrogen (N_2) 932 • Oxygen (O_2) 932 • Oxides of Nitrogen (NO_x) 932 • Ozone 936 • Rich indicator 935 • Smog 936 • Stoichiometric ratio 932 • Water (H_2O) 932

NORMAL ENGINE COMBUSTION

AIR AND GASOLINE Engines consume about 15 times more air by weight than gasoline; this ratio of air to fuel is called the **stoichiometric ratio**. This ratio, which is 14.7:1 for gasoline, is the ratio where all of the fuel is consumed in the combustion process and uses all of the available oxygen.

- Entering the engine combustion chamber is fuel (HC) plus air (**nitrogen (N_2)** is 78% and **oxygen (O_2)** is 21% of the air). ● **SEE FIGURE 79–1**.
- During combustion, the HC combines with the air to form **water (H_2O)**, carbon dioxide (CO_2) plus nitrogen (N_2) and some other non-desirable gases.
- Engines consume about 15 times more air by with than gasoline (14.7:1 at stoichiometric ratio). Some of the other gases include the following:
    - Unburned **hydrocarbons (HC)**—If perfect combustion occurs inside the engine, there should not be any leftover unburned fuel. If there is HC gas exiting the tailpipe, it indicates that all of the fuel has not been burned. ● **SEE FIGURE 79–2**.

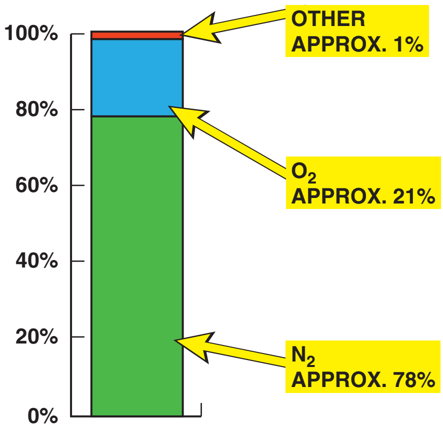


FIGURE 79–1 The air entering the engine consists of mostly nitrogen (78%) with about 21% oxygen and about 1% other gases.

- **Carbon monoxide (CO)**—During combustion, all of the carbon in the fuel should be converted to **carbon dioxide (CO_2)**, if there is enough oxygen available. If there is not enough oxygen available in the combustion chamber, incomplete combustion occurs, creating CO instead of. ● **SEE FIGURE 79–3**.
- **Oxides of Nitrogen (NO_x)**—Nitrogen is 78% of the air, so having some leftover is normal; however, if the

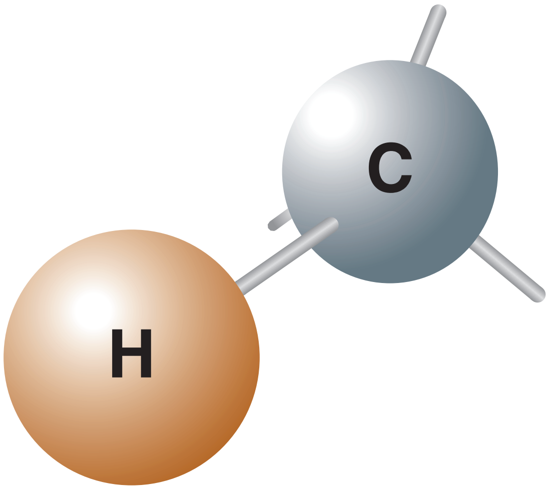


FIGURE 79–2 Hydrocarbons can include many combinations of hydrogen and carbon.

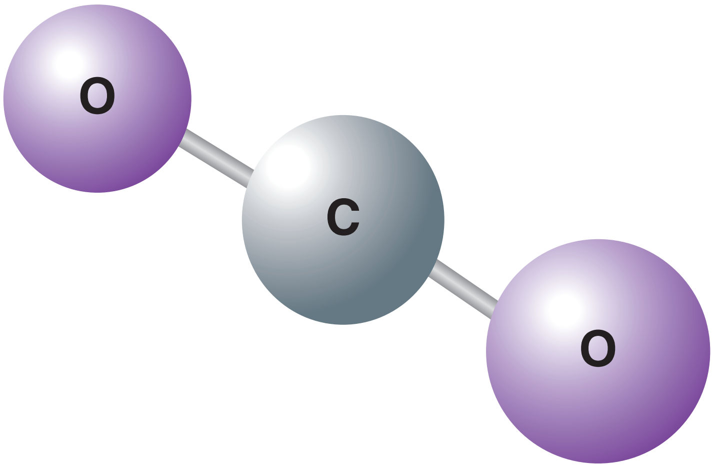


FIGURE 79–3 Carbon dioxide has two oxygen atoms attached to the one carbon atom and is a stable molecule.

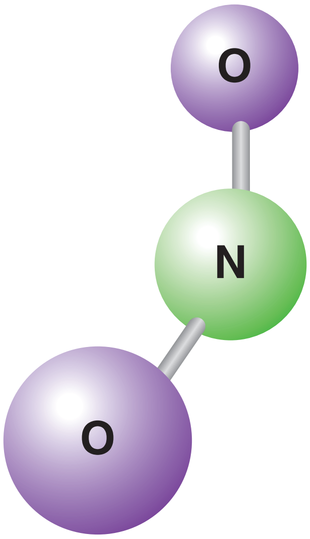


FIGURE 79–4 NO and NO_2 shown together are referred to as NO_x.

combustion temperatures and pressures are high enough, some of the nitrogen (N_2) combines with the oxygen to form NO and NO_2, which are harmful exhaust gases and referred to as oxides of nitrogen (NO_x), where the "x" represents the a number. ● **SEE FIGURE 79–4.**

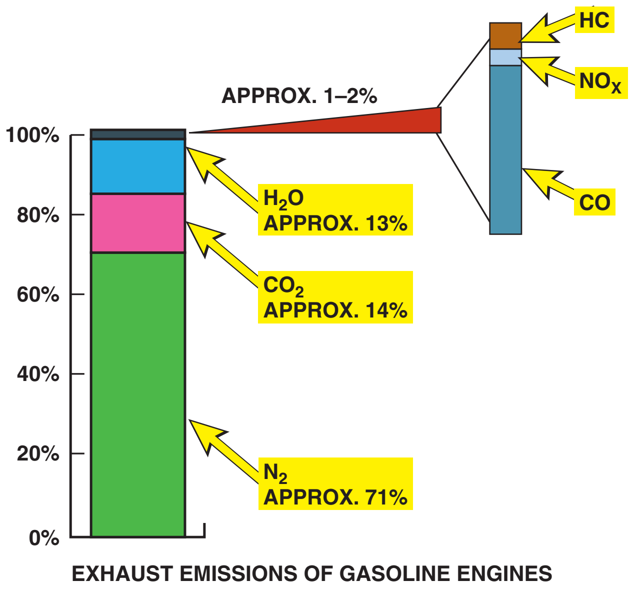


FIGURE 79–5 A chart showing that about 13% of the exhaust emissions is water (H_2O) in the form of steam.

FREQUENTLY ASKED QUESTION

Why Is Steam Seen from the Tailpipe When Cold Outside, But Not Always?

Steam is water vapor and is invisible. However, when an engine is cold, the water vapor created by combustion partially condenses into small droplets of water that are visible as "steam" from the tailpipe of vehicle when the engine is cold. After the exhaust system has been heated, the water vapor no longer condenses in the exhaust system, so it is not visible after the engine is warm. ● **SEE FIGURE 79–5.**

EXHAUST ANALYSIS AND COMBUSTION EFFICIENCY

HYDROCARBONS Hydrocarbons are unburned gasoline and are measured in parts per million (ppm). A correctly operating engine should burn (oxidize) almost all the gasoline; therefore, very little unburned gasoline should be present in the exhaust. Acceptable levels of HC are 50 ppm or less. High levels of HC could be due to excessive oil consumption caused by weak piston rings or worn valve guides. The most common cause of excessive HC emissions is a fault in the ignition system. Items that should be checked include the following:

- Spark plugs
- Secondary ignition fault such as coils, spark plug boots, or wiring

CARBON MONOXIDE **Carbon monoxide (CO)** is unstable and will easily combine with any oxygen to form stable CO_2. The fact that CO combines with oxygen is the reason that CO is a poisonous gas (in the lungs, it combines with oxygen to form CO_2 and deprives the brain of oxygen). CO levels of a properly operating engine should be less than 0.5%. High levels of CO can be caused by clogged or restricted crankcase ventilation devices, such as the pressure control valve (PCV) valve, hose(s), and tubes. Other items that might cause excessive CO include the following:

- Incorrect idle speed
- Too-high fuel-pump pressure
- Any other items that can cause a rich condition

CARBON DIOXIDE Carbon dioxide is the result of oxygen in the engine combining with the carbon of the gasoline. An acceptable level of CO_2 is between 12% and 15%. A high reading indicates an efficiently operating engine. If the CO_2 level is low, the mixture may be either too rich or too lean.

OXYGEN There is about 21% oxygen in the atmosphere, and most of this oxygen should be "used up" during the combustion process to oxidize all the hydrogen and carbon (hydrocarbons) in the gasoline. Levels of O_2 should be very low (about 0.5%). High levels of O_2, especially at idle, could be due to an exhaust system leak.

NOTE: Adding 10% alcohol to gasoline provides additional oxygen to the fuel and will result in lower levels of CO and higher levels of O_2 in the exhaust.

OXIDES OF NITROGEN (NO_X) An **oxide of nitrogen (NO)** is a colorless, tasteless, and odorless gas when it leaves the engine, but as soon as it reaches the atmosphere and mixes with more oxygen, nitrogen oxides (NO_2) are formed. NO_2 is reddish-brown and has an acid and pungent smell. NO and NO_2 are grouped together and referred to as NO_X, where *x* represents any number of oxygen atoms. NO_X, the symbol used to represent all oxides of nitrogen, is the fifth gas commonly tested using a five-gas analyzer. The exhaust gas recirculation (EGR) system is the major controlling device limiting the formation of NO_X. ● **SEE FIGURE 79–6**.

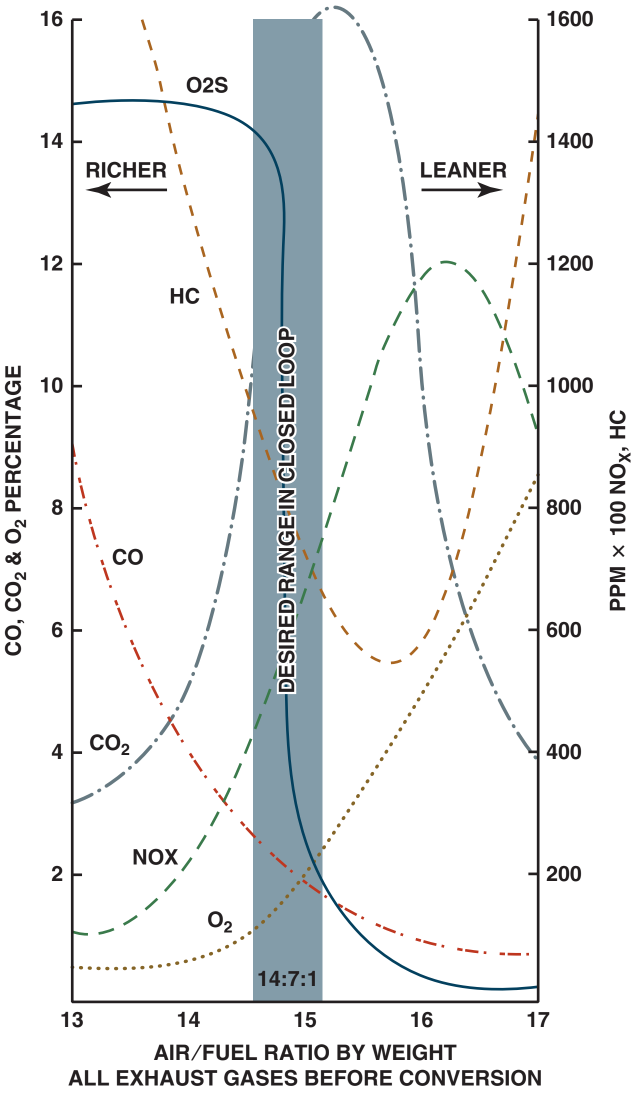


FIGURE 79–6 Exhaust emissions are very complex. When the air–fuel mixture becomes richer, some exhaust emissions are reduced, while others increase.

CATALYTIC CONVERTER

EFFECT ON EXHAUST GASES The catalytic converter is used to help reduce exhaust emissions by helping the oxygen in the exhaust to oxidize the HC and CO in the exhaust stream to form harmless water (H_2O) and CO_2. It also helps separate the nitrogen from the oxygen in NO_X to produce just nitrogen (N_2) and oxygen (O_2). ● **SEE FIGURE 79–7** and **CHART 79–1**.

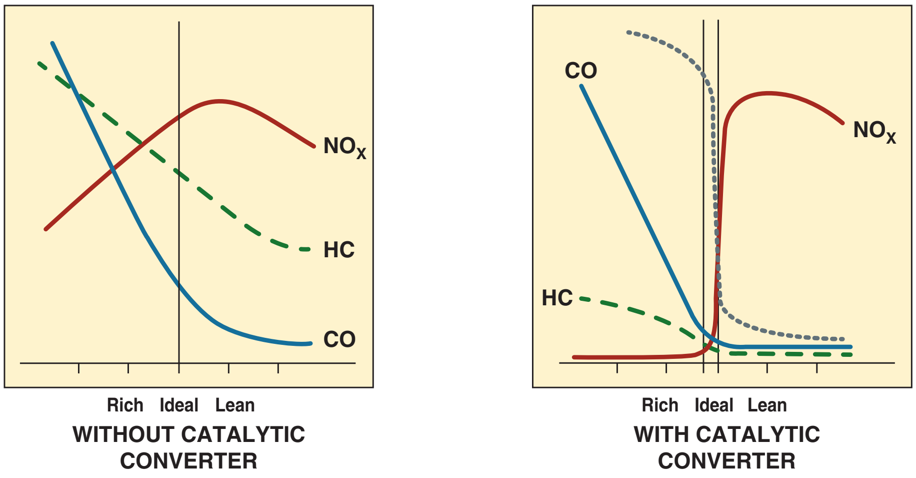


FIGURE 79–7 The image on the left shows exhaust gases exiting an engine without a catalytic converter with rich exhaust being toward the left of the vertical line and lean exhaust to the right of the line. The image on the right shows the exhaust after it has been treated by the catalytic converter.

EXHAUST GAS	TYPICAL SPECIFICATIONS
Unburned hydrocarbons (HC)	30–50 ppm or less
Carbon Monoxide (CO)	0.3%–0.5% or less
Oxygen (O_2)	0%–2%
Carbon Dioxide (CO_2)	12%–15% or higher
Oxides of Nitrogen (NO_x)	Less than 100 ppm at idle and less than 1,000 ppm at wide-open throttle (WOT)

CHART 79–1

Typical specifications for gases for a vehicle equipped with a catalytic converter.

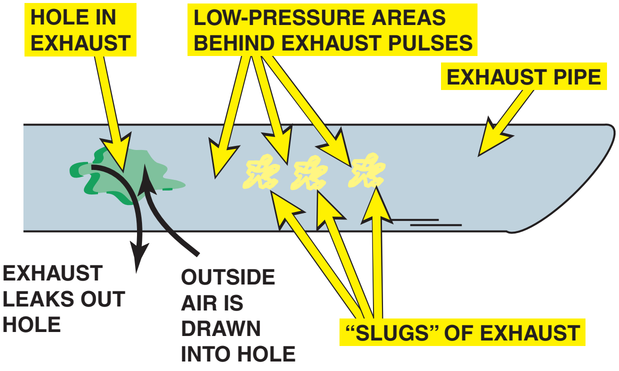

HOLE IN EXHAUST
LOW-PRESSURE AREAS BEHIND EXHAUST PULSES
EXHAUST PIPE
EXHAUST LEAKS OUT HOLE
OUTSIDE AIR IS DRAWN INTO HOLE
“SLUGS” OF EXHAUST

FIGURE 79–8 A hole in the exhaust system can cause outside air (containing oxygen) to be drawn into the exhaust system. This extra oxygen can be confusing to a service technician because the extra O_2 in the exhaust stream could be misinterpreted as a too-lean air–fuel mixture.

EXHAUST ANALYSIS AS A DIAGNOSTIC TOOL

RICH OR LEAN EXHAUST If the exhaust is rich, CO emissions will be higher than normal. If the exhaust is lean, O_2 emissions will be higher than normal.

- If CO is high, the exhaust is rich. This is why CO is called the “**rich indicator**.”
- If O_2 is high, the exhaust is lean. This is why O_2 is called the “**lean indicator**.”

Therefore, if the CO reading is the same as the O_2 reading, the engine is operating correctly. For example, if both CO and O_2 are 0.5% and the engine develops a vacuum leak, the O_2 will rise. If a fuel-pressure regulator were to malfunction, the resulting richer air–fuel mixture would increase CO emissions. Therefore, if both the rich indicator (CO) and the lean indicator (O_2) are equal, the engine is operating correctly.

If the exhaust is rich (too much fuel or not enough air), then the following can be observed:

- Both CO and HC will be high
- O_2 will be low
- CO_2 will be low

If the exhaust is lean (not enough fuel or too much air), then it will result in the following:

- O_2 will be high
- CO_2 will be low

TECH TIP

How to Find a Leak in the Exhaust System

A hole in the exhaust system can dilute the exhaust gases with additional oxygen (O_2). ● **SEE FIGURE 79–8**.

This additional O_2 in the exhaust can lead the service technician to believe that the air–fuel mixture is too lean. To help identify an exhaust leak, perform an exhaust analysis at idle and at 2,500 RPM (fast idle) and compare with the following:

- If the O_2 is high at idle and at 2,500 RPM, the mixture is lean at both idle and at 2,500 RPM.
- If the O_2 is low at idle and high at 2,500 RPM, this usually means the vehicle is equipped with a working AIR pump.
- If the O_2 is high at idle, but okay at 2,500 RPM, a hole in the exhaust or a small vacuum leak that is “covered up” at higher speed is indicated.

ENGINE FAULT POSSIBILITIES

HC TOO HIGH High HC exhaust emissions are usually caused by an engine misfire. What burns the fuel in an engine? The ignition system produces a spark at the spark plug to ignite the proper fuel–air mixture inside the combustion chamber. If a spark plug does not ignite the mixture, the resulting unburned fuel is pushed out of the cylinder on the exhaust stroke by the piston through the exhaust valves and into the exhaust system. Therefore, if any of the following ignition components or adjustments are not correct, excessive HC emission is likely:

1. Defective or worn spark plugs
2. Defective or loose spark plug boots or other faults in the primary or secondary ignition system

A lean air–fuel mixture can also cause a misfire. This condition is referred to as a *lean misfire*. A lean air–fuel mixture can be caused by low fuel pump pressure, a clogged fuel filter, or a restricted fuel injector.

CO TOO HIGH Excessive CO is an indication of too rich an air–fuel mixture. CO is the rich indicator. The higher the CO reading, the richer the air–fuel mixture. High concentrations of CO indicate that not enough oxygen was available for the amount of fuel. Common causes of high CO include the following:

- Too-high fuel pressure
- Clogged air intake or PCV valve
- Defective injectors

CASE STUDY

O2S Shows Rich, But Pulse Width Is Low

A service technician was attempting to solve a driveability problem. The powertrain control module (PCM) did not indicate any diagnostic trouble codes (DTCs). A check of the oxygen sensor voltage indicated a higher-than-normal reading almost all the time. The pulse width to the port injectors was lower than normal. The lower-than-normal pulse width indicates that the PCM is attempting to reduce fuel flow into the engine by decreasing the amount of on-time for all the injectors. What could cause a rich mixture if the injectors were being commanded to deliver a lean mixture?

Finally, the technician shut off the engine and took a careful look at the entire fuel-injection system. When the vacuum hose was removed from the fuel-pressure regulator, fuel was found dripping from the vacuum hose. The problem was a defective fuel-pressure regulator that allowed an uncontrolled amount of fuel to be drawn by the intake manifold vacuum into the cylinders. While the PCM tried to reduce fuel by reducing the pulse width signal to the injectors, the extra fuel being drawn directly from the fuel rail caused the engine to operate with too rich an air–fuel mixture.

Summary:

Complaint—Customer stated that the engine did not perform correctly.
Cause—No stored diagnostic trouble codes (DTCs) were found but the oxygen sensor reading was higher than normal indicating that the exhaust air–fuel mixture was too rich.
Correction—The fuel pressure regulator was found to be leaking causing fuel to be drawn into the intake causing the richer-then-normal air–fuel mixture. Replacing the fuel pressure regulator solved the driveability complaint.

TECH TIP

Your Nose Knows

Using the nose, a technician can often identify a major problem without having to connect the vehicle to an exhaust analyzer. For example,

- The strong smell of exhaust is due to excessive unburned hydrocarbon (HC) emissions. Look for an ignition system fault that could prevent the proper burning of the fuel.
- If your eyes start to burn or water, suspect excessive oxides of nitrogen (NO_x) emissions. The NO_X combine with the moisture in the eyes to form a mild solution of nitric acid. The acid formation causes the eyes to burn and water. Excessive NO_x exhaust emissions can be caused by a lack of proper amount of exhaust gas recirculation (EGR) or a variable valve timing issue. (This is usually noticed above idle on most vehicles.)
- Dizzy feeling or headache. This is commonly caused by excessive carbon monoxide (CO) exhaust emissions. Get into fresh air as soon as possible. A probable cause of high levels of CO is an excessively rich air–fuel mixture.

O_2 AND CO_2 RELATIONSHIP Two gas exhaust analyzers (HC and CO) work well, but both HC and CO are consumed (converted) inside the catalytic converter. The amount of leftover oxygen coming out of the tailpipe is an indication of leanness. The higher the O_2 level, the leaner the exhaust. Oxygen therefore is the lean indicator. Acceptable levels of O_2 are 0% to 2%.

NOTE: A hole in the exhaust system can draw outside air (oxygen) into the exhaust system. Therefore, to be assured of an accurate reading, carefully check the exhaust system for leaks. Using a smoke machine is an easy method to locate leaks in the exhaust system.

Carbon dioxide is a measure of efficiency. The higher the level of CO_2 in the exhaust stream, the more efficiently the engine is operating. Levels of 12% to 17% are considered to be acceptable. Because CO_2 levels peak at an air–fuel mixture of 14.7:1, a lower level of CO_2 indicates either a too-rich or a too-lean condition. The CO_2 measurement by itself does not indicate which condition is present. For example, if the CO_2 is 8%, it means the combustion efficiency is low and the air–fuel mixture is not correct. Look at O_2 and CO levels; a high O_2 indicates lean and a high CO indicates rich.

SMOG AND NO_x Oxides of nitrogen are formed by high temperature—over 2,500°F (1,370°C)—and/or pressures inside the combustion chamber. Oxides of nitrogen contribute to the formation of photochemical smog when sunlight reacts chemically with NO_x and unburned hydrocarbons. "**Smog**" is a term derived by combining the words *smoke* and *fog*. Ground-level ozone is a constituent of smog. **Ozone** is an enriched oxygen molecule with three atoms of oxygen (O_3) instead of the normal two atoms of oxygen (O_2). Ozone in the upper atmosphere is beneficial because it blocks out harmful ultraviolet rays that contribute to skin cancer. However, at ground level, this ozone (smog) is an irritant to the respiratory system. Because the formation of NO_x occurs mostly under load, the most efficient method to test for NO_x is to use a portable exhaust analyzer that can be carried in the vehicle while the vehicle is being driven under a variety of conditions.

A maximum reading of 1,000 ppm of NO_x under loaded driving conditions will generally mean that the vehicle will pass an enhanced I/M roller test. A reading of over 100 ppm at idle should be considered excessive.

ABNORMAL GAS READINGS The exhaust gases each have their own cause for being higher than normal or lower than normal and they are interconnected. ● **SEE CHART 79–2**.

EMISSION STANDARDS

TIER 1 AND TIER 2 Federal emissions standards are set by the Clean Air Act Amendments (CAAA) of 1990 and these standards are grouped by tier. All vehicles sold in the United States must meet Tier 1 standards that went into effect in 1994 and are

CARBON MONOXIDE (CO)	CARBON DIOXIDE (CO_2)	HYDROCARBONS (HC)	OXYGEN (O_2)	POSSIBLE ISSUES
Low	High	Low	Low	Normal readings. No issues
High	Low	High	High	Rich exhaust and misfire
Low	Low	High	High	Lean exhaust and misfire
High	High	High	High	Catalytic converter not working as designed plus possible other air–fuel ratio issues
High	Low	High	High	Rich exhaust
High	Low	High	Low	Possible defective thermostat

CHART 79–2

Possible issues based on the relative readings of the four exhaust gases.

CASE STUDY

The Case of the Retarded Exhaust Camshaft

A Toyota equipped with a double overhead camshaft (DOHC) six-cylinder engine failed the state-mandated enhanced exhaust emissions test for NO_x. The engine ran perfectly without spark knocking (ping), which is usually a major reason for excessive NO_x emissions. The technician checked the following:

- The cylinders, which were decarbonized using top engine cleaner
- The EGR valve, which was inspected and the EGR passages cleaned

After all the items were completed, the vehicle was returned to the inspection station where the Vehicle again failed for excessive NO_x emissions (better, but still over the maximum allowable limit). After additional hours of troubleshooting, the technician decided to go back to basics and start over again. A check of the vehicle history with the owner indicated that the only previous work performed on the engine was a replacement timing belt over a year before. The technician discovered that the exhaust cam timing was retarded by two teeth, resulting in late closing of the exhaust valve. The proper exhaust valve timing resulted in a slight amount of exhaust gas being retained in the cylinder. This extra exhaust was helped reduce NO_x emissions.

After repositioning the timing belt, the vehicle passed the emissions test well within the limits.

Summary:

Complaint—Customer stated that the vehicle failed an emission test due to excessive NO_x exhaust emissions.
Cause—The exhaust cam was discovered to be retarded by two teeth as a result of the timing belt being incorrectly installed during a previous repair.
Correction—The timing belt was properly aligned and the vehicle passed the emission test.

the least stringent. Additional Tier 2 standards which had been optional since 2001 were fully adopted by 2009. The current Tier 1 standards are different between automobiles and light trucks (SUVs, pickup trucks, and minivans), but Tier 2 standards are the same for both types.

There are several emission ratings that can be given to vehicles, and a certain percentage of a manufacturer's vehicles must meet different levels of ratings in order for the company to sell its products in affected regions. Beyond Tier 1, and in order of stringency, are the following levels:

- **TLEV** (Transitional Low-Emission Vehicle). More stringent for HC than Tier 1.
- **LEV** (also known as LEV I) (Low-Emission Vehicle). An intermediate California standard about twice as stringent as Tier 1 for HC and NO_x.
- **ULEV** (also known as ULEV I) (Ultra-Low-Emission Vehicle). A stronger California standard emphasizing very low HC emission.
- **ULEV II** (Ultra-Low-Emission Vehicle). A cleaner-than-average vehicle certified under the Phase II LEV standard.

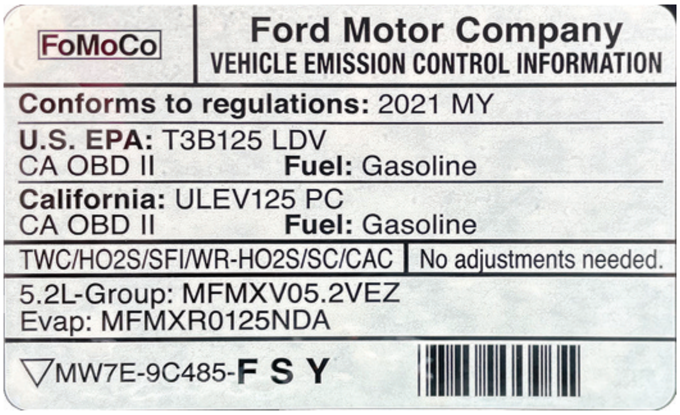
Hydrocarbon and carbon monoxide emissions levels are nearly 50% lower than those of a LEV II-certified vehicle.

- **SULEV** (Super-Ultra-Low-Emission Vehicle). A California standard even tighter than ULEV, including much lower HC and NO_x emissions; roughly equivalent to Tier 2 Bin 2 vehicles.
- **ZEV** (Zero-Emission Vehicle). A California standard prohibiting any tailpipe emissions. The ZEV category is largely restricted to electric vehicles and hydrogen-fueled vehicles.

In these cases, any emissions that are created are produced at another site, such as a power plant or hydrogen reforming center, unless such sites run on renewable energy.

NOTE: A battery-powered electric vehicle charged from the power grid will still be up to 10 times cleaner than even the cleanest gasoline vehicles over their respective lifetimes.

- **PZEV** (Partial Zero-Emission Vehicle). Compliant with the SULEV standard and has near-zero evaporative emissions and a 15-year/150,000-mile warranty on its emission control equipment. Tier 2 standards are even more stringent. Tier 2 variations are appended with "II," such as LEV II or SULEV II.
- **ILEV** (Inherently Low-Emission Vehicle). Used by some states that allow certain vehicles to use the HOV lanes regardless of the number of people in the vehicle. Check state and local laws and regulations for the list of vehicles included.
- **AT-PZEV** (Advanced Technology Partial Zero-Emission Vehicle). If a vehicle meets the PZEV standards and is using



FoMoCo

Ford Motor Company

VEHICLE EMISSION CONTROL INFORMATION

Conforms to regulations: 2021 MY

U.S. EPA: T3B125 LDV

CA OBD II **Fuel:** Gasoline

California: ULEV125 PC

CA OBD II **Fuel:** Gasoline

TWC/HO2S/SFI/WR-HO2S/SC/CAC | No adjustments needed.

5.2L-Group: MFMXV05.2VEZ

Evap: MFMXR0125NDA

▽MW7E-9C485-**F S Y**

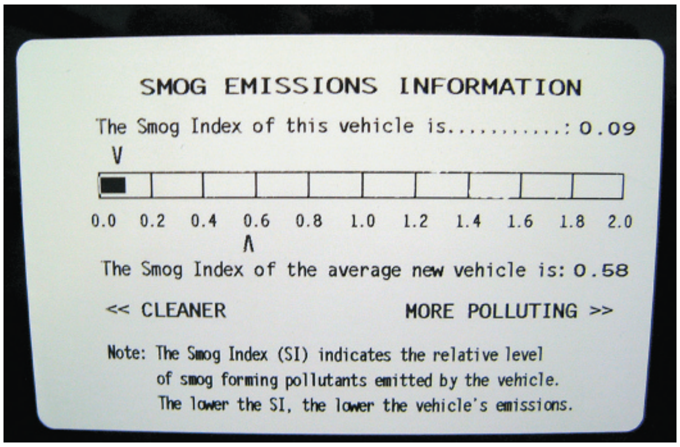
FIGURE 79–9 This vehicle emission control information (VECI) decal indicates this vehicle meets both national EPA Tier3. Bin 125 (T3B125) and California ULEV125 PC (passenger car) standard.

high-technology features, such as an electric motor or high-pressure gaseous fuel tanks for compressed natural gas, it qualifies as an AT-PZEV. Hybrid electric vehicles such as the Toyota Prius can qualify, as can internal combustion engine vehicles that run on natural gas (CNG), such as the Honda Civic GX. These vehicles are classified as "partial" ZEV because they receive partial credit for the number of ZEV vehicles that automakers would otherwise be required to sell in California.

- **NLEV** (National Low-Emission Vehicle). All vehicles nationwide must meet this standard, which started in 2001.

FEDERAL EPA BIN NUMBER The higher the tier number, the newer the regulation; the lower the bin number, the cleaner the vehicle. The Toyota Prius is a very clean Bin 2, while dirtier vehicles are given a higher bin number. ● **SEE FIGURE 79–9**.

SMOG EMISSION INFORMATION New vehicles are equipped with a sticker that shows the relative level of smog-causing emissions created by the vehicle compared to others on the market. Smog-causing emissions include unburned HC and NO_x. ● **SEE FIGURE 79–10**.



SMOG EMISSIONS INFORMATION

The Smog Index of this vehicle is...........: 0.09

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

The Smog Index of the average new vehicle is: 0.58

<< CLEANER MORE POLLUTING >>

Note: The Smog Index (SI) indicates the relative level of smog forming pollutants emitted by the vehicle. The lower the SI, the lower the vehicle's emissions.

FIGURE 79–10 This label on a Toyota Camry hybrid shows the relative smog-producing emissions, but this does not include CO_2, which may increase global warming.

CALIFORNIA STANDARDS The pre-2004 CARB standards as a whole were known as LEV I. Within that, there were four possible ratings: Tier 1, TLEV, LEV, and ULEV. The newest CARB-rating system (since January 1, 2004) is known as LEV II. Within that rating system there are three primary ratings: LEV, ULEV, and SULEV. States other than California are given the option to use the federal EPA standards, or they can adopt California's standards.

LEV III The latest emissions standards include maintaining the reduced emissions for 150,000 miles has several emission categories, depending on the level of emissions. The standards are more stringent than Tier 2 standards and include a number of other important changes:

- The required emission durability has been increased to 150,000 miles, up from 120,000 miles.
- Gasoline vehicles are tested—for exhaust and evaporative emissions—using gasoline containing 10% of ethanol (E10).
- Standards are for 2015–2025 vehicles sold in the United States. ● **SEE CHART 79–3**.

EUROPEAN STANDARDS Exhaust emissions of nitrogen oxides (NO_x), total hydrocarbon (THC), non-methane hydrocarbons (NMHC), carbon monoxide (CO), and particulate matter (PM) are regulated for most vehicle types, including cars, trucks in the European Union (EU). The EU also sets limits for CO_2 emission in units of grams per kilometer with the latest standard being 95 grams per km after 2020. Carbon dioxide is created by the combustion of fuel inside an internal combustion engine. Reducing the CO_2 emissions requires the less fuel be consumed which is one way the EU is mandating fuel economy standards. The ratings include the following:

- **Euro 1** (1993)
- **Euro 2** (1996)
- **Euro 3** (2000)
- **Euro 4** (2005)
- **Euro 5** (2009)
- **Euro 6** (2014)
- **Euro 7** (2025)

EMISSION CATEGORY	$NMOG + NO_x$ GRAM PER MILE (G/MI)	CO GRAM PER MILE (G/MI)	PARTICULATE MATTER (PM) GRAM PER MILE (G/MI)
LEV 160	0.160	4.2	0.01
ULEV 125	0.125	2.1	0.01
ULEV 70	0.070	1.7	0.01
ULEV 50	0.050	1.7	0.01
SULEV 30	0.030	1.0	0.01
SULEV 20	0.020	1.0	0.01

CHART 79–3

Non-methane organic gases (NMOG) and oxides of nitrogen are combined under one limit meaning that the hydrocarbons and the NO_x have to be both controlled to meet these standards. Particulate matter (PM) has in the past been associated with diesel engine emissions, but are now being tested on gasoline powered vehicles.

VEHICLE EMISSION TESTING

OBD-II TESTING In 1999, the EPA requested that states adopt OBD-II systems testing for 1996 and newer vehicles. The OBD-II system is designed to illuminate the malfunction indicator lamp (MIL) light and store trouble codes any time a malfunction exists that would cause the vehicle emissions to exceed 1 1/2 times the **Federal Test Procedure (FTP)** limits. If the OBD-II system is working correctly, the system should be able to detect a vehicle failure that would cause emissions to increase to an unacceptable level. The EPA has determined that the OBD-II system should detect emission failures of a vehicle even before that vehicle would fail an emissions test of the type that most states are employing.

The EPA has determined that, as the population of OBD-II-equipped vehicles increases and the population of older non-OBD-II-equipped vehicles decreases, tailpipe testing will no longer be necessary.

NOTE: If a state or local emission testing program still uses exhaust emission testing for older vehicles, check the information about the program and test procedures before having the vehicle tested.

The OBD-II testing program consists of a computer that can scan the vehicle OBD-II system using the DLC connector. The technician first performs a visual check of the vehicle MIL light to determine if it is working correctly. Next, the computer is connected to the vehicle's DLC connector. The computer will scan the vehicle OBD-II system and determine if there are any codes stored that are commanding the MIL light on. In addition, it will scan the status of the readiness monitors and determine if they have all run and passed. If the readiness monitors have all run and passed, it indicates that the OBD-II system has tested all the components of the emission control system. An OBD-II vehicle would fail this OBD-II test if the following conditions are present:

- The MIL light does not come on with the key on, engine off
- The MIL is commanded on
- A number (varies by state) of the readiness monitors has not been run. If none of these conditions are present, the vehicle will pass the emissions test.

REMOTE SENSING The EPA requires that, in high-enhanced areas, states perform on-the-road testing of vehicle emissions. The state must sample 0.5% of the vehicle population base in high-enhanced areas. This may be accomplished by using a remote sensing device. This type of sensing may be done through equipment that projects an infrared light through the exhaust stream of a passing vehicle. The reflected beam can then be analyzed to determine the pollutant-emission levels of the vehicle. If a vehicle fails this type of test, vehicle owners will receive notification in the mail that they must take the vehicle to a test facility to have the emissions tested.

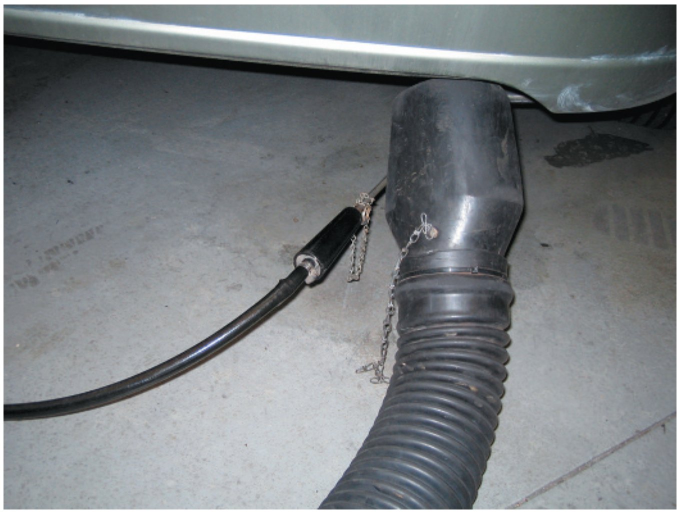


FIGURE 79–11 A partial stream sampling exhaust probe being used to measure exhaust gases in parts per million (ppm) or percent (%).

RANDOM ROADSIDE TESTING Some states may implement random roadside testing that would usually involve visual checks of the emission control devices to detect tampering. Obviously, this method is not very popular as it can lead to traffic tie-ups and delays on the part of commuters. Exhaust analysis is an excellent tool to use for the diagnosis of engine performance concerns. In areas of the country that require exhaust testing to be able to get license plates, exhaust analysis must be able to carry out the following:

- Establish a baseline for failure diagnosis and service.
- Identify areas of engine performance that are and are not functioning correctly.
- Determine that the service and repair of the vehicle have been accomplished and are complete.

● **SEE FIGURE 79–11**.

REVIEW QUESTIONS

1. What are the five exhaust gases and their maximum allowable readings for a fuel-injected vehicle equipped with a catalytic converter?
2. How is water formed during the combustion process?
3. What is the stoichiometric ratio and what does it mean?
4. How are oxides of nitrogen (NO_X) formed?
5. What is the most common cause of excessive hydrocarbon (HC) emissions?

CHAPTER QUIZ

1. Technician A says that high HC emission levels are often caused by a fault in the ignition system. Technician B says that high CO_2 emissions are usually caused by a richer-than-normal air–fuel mixture. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. HC and CO are high and CO_2 and O_2 are low. This could be caused by a ___________.
   a. rich mixture
   b. lean mixture
   c. defective ignition component
   d. clogged EGR passage

3. Which gas is generally considered to be the rich indicator? (The higher the level of this gas, the richer the air–fuel mixture.)
   a. HC
   b. CO
   c. CO_2
   d. O_2
4. The catalytic converter is used to help reduce exhaust emissions by helping the oxygen in the exhaust to oxidize the HC and CO in the exhaust stream to form ___________.
   a. oxides of nitrogen
   b. carbon dioxide
   c. carbon monoxide
   d. water and carbon dioxide
5. Which of these levels would apply to an electric vehicle?
   a. ULEV
   b. ZEV
   c. LEV
   d. TLEV
6. All of the gases are measured in percentages except ___________.
   a. HC
   b. CO
   c. CO_2
   d. O_2
7. After the following exhaust emissions were measured, how was the engine operating?
   HC 5,766 ppm, CO_2 8.2%, CO 4.6%, O_2 0.1%
   a. Too rich
   b. Too lean
   c. Operating at stoichiometric ratio
   d. Engine operating (coolant) temperature too high
8. Technician A says that NO_X formation is limited by the EGR system. Technician B says that NO_X is converted to N_2 and O_2 in the catalytic converter. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A clogged EGR passage could cause excessive ___________ exhaust emissions.
   a. HC
   b. CO
   c. NO_X
   d. CO_2
10. A vehicle could fail a state emission inspection due to which of these?
    a. MIL is on
    b. MIL does not come on with key on, engine off
    c. Readiness monitors not run
    d. Any of these

Chapter 80

EVAPORATIVE EMISSIONS CONTROL AND EGR SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the operation of an evaporative emission control (EVAP) system.
- Discuss enhanced evaporative control systems.
- Discuss leak detection pump systems.
- Discuss onboard refueling vapor recovery.
- Explain how to diagnose the EVAP system.
- Discuss the functions of an evaporative system monitor.
- Discuss the purpose and function of exhaust gas recirculation (EGR) systems.
- Explain the strategies to monitor on-board diagnostics generation II (OBD-II) exhaust gas recirculation (EGR) systems.
- Explain how to diagnose a defective EGR system.

KEY TERMS:

Adsorption 942 • Delta pressure feedback EGR (DPFE) sensor 951 • Detonation 950 • Digital EGR valve 950 • EGR valve position (EVP) sensor 950 • Evaporative control (EVAP) system 941 • Exhaust gas recirculation (EGR) 948 • Fuel tank pressure (FTP) 947 • Inert 949 • Leak detection pump (LDP) 944 • Linear EGR valve 950 • Nitrogen oxides (NO_X) 948 • Onboard refueling vapor recovery (ORVR) 945 • Pressure feedback EGR (PFE) sensor 950 • Purge valve 943 • Vent valve 943 • Volatile organic compounds (VOCs) 941

EVAPORATIVE EMISSION CONTROL SYSTEM

PURPOSE AND FUNCTION The purpose of the evaporative emission control system is to trap and hold gasoline vapors, also called **volatile organic compounds (VOCs)**. The **evaporative control (EVAP) system** includes the charcoal canister, hoses, and valves. These vapors are routed into a charcoal canister, then into the intake airflow, where they are burned in the engine, instead of being released into the atmosphere.

COMMON COMPONENTS The fuel tank filler caps used on vehicles with modern EVAP systems are a special design. Most EVAP fuel tank filler caps have a built-in pressure-vacuum relief valve. When pressure or vacuum exceeds a calibrated value, the valve opens. Once the pressure or vacuum has been relieved, the valve closes. If a sealed cap is used on an EVAP system that requires a pressure-vacuum relief design, a vacuum may develop in the fuel system, or the fuel tank may be damaged by fuel expansion or contraction. ● **SEE FIGURE 80–1**.

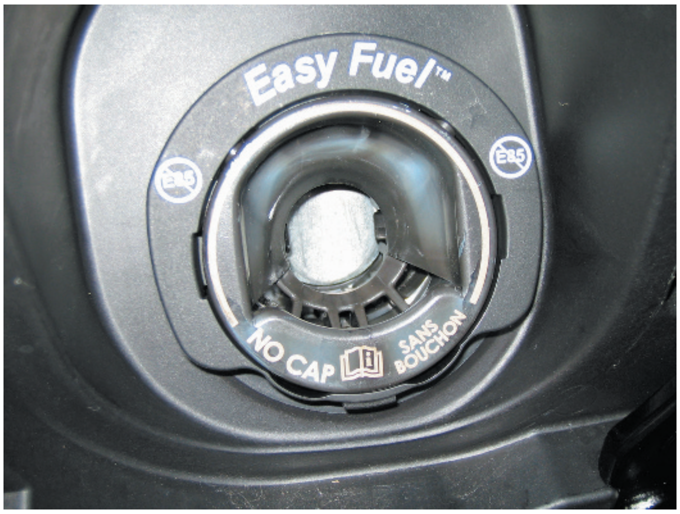


FIGURE 80–1 A capless system from a Ford does not use a replaceable cap; instead, it is spring-loaded closed.

FREQUENTLY ASKED QUESTION

When Filling My Fuel Tank, Why Should I Stop When the Pump Clicks Off?

Every fuel tank has an upper volume chamber that allows for expansion of the fuel when hot. The volume of the chamber is between 10% and 20% of the volume of the tank. For example, if a fuel tank has a capacity of 20 gallons, the expansion chamber volume is from 2 to 4 gallons. A hose is attached at the top of the chamber and vented to the charcoal canister. If extra fuel is forced into this expansion volume, liquid gasoline can be drawn into the charcoal canister. This liquid fuel can saturate the canister and create an overly rich air–fuel mixture when the canister purge valve is opened during normal vehicle operation. This extra-rich air–fuel mixture can cause the vehicle to fail an exhaust emissions test, reduce fuel economy, and possibly damage the catalytic converter. To avoid problems, simply add fuel to the next dime's worth after the nozzle clicks off. This ensures that the tank is full, yet not overfilled.

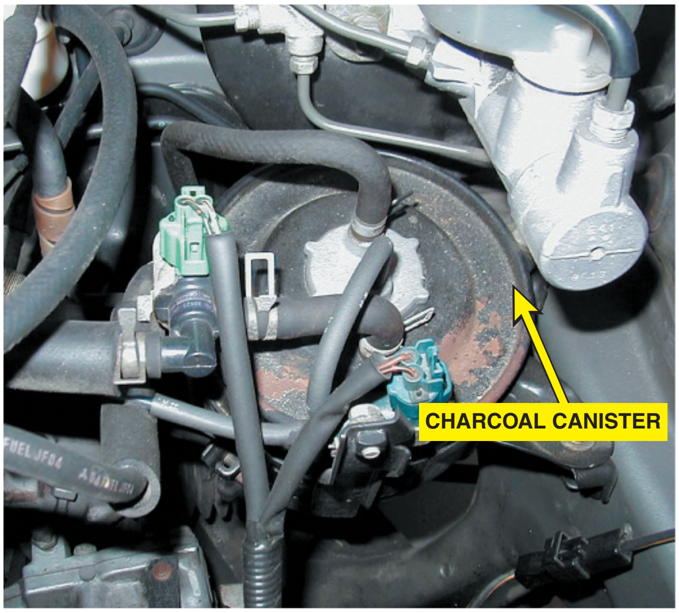


FIGURE 80–2 A charcoal canister can be located under the hood or underneath the vehicle.

EVAP SYSTEM OPERATION

The canister is located under the hood or underneath the vehicle and is filled with activated charcoal granules that can hold up to one-third of their own weight in fuel vapors. ● **SEE FIGURE 80–2**.

NOTE: Some vehicles with large or dual fuel tanks may have dual canisters.

Activated charcoal is an effective vapor trap because of its great surface area. Each gram of activated charcoal has a surface area of 1,100 square meters, or more than 1/4 acre. Typical canisters hold either 300 or 625 grams of charcoal *with a surface area equivalent to 80 or 165 football fields.* By a process called **adsorption**, the fuel vapor molecules adhere to the carbon surface. This attaching force is not strong, so the system purges the vapor molecules quite simply by sending a fresh airflow through the charcoal:

- **Vapor purging.** During engine operation, stored vapors are drawn from the canister into the engine through a hose connected to the throttle body or the air cleaner. This "purging" process mixes unburned gasoline (hydrocarbons, abbreviated HCs) vapors from the canister with the existing air–fuel charge. ● **SEE FIGURES 80–3 AND 80–4**.
- **Computer-controlled purge.** The PCM controls when the canister purges on most engines. This is done by an electric vacuum solenoid and one or more purge valves. Under normal conditions, most engine control systems permit purging only during closed-loop operation at cruising speeds. During other engine operation conditions, such as open-loop mode, idle, deceleration, or wide-open throttle, the PCM prevents canister purging.

EVAPORATIVE PRESSURES

Pressures can build inside the fuel system and are usually measured in units of inches of water, abbreviated "in. H_2O" (28 inches H_2O equals 1 pound per square inch, or 1 PSI). Pressure buildup can be caused by the following:

- Fuel evaporation rates (volatility)
- Gas tank size (fuel surface area and volume)
- Fuel level (liquid versus vapor)

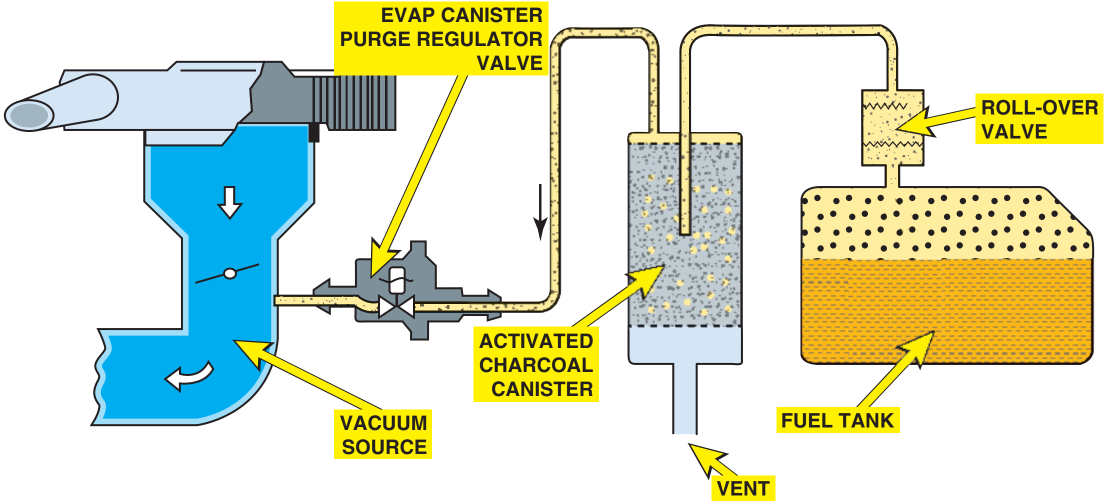

EVAP CANISTER PURGE REGULATOR VALVE
ROLL-OVER VALVE
ACTIVATED CHARCOAL CANISTER
VACUUM SOURCE
FUEL TANK
VENT

FIGURE 80–3 The EVAP system includes all of the lines, hoses, and valves, plus the charcoal canister.

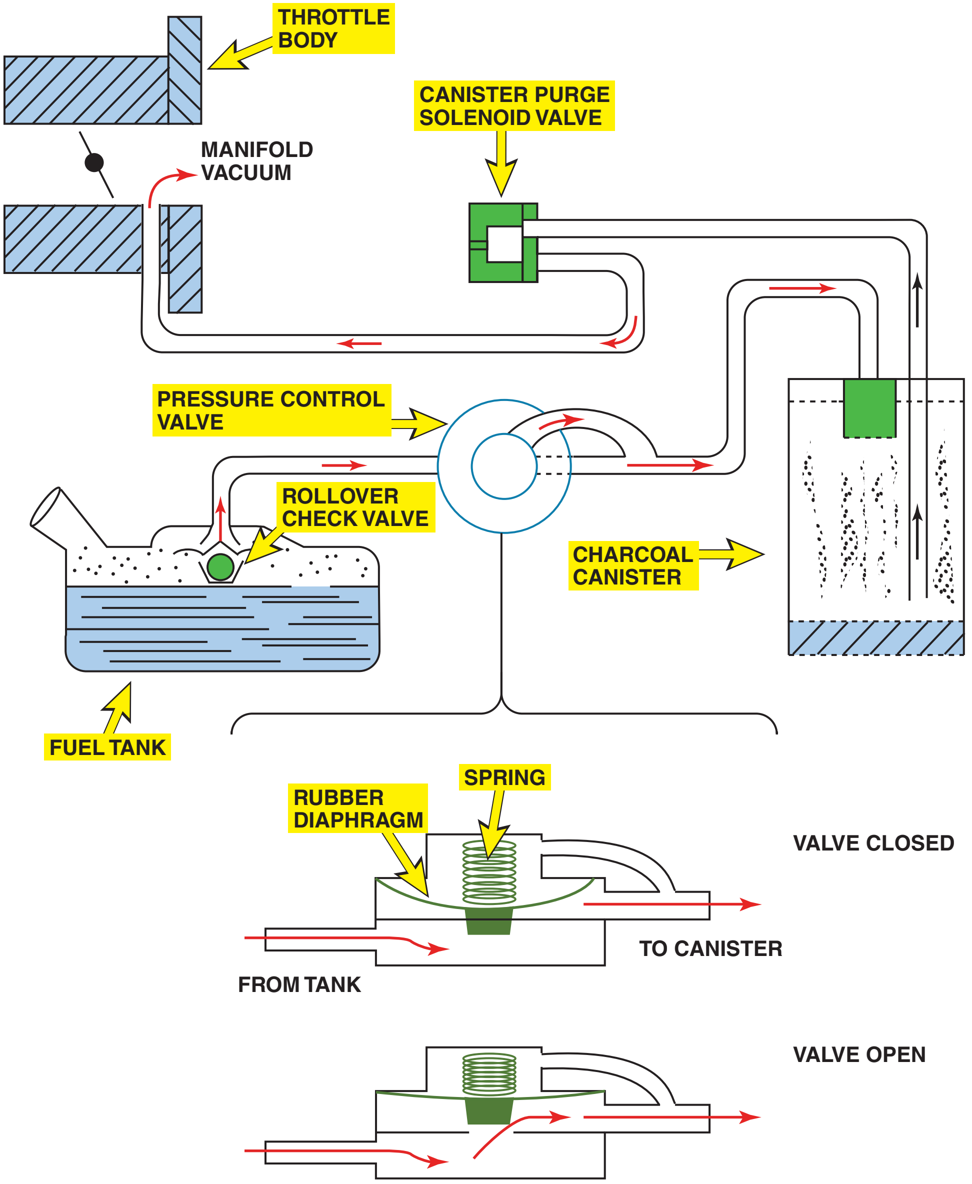


FIGURE 80–4 A typical EVAP system. Note that when the computer turns on the canister purge solenoid valve, manifold vacuum draws any stored vapors from the canister into the engine. Manifold vacuum also is applied to the pressure control valve. When this valve opens, fumes from the fuel tank are drawn into the charcoal canister and eventually into the engine. When the solenoid valve is turned off (or the engine stops and there is no manifold vacuum), the pressure control valve is spring-loaded shut to keep vapors inside the fuel tank from escaping to the atmosphere.

- Fuel slosh (driving conditions)
- Temperature (ambient, in-tank, close to the tank)
- Returned fuel from the rail

Some scan tools display other units of measure for the EVAP system that makes understanding the system difficult. ● **SEE CHART 80–1** for pressure conversions between pounds per square inch (PSI), inches of mercury (in. Hg), and inches of water (in. H_2O).

ENHANCED EVAPORATIVE CONTROL SYSTEM

BACKGROUND Beginning in 1996 with OBD-II vehicles, manufacturers are required to install systems that are able to detect both purge flow and evaporative system leakage:

- The systems on models produced between 1996 and 2000 must be able to detect a leak as small as 0.040 inches in diameter.
- Beginning in the model year 2000, the enhanced systems started a phase-in of 0.020-inch diameter leak detection.
- All vehicles built after 1995 have enhanced EVAP systems with the ability to detect purge flow and system leakage. If either of these two functions fails, the system is required to set a diagnostic trouble code (DTC) and turn on the malfunction indicator lamp (MIL) to warn the driver of the failure. ● **SEE FIGURE 80–5**.

VENT VALVE The canister **vent valve** is a *normally open* valve and is closed only when commanded by the PCM during testing of the system. The vent valve is closed only during testing by the PCM as part of the mandated OBD-II standards. The vent solenoid is located under the vehicle, in most cases, and is exposed to the environment, making this valve subject to rust and corrosion.

PURGE VALVE The canister **purge valve**, also called the *canister purge (CANP) solenoid,* is normally closed and is pulsed open by

PSI	INCHES HG	INCHES H_2O
14.7	29.93	407.19
1.0	2.036	27.7
0.9	1.8	24.93
0.8	1.63	22.16
0.7	1.43	19.39
0.6	1.22	16.62
0.5	1.018	13.85
0.4	0.814	11.08
0.3	0.611	8.31
0.2	0.407	5.54
0.1	0.204	2.77
0.09	0.183	2.49
0.08	0.163	2.22
0.07	0.143	1.94
0.06	0.122	1.66
0.05	0.102	1.385

CHART 80–1

Pressure conversions.

NOTE: 1 PSI = 28 in. H_2O
0.25 PSI = 7 in. H_2O

the PCM during purging. The purge valve is connected to intake manifold vacuum using a rubber hose to draw gasoline vapors from the charcoal canister into the engine when the purge valve is commanded open. Most purge valves are pulsed on and off to better control the amount of fumes being drawn into the intake manifold.

TECH TIP

Problems after Refueling? Check the Purge Valve

The purge valve is normally closed and open only when the PCM is commanding the system to purge. If the purge solenoid becomes stuck in the open position, gasoline fumes are allowed to flow directly from the gas tank to the intake manifold. When refueling, this results in a lot of fumes being forced into the intake manifold and, as a result, causes a hard-to-start condition after refueling. This also results in a rich exhaust, and likely black exhaust, when first starting the engine after refueling. While the purge solenoid is usually located under the hood of most vehicles and is less subject to rust and corrosion, as with the vent valve, it can still fail.

LEAK DETECTION PUMP SYSTEM

FUNCTION Many vehicles use a vacuum operated **leak detection pump (LDP)** as part of the evaporative control system diagnosis equipment. ● **SEE FIGURE 80–6.**

OPERATION The system works to test for leaks as follows:

- The purge solenoid is normally closed.
- The vent valve in the LDP is normally open. Filtered fresh air is drawn through the LDP to the canister.

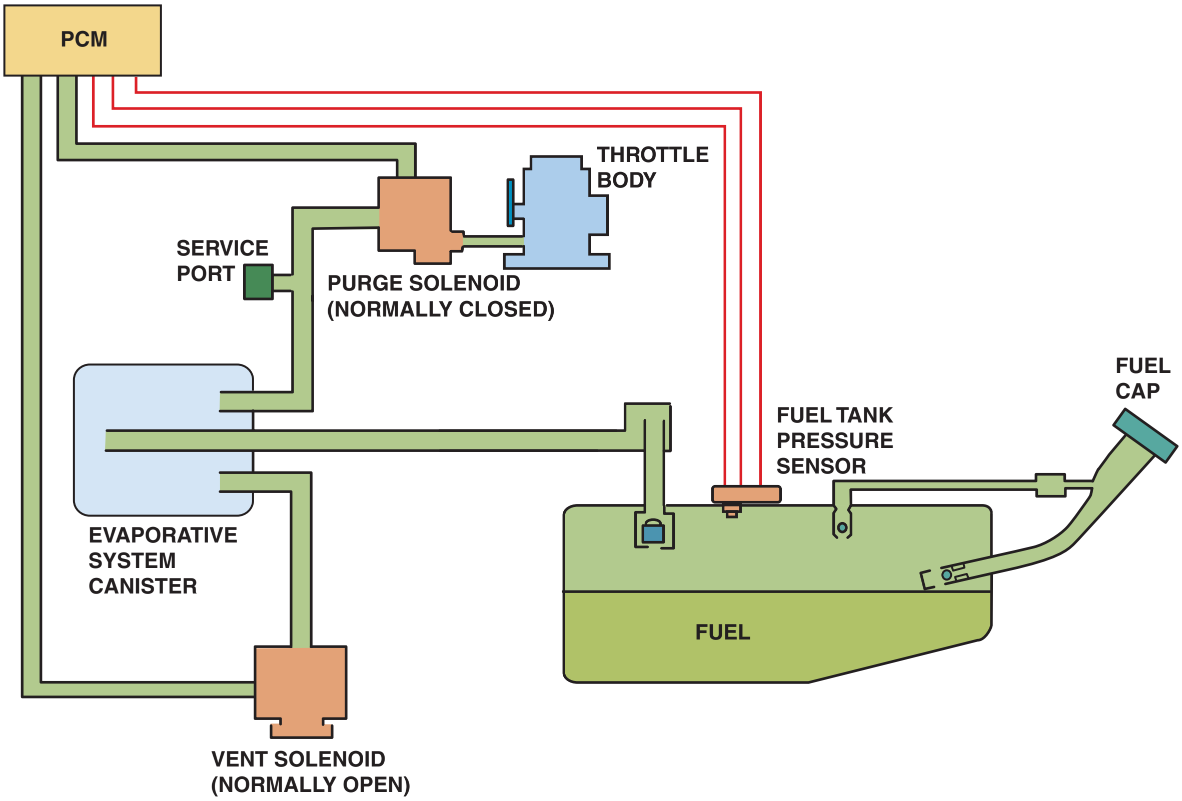

PCM
THROTTLE BODY
SERVICE PORT
PURGE SOLENOID (NORMALLY CLOSED)
FUEL CAP
FUEL TANK PRESSURE SENSOR
EVAPORATIVE SYSTEM CANISTER
FUEL
VENT SOLENOID (NORMALLY OPEN)

FIGURE 80–5 An enhanced EVAP system is able to perform system and leak detection diagnosis.

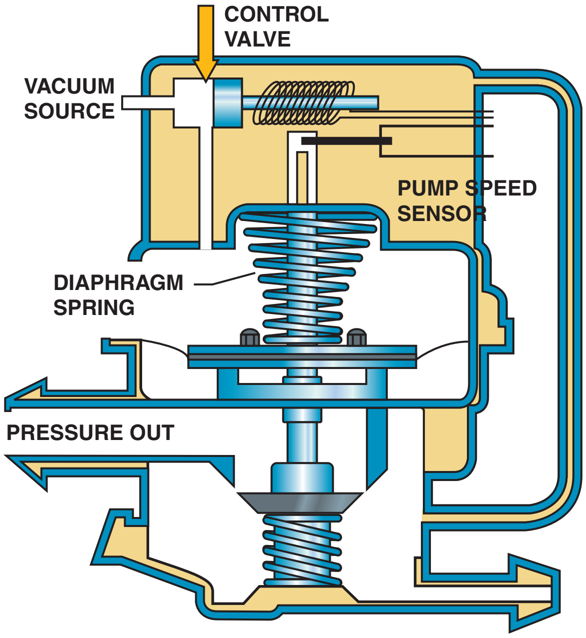


FIGURE 80–6 A leak detection pump (LDP) used on some Chrysler and other vehicles to pressurize (slightly) the fuel system to check for leaks.

- The LDP uses a spring attached to a diaphragm to apply pressure (7.5 in. H_2O) to the fuel tank.
- The PCM monitors the LDP switch that is triggered if the pressure drops in the fuel tank.
- The time between LDP solenoid off and LDP switch close is called the pump period. This time period is inversely proportional to the size of the leak. The shorter the pump period, the larger the leak. The longer the pump period, the smaller the leak.

EVAP large leak (greater than 0.080 inch): less than 0.9 second
EVAP medium leak (0.040 to 0.080 inch): 0.9 to 1.2 seconds
EVAP small leak (0.020 to 0.040 inch): 1.2 to 6 seconds

ONBOARD REFUELING VAPOR RECOVERY

PURPOSE The **onboard refueling vapor recovery (ORVR)** system was first introduced on some 1998 vehicles. Previously designed EVAP systems allowed fuel vapor to escape to the atmosphere during refueling.

OPERATION The primary feature of most ORVR systems is the restricted tank filler tube, which is about 1 inch (25 mm) in diameter. This reduced-size filler tube creates an aspiration effect, which tends to draw outside air into the filler tube. During refueling, the fuel tank is vented to the charcoal canister, which captures the gas fumes and, with air flowing into the filler tube, no vapors can escape to the atmosphere. ● **SEE FIGURE 80–7**.

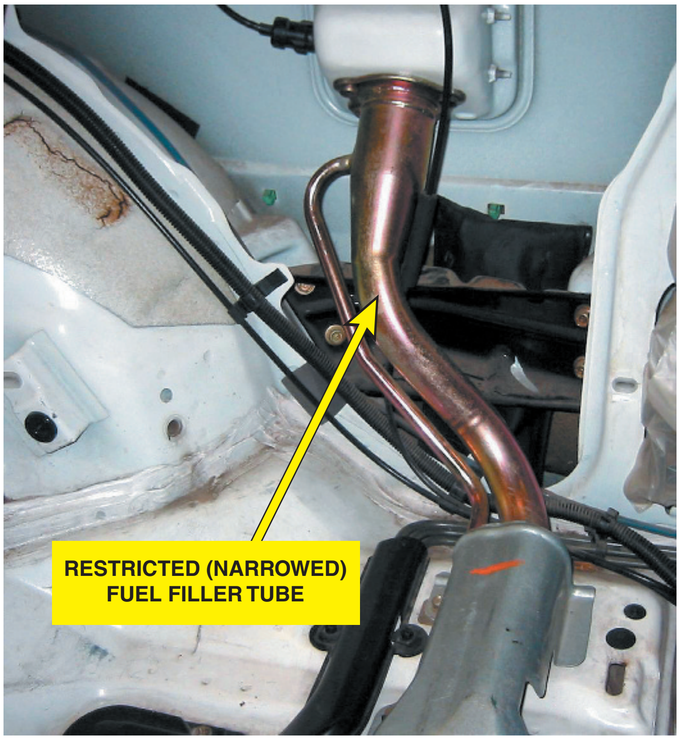


FIGURE 80–7 A restricted fuel fill pipe shown on vehicle with the interior removed.

DIAGNOSING THE EVAP SYSTEM

SYMPTOMS Before vehicle emissions testing began in many parts of the country, little service work was done on the evaporative emission system. Common engine performance problems that can be caused by a fault in this system include the following:

- **Poor fuel economy.** A leak in a vacuum-valve diaphragm can result in engine vacuum drawing in a constant flow of gasoline vapors from the fuel tank. This usually results in a drop in fuel economy of 2 to 4 miles per gallon (mpg). Use a hand-operated vacuum pump to check that the vacuum diaphragm can hold vacuum.
- **Poor performance.** A vacuum leak in the system can cause the engine to run rough. Age, heat, and time all contribute to the deterioration of rubber hoses.

STATE EVAP TESTS Enhanced exhaust emissions (I/M-240) testing tests the evaporative emission system. A leak in the system is tested by pressurizing the entire fuel system to a level below 1 PSI (about 14 in. H_2O). The system is typically pressurized with nitrogen, a nonflammable gas that makes up 78% of our atmosphere. The pressure in the system is then shut off and the pressure monitored. If the pressure drops below a set standard, then the vehicle fails the test. This test determines if there is a leak in the system.

HINT: To help pass the evaporative section of an enhanced emissions test, arrive at the test site with less than a half tank of fuel. This means that the rest of the volume of the fuel tank is filled with air. It takes longer for the pressure to drop from a small leak when the volume of the air is greater compared to when the tank is full and the volume of air remaining in the tank is small.

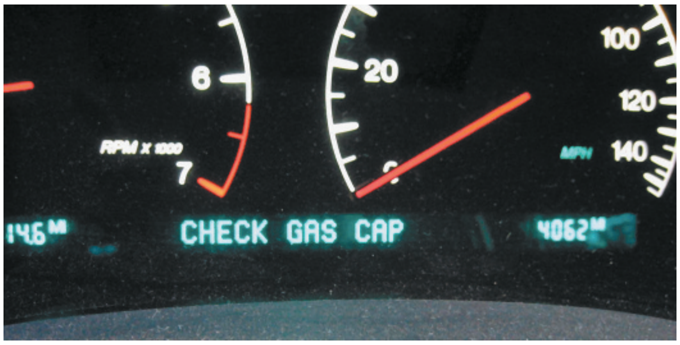

6
20
100
120
140
RPM x 1000
7
MPH
146 M
CHECK GAS CAP
4062 M

FIGURE 80–8 Some vehicles display a message if an evaporative control system leak is detected that could be the result of a loose gas cap.

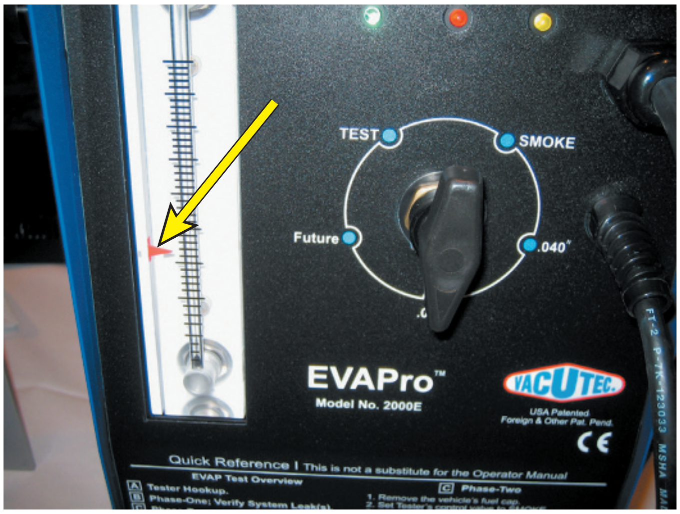

TEST
SMOKE
Future
.040"
EVAPro™
Model No. 2000E
VACUTEC
USA Patented
Foreign & Other Pat. Pend.
CE
Quick Reference | This is not a substitute for the Operator Manual

FIGURE 80–9 To test for a leak, this tester was set to the 0.020-inch hole and turned on. The ball rose in the scale on the left, and the red arrow was moved to that location. If, when testing the system for leaks, the ball rises higher than the arrow, then the leak is larger than 0.02 inch. If the ball does not rise to the level of the arrow, the leak is smaller than 0.020 inch.

LOCATING LEAKS IN THE SYSTEM Leaks in the evaporative emission control system cause the malfunction check gas cap indication lamp to light on some vehicles. ● **SEE FIGURE 80–8.**

A leak also causes a gas smell, which is most noticeable if the vehicle is parked in an enclosed garage. The first step is to determine if there is a leak in the system by setting the EVAP tester to rate the system for either a 0.040-inch or a 0.020-inch-hole-size leak. ● **SEE FIGURE 80–9.**

After it has been determined that a leak exists and it is larger than specified, one of two methods can be used to check for leaks in the evaporative system:

- **Smoke machine testing.** The most efficient method of leak detection is to introduce smoke under low pressure from a machine specifically designed for this purpose. ● **SEE FIGURE 80–10.**
- **Nitrogen gas pressurization.** This method uses nitrogen gas under a very low pressure (lower than 1 PSI) in the fuel system. The service technician then listens for the escaping air, using amplified headphones. ● **SEE FIGURE 80–11.**

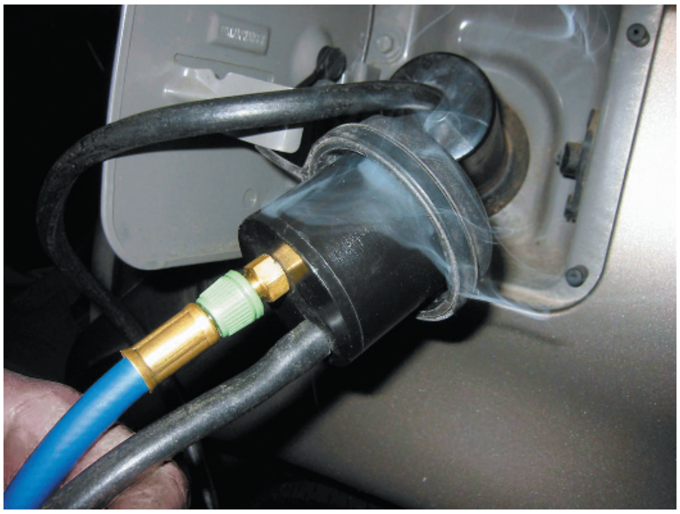


FIGURE 80–10 This unit is applying smoke to the fuel tank through an adapter, and the leak was easily found to be the gas cap seal.

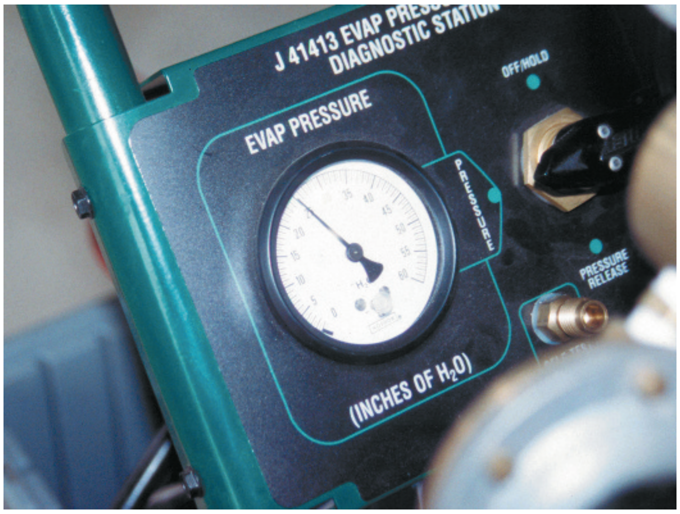

J 41413 EVAP PRESSURE
DIAGNOSTIC STATION
OFF/HOLD
EVAP PRESSURE
PRESSURE
(INCHES OF H2O)
PRESSURE RELEASE

FIGURE 80–11 An emission tester that uses nitrogen to pressurize the fuel system.

EVAPORATIVE SYSTEM MONITOR

OBD-II REQUIREMENTS OBD-II computer programs not only detect faults, but also *periodically test various systems* and alert the driver before emissions-related components are harmed by system faults:

- Serious faults cause a blinking MIL or even an engine shutdown.
- Less serious faults may simply store a code, but not illuminate the MIL.

The OBD-II requirements did not affect fuel system design. However, one new component, a fuel evaporative canister purge line pressure sensor, was added for monitoring purge line pressure during tests. The OBD-II requirements state that vehicle fuel systems are to be routinely tested *while under way* by the PCM.

All OBD-II vehicles perform a canister purge system pressure test, as commanded by the PCM. While the vehicle is being driven, the vapor line between the canister and the purge valve is monitored for pressure changes:

- When the canister purge solenoid is open, the line should be under a vacuum since vapors must be drawn from the canister into the intake system. However, when the purge solenoid is closed, there should be no vacuum in the line. The pressure sensor detects if a vacuum is present, and the information is compared to the command given to the solenoid.
- If, during the canister purge cycle, no vacuum exists in the canister purge line, a code is set indicating a possible fault, which could be caused by an inoperative or clogged solenoid or a blocked or leaking canister purge fuel line. Likewise, if vacuum exists when no command for purge is given, a stuck solenoid is evident, and a code is set. The EVAP system monitor tests for purge volume and leaks.

A typical EVAP monitor first closes off the system to atmospheric pressure and opens the purge valve during cruise operation. A **fuel tank pressure (FTP)** sensor then monitors the rate with which vacuum increases in the system. The monitor uses this information to determine the purge volume flow rate. To test for leaks, the EVAP monitor closes the purge valve, creating a completely closed system. The fuel tank pressure sensor then monitors the leak-down rate. If the rate exceeds PCM-stored values, a leak greater than or equal to the OBD-II standard of 0.04 inch (1 mm) or 0.02 inch (0.5 mm) exists. After two consecutive failed trips testing either purge volume or the presence of a leak, the PCM lights the MIL and sets a DTC.

The fuel tank pressure sensor is similar to a MAP sensor, and instead of monitoring intake manifold absolute pressure, it is used to monitor fuel tank pressure. ● **SEE FIGURE 80–12**.

ENGINE-OFF NATURAL VACUUM System integrity (leakage) can also be checked after the engine is shut off. The premise is that a warm evaporative system cools down after the engine is shut off and the vehicle is stable. A slight vacuum is created in the gas tank during this cool-down period. If a specific level of vacuum is reached and maintained, the system is said to have integrity (no leakage). Actually, the vacuum is created after a period of time because the vapor pressure tends to increase after the engine is shut off and gradually decreases over time.

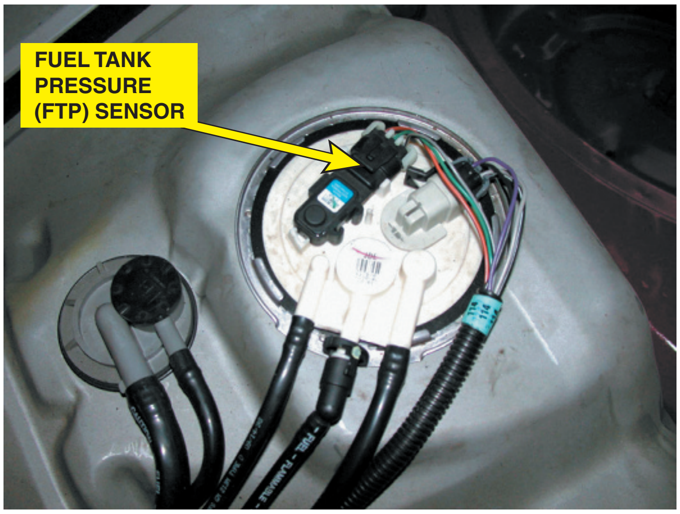


FIGURE 80–12 The fuel tank pressure sensor (black unit with three wires) looks like a MAP sensor and is usually located on top of the fuel pump module (white unit).

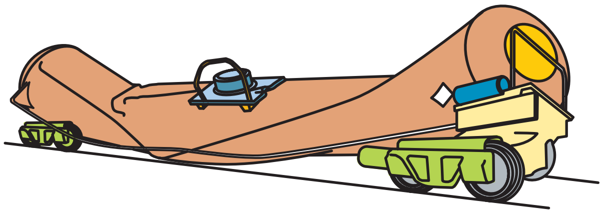


FIGURE 80–13 A tank car was cleaned using steam, and then both the bottom drain and the top vent were closed. The next day, the tank had collapsed because of the air pressure difference when the inside cooled. The higher outside air pressure caused the tank to collapse.

The PCM monitors the pressure rise and decrease over time and triggers a DTC if the pressure indicates a leak in the system. ● **SEE FIGURE 80–13**.

TYPICAL EVAP MONITOR The PCM runs the EVAP monitor when the following enable criteria are met:

- Barometric pressure (BARO) greater than 70 kPa (20.7 in. Hg or 10.2 PSI)
- Intake air temperature (IAT) between 39°F and 86°F (4°C to 30°C) at engine start-up
- Engine coolant temperature (ECT) between 39°F and 86°F (4°C to 30°C) at engine start-up
- ECT and IAT within 3°F of each other at engine start-up
- Fuel level within 15% to 85%
- Throttle position (TP) sensor between 9% and 35%

TECH TIP

Always Tighten the Cap Correctly

Many DTCs are set because the gas cap has not been properly installed. To be sure that a screw-type gas cap is properly sealed, tighten it until you hear three clicks. The clicking is a ratchet device, and the clicking does not harm the cap. Therefore, if a P0440 or similar DTC is set, check the cap. ● **SEE FIGURE 80–14**.

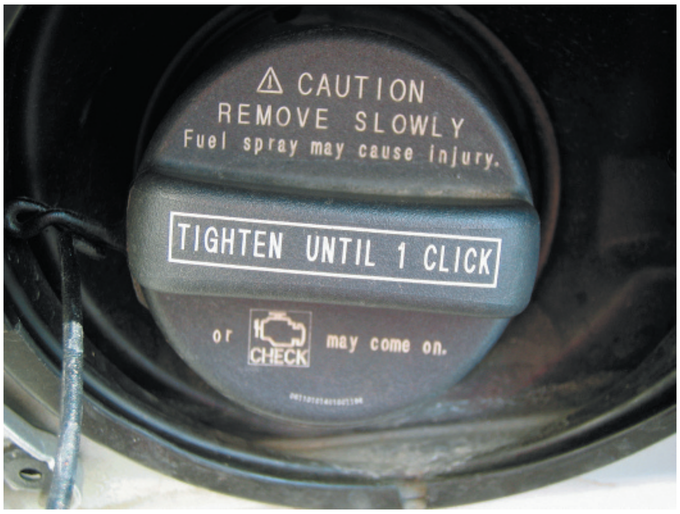


FIGURE 80–14 This Toyota cap warns that the check engine light comes on if not tightened until one click.

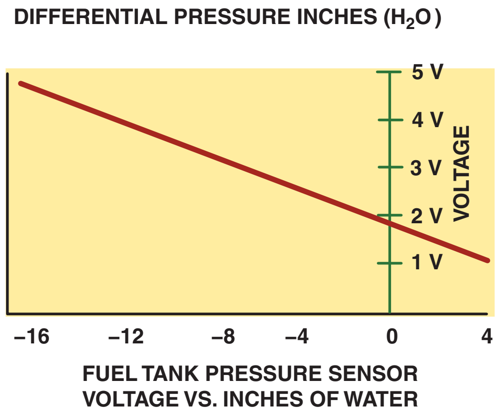


FIGURE 80–15 To easily check the fuel tank pressure sensor, remove the cap, and the sensor should read about 1.7 volts.

A typical EVAP monitor first closes off the system to atmospheric pressure and opens the purge valve during cruise operation. A FTP sensor then monitors the rate with which vacuum increases in the system. ● **SEE FIGURE 80–15.**

The monitor uses this information to determine the purge volume flow rate. To test for leaks, the EVAP monitor closes the purge valve, creating a completely closed system. The fuel tank pressure sensor then monitors the leak-down rate. If the rate exceeds PCM-stored values, a leak greater than or equal to the OBD-II standard of 0.04 inch (1 mm) or 0.02 inch (0.5 mm) exists.

RUNNING THE EVAP MONITOR Four tests are performed during a typical EVAP monitor. A DTC is assigned to each test:

1. **Weak vacuum test (P0440–large leak).** This test identifies gross leaks. During the monitor, the vent solenoid is closed, and the purge solenoid is duty cycled. The FTP should indicate a vacuum of approximately 6 to 10 inches H_2O.
2. **No flow during purging (P0441–no flow during purging).** This test uses the FTP sensor to determine that there was no change in fuel tank pressure during purging. This fault could be due to a defective purge valve or a gross leak caused by faults, such as a defective or missing gas cap.
3. **Small leak test (P0442–small leak).** After the large leak test passes, the PCM checks for a small leak by keeping the vent solenoid closed and closing the purge solenoid. The system is now sealed. The PCM measures the change in FTP voltage over time.
4. **Excess vacuum test (P0446).** This test checks for vent path restrictions. With the vent solenoid open and purge commanded, the PCM should not see excessive vacuum in the EVAP system. Typical EVAP system vacuum with the vent solenoid open is about 5 to 6 in. H_2O.

TECH TIP

Keep the Fuel Tank Properly Filled

Most evaporative system monitors do not run unless the fuel level is between 15% and 85%. In other words, if a driver always runs with close to an empty tank or always tries to keep the tank full, the EVAP monitor may not run. ● **SEE FIGURE 80–16.**

FIGURE 80–16 The fuel level must be above 15% and below 85% before the EVAP monitor runs on most vehicles.

EVAP SYSTEM-RELATED DIAGNOSTIC TROUBLE CODES

Diagnostic Trouble Code	Description	Possible Causes
P0440	Evaporative system fault	■ Loose gas cap ■ Defective EVAP vent ■ Cracked charcoal canister ■ EVAP vent or purge vapor line problems
P0442	Small leak detected	■ Loose gas cap ■ Defective EVAP vent or purge solenoid ■ EVAP vent or purge line problems
P0446	EVAP canister vent blocked	■ EVAP vent or purge solenoid electrical problems ■ Restricted EVAP canister vent line

EXHAUST GAS RECIRCULATION SYSTEMS

INTRODUCTION **Exhaust gas recirculation (EGR)** is an emission control system that lowers the amount of **nitrogen oxides (NO_x)** formed during combustion. In the presence of sunlight, NO_x reacts with hydrocarbons in the atmosphere to form ozone (O_3) or photochemical smog, an air pollutant.

NO_x FORMATION Nitrogen (N_2) and oxygen (O_2) molecules are separated into individual atoms of nitrogen and oxygen during the combustion process. These molecules then bond to form NO_x (NO, NO_2). When combustion flame front temperatures exceed 2,500°F (1,370°C), NO_x is formed inside the cylinder, which is then discharged into the atmosphere from the tailpipe. ● **SEE FIGURE 80–17.**

FIGURE 80–17 Nitrogen oxides (NO_x) create a red-brown haze that often hangs over major cities.

CONTROLLING NO_x To handle the NO_x generated above 2,500°F (1,370°C), the most efficient method to meet NO_x emissions without significantly affecting engine performance, fuel economy, and other exhaust emissions is to use exhaust gas recirculation (EGR). The EGR system routes small quantities, usually between 6% and 10%, of exhaust gas into the intake manifold.

Here, the exhaust gas mixes with and takes the place of some intake charge. This leaves less room for the intake charge to enter the combustion chamber. The recirculated exhaust gas is **inert** (chemically inactive) and does not enter into the combustion process. The result is a lower peak combustion temperature. When the combustion temperature is lowered, the production of oxides of nitrogen is reduced.

The EGR system has some means of interconnecting the exhaust and intake manifolds. ● **SEE FIGURE 80–18**.

The EGR valve controls the flow of exhaust gases through the interconnecting passages:

- On V-type engines, the intake manifold crossover is used as a source of exhaust gas for the EGR system. A cast passage connects the exhaust crossover to the EGR valve. The exhaust gas is sent from the EGR valve to openings in the manifold.
- On inline-type engines, an external tube is generally used to carry exhaust gas to the EGR valve. This tube is often designed to be long so that the exhaust gas is cooled before it enters the EGR valve.

EGR SYSTEM OPERATION Since small amounts of exhaust are all that is needed to lower peak combustion temperatures, the orifice through which the exhaust passes is small.

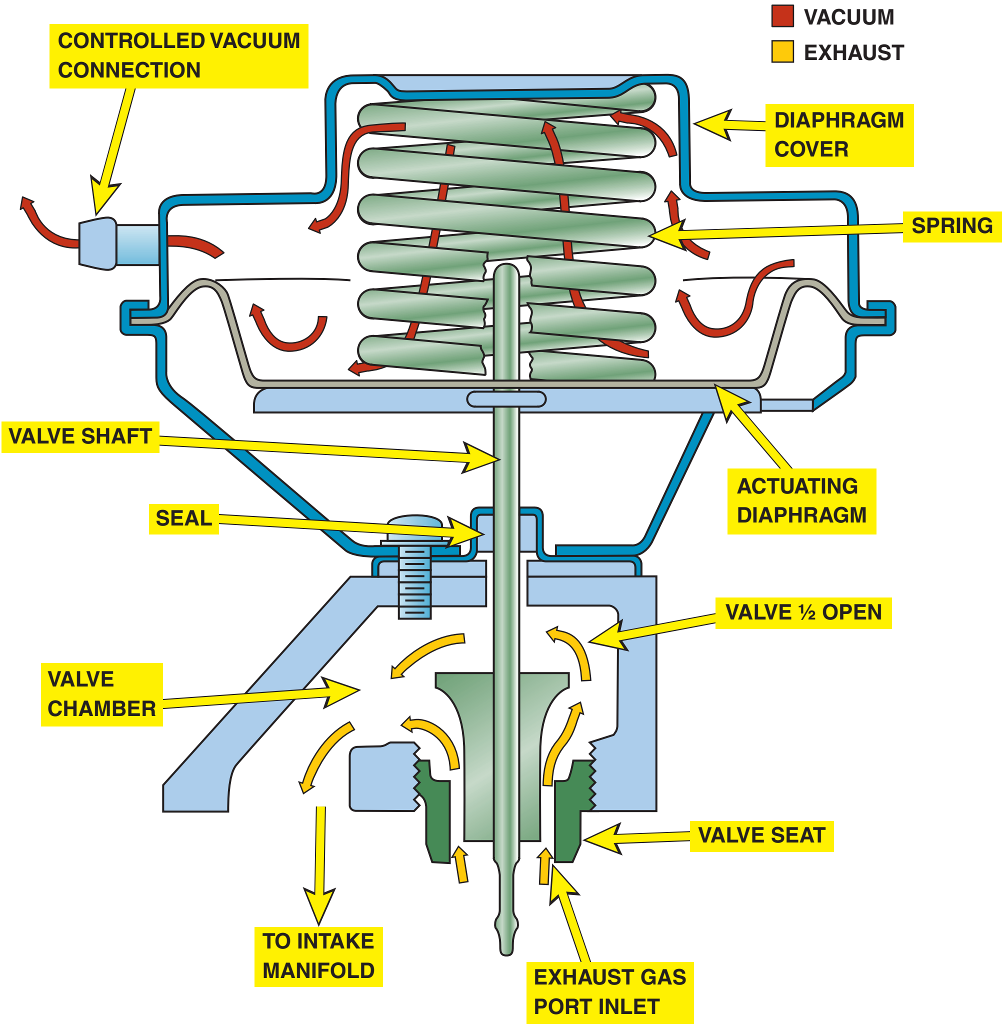


FIGURE 80–18 When the EGR valve opens, the exhaust gases flow through the valve and into passages in the intake manifold.

EGR is usually not required during the following conditions because the combustion temperatures are low:

- During idle speed
- When the engine is cold
- At wide-open throttle (WOT) (Not allowing EGR allows the engine to provide extra power when demanded. While the NO_x formation is high during these times, the overall effect of not using EGR during WOT conditions is minor.)

The level of NO_x emission changes according to engine speed, temperature, and load. Many systems use a cooler to reduce the temperature of the exhaust gases before they enter the intake manifold. The cooler the exhaust gases, the more effective they are at reducing the formation of NO_x.

EGR BENEFITS In addition to lowering NO_x levels, the EGR system also helps control detonation. **Detonation**, also called spark knock or ping, occurs when high pressure and heat cause the air–fuel mixture to ignite. This uncontrolled combustion can severely damage the engine.

Using the EGR system allows for greater ignition timing advance, and for the advance to occur sooner without detonation problems, which increases power and efficiency.

EGR VALVE POSITION SENSORS Most PCM vacuum-operated EGR systems use a sensor to indicate EGR operation. Onboard diagnostics generation II (OBD-II) EGR system monitors require an EGR sensor to verify that the valve opened. A linear potentiometer on the top of the EGR valve stem indicates valve position to the PCM. This is called an **EGR valve position (EVP) sensor**. Some later-model Ford EGR systems, however, use a feedback signal provided by an EGR exhaust back pressure sensor that converts the exhaust back pressure to a voltage signal. This sensor is called a **pressure feedback EGR (PFE) sensor**.

On some EGR systems, the top of the valve contains a vacuum regulator and EGR pintle-position sensor in one assembly sealed inside a nonremovable plastic cover. The pintle-position sensor provides a voltage output to the PCM, which increases as the duty cycle increases, allowing the PCM to monitor valve operation. ● **SEE FIGURE 80–19**.

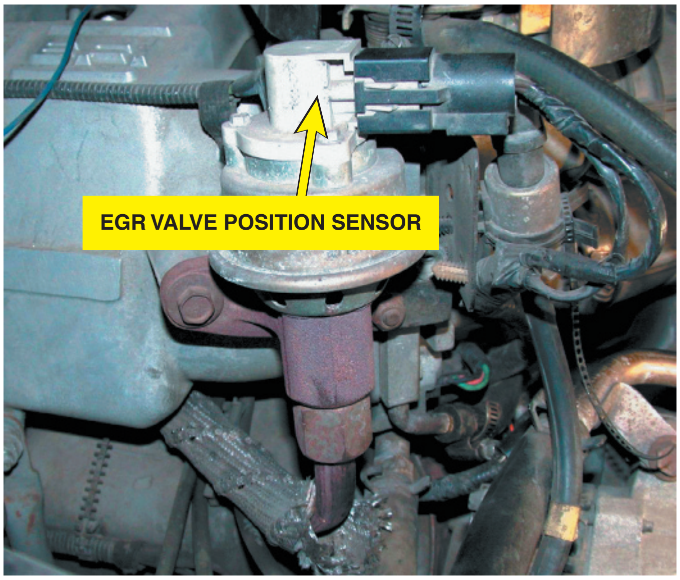


FIGURE 80–19 An EGR valve position sensor on top of an EGR valve.

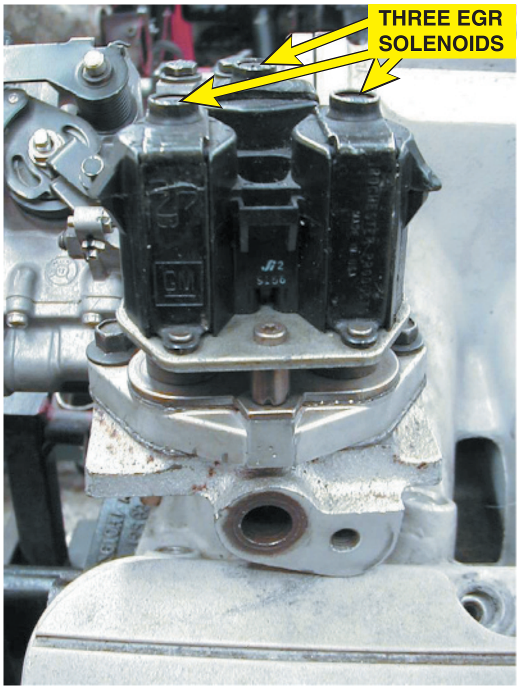


FIGURE 80–20 Digital EGR valve as used on some older General Motors engines.

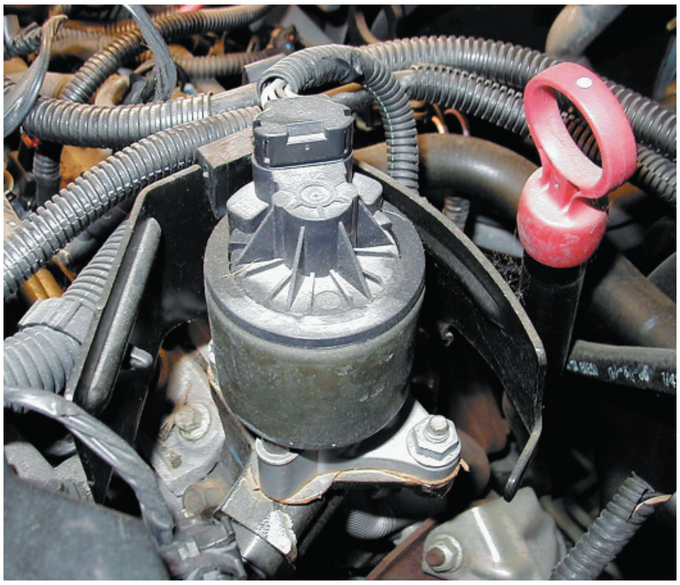


FIGURE 80–21 A General Motors linear EGR valve.

DIGITAL EGR VALVES General Motors used **a digital EGR valve** design on some engines. Unlike vacuum-operated EGR valves, the digital EGR valve consists of three solenoids controlled by the powertrain control module (PCM). Each solenoid controls a different size orifice in the base—small, medium, and large. The PCM controls the ground circuit of each of the solenoids individually. It can produce any of seven different flow rates, using the solenoids to open the three valves in different combinations. The digital EGR valve offers precise control and using a swivel pintle design helps prevent carbon deposit problems. ● **SEE FIGURE 80–20**.

LINEAR EGR Most General Motors and many other vehicles use a **linear EGR valve** that contains a pulse-width modulated solenoid to precisely regulate exhaust gas flow and a feedback potentiometer that signals the PCM regarding the actual position of the valve. ● **SEE FIGURES 80–21 AND 80–22**.

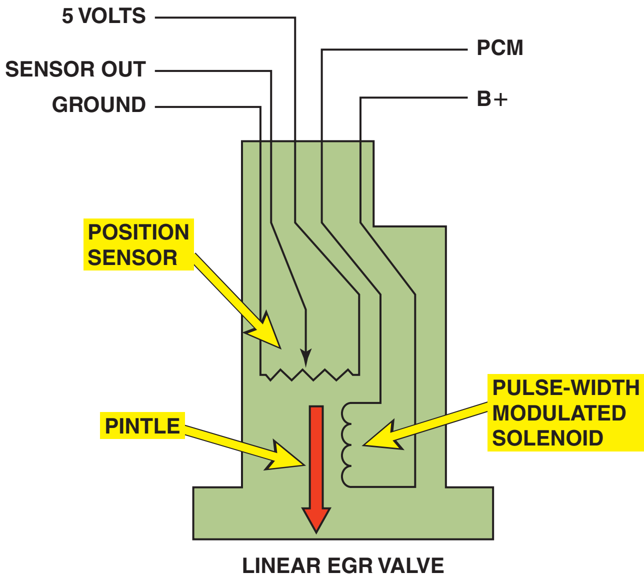

5 VOLTS
SENSOR OUT
GROUND
PCM
B+
POSITION SENSOR
PINTLE
PULSE-WIDTH MODULATED SOLENOID
LINEAR EGR VALVE

FIGURE 80–22 The EGR valve pintle is pulse-width modulated and a three-wire potentiometer provides pintle-position information back to the PCM.

TECH TIP

Find the Root Cause

Excessive back pressure, such as that caused by a partially clogged exhaust system, could cause the plastic sensors on the EGR valve to melt. Always check for a restricted exhaust whenever replacing a failed EGR valve sensor.

OBD-II EGR MONITORING STRATEGIES

PURPOSE AND FUNCTION In 1996, the U.S. Environmental Protection Agency (EPA) began requiring OBD-II systems in all passenger cars and most light-duty trucks. These systems include emission system monitors that alert the driver and the technician if an emission system is malfunctioning. The OBD-II system performs this test by opening and closing the EGR valve. The PCM monitors either the oxygen or MAP sensor for a change in signal voltage. If the EGR system fails, a DTC is set. If the system fails two consecutive times, the MIL is lit.

MONITORING STRATEGIES EGR monitoring strategies include the following:

- Some vehicle manufacturers, such as Chrysler, monitor the difference in the exhaust oxygen sensor's voltage activity as the EGR valve opens and closes. Oxygen in the exhaust decreases when the EGR valve is open and increases when the EGR valve is closed because exhaust gas is inert (contains very little oxygen) and actually displaces oxygen. The PCM sets a DTC if the sensor signal does not change.
- Most Fords use an EGR monitor test sensor called a **delta pressure feedback EGR (DPFE) sensor**. This sensor measures the pressure differential between two sides of a metered orifice positioned just below the EGR valve's exhaust side. Pressure between the orifice and the EGR valve decreases when the EGR opens because it becomes exposed to the lower pressure in the intake. The DPFE sensor recognizes this pressure drop, compares it to the relatively higher pressure on the exhaust side of the orifice, and signals the value of the pressure difference to the PCM. ● **SEE FIGURE 80–23**.
- Many vehicle manufacturers use the manifold absolute pressure (MAP) sensor as the EGR monitor on some applications. After meeting the enable criteria (operating condition requirements), the EGR monitor is run. The PCM monitors the MAP sensor while it commands the EGR valve to open. The MAP sensor signal should change in response to the sudden change in manifold pressure or the fuel trim changes created by a change in the oxygen sensor voltage. If the signal value falls outside the acceptable value in the lookup table, a DTC sets. If the EGR fails on two consecutive trips, the PCM lights the MIL. ● **SEE FIGURE 80–24**.

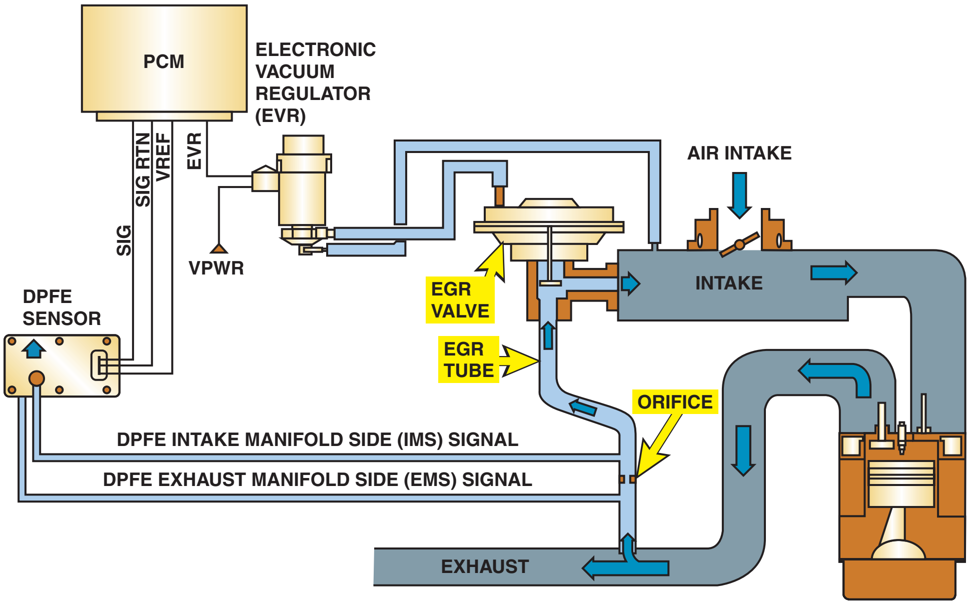

PCM
ELECTRONIC VACUUM REGULATOR (EVR)
SIG
SIG RTN
VREF
EVR
VPWR
AIR INTAKE
INTAKE
EGR VALVE
EGR TUBE
DPFE SENSOR
ORIFICE
DPFE INTAKE MANIFOLD SIDE (IMS) SIGNAL
DPFE EXHAUST MANIFOLD SIDE (EMS) SIGNAL
EXHAUST

FIGURE 80–23 A typical Ford DPFE sensor and related components.

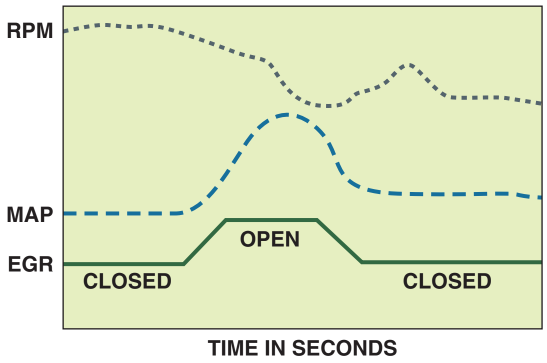


FIGURE 80–24 An OBD-II active test. The PCM opens the EGR valve and then monitors the MAP sensor and/or engine speed (RPM) to verify that it meets acceptable values.

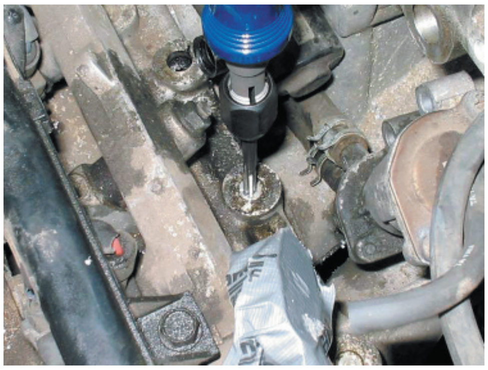


FIGURE 80–25 Removing the EGR passage plugs from the intake manifold on a Honda.

TECH TIP

Watch Out for Carbon Balls!

EGR valves can get stuck partially open by a chunk of carbon, and the valve or solenoid tests as defective. When the valve (or solenoid) is removed, small chunks or balls of carbon often fall into the exhaust manifold passage. When the replacement valve is installed, the carbon balls can be drawn into the new valve again, causing the engine to idle roughly or stall.

To help prevent this problem, start the engine with the EGR valve or solenoid removed. Any balls or chunks of carbon are blown out of the passage by the exhaust. Stop the engine and install the replacement EGR valve or solenoid.

TECH TIP

The Snake Trick

The EGR passages on many intake manifolds become clogged with carbon, which reduces the flow of exhaust and the amount of exhaust gases in the cylinders. This reduction can cause spark knock (detonation) and increased emissions of oxides of nitrogen (NO_X) (especially important in areas with enhanced exhaust emissions testing).

To quickly and easily remove carbon from exhaust passages, cut an approximately 1-foot (30-cm) length from stranded wire, such as garage door guide wire or an old speedometer cable. Flare the end and place the end of the wire into the passage. Set your drill on reverse and turn it on, and the wire pulls its way through the passage, cleaning the carbon as it goes, just like a snake in a drainpipe. Some vehicles, such as Hondas, require that plugs be drilled out to gain access to the EGR passages. ● **SEE FIGURE 80–25**.

DIAGNOSING A DEFECTIVE EGR SYSTEM

SYMPTOMS If the EGR valve is not opening or the flow of the exhaust gas is restricted, then the following symptoms are likely:

- Detonation (spark knock or ping) during acceleration or during cruise (steady-speed driving)
- Excessive oxides of nitrogen (NO_x) exhaust emissions

If the EGR valve is stuck open or partially open, then the following symptoms are likely:

- Rough idle or frequent stalling
- Poor performance/low power, especially at low engine speed

EGR TESTING PROCEDURES The first step in almost any diagnosis is to perform a thorough visual inspection. To check for proper operation of a vacuum-operated EGR valve, follow these steps:

STEP 1 **Check the vacuum diaphragm of the EGR valve to see if it can hold vacuum.** Because many EGR valves require exhaust back pressure to function correctly, the engine should be running at a fast idle during this test.

STEP 2 **Apply vacuum from a hand-operated vacuum pump and check for proper operation.** The valve itself should move when vacuum is applied, and the engine operation should be affected. The EGR valve should be able to hold the vacuum that was applied. If the vacuum drops off, then the valve is likely to be defective.

STEP 3 **Monitor engine vacuum drop.** Connect a vacuum gauge to an intake manifold vacuum source and monitor the engine vacuum at idle (should be 17 to 21 in. Hg at sea level). Raise the speed of the engine to 2,500 RPM and note the vacuum reading (should be 17 to 21 in. Hg or higher).

Activate the EGR valve using a scan tool or vacuum pump, if vacuum-controlled, and observe the vacuum gauge. The results are as follows:

- The vacuum should drop 6 to 8 in. Hg.
- If the vacuum drops less than 6 to 8 in. Hg, the valve or the EGR passages are clogged.
- If the EGR valve is able to hold vacuum, but the engine is not affected when the valve is opened, then the exhaust passage(s) must be checked for restriction.

See the Tech Tip “The Snake Trick.” If the EGR valve does not hold vacuum, the valve itself is likely to be defective and requires replacement.

EGR-RELATED OBD-II DIAGNOSTIC TROUBLE CODES

Diagnostic Trouble Code	Description	Possible Causes
P0400	Exhaust gas recirculation flow problems	■ EGR valve ■ EGR valve hose or electrical connection ■ Defective PCM
P0401	Exhaust gas recirculation flow insufficient	■ EGR valve ■ Clogged EGR ports or passages
P0402	Exhaust gas recirculation flow excessive	■ Stuck-open EGR valve ■ Vacuum hose(s) misrouted ■ Electrical wiring shorted

REVIEW QUESTIONS

1. What components are used in a typical evaporative emission control system?
2. Why is the vent valve subject to rust and corrosion?
3. What are the parameters (enable criteria) that must be met for the evaporative system monitor to run?
4. What causes the formation of oxides of nitrogen?
5. How does the use of exhaust gas reduce NOx exhaust emission?

CHAPTER QUIZ

1. What is the substance used in a vapor canister to absorb volatile organic compounds?
   a. Desiccant
   b. Organic absorber
   c. Pleated paper
   d. Charcoal
2. Which valve(s) is (are) normally closed?
   a. Canister purge valve
   b. Canister vent valve
   c. Both canister purge and canister vent valves
   d. Neither canister purge nor canister vent valve
3. All of the following can increase the pressure in the evaporative emission control system *except* ____________.
   a. fuel temperature
   b. returned fuel from the fuel-injection system
   c. inlet fuel to the fuel pump
   d. volatility of the fuel
4. Inadequate purge flow rate triggers which DTC?
   a. P0440
   b. P0446
   c. P0300
   d. P0440 or P0446
5. Which EVAP valve is subject to rust and corrosion more than all of the others?
   a. Purge valve
   b. Vacuum control valve
   c. Vent valve
   d. Rollover check valve
6. A small leak is detected by the evaporative emission control system monitor that could be caused by a loose gas cap. Which DTC is likely set?
   a. P0440
   b. P0442
   c. P0446
   d. P0440, P0441, or P0442
7. Exhaust gas recirculation (EGR) is generally not needed under all the following conditions *except* ____________.
   a. idle speed
   b. cold engine
   c. cruise speed
   d. wide-open throttle (WOT)
8. EGR is used to control which exhaust emission?
   a. Unburned hydrocarbons (HC)
   b. Oxides of nitrogen (NOx)
   c. Carbon monoxide (CO)
   d. Both NOx and CO
9. When testing an EGR system for proper operation using a vacuum gauge, how much should the vacuum drop when the EGR is commanded on by a scan tool?
   a. 1 to 2 in. Hg
   b. 3 to 5 in. Hg
   c. 6 to 8 in. Hg
   d. 8 to 10 in. Hg
10. A P0401 DTC (exhaust gas recirculation flow insufficient) is being discussed. Technician A says that a defective EGR valve could be the cause. Technician B says that clogged EGR passages could be the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

Chapter

81

POSITIVE CRANKCASE VENTILATION AND SECONDARY AIR-INJECTION SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the purpose and function of the positive crankcase ventilation (PCV) system.
- Discuss PCV system diagnosis.
- Explain the purpose and function of the secondary air-injection (SAI) system.
- Explain how to diagnose faults in the secondary air-injection system.

KEY TERMS:

Air-injection reaction (AIR) 957 • Blowby 954 • Check valve 958 • Positive crankcase ventilation (PCV) 954 • Secondary air injection (SAI) 957 • Smog pump 957 • Thermactor pump 957

CRANKCASE VENTILATION

PURPOSE AND FUNCTION The problem of crankcase ventilation has existed since the beginning of the automobile because no piston ring, new or old, can provide a perfect seal between the piston and the cylinder wall. When an engine is running, the pressure of combustion forces the piston downward. This same pressure also forces gases and unburned fuel from the combustion chamber, past the piston rings, and into the crankcase. This process of gases leaking past the rings is called **blowby**, and the gases form crankcase vapors.

These combustion by-products, particularly unburned hydrocarbons (HC) caused by blowby, must be ventilated from the crankcase. However, the crankcase cannot be vented directly to the atmosphere because the hydrocarbon vapors add to air pollution. **Positive crankcase ventilation (PCV)** systems were developed to ventilate the crankcase and recirculate the vapors to the engine's induction system so they can be burned in the cylinders. PCV systems help reduce HC and CO emissions.

All systems use the following:

1. PCV valve or calibrated orifice, or orifice and separator
2. PCV inlet air filter plus all connecting hoses

● **SEE FIGURE 81–1.**

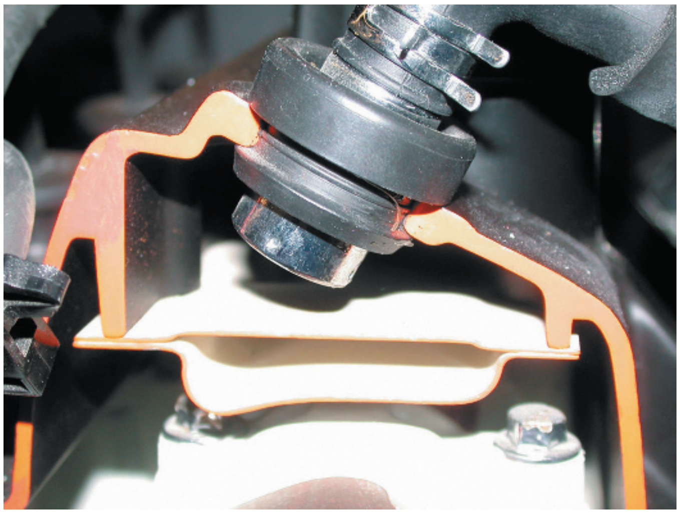


FIGURE 81–1 A PCV valve in a cutaway valve cover, showing the baffles that prevent liquid oil from being drawn into the intake manifold.

An oil/vapor or oil/water separator is used in some systems instead of a valve or orifice, particularly with turbocharged and fuel-injected engines. The oil/vapor separator lets oil condense and drain back into the crankcase. The oil/water separator

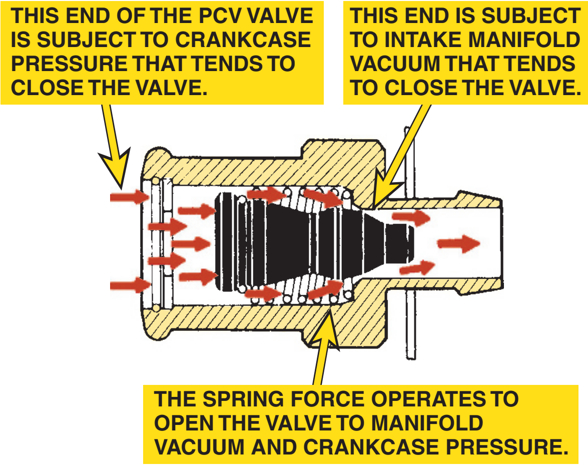

THIS END OF THE PCV VALVE IS SUBJECT TO CRANKCASE PRESSURE THAT TENDS TO CLOSE THE VALVE.
THIS END IS SUBJECT TO INTAKE MANIFOLD VACUUM THAT TENDS TO CLOSE THE VALVE.
THE SPRING FORCE OPERATES TO OPEN THE VALVE TO MANIFOLD VACUUM AND CRANKCASE PRESSURE.

FIGURE 81–2 Spring force, crankcase pressure, and intake manifold vacuum work together to regulate the flow rate through the PCV valve.

accumulates moisture and prevents it from freezing during cold engine starts.

The air for the PCV system is drawn after the air cleaner filter, which acts as a PCV filter.

NOTE: Some older designs drew from the dirty side of the air cleaner, where a separate crankcase ventilation filter was used.

PCV VALVES The PCV valve in most systems is a one-way valve containing a spring-operated plunger that controls valve flow rate. ● **SEE FIGURE 81–2**.

Flow rate is established for each engine, and a valve for a different engine should not be substituted. The flow rate is determined by the size of the plunger and the holes inside the valve. PCV valves usually are located in the valve cover or intake manifold.

The PCV valve regulates airflow through the crankcase under all driving conditions and speeds. When manifold vacuum is high (at idle, cruising, and light-load operation), the PCV valve restricts the airflow to maintain a balanced air–fuel ratio. ● **SEE FIGURE 81–3**.

It also prevents high intake manifold vacuum from pulling oil out of the crankcase and into the intake manifold. Under high speed or heavy loads, the valve opens and allows maximum airflow. ● **SEE FIGURE 81–4**.

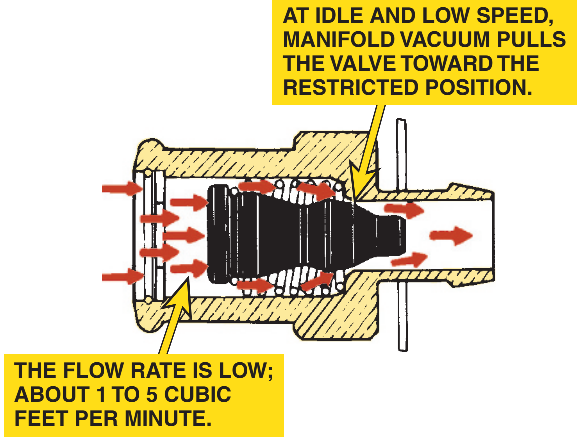

AT IDLE AND LOW SPEED, MANIFOLD VACUUM PULLS THE VALVE TOWARD THE RESTRICTED POSITION.
THE FLOW RATE IS LOW; ABOUT 1 TO 5 CUBIC FEET PER MINUTE.

FIGURE 81–3 Air flows through the PCV valve during idle, cruising, and light-load conditions.

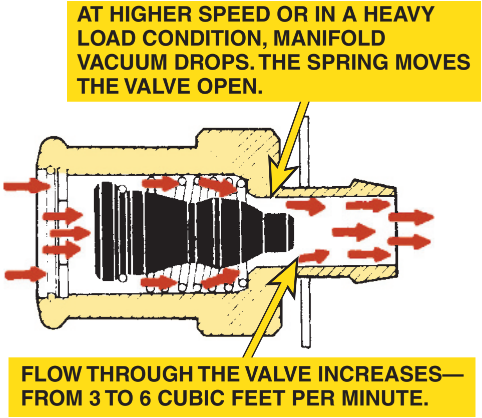

AT HIGHER SPEED OR IN A HEAVY LOAD CONDITION, MANIFOLD VACUUM DROPS. THE SPRING MOVES THE VALVE OPEN.
FLOW THROUGH THE VALVE INCREASES— FROM 3 TO 6 CUBIC FEET PER MINUTE.

FIGURE 81–4 Air flows through the PCV valve during acceleration and when the engine is under a heavy load.

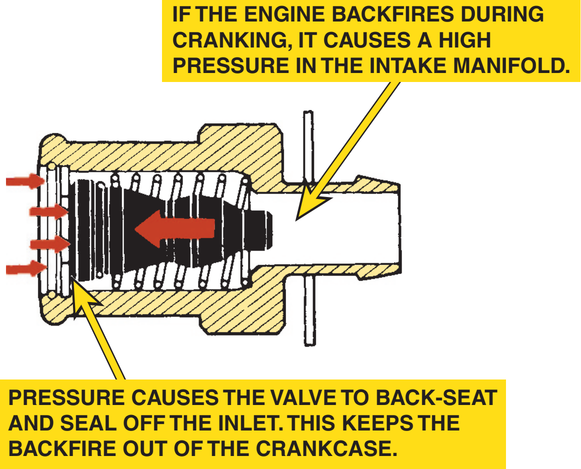

IF THE ENGINE BACKFIRES DURING CRANKING, IT CAUSES A HIGH PRESSURE IN THE INTAKE MANIFOLD.
PRESSURE CAUSES THE VALVE TO BACK-SEAT AND SEAL OFF THE INLET. THIS KEEPS THE BACKFIRE OUT OF THE CRANKCASE.

FIGURE 81–5 PCV valve operation in the event of a backfire.

If the engine backfires, the valve closes instantly to prevent a crankcase explosion. ● **SEE FIGURE 81–5**.

ORIFICE-CONTROLLED SYSTEMS The closed PCV system used on some 4-cylinder engines contains a calibrated orifice instead of a PCV valve. The orifice may be located in the valve cover or intake manifold, or in a hose connected between the valve cover, air cleaner, and intake manifold.

While most orifice flow control systems work the same as a PCV valve system, they may not use fresh air scavenging of the crankcase. Crankcase vapors are drawn into the intake manifold in calibrated amounts, depending on manifold pressure and the orifice size. If vapor availability is low, as during idle, air is drawn in with the vapors. During off-idle operation, excess vapors are sent to the air cleaner.

At idle, PCV flow is controlled by a 0.05-inch (1.3-mm) orifice. As the engine moves off idle, ported vacuum pulls a spring-loaded valve off of its seat, allowing PCV flow to pass through a 0.09-inch (2.3-mm) orifice.

SEPARATOR SYSTEMS Turbocharged and many fuel-injected engines use an oil/vapor or oil/water separator and a calibrated orifice instead of a PCV valve. In the most common applications, the air intake throttle body acts as the source for crankcase ventilation vacuum, and a calibrated orifice acts as the metering device.

CASE STUDY

The Whistling Engine

An older vehicle was being diagnosed for a whistling sound whenever the engine was running, especially at idle. It was finally discovered that the breather in the valve cover was plugged and caused high vacuum in the crankcase. The engine was sucking air from what was likely the rear main seal lip, making the "whistle" noise. After replacing the breather and PCV, the noise stopped.

Summary:

Complaint—The customer stated that the engine made a whistling sound when it was running.
Cause—A clogged PCV breather was found to be the cause of air being drawn into the engine through the rear main seal.
Correction—The PCV breather and check valve were replaced, which corrected the whistling noise concern.

PCV SYSTEM DIAGNOSIS

SYMPTOMS If the PCV valve or orifice is not clogged, intake air flows freely and the PCV system functions properly. Engine design includes the air and vapor flow as a calibrated part of the air–fuel mixture. In fact, some engines receive as much as 30% of the idle air through the PCV system. For this reason, a flow problem in the PCV system results in driveability problems.

A blocked or plugged PCV system may cause the following to occur:

- Rough or unstable idle
- Excessive oil consumption
- Oil in the air filter housing
- Oil leaks due to excessive crankcase pressure

Before attempting expensive engine repairs, check the condition of the PCV system.

TECH TIP

Check for Oil Leaks with the Engine Off

The owner of an older vehicle equipped with a V-6 engine complained to their technician that they smelled burning oil, but only *after* shutting off the engine. The technician found that the rocker cover gaskets were leaking. But why did the owner only notice the smell of hot oil when the engine was shut off? Because of the PCV system, engine vacuum tends to draw oil away from gasket surfaces. When the engine stops, however, engine vacuum disappears, and the oil remaining in the upper regions of the engine tend to flow down and out through any opening. Therefore, a good technician should check an engine for oil leaks, not only with the engine running, but also shortly after shutdown.

PCV SYSTEM PERFORMANCE CHECK A properly operating PCV system should be able to draw vapors from the crankcase and into the intake manifold. If the pipes, hoses, and PCV valve itself are not restricted, vacuum is applied to the crankcase. A slight vacuum is created in the crankcase (usually less than 1 in. Hg if measured at the dipstick) and is also applied to other areas of the engine. Oil drainback holes provide a path for oil to drain back into the oil pan. These holes also allow crankcase vacuum to be applied under the rocker covers and in the valley area of most V-type engines. Several methods can be used to test a PCV system.

RATTLE TEST The rattle test is performed by simply removing the PCV valve and giving it a shake:

- If the PCV valve does *not* rattle, it is definitely defective and must be replaced.
- If the PCV valve *does* rattle, it does not necessarily mean that the PCV valve is good. All PCV valves contain springs that can become weaker with age and with heating and cooling cycles. Replace any PCV valve with the *exact* replacement according to the vehicle manufacturer's recommended intervals.

THE 3 × 5 CARD TEST Remove the oil-fill cap (where oil is added to the engine) and start the engine.

NOTE: Use care on some overhead camshaft engines. With the engine running, oil may be sprayed from the open oil-fill opening.

Hold a 3 × 5 card over the opening (a dollar bill or any other piece of paper can be used for this test):

- If the PCV system, including the valve and hoses, is functioning correctly, the card should be held down on the oil-fill opening by the slight vacuum inside the crankcase.
- If the card does not stay, carefully inspect the PCV valve, hose(s), and manifold vacuum port for carbon buildup (restriction). Clean or replace as necessary.

NOTE: On some 4-cylinder engines, the 3 × 5 card may vibrate on the oil-fill opening when the engine is running at idle speed. This is normal because of the time intervals between intake strokes on a 4-cylinder engine.

SNAP-BACK TEST The proper operation of the PCV valve can be checked by placing a finger over the inlet hole in the valve when the engine is running and removing the finger rapidly. Repeat several times. The valve should "snap back." If the valve does not snap back, replace the valve.

CRANKCASE VACUUM TEST Sometimes the PCV system can be checked by testing for a weak vacuum at the oil dipstick tube using an inches-of-water manometer or gauge, as follows:

STEP 1 Remove the oil-fill cap or vent PCV opening and cover the opening.

STEP 2 Remove the oil dipstick (oil level indicator).

STEP 3 Connect a water manometer or gauge to the dipstick tube.

STEP 4 Start the engine and observe the gauge at idle and at 2,500 RPM. ● **SEE FIGURE 81–6**.

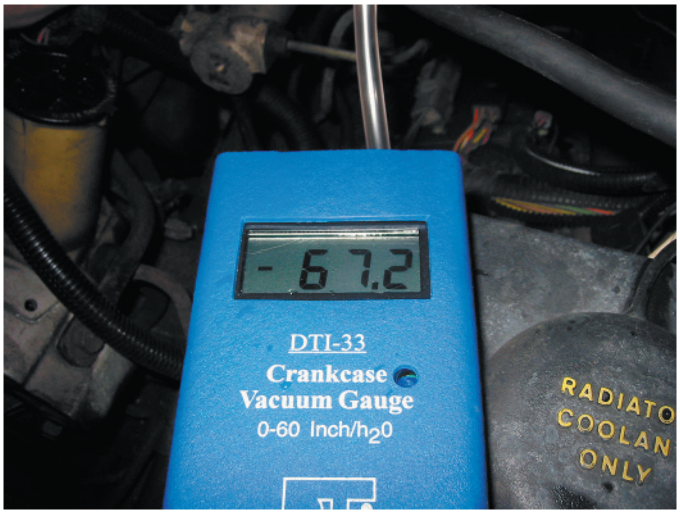


FIGURE 81–6 Using a gauge that measures vacuum in units of inches of water to test the vacuum at the dipstick tube, being sure that the PCV system is capable of drawing a vacuum on the crankcase (28 inches $H_2O = 1$ PSI, or about 2 in. Hg of vacuum).

FREQUENTLY ASKED QUESTION

What Are the Wires for at the PCV Valve?

Ford uses an electric heater to prevent ice from forming inside the PCV valve and causing blockage.

Water is a by-product of combustion, and resulting moisture can freeze when the outside air temperature is low. General Motors and others clip a heater hose to the PCV hose to provide the heat needed to prevent an ice blockage.

The gauge should show some vacuum, especially at 2,500 RPM. If not, carefully inspect the PCV system for blockages or other faults.

PCV MONITOR Starting with 2004 and newer vehicles, all vehicle PCMs monitor the PCV system for proper operation as part of the OBD-II system. The PCV monitor fails if the PCM detects an opening between the crankcase and the PCV valve or between the PCV valve and the intake manifold. ● **SEE FIGURE 81–7**.

PCV-RELATED DIAGNOSTIC TROUBLE CODES

Diagnostic Trouble Code	Description	Possible Causes
P0101	MAF or airflow circuit range problem	■ Defective PCV valve or hose/connections or MAF circuit fault
P0505	Idle control system problem	■ Defective PCV valve or hose/connections

SECONDARY AIR-INJECTION SYSTEM

PURPOSE AND FUNCTION The **secondary air-injection (SAI)** system provides the air necessary for the oxidizing process either at the exhaust manifold or inside the catalytic converter.

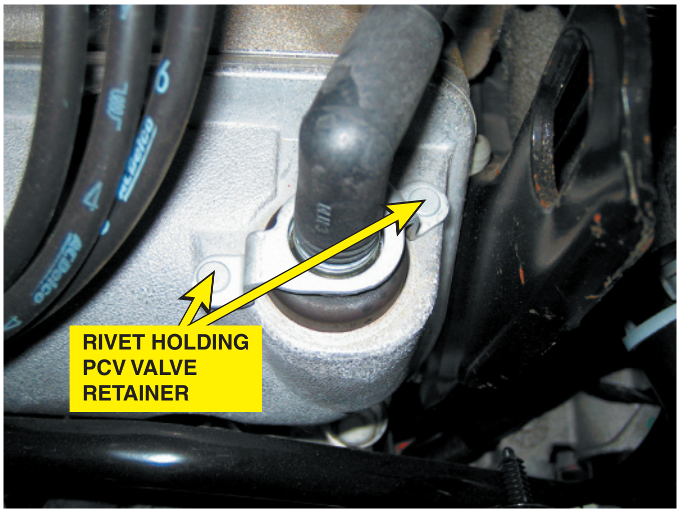


FIGURE 81–7 Most PCV valves used on newer vehicles are secured with fasteners, making it more difficult to disconnect, and thereby less likely to increase emissions.

NOTE: This system is commonly called AIR, meaning air-injection reaction. Therefore, an AIR pump does pump air.

PARTS AND OPERATION The SAI pump, also called an AIR pump, a **smog pump**, or **thermactor pump**, is mounted at the front of the engine and can be driven by a belt from the crankshaft pulley. It pulls fresh air in through an external filter and pumps the air under slight pressure to each exhaust port through connecting hoses or a manifold. The typical SAI system includes the following components:

- A belt-driven pump with inlet air filter (older models) (● **SEE FIGURE 81–8**.)
- An electrically driven air pump (newer models)
- One or more air distribution manifolds and nozzles
- One or more exhaust check valves
- Connecting hoses for air distribution
- Air management valves and solenoids on all newer applications

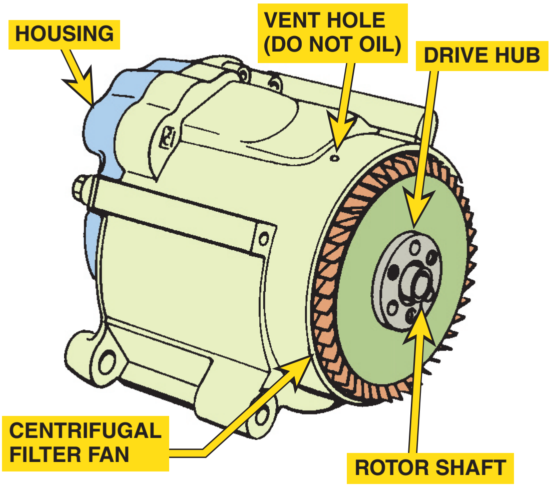


FIGURE 81–8 A typical belt-driven AIR pump. Air enters through the revolving fins behind the drive pulley. The fins act as an air filter because dirt is heavier than air and, therefore, the dirt is deflected off of the fins at the same time air is being drawn into the pump.

With the introduction of NOx reduction converters (also called dual-bed, three-way converters, or TWC), the output of the SAI pump is sent to the center of the converter, where the extra air can help oxidize unburned hydrocarbons (HC) and carbon monoxide (CO) into water vapor (H_2O) and carbon dioxide (CO_2).

The computer controls the airflow from the pump by switching on and off various solenoid valves.

AIR DISTRIBUTION MANIFOLDS AND NOZZLES The secondary air-injection system sends air from the pump to a nozzle installed near each exhaust port in the cylinder head. This provides equal air injection for the exhaust from each cylinder and makes it available at a point in the system where exhaust gases are the hottest.

Air is delivered to the exhaust system in one of two ways:

1. An external air manifold, or manifolds, distributes the air through injection tubes with stainless-steel nozzles. The nozzles are threaded into the cylinder heads or exhaust manifolds close to each exhaust valve. This method is used primarily with smaller engines.
2. An internal air manifold distributes the air to the exhaust ports near each exhaust valve through passages cast in the cylinder head or the exhaust manifold. This method is used mainly with larger engines.

EXHAUST CHECK VALVES All air-injection systems use one or more one-way check valves to protect the air pump and other components from reverse exhaust flow. A **check valve** contains a spring-type metallic disc or reed that closes under exhaust back pressure. Check valves are located between the air manifold and the switching valve(s). If exhaust pressure exceeds injection pressure or if the air pump fails, the check valve spring closes the valve to prevent reverse exhaust flow. ● **SEE FIGURE 81–9**.

NOTE: These check valves commonly fail, resulting in excessive exhaust emissions (CO, especially). When the check valve fails, hot exhaust can travel up to and destroy the switching valve(s) and air pump itself.

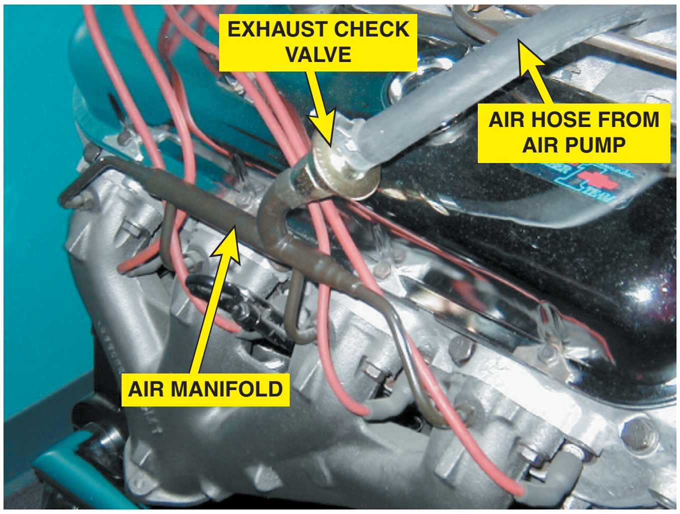


FIGURE 81–9 The external air manifold and exhaust check valve on a restored muscle car engine.

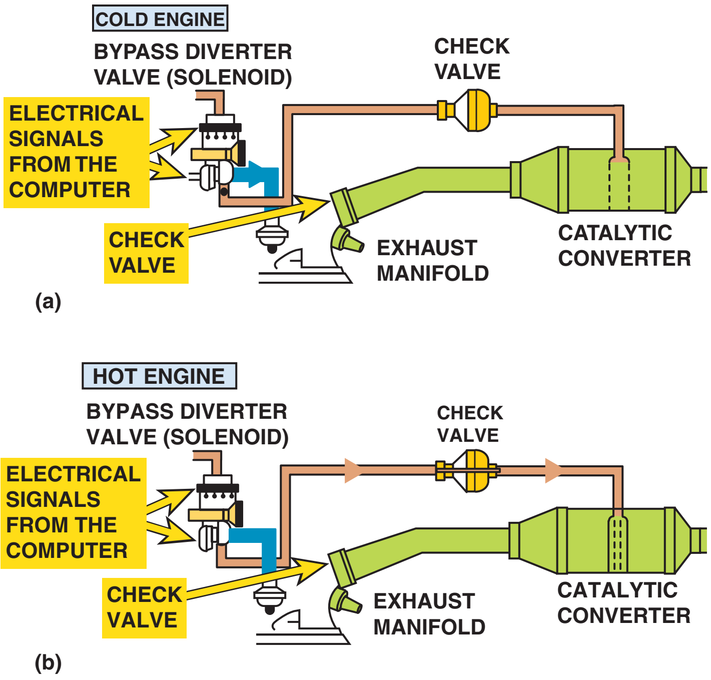


FIGURE 81–10 (a) When the engine is cold and before the oxygen sensor is hot enough to achieve closed loop, the airflow from the air pump is directed to the exhaust manifold(s) through the one-way check valves, which keep the exhaust gases from entering the switching solenoids and the pump itself. (b) When the engine achieves closed loop, the air is directed to the catalytic converter.

BELT-DRIVEN AIR PUMPS The belt-driven air pump uses a centrifugal filter just behind the drive pulley. As the pump rotates, underhood air is drawn into the pump and slightly compressed. The system uses either vacuum- or solenoid-controlled diverter valves to air directed to the following:

- The exhaust manifold, when the engine is cold to help oxidize CO and unburned HCs into CO_2 and H_2O vapor
- The catalytic converter when the engine is warm on some models to help provide the extra oxygen needed for the efficient conversion of CO and HC into CO_2 and H_2O
- The air cleaner, during deceleration or wide-open throttle (WOT) engine operation. ● **SEE FIGURE 81–10**.

ELECTRIC MOTOR–DRIVEN AIR PUMPS This style of pump is generally used only during cold engine operation and is computer controlled. The SAI system helps reduce HCs and CO. The air flowing to the exhaust manifold also helps to warm the three-way catalytic converters quickly on engine start-up so conversion of exhaust gases may occur sooner:

- The SAI pump solenoids are controlled by the PCM. The PCM turns on the SAI pump by providing the ground to complete the circuit, which energizes the SAI pump solenoid relay. When air to the exhaust ports is desired, the PCM energizes the relay in order to turn on the solenoid and the SAI pump. ● **SEE FIGURE 81–11**.
- The PCM turns on the SAI pump during start-up any time the engine coolant temperature is above 32°F (0°C). A typical electric SAI pump operates for a maximum of four minutes or until the system enters closed-loop operation.

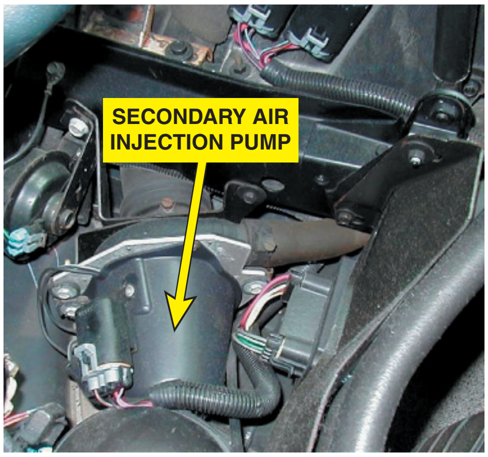


FIGURE 81–11 A typical electric motor-driven SAI pump. This unit is on a Chevrolet Corvette and only works when the engine is cold.

SECONDARY AIR-INJECTION SYSTEM DIAGNOSIS

SYMPTOMS The air pump system should be inspected if an exhaust emissions test failure occurs. In severe cases, the exhaust enters the air cleaner assembly, resulting in a horribly running engine, because the extra exhaust displaces the oxygen needed for proper combustion. With the engine running, check for normal operation. ● **SEE CHART 81–1**.

ENGINE OPERATION	NORMAL OPERATION OF A TYPICAL SAI SYSTEM
Cold engine (open-loop operation)	Air is diverted to the exhaust manifold(s) or cylinder head
Warm engine (closed-loop operation)	Air is diverted to the catalytic converter
Deceleration	Air is diverted to the air cleaner assembly
Wide-open throttle	Air is diverted to the air cleaner assembly

CHART 81–1

Typical SAI system operation showing location of airflow from the pump.

VISUAL INSPECTION Carefully inspect all parts of the SAI system, including the following:

- Hoses and pipes (Any that have holes and leak air or exhaust require replacement.)
- Check valve(s), when a pump has become inoperative
- Exhaust gases, which could have gotten past the check valve and damaged the pump (Look for signs of overheated areas upstream from the check valves. In severe cases, the exhaust can enter the air cleaner assembly, destroying the air filter and greatly reducing engine power.)
- Drive belt on an engine-driven pump, for wear and proper tension (If the belt is worn or damaged, check that the AIR pump rotates.)

FOUR-GAS EXHAUST ANALYSIS An SAI system can be easily tested using an exhaust gas analyzer and the following steps:

1. Start the engine and allow it to run until normal operating temperature is achieved.
2. Connect the analyzer probe to the tailpipe and observe the exhaust readings for HCs and CO.
3. Using the appropriate pinch-off pliers, shut off the airflow from the SAI system. Observe the HC and CO readings. If the SAI system is working correctly, the HC and CO levels should increase when the SAI system is shut off.
4. Record the O_2 reading with the SAI system still inoperative. Unclamp the pliers and watch the O_2 readings. If the system is functioning correctly, the O_2 level should increase by 1% to 4%.

SAI-RELATED DIAGNOSTIC TROUBLE CODE

Diagnostic Trouble Code	Description	Possible Causes
P0410	SAI solenoid circuit fault	■ Defective SAI solenoid ■ Loose or corroded electrical connections ■ Loose, missing, or defective rubber hose(s)

REVIEW QUESTIONS

1. What exhaust emissions do the PCV valve and the SAI system control?
2. How does a PCV valve work?
3. What prevents a backfire in the intake manifold from causing the fumes in the crankcase from exploding?
4. Why do some PCV valves have an electric heater?
5. What keeps the exhaust gases from flowing up from the exhaust manifold and into the secondary air injection (SAI) pump?

CHAPTER QUIZ

1. The PCV system controls which exhaust emission(s)?
a. HC
b. CO
c. NO_x
d. Both HC and CO

2. How much of the air needed by the engine flows through the PCV system when the engine is at idle speed?
a. 1% to 3%
b. 5% to 10%
c. 10% to 20%
d. Up to 30%

3. Technician A says that if the PCV value is defective or clogged, the engine could idle rough. Technician B says that the engine may stall. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

4. Technician A says that if a PCV valve rattles, then it is okay and does not need to be replaced. Technician B says that if a PCV valve does not rattle, it should be replaced. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

5. Technician A says that the PCV system should create a slight pressure in the crankcase at idle. Technician B says that the PCV system should create a slight vacuum in the crankcase at 2,500 RPM. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

6. The SAI system is used to reduce which exhaust emission(s)?
a. HC
b. CO
c. NO_x
d. Both HC and CO

7. Two technicians are discussing exhaust check valves used in SAI systems. Technician A says that they are used to prevent the output from the SAI pump from entering the intake manifold. Technician B says the check valves are used to keep the exhaust from entering the AIR pump. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

8. Where is the output of the AIR pump directed when the engine is cold?
a. Exhaust manifold
b. Catalytic converter
c. Air cleaner assembly
d. To the atmosphere

9. The switching valves on the AIR pump have failed several times. Technician A says that a defective exhaust check valve could be the cause. Technician B says that a leaking exhaust system at the muffler could be the cause. Which technician is correct?
a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

10. When checking for the proper operation of the AIR system using an exhaust gas analyzer, how much should the oxygen (O_2) levels increase when the pump is allowed to function?
a. 1% to 4%
b. 5% to 10%
c. 10% to 20%
d. Up to 30%

Chapter 82

CATALYTIC CONVERTERS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose, function, construction, and operation of catalytic converters.
- Describe catalytic converter performance in OBD-II vehicles.
- Discuss the diagnosis of catalytic converters.
- Discuss the replacement of catalytic converters.

KEY TERMS:

Catalysts 961 • Catalytic converter 961 • Cerium 962 • Light-off temperature 962 • Light-off converter (LOC) 963 • Oxygen storage capacity (OSC) 963 • Palladium 962 • Platinum 962 • Preconverter 963 • Pup (mini) converter 963 • Rhodium 962 • Tap test 964 • Three-way converter (TWC) 962 • Washcoat 962

CATALYTIC CONVERTERS

PURPOSE AND FUNCTION A **catalytic converter** is an after-treatment device used to reduce exhaust emissions outside of the engine. The catalytic converter uses a *catalyst:*

- A **catalyst** is a chemical that helps start a chemical reaction, but does not enter into the chemical reaction.
- The catalyst materials on the surface of the material inside the converter help create a chemical reaction.
- The chemical reaction changes harmful exhaust emissions into nonharmful exhaust emissions.
- The *converter*, therefore, converts harmful exhaust gases into water vapor (H_2O) and carbon dioxide (CO_2).

This device is installed in the exhaust system between the exhaust manifold and the muffler and usually is positioned beneath the passenger compartment. The location of the converter is important since as much of the exhaust heat as possible must be retained for effective operation. The nearer it is to the engine, the better. ● **SEE FIGURE 82–1**.

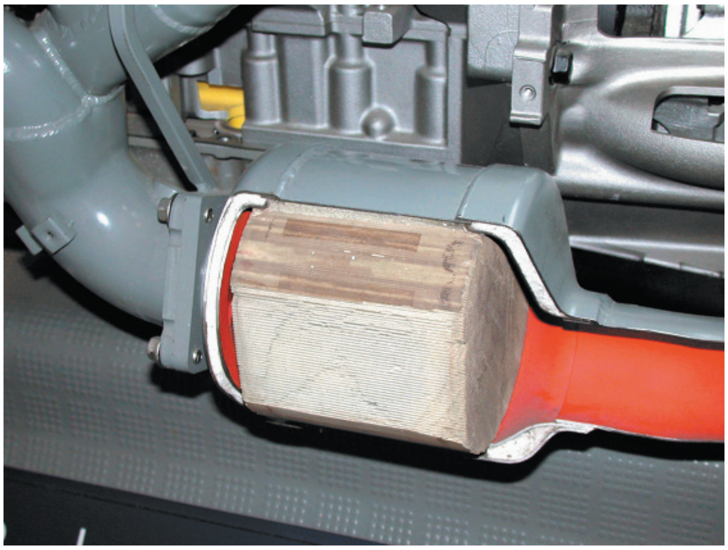


FIGURE 82–1 Most catalytic converters are located as close to the exhaust manifold as possible, as seen in this display of a Chevrolet Corvette.

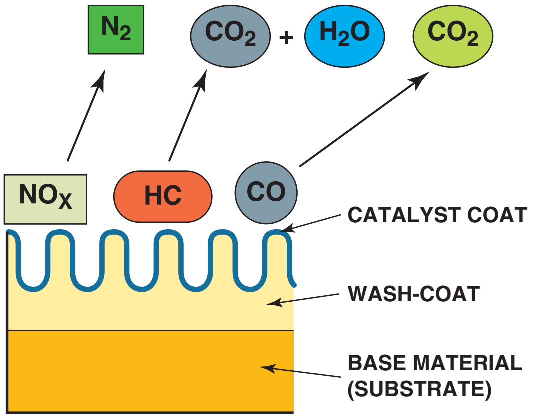


FIGURE 82–2 The base material, called the substrate, is used to support the wash coat, which is a porous material that is used to hold the catalyst materials.

CATALYTIC CONVERTER CONSTRUCTION

Most catalytic converters are constructed of a ceramic material in a honeycomb shape with square openings for the exhaust gases:

- There are approximately 400 openings per square inch (62 per sq. cm), and the wall thickness is about 0.006 inch (1.5 mm).
- The substrate is then coated with a porous aluminum material called the **washcoat**, which makes the surface rough.
- The catalytic materials are then applied on top of the washcoat. The substrate is contained within a round or oval shell made by welding together two stamped pieces of alumina or stainless steel. ● **SEE FIGURE 82–2.**

The ceramic substrate in monolithic converters is not restrictive; however, the converter can be physically broken if exposed to shock or severe jolts. Monolithic converters can be serviced only as a unit.

An exhaust pipe is connected to the manifold or header to carry gases through a catalytic converter and then to the muffler or silencer. V-type engines can use dual converters or route the exhaust into one catalytic converter by using a Y-exhaust pipe.

CATALYTIC CONVERTER OPERATION

The converter substrate contains small amounts of **rhodium**, **palladium**, and **platinum**. These elements act as catalysts. As mentioned, a catalyst is an element that starts a chemical reaction without becoming a part of, or being consumed in, the process. In a **three-way (catalytic) converter (TWC)** all three exhaust emissions (NO_x, HC, and CO) are converted to carbon dioxide (CO_2) and water (H_2O). As the exhaust gas passes through the catalyst, oxides of nitrogen (NO_x) are chemically reduced (i.e., nitrogen and oxygen are separated) in the first section of the catalytic converter. In the second section of the catalytic converter, most of the HCs and CO remaining in the exhaust gas are oxidized to form harmless CO_2 and H_2O. ● **SEE FIGURE 82–3.**

Since the early 1990s, many converters also contain **cerium**, an element that can store oxygen. The purpose of the cerium is to provide oxygen to the oxidation bed of the converter when the exhaust is rich and lacks enough oxygen for proper oxidation. When the exhaust is lean, the cerium absorbs the extra oxygen. For the most efficient operation, the converter should have a 14.7:1 air–fuel ratio, but can use a mixture that varies slightly:

- A rich exhaust is required for reduction—stripping the oxygen (O_2) from the nitrogen in NO_x.
- A lean exhaust is required to provide the oxygen necessary to oxidize HC and CO (combining oxygen with HC and CO to form H_2O and CO_2).

If the catalytic converter is not functioning correctly, ensure that the air–fuel mixture being supplied to the engine is correct and that the ignition system is free of defects.

CONVERTER LIGHT-OFF TEMPERATURE

The catalytic converter does not work when cold, so it must be heated to its **light-off temperature** of close to 500°F (260°C) before it starts working at 50% effectiveness. When fully effective, the converter reaches a temperature range of 900°F to 1,600°F (482°C to 871°C). In spite of the intense heat, however, catalytic reactions do not generate a flame associated with a simple burning reaction. Because of the extreme heat (almost as hot as combustion chamber temperatures), a converter remains hot long after the engine is shut off. Most vehicles use a series of heat shields to protect the passenger compartment

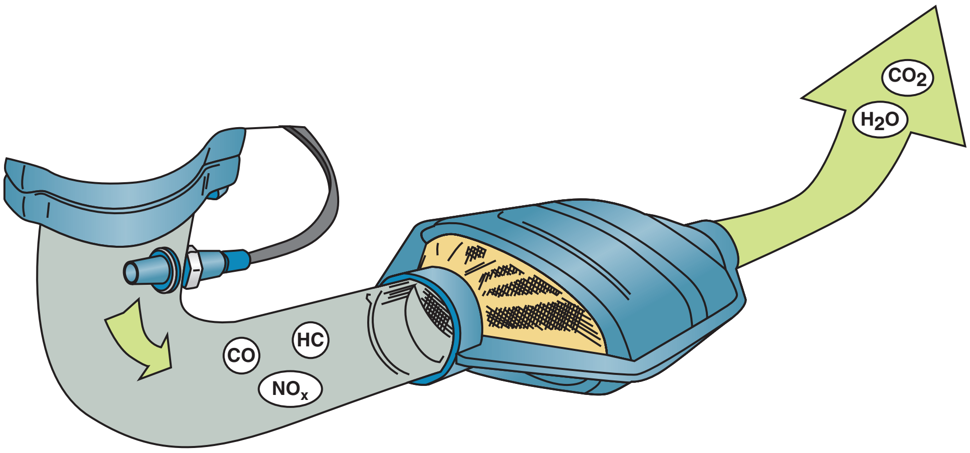


FIGURE 82–3 The three-way catalytic converter first separates the NO_x into nitrogen and oxygen and then converts the HC and CO into harmless water (H_2O) and carbon dioxide (CO_2). The nitrogen (N) passes through the converter and exits the tailpipe and enters the atmosphere, which is about 78% nitrogen.

and other parts of the chassis from excessive heat. Vehicles have been known to start fires because of the hot converter causing tall grass or dry leaves beneath the just-parked vehicle to ignite, especially if the engine is idling. This is most likely to occur if the heat shields have been removed from the converter.

CONVERTER USAGE A catalytic converter must be located as close as possible to the exhaust manifold to work effectively. The farther back the converter is positioned in the exhaust system, the more the exhaust gases cool before they reach the converter. Since positioning in the exhaust system affects the oxidation process, vehicle manufacturers that use only an oxidation converter generally locate it underneath the front of the passenger compartment.

Some vehicles have used a small, quick heating oxidation converter, called a **preconverter** or a **pup (mini) converter**, that connects directly to the exhaust manifold outlet. These have a small catalyst surface area close to the engine that heats up rapidly to start the oxidation process more quickly during cold engine warm-up. For this reason, they were often called **light-off converters (LOCs)**. The larger main converter, under the passenger compartment, completes the oxidation reaction started in the LOC.

Most older vehicles used a catalytic converter that had the reduction section first to separate the oxygen from the nitrogen in NOx. The oxygen released during this action helps provide extra oxygen to help oxidize the HC and CO into harmless H_2O and CO_2. However, since 2007, emission standards for oxides of nitrogen are stricter and, therefore, a larger reduction section is often needed. Therefore, the reduction section is now often after the oxidation section, which is the opposite of the way it was in converters for older models. ● **SEE FIGURE 82–4**.

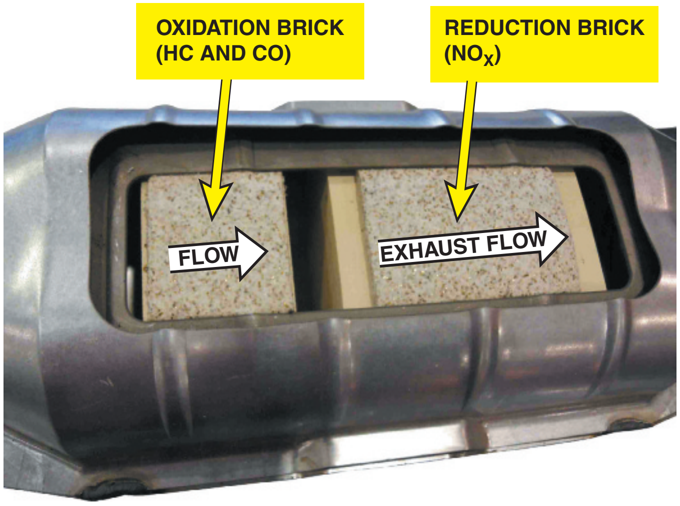


FIGURE 82–4 The small oxidation section of the converter helps build heat for the reduction section to reduce NO_x emissions in the rear brick on most newer vehicles. Older catalytic converters had the reduction brick first then the oxidation brick. Since about 2007, the allowable NO_x levels were greatly reduced and the engines became more efficient at controlling HC and CO and that was when the position of the bricks were changed.

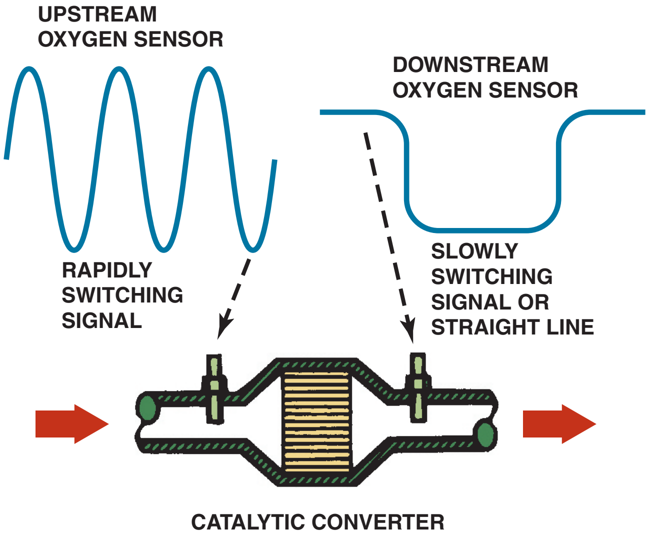


FIGURE 82–5 The OBD-II catalytic converter monitor compares the signals of upstream and downstream oxygen sensors to determine converter efficiency.

OBD-II CATALYTIC CONVERTER PERFORMANCE

With OBD-II-equipped vehicles, catalytic converter performance is monitored by a heated oxygen sensor (HO_2S) both before and after the converter. ● **SEE FIGURE 82–5**.

The converters used on these vehicles have **oxygen storage capacity (OSC)**, due mostly to the cerium coating in the catalyst rather than the precious metals used. When the three-way converter (TWC) is operating as it should, the postconverter HO_2S is far less active than the preconverter sensor. The converter stores, then releases, the oxygen during normal reduction and oxidation of the exhaust gases, smoothing out the variations in oxygen being released.

The PCM determines if the catalytic converter is ready for testing based on the following conditions, which may vary by vehicle make, model, and year:

- Closed-loop status achieved
- IAT sensor temperature higher than 32°F (0°C)
- ECT sensor temperature higher than 165°F (18°C)
- MAF sensor input from 15 to 32 g/sec
- Engine load less than 65% and steady
- Engine speed less than 4,000 RPM
- All of the above conditions met for at least four minutes

These factors are the enable criteria that must be achieved before the OBD-II catalyst monitor runs.

Where a cycling sensor voltage output is expected before the converter, because of the converter action, the postconverter HO_2S should read a steady signal with little fluctuation. ● **SEE FIGURE 82–6**.

CONVERTER-DAMAGING CONDITIONS Since converters have no moving parts, they require no periodic service. Under federal law, catalyst effectiveness is warranted for 80,000 miles or eight years.

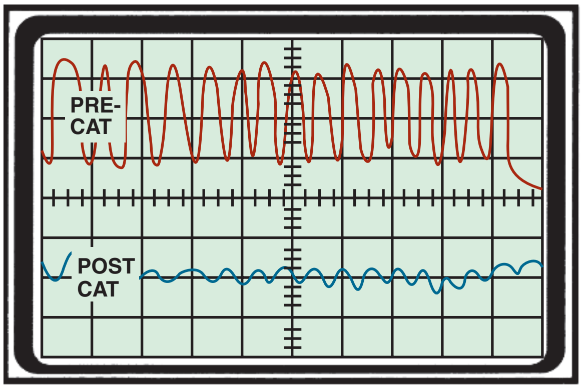


FIGURE 82–6 The waveform of a downstream O2S sensor from a properly functioning converter shows little, if any, activity.

The three main causes of premature converter failure are the following:

- **Contamination.** Substances that can destroy the converter include exhaust that contains excess engine oil, antifreeze, sulfur (from poor fuel), and various other chemical substances.
- **Excessive temperatures.** Although a converter operates at high temperatures, it can be destroyed by excessive temperatures. This most often occurs either when too much unburned fuel enters the converter, or with excessively lean mixtures. Excessive temperatures may be caused by long idling periods on some vehicles since more heat develops at those times than when driving at normal highway speeds. Severe high temperatures can cause the converter to melt down, leading to the internal parts breaking apart and either clogging the converter or moving downstream to plug the muffler. In either case, the restricted exhaust flow severely reduces engine power.
- **Improper air–fuel mixtures.** Rich mixtures or raw fuel in the exhaust can be caused by engine misfiring or an excessively rich air–fuel mixture resulting from a defective coolant temp sensor or defective fuel injectors. Lean mixtures are commonly caused by intake manifold leaks. When either of these circumstances occurs, the converter can become a catalytic furnace, causing the previously described damage. For most efficient catalytic converter operation, the air–fuel mixture should be near 14.7:1. ● **SEE FIGURE 82–7**.

To avoid excessive catalyst temperatures and the possibility of fuel vapors reaching the converter, observe the following rules:

1. Do not use fuel additives or cleaners that are not converter safe.
2. Do not crank an engine for more than 40 seconds when it is flooded or misfiring.
3. Do not turn off the ignition switch when the vehicle is in motion.
4. Do not disconnect a spark plug wire for more than 30 seconds.
5. Repair engine problems, such as dieseling, misfiring, or stumbling, as soon as possible.

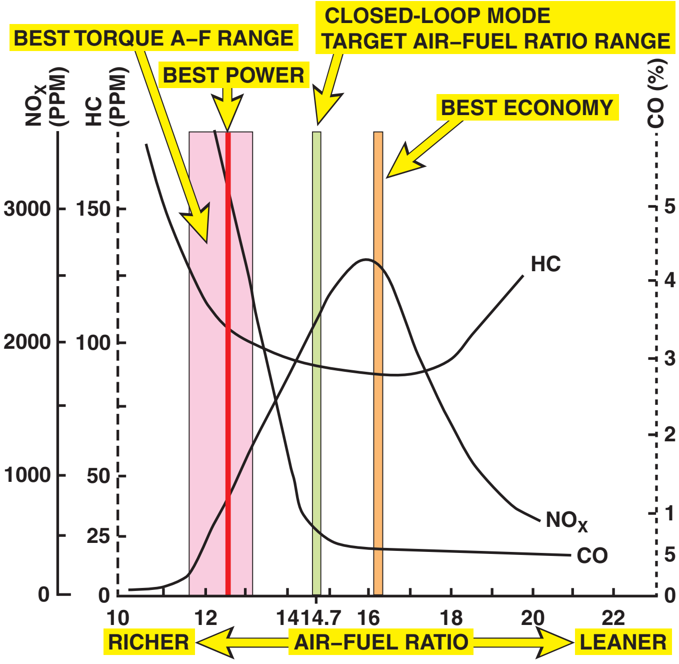


FIGURE 82–7 The highest catalytic converter efficiency occurs when the air–fuel mixture is about 14.7:1.

FREQUENTLY ASKED QUESTION

Can a Catalytic Converter Be Defective without Being Clogged?

Yes. Catalytic converters can fail by being chemically damaged or poisoned without being mechanically clogged. Therefore, the catalytic converter should be tested not only for physical damage (clogging) by performing a back pressure or vacuum test and a rattle test, but also for temperature rise, usually with a pyrometer or propane test, to check the efficiency of the converter.

DIAGNOSING CATALYTIC CONVERTERS

TAP TEST The simple **tap test** involves tapping (not pounding) on the catalytic converter using a rubber mallet. If the substrate inside the converter is broken, the converter rattles when hit. If the converter rattles, a replacement converter is required. ● **SEE FIGURE 82–8**.

TESTING BACK PRESSURE WITH A PRESSURE GAUGE

Exhaust system back pressure can be measured directly by installing a pressure gauge in an exhaust opening. This can be accomplished in one of the following ways:

1. To test backpressure, remove the inside of an old, discarded oxygen sensor and thread in an adapter to convert it to a vacuum or pressure gauge.

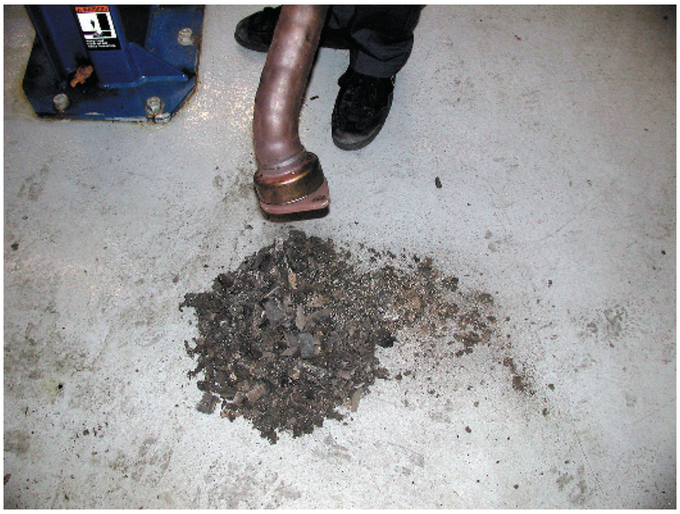


FIGURE 82–8 A catalytic converter that rattles when tapped was removed, and the substrate, or what was left of it, fell out. This converter has to be replaced and the root cause of why it failed found and corrected.

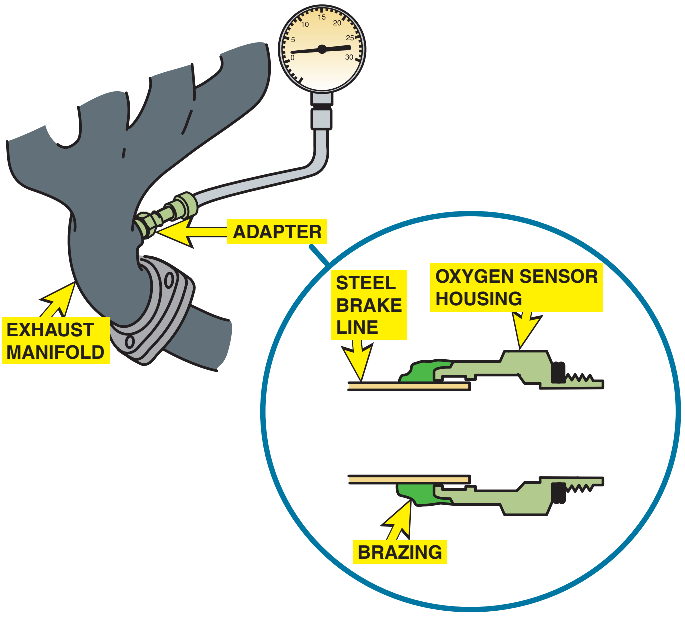


FIGURE 82–9 A back pressure tool can be made by using an oxygen sensor housing and epoxy or braze to hold the tube to the housing.

NOTE: An adapter can be easily made by inserting a metal tube or pipe into an old oxygen sensor housing. A short section of brake line works great. The pipe can be brazed to the oxygen sensor housing, or it can be glued with epoxy. An 18-mm compression gauge adapter can also be adapted to fit into the oxygen sensor opening. ● **SEE FIGURE 82–9**.

2. To test the exhaust back pressure at the exhaust gas recirculation (EGR) valve, remove the EGR valve and fabricate a plate equipped with a fitting for a pressure gauge.
3. To test at the secondary air-injection (SAI) check valve, remove the check valve from the exhaust tubes leading to the exhaust manifold. Use a rubber cone with a tube inside to seal against the exhaust tube. Connect the tube to a pressure gauge.

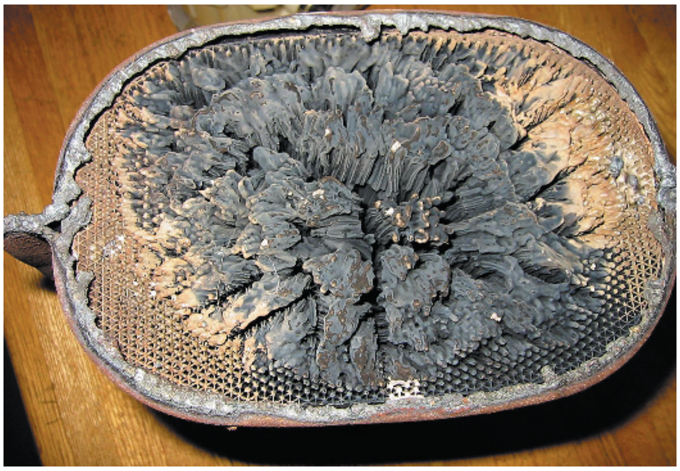


FIGURE 82–10 This partially melted catalytic converter tested okay at idle, but had excessive back pressure at higher engine speeds.

At idle, the maximum back pressure should be less than 1.5 PSI (10 kPa), and it should be less than 2.5 PSI (15 kPa) at 2,500 RPM. Pressure readings higher than these indicate that the exhaust system is restricted, and further testing is needed to determine the location of the restriction. ● **SEE FIGURE 82–10**.

TESTING FOR BACK PRESSURE USING A VACUUM GAUGE

An exhaust restriction can be tested indirectly by checking the intake manifold vacuum with the engine operating at a fast idle speed (about 2,500 RPM). If the exhaust is restricted, some exhaust can pass, and the effect may not be noticeable when the engine is at idle speed. However, when the engine is operating at a higher speed, the exhaust gases build up behind the restriction and eventually are not able to leave the combustion chamber. When some of the exhaust is left behind at the end of the exhaust stroke, the resulting pressure in the combustion chamber reduces engine vacuum. To test for an exhaust restriction using a vacuum gauge, perform the following steps:

STEP 1 Attach a vacuum gauge to an intake manifold vacuum source.

STEP 2 Start the engine. Record the engine manifold vacuum reading. The engine vacuum should read 17 to 21 in. Hg when the engine is at idle speed.

STEP 3 Increase the engine speed to 2500 RPM and hold that speed for 60 seconds while looking at the vacuum gauge.

Results

- If the vacuum reading is equal to or higher than the vacuum reading when the engine was at idle speed, the exhaust system is *not* restricted.
- If the vacuum reading is lower than the vacuum reading when the engine was at idle speed, then the exhaust *is* restricted. Further testing is needed to determine the location of the restriction.

TESTING A CATALYTIC CONVERTER FOR TEMPERATURE RISE

A properly working catalytic converter should be able to reduce NO_x exhaust emissions into nitrogen (N) and oxygen (O_2)

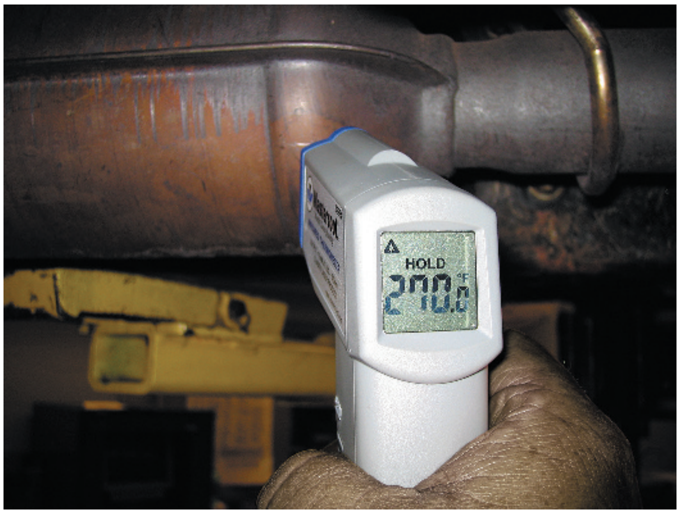


FIGURE 82–11 The temperature of the outlet should be at least 10% hotter than the temperature of the inlet. If a converter is not working, the inlet temperature is hotter than the outlet temperature.

TECH TIP

Aftermarket Catalytic Converters

Some replacement aftermarket (nonfactory) catalytic converters do not contain the same amount of cerium as the original part. Cerium is the element that is used in catalytic converters to store oxygen. As a result of the lack of cerium, the correlation between the oxygen storage and the conversion efficiency may be affected enough to set a false diagnostic trouble code (P0422).

NOTE: If an aftermarket converter is being installed, be sure that the distance between the rear of the catalyst block is the same distance from the rear oxygen sensor as the factory converter to be ensured of proper operation. Always follow the instructions that come with the replacement converter. ● **SEE FIGURE 82–12**.

TECH TIP

Catalytic Converters

Catalytic converters start a chemical reaction, but do not enter into the chemical reaction. Therefore, catalytic converters neither wear out nor die of old age. If a catalytic converter is found to be defective (nonfunctioning or clogged), look for the *root* cause.

Items that should be checked when a defective catalytic converter is discovered include all components of the ignition and fuel systems. Excessive unburned fuel can cause the catalytic converter to overheat and fail. The oxygen sensor must be working and fluctuating from 0.5 to 5 Hz (times per second) to provide the necessary air–fuel mixture variations for maximum catalytic converter efficiency.

and oxidize unburned HC and CO into harmless CO_2 and H_2O vapor. During these chemical processes, the catalytic converter should increase in temperature at least 10% if the converter is working properly. To test the converter, operate the engine at 2,500 RPM for at least two minutes to fully warm the converter. Measure the inlet and the outlet temperatures using an infrared pyrometer, as shown in ● **FIGURE 82–11**.

NOTE: If the engine is extremely efficient, the converter may not have any excessive unburned HCs or CO to convert! In this case, a spark plug wire could be grounded out using a vacuum hose and a test light to create some unburned HC in the exhaust. Do not ground out a cylinder for longer than 10 seconds, or the excessive amount of unburned HC could overheat and damage the converter.

CATALYTIC CONVERTER EFFICIENCY TESTS The efficiency of a catalytic converter can be determined using an exhaust gas analyzer:

- **Oxygen level test.** With the engine warm and in closed loop, check the O_2 and CO levels. A good converter should be able to oxidize the extra HCs caused by the rapid acceleration:
  - If O_2 is zero, go to the snap-throttle test.
  - If O_2 is greater than zero, check the CO level.

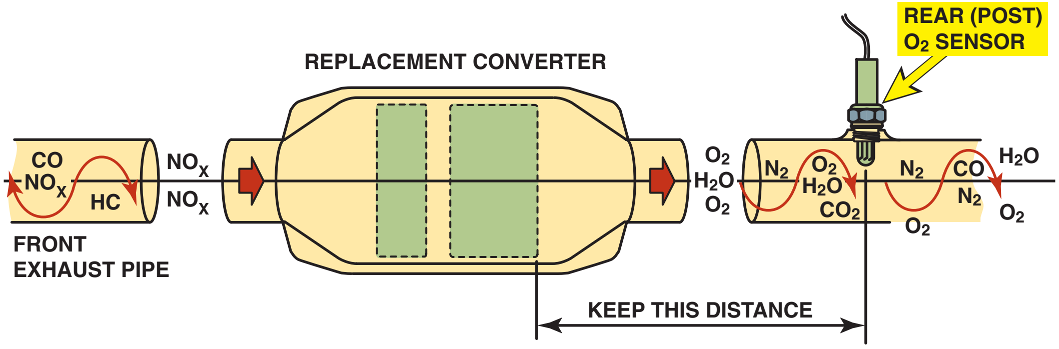


FIGURE 82–12 Whenever replacing a catalytic converter with a universal unit, first measure the distance between the rear brick and the center of the rear oxygen sensor. Be sure that the replacement unit is installed to the same dimension.

    - If CO is greater than zero, the converter is *not* functioning correctly.
- **Snap-throttle test.** With the engine warm and in closed loop, snap the throttle to wide-open throttle (WOT) in park or neutral and observe the oxygen reading:
    - The O_2 reading should not exceed 1.2%; if it does, the converter is *not* working.
    - If the O_2 rises to 1.2%, the converter may have low efficiency.
    - If the O_2 remains below 1.2%, then the converter is okay.

CATALYTIC CONVERTER–RELATED DIAGNOSTIC TROUBLE CODE

Diagnostic Trouble Code	Description	Possible Causes
P0422	Catalytic converter efficiency failure	■ Engine mechanical fault ■ Exhaust leaks ■ Fuel contaminants, such as engine oil, coolant, or sulfur

CATALYTIC CONVERTER REPLACEMENT GUIDELINES

Because a catalytic converter is a major exhaust gas emission control device, the U.S. Environmental Protection Agency (EPA) has strict guidelines for its replacement, including the following:

- If a converter is replaced on a vehicle with less than 80,000 miles or eight years, depending on the year of the vehicle, an original equipment catalytic converter *must* be used as a replacement.
- The replacement converter must be of the same design as the original. If the original had an AIR pump fitting, so must the replacement.
- The old converter must be kept for possible inspection by the authorities for 60 days.
- A form must be completed and signed by both the vehicle owner and a representative from the service facility. This form must state the cause of the converter failure and must remain on file for two years.

REVIEW QUESTIONS

1. What are the three most commonly used catalysts in a catalytic converter?
2. How does a catalytic converter reduce NO_x to nitrogen and oxygen?
3. Why must a catalytic converter be mounted close to the exhaust ports of the engine?
4. How does the computer monitor catalytic converter performance?
5. What tests can be performed by a service technician to test the catalytic converter?

CHAPTER QUIZ

1. What is applied to the ceramic substrate to make the surface porous?
    a. Honeycomb filler
    b. Washcoat
    c. Aluminum
    d. Cerium
2. Two technicians are discussing catalytic converters. Technician A says that the exhaust mixture should be 14.7:1 for the best efficiency. Technician B says that the air–fuel mixture must be leaner than 14.7:1 for best performance from a three-way catalytic converter. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B
3. A catalytic converter has to be at least how hot before it starts to work?
    a. 500°F (260°C)
    b. 1,000°F (540°C)
    c. 1,500°F (815°C)
    d. 2,000°F (1,100°C)
4. What two primary sensors does the PCM use to check the catalytic converter?
    a. Catalytic converter temperature sensor and rear oxygen sensor
    b. Precat and postcat oxygen sensor
    c. Precat oxygen sensor and MAF
    d. MAP and TP
5. A catalytic converter can be harmed by ___________.
    a. excessive engine oil
    b. antifreeze
    c. sulfur from poor-quality fuel
    d. Any of the above
6. Two technicians are discussing testing a catalytic converter. Technician A says that a vacuum gauge can be used and observed to see if the vacuum drops with the engine at 2,500 RPM for 30 seconds. Technician B says that a pressure gauge can be used to check for back pressure. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B
7. A catalytic converter is being tested with an infrared pyrometer. Which is an acceptable (good converter) result?
    a. The inlet should be hotter than the outlet by 10%.
    b. The outlet should be hotter than the inlet by 10%.
    c. Both the inlet and the outlet should be the same temperature after the converter reaches operating temperature.
    d. The temperature of a catalytic converter is the best test to perform to locate a restricted (clogged) unit.

8. Which exhaust gas reading indicates a good catalytic converter?
   - **a.** O_2 is zero
   - **b.** CO is zero
   - **c.** Both a and b
   - **d.** Neither a nor b

9. A P0422 (catalytic converter efficiency failure) is set. What is a possible cause?
   - **a.** Engine mechanical fault
   - **b.** Exhaust leak
   - **c.** Fuel contamination
   - **d.** Any of the above

10. Technician A says that the catalytic converter is warranted for eight years or 80,000 miles, whichever comes first. Technician B says that after replacing the catalytic converter, the old converter must be kept for possible inspection for 60 days. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B

Chapter 83

ONBOARD DIAGNOSIS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and function of OBD systems.
- Discuss the diagnostic executive.
- List the various continuous and noncontinuous monitors.
- Discuss OBD-II monitor information.
- Explain enabling criteria.
- Explain the numbering designation of OBD-II diagnostic trouble codes.
- Explain the information captured by freeze-frame.
- Describe the criteria to enable an OBD monitor.
- Describe PCM tests related to OBD systems.
- List the operation modes of a global scan tool.
- Describe mode six diagnosis.

KEY TERMS:

California Air Resources Board (CARB) 969 • Component identification (CID) 976 • Comprehensive component monitor (CCM) 970 • Diagnostic executive 970 • Enable criteria 972 • Exponentially weighted moving average (EWMA) monitor 972 • Federal Test Procedure (FTP) 970 • Freeze-frame 970 • Functionality 971 • Malfunction indicator lamp (MIL) 969 • On-Board Diagnostics (OBD) 969 • Parameter identification (PID) 976 • Rationality 971 • Society of Automotive Engineers (SAE) 972 • Task manager 970 • Test identification (TID) 976

ON-BOARD DIAGNOSTICS GENERATION-II (OBD-II) SYSTEMS

PURPOSE AND FUNCTION OF OBD II During the 1980s, most manufacturers began equipping their vehicles with full-function control systems capable of alerting the driver of a malfunction and of allowing the technician to retrieve codes that identify circuit faults. These early diagnostic systems were meant to reduce emissions and speed up vehicle repair.

The automotive industry calls these systems **On-Board Diagnostics (OBD)**. The **California Air Resources Board (CARB)** developed the first regulation requiring manufacturers selling vehicles in that state to install OBD. OBD Generation I (OBD I) applies to all vehicles sold in California beginning with the 1988 model year. It specifies the following requirements:

1. An instrument panel warning lamp able to alert the driver of certain control system failures, now called a **malfunction indicator lamp (MIL)**. ● **SEE FIGURE 83–1**.
2. The system's ability to record and transmit diagnostic trouble codes (DTCs) for emission-related failures.

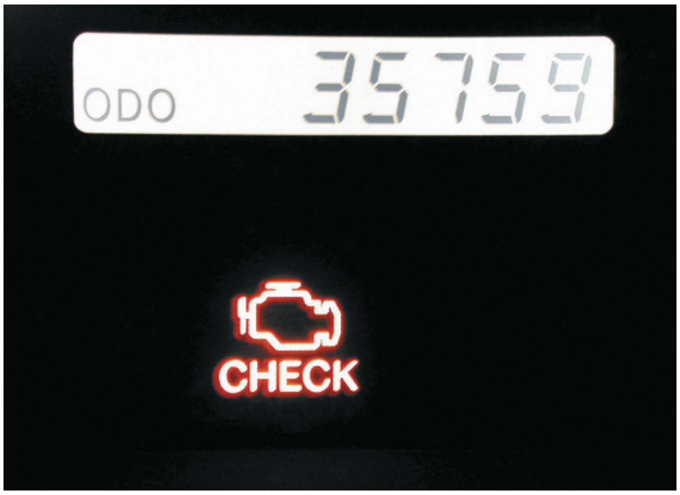


FIGURE 83–1 A typical malfunction indicator lamp (MIL) often labeled "check engine" or "service engine soon" (SES).

All light-duty vehicles (less than 8,500 pounds) sold in North America since 1996, as well as medium-duty vehicles (8,500–14,000 pounds) beginning in 2005, and heavy-duty vehicles (greater than 14,000 pounds) beginning in 2010, are required to support OBD-II diagnostics, using a standardized data link connector, and a subset of the SAE J/1979 defined PIDs (or SAE J1939 as applicable for medium/heavy-duty vehicles), primarily for state-mandated emissions inspections.

OBD-II OBJECTIVES Generally, the CARB defines an OBD-II-equipped vehicle by its ability to do the following:

1. Detect component degradation or a faulty emission-related system that prevents compliance with federal emission standards.
2. Alert the driver of needed emission-related repair or maintenance.
3. Use standardized DTCs and accept a generic scan tool.

These requirements apply to all 1996 and later-model light-duty vehicles. The Clean Air Act of 1990 directed the Environmental Protection Agency (EPA) to develop new regulations for OBD. The primary purpose of OBD II is emission-related, whereas the primary purpose of OBD I (1988) was to detect faults in sensors or sensor circuits. OBD-II regulations require that not only sensors be tested, but also all exhaust emission-control devices, and that they be verified for proper operation.

All new vehicles must pass the **Federal Test Procedure (FTP)** for exhaust emissions while being tested for 1874 seconds on dynamometer rollers that simulate the urban drive cycle around downtown Los Angeles.

NOTE: IM 240 is simply a shorter 240-second version of the 505-second federal test procedure.

The regulations for OBD-II vehicles state that the vehicle powertrain control module (PCM) must be capable of testing for, and determining, if the exhaust emissions are within 1.5 times the FTP limits. To achieve this goal, the PCM must do the following:

1. Test all exhaust emission system components for correct operation.
2. Actively operate the system and measure the results.
3. Continuously monitor all aspects of the engine operation to be certain that the exhaust emissions do not exceed 1.5 times the FTP.
4. Check engine operation for misfire.
5. Turn on the MIL (check engine) if the computer senses a fault in a circuit or system.
6. Record a **freeze-frame**, which is a snapshot of important engine data at the time the DTC was set.
7. Flash the MIL if an engine misfire occurs that could damage the catalytic converter.

DIAGNOSTIC EXECUTIVE AND TASK MANAGER

On OBD-II systems, the powertrain control module (PCM) incorporates a special segment of software. On Ford and GM systems, this software is called the **diagnostic executive**. On Chrysler systems, it is called the **task manager**. This software program is designed to manage the operation of all OBD-II monitors by controlling the sequence of steps necessary to execute the diagnostic tests and monitors.

MONITORS

PURPOSE AND FUNCTION A monitor is an organized method of testing a specific part of the system. Monitors are simply tests that the computer performs to evaluate components and systems. If a component or system failure is detected while a monitor is running, a DTC is stored and the MIL illuminated during the second trip. The two types of monitors are continuous and noncontinuous.

CONTINUOUS MONITORS As required conditions are met, continuous monitors begin to run. These continuous monitors run for the remainder of the vehicle drive cycle. The three continuous monitors are as follows:

- **Comprehensive component monitor (CCM).** This monitor watches the sensors and actuators in the OBD-II system. Sensor values are constantly compared with known-good values stored in the PCM's memory.

  The CCM is an internal program in the PCM designed to monitor a failure in any electronic component or circuit (including emission-related and non-emission-related circuits) that provide input or output signals to the PCM. The PCM considers that an input or output signal is inoperative when a failure exists due to an open circuit, out-of-range value, or if an on-board rationality check fails. If an emission-related fault is detected, the PCM sets a code and activates the MIL (requires two consecutive trips).

  Many PCM sensors and output devices are tested at key-on or immediately after engine start-up. However, some devices are only tested by the CCM after the engine meets certain engine conditions. The number of times the CCM must detect a fault before it activates the MIL depends upon the manufacturer, but most require two consecutive trips to activate the MIL. The components tested by the CCM include

  Four-wheel-drive low switch
  Brake switch
  Camshaft position (CMP) and crankshaft position (CKP) sensors
  Clutch switch (manual transmissions/transaxles only)
  Cruise servo switch
  Engine coolant temperature (ECT) sensor
  EVAP purge sensor or switch
  Fuel composition sensor
  Intake air temperature (IAT) sensor
  Knock sensor (KS)
  Manifold absolute pressure (MAP) sensor
  Mass airflow (MAF) sensor
  Throttle-position (TP) sensor
  Transmission temperature sensor
  Transmission turbine speed sensor
  Vacuum sensor
  Vehicle speed (VS) sensor
  EVAP canister purge and EVAP purge vent solenoid
  Idle air control (IAC)
  Ignition control system
  Transmission torque converter clutch solenoid
  Transmission shift solenoids

- **Misfire monitor.** This monitor watches for engine misfire. The PCM uses the information received from the crankshaft position sensor (CKP) to calculate the time between the edges of the reluctor, as well as the rotational speed and acceleration. By comparing the acceleration of each firing event, the PCM can determine if a cylinder is not firing correctly.

Misfire type A. Upon detection of a misfire type A (200 revolutions), which causes catalyst damage, the MIL blinks once per second during the actual misfire, and a DTC is stored.

Misfire type B. Upon detection of a misfire type B (1,000 revolutions), which exceeds 1.5 times the EPA federal test procedure (FTP) standard or causes a vehicle to fail an inspection and maintenance tailpipe emissions test, the MIL illuminates and a DTC is stored.

The DTC associated with multiple cylinder misfire for a type A or type B misfire is DTC P0300. The DTCs associated with an individual cylinder misfire for a type A or type B misfire are DTCs P0301, P0302, P0303, P0304, P0305, P0306, P0307, P0308, P0309, and P0310.

- **Fuel trim monitor.** The PCM continuously monitors short- and long-term fuel trim. Constantly updated adaptive fuel tables are stored in long-term memory (KAM), and used by the PCM for compensation due to wear and aging of the fuel system components. The MIL illuminates when the PCM determines the fuel trim values have reached and stayed at their limits for too long a period of time.

NONCONTINUOUS MONITORS

Noncontinuous monitors run (at most) once per vehicle drive cycle. The noncontinuous monitors are as follows:

O2S monitor
O2S heater monitor
Catalyst monitor
EGR monitor
EVAP monitor
Secondary AIR monitor
Transmission monitor
PCV system monitor
Thermostat monitor

Once a noncontinuous monitor has run to completion, it does not run again until the conditions are met during the next vehicle drive cycle. Also, after a noncontinuous monitor has run to completion, the readiness status on the scan tool shows "complete" or "done" for that monitor. Monitors that have not run to completion show up on the scan tool as "incomplete."

OBD-II MONITOR INFORMATION

COMPREHENSIVE COMPONENT MONITOR

The circuits and components covered by the comprehensive component monitor (CCM) do not include those directly monitored by another monitor.

However, OBD II also requires that inputs from powertrain components to the PCM be tested for **rationality**, and that outputs to powertrain components from the PCM be tested for **functionality**. Both inputs and outputs are to be checked *electrically*. Rationality checks refer to a PCM comparison of input values to values from other sensors to determine if they make sense and are normal (rational).

Example:

TPS	3 V
MAP	18 in. Hg
RPM	700 RPM
PRNDL	Park

NOTE: Comprehensive component monitors are continuous. Therefore, enabling conditions do not apply.

- Monitor runs continuously
- Monitor includes sensors, switches, relays, solenoids, and PCM hardware
- All are checked for opens, shorts-to-ground, and shorts-to-voltage
- Inputs are checked for rationality
- Outputs are checked for functionality
- Most are one-trip DTCs
- Freeze-frame is priority 3
- Three consecutive good trips are used to extinguish the MIL
- Forty warm-up cycles are necessary to self-erase the DTC and freeze-frame
- Two minutes run time without reoccurrence of the fault constitutes a "good trip"

CONTINUOUS RUNNING MONITORS

Continuous monitors run continuously and only stop if they fail and include

- Fuel system: rich/lean
- Misfire: catalyst damaging/FTP (emissions)
- Two-trip faults (except early-generation catalyst damaging misfire)
- MIL, DTC, freeze-frame after two consecutive faults
- Freeze-frame is priority 2 on first trip
- Freeze-frame is priority 4 on maturing trip
- Three consecutive good trips in a similar condition window are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame (80 to erase one-trip failure, if similar conditions cannot be met)

ONCE PER TRIP MONITORS

- Monitor runs once per trip, pass or fail
- O_2 response, O_2 heaters, EGR, purge flow EVAP leak, secondary air, catalyst
- Two-trip DTCs
- MIL, DTC, freeze-frame after two consecutive faults
- Freeze-frame is priority 1 on first trip
- Freeze-frame is priority 3 on maturing trip
- Three consecutive good trips are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame

EXPONENTIALLY WEIGHTED MOVING AVERAGE (EWMA) MONITORS The **exponentially weighted moving average (EWMA) monitor** is a mathematical method used to determine performance.

This method smooths out any variables in the readings over time and results in a running average. This method is used by some vehicle manufacturers for two monitors.

1. Catalyst monitor
2. EGR monitor

ENABLING CRITERIA

With so many different tests (monitors) to run, the PCM needs an internal director to keep track of when each monitor should run. As mentioned, different manufacturers have different names for this director, such as the diagnostic executive or the task manager. Each monitor has enabling criteria. These criteria are a set of conditions that must be met before the task manager gives the go-ahead for each monitor to run. Most enabling criteria follow simple logic, for example:

- The task manager does not authorize the start of the O2S monitor until the engine has reached operating temperature and the system has entered closed loop.
- The task manager does not authorize the start of the EGR monitor when the engine is at idle, because the EGR is always closed at this time.

Because each monitor is responsible for testing a different part of the system, the enabling criteria can differ greatly from one monitor to the next. The task manager must decide when each monitor should run, and in what order, to avoid confusion.

There may be a conflict if two monitors run at the same time. The results of one monitor might also be tainted if a second monitor runs simultaneously. In such cases, the task manager decides which monitor has a higher priority. Some monitors also depend on the results of other monitors before they can run.

A monitor may be classified as pending if a failed sensor or other system fault is keeping it from running on schedule.

The task manager may suspend a monitor if the conditions are not correct to continue. For example, if the catalyst monitor is running during a road test and the PCM detects a misfire, the catalyst monitor is suspended for the duration of the misfire.

TRIP A trip is defined as a key-on condition that contains the necessary conditions for a particular test to be performed, followed by a key-off. These conditions are called the **enable criteria**. For example, for the EGR test to be performed, the engine must be at normal operating temperature and decelerating for a minimum amount of time. Some tests are performed when the engine is cold, whereas others require that the vehicle be cruising at a steady highway speed.

WARM-UP CYCLE Once a MIL is deactivated, the original code remains in memory until 40 warm-up cycles are completed without the fault reappearing. A warm-up cycle is defined as a trip with an engine temperature increase of at least 40°F and where engine temperature reaches at least 160°F (71°C).

MIL CONDITION: OFF This condition indicates that the PCM has not detected any faults in an emissions-related component or system, or that the MIL circuit is not working.

MIL CONDITION: ON STEADY This condition indicates a fault in an emissions-related component or system that could affect the vehicle emission levels.

MIL CONDITION: FLASHING This condition indicates a misfire or fuel control system fault that could damage the catalytic converter.

NOTE: In a misfire condition with the MIL on steady, if the driver reaches a vehicle speed and load condition with the engine misfiring at a level that could cause catalyst damage, the MIL starts flashing. It continues to flash until engine speed and load conditions cause the level of misfire to subside. Then, the MIL goes back to the on-steady condition. This situation might result in a customer complaint of a MIL with an intermittent flashing condition.

MIL: OFF The PCM turns off the MIL if any of the following actions or conditions occur:

- The codes are cleared with a scan tool.
- Power to the PCM is removed at the battery or with the PCM power fuse for an extended period of time (may be up to several hours or longer).
- A vehicle is driven on three consecutive trips with a warm-up cycle and meets all code set conditions without the PCM detecting any faults.

The PCM sets a code if a fault is detected that could cause tailpipe emissions to exceed 1.5 times the FTP standard; however, the PCM does not deactivate the MIL until the vehicle has been driven on three consecutive trips with vehicle conditions similar to actual conditions present when the fault was detected. This is not merely three vehicle start-ups and trips. It means three trips during which certain engine operating conditions are met, so that the OBD-II monitor that found the fault can run again and pass the diagnostic test.

OBD-II DTC NUMBERING DESIGNATION

A scan tool is required to retrieve DTCs from an OBD-II vehicle. Every OBD-II scan tool is able to read all generic **Society of Automotive Engineers (SAE)** DTCs from any vehicle. ● **SEE FIGURE 83–2** for definitions and explanations of OBD alphanumeric DTCs. The DTCs are grouped into major

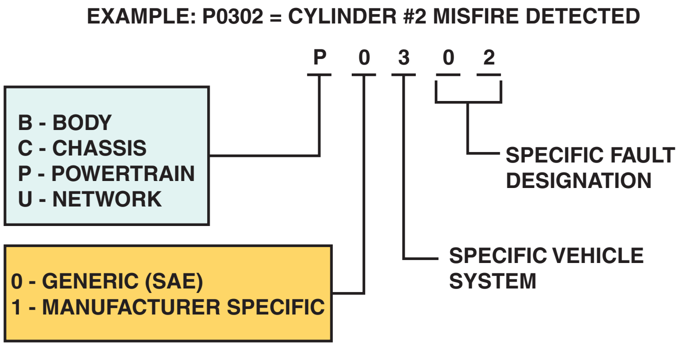

EXAMPLE: P0302 = CYLINDER #2 MISFIRE DETECTED
P 0 3 0 2
B - BODY
C - CHASSIS
P - POWERTRAIN
U - NETWORK
0 - GENERIC (SAE)
1 - MANUFACTURER SPECIFIC
SPECIFIC FAULT DESIGNATION
SPECIFIC VEHICLE SYSTEM

FIGURE 83–2 OBD-II DTC identification format.

FREQUENTLY ASKED QUESTION

What Is a Drive Cycle?

A drive cycle is a vehicle being driven under specified speed and times that allows all monitors to run. In other words, the PCM is looking at a series of data points representing speed and time and determines from these data points when the conditions are right to perform a monitor or a test of a component. These data points and, therefore, the drive cycle are vehicle-specific and are not the same for each vehicle. Some common conditions for a drive cycle to successfully run all of the monitors include

1. Cold start with intake air temperature (IAT) and engine coolant temperature (ECT) close to each other, indicating that the engine has cooled to the temperature of the surrounding air temperature.
2. Fuel level within a certain range, usually between 15% and 85%.
3. Vehicle speed within a certain speed range for certain amount of time, usually 4 to 12 minutes.
4. Stop and idle for a certain time.

Each monitor requires its own set of parameters needed to run the test, and sometimes these conditions cannot be met. For example, some evaporate emissions control (EVAP) systems require a temperature that may not be possible in winter months in a cold climatic area.

A typical universal drive cycle that works for many vehicles includes the following steps.

MIL must be off.
No DTCs present.
Fuel fill between 15% and 85%.
Cold start—Preferred = 8-hour soak at 68°F to 86°F.
Alternative = ECT below 86°F.

STEP 1 With the ignition off, connect scan tool.
STEP 2 Start engine and drive between 20 and 30 mph for 22 minutes, allowing speed to vary.
STEP 3 Stop and idle for 40 seconds, gradually accelerate to 55 mph.
STEP 4 Maintain 55 mph for 4 minutes using a steady throttle input.
STEP 5 Stop and idle for 30 seconds, then accelerate to 30 mph.
STEP 6 Maintain 30 mph for 12 minutes.
STEP 7 Repeat steps 4 and 5 four times.

Using scan tool, check readiness. Always check service information for the exact drive cycle conditions for the vehicle being serviced for best results.

categories, depending on the location of the fault on the system involved.

Pxxx codes—powertrain DTCs (engine, transmission-related faults)

Bxxx codes—body DTCs (accessories, interior-related faults)

Cxxx codes—chassis DTCs (suspension and steering-related faults)

Uxxx codes—network DTCs (module communication-related faults)

DTC NUMBERING EXPLANATION The number in the hundredth position indicates the specific vehicle system or subgroup that failed. This position should be consistent for P0xxx and P1xxx type codes. The following numbers and systems were established by SAE:

- P0100—Air metering and fuel system fault
- P0200—Fuel system (fuel injector only) fault
- P0300—Ignition system or misfire fault
- P0400—Emission control system fault
- P0500—Idle speed control, vehicle speed (VS) sensor fault
- P0600—Computer output circuit (relay, solenoid, etc.) fault
- P0700—Transaxle, transmission faults

NOTE: The tens and ones numbers indicate the part of the system at fault.

TYPES OF DTCS Not all OBD-II DTCs are of the same importance for exhaust emissions. Each type of DTC has different requirements for it to set, and the computer only turns on the MIL for emissions-related DTCs.

TYPE A CODES A type A DTC is emission-related and causes the MIL to be turned on the first trip if the computer has detected a problem. Engine misfire or a very rich or lean air–fuel ratio, for example, causes a type A DTC. These codes alert the driver to an emission problem that may cause damage to the catalytic converter.

TYPE B CODES A type B code is stored and the MIL is turned on during the second consecutive trip, alerting the driver to the fact that a diagnostic test was performed and failed.

NOTE: Type A and B codes are emission-related codes that cause the lighting of the MIL, usually labeled "check engine" or "service engine soon."

TYPE C AND D CODES Type C and D codes are for use with non-emission-related diagnostic tests; they cause the lighting of a "service" lamp (if the vehicle is so equipped). Type C codes are also called type C1 codes and D codes are also called type C0 codes.

DIAGNOSTIC TROUBLE CODE PRIORITY CARB has also mandated that all diagnostic trouble codes (DTCs) be stored according to individual priority. DTCs with a higher priority overwrite those with a lower priority. The OBD-II System DTC Priority is listed below.

Priority 0—Non-emission-related codes

Priority 1—One-trip failure of two-trip fault for non-fuel, non-misfire codes

Priority 2—One-trip failure of two-trip fault for fuel or misfire codes

Priority 3—Two-trip failure or matured fault of non-fuel, non-misfire codes

Priority 4—Two-trip failure or matured fault for fuel or misfire codes

OBD-II FREEZE-FRAME

To assist the service technician, OBD II requires the computer to take a “snapshot” or freeze-frame of all data at the instant an emission-related DTC is set. A scan tool is required to retrieve this data.

NOTE: Although OBD II requires that just one freeze-frame of data be stored, the instant an emission-related DTC is set, vehicle manufacturers usually provide expanded data about the DTC beyond that required. However, retrieving this enhanced data usually requires the use of the vehicle-specific scan tool.

Freeze-frame items include

- Calculated load value
- Engine speed (RPM)
- Short-term and long-term fuel trim percent
- Fuel system pressure (on some vehicles)
- Vehicle speed (mph)
- Engine coolant temperature
- Intake manifold pressure
- Closed-open-loop status
- Fault code that triggered the freeze-frame
- If a misfire code is set, identify which cylinder is misfiring

A DTC should not be cleared from the vehicle computer memory unless the fault has been corrected and the technician is so directed by the diagnostic procedure. If the problem that caused the DTC to be set has been corrected, the computer automatically clears the DTC after 40 consecutive warm-up cycles with no further faults detected. It requires 80 warm-up cycles to erase the pending fault if similar conditions cannot be met. The codes can also be erased by using a scan tool. ● **SEE CHART 83–1**.

FREQUENTLY ASKED QUESTION

What Are Pending Codes?

Pending codes are set when operating conditions are met and the component or circuit is not within the normal range, yet the conditions have not yet been met to set a DTC. For example, a sensor may require two consecutive faults before a DTC is set. If a scan tool displays a pending code or a failure, a driveability concern could also be present. The pending code can help the technician to determine the root cause before the customer complains of a check engine light indication.

NOTE: Disconnecting the battery may not erase OBD-II DTCs or freeze-frame data. Most vehicle manufacturers recommend using a scan tool to erase DTCs, rather than disconnecting the battery, because the memory for the radio, seats, and learned engine operating parameters is lost if the battery is disconnected.

ENABLING CONDITIONS

These are the exact engine operating conditions required for a diagnostic monitor to run.

Example:

Specific RPM
Specific ECT, MAP, run time, etc.

PENDING Under some situations, the PCM does not run a monitor if the MIL is illuminated and a fault is stored from

MONITOR NAME	MONITOR TYPE (HOW OFTEN IT COMPLETES)	NUMBER OF FAULTS ON SEPARATE TRIPS TO SET A PENDING DTC	NUMBER OF SEPARATE CONSECUTIVE TRIPS TO LIGHT MIL, STORE A DTC	NUMBER OF TRIPS WITH NO FAULTS TO ERASE A MATURING DTC	NUMBER OF TRIPS WITH NO FAULT TO TURN THE MIL OFF	NUMBER OF WARM-UP CYCLES TO ERASE DTC AFTER MIL IS TURNED OFF
CCM	Continuous (when trip conditions allow it)	1	2	1–Trip	3–Trips	40
Catalyst	Once per drive cycle	1	3	1–Trip	3–OBD-II drive cycle	40
Misfire Type A	Continuous		1		3–Similar conditions	80
Misfire Type B	Continuous	1	2	1–Trip	3–Similar conditions	80
Fuel System	Continuous	1	2	1–Trip	3–Similar conditions	80
Oxygen Sensor	Once per trip	1	2	1–Trip	3–Trips	40
EGR	Once per trip	1	2	1–Trip	3–Trips	40
EVAP	Once per trip	1	1	1–Trip	3–Trips	40
AIR	Once per trip	1	2	1–Trip	3–Trips	40

CHART 83–1

PCM Determination of faults chart.

another monitor. In these situations, the PCM postpones monitors pending a resolution of the original fault. The PCM does not run the test until the problem is remedied.

For example, when the MIL is illuminated for an oxygen sensor fault, the PCM does not run the catalyst monitor until the oxygen sensor fault is remedied. Since the catalyst monitor is based on signals from the oxygen sensor, running the test produces inaccurate results.

CONFLICT There are also situations when the PCM does not run a monitor if another monitor is in progress. In these situations, the effects of another monitor running could result in an erroneous failure. If this conflict is present, the monitor is not run until the conflicting condition passes. Most likely, the monitor runs later, after the conflicting monitor has passed.

For example, if the fuel system monitor is in progress, the PCM does not run the EGR monitor. Since both tests monitor changes in air–fuel ratio and adaptive fuel compensation, the monitors conflict with each other.

SUSPEND Occasionally, the PCM may not allow a two-trip fault to mature. The PCM suspends the maturing fault if a condition exists that may induce erroneous failure. This prevents illuminating the MIL for the wrong fault and allows more precise diagnosis.

For example, if the PCM is storing a one-trip fault for the oxygen sensor and the EGR monitor, the PCM may still run the EGR monitor, but suspends the results until the oxygen sensor monitor either passes or fails. At that point, the PCM can determine if the EGR system is actually failing or if an oxygen sensor is failing.

PCM TESTS

RATIONALITY TEST While input signals to the PCM are constantly being monitored for electrical opens and shorts, they are also tested for rationality. This means that the input signal is compared against other inputs and information to see if it makes sense under the current conditions.

PCM sensor inputs that are checked for rationality include

- MAP sensor
- O_2 sensor
- ECT
- Camshaft position (CMP) sensor
- VS sensor
- Crankshaft position (CKP) sensor
- IAT sensor
- TP sensor
- Ambient air temperature sensor
- Power steering switch
- O_2 sensor heater
- Engine controller
- Brake switch
- P/N switch (range switch)
- Transmission controls

FUNCTIONALITY TEST A functionality test refers to PCM inputs checking the operation of the outputs.

Example

PCM commands the IAC open; expected change in engine RPM is not seen
IAC 60 counts
RPM 700 RPM
PCM outputs that are checked for functionality include

- EVAP canister purge solenoid
- EVAP purge vent solenoid
- Cooling fan
- Idle air control solenoid
- Ignition control system
- Transmission torque converter clutch solenoid
- Transmission shift solenoids (A, B, 1–2, etc.)

ELECTRICAL TEST Refers to the PCM check of both input and outputs for the following:

- Open
- Shorts
- Ground

Example:

ECT

Shorted high (input to PCM) above capable voltage, that is, 5-volt sensor with 12-volt input to PCM indicates a short to voltage.

Monitor Type	Conditions to Set DTC and Illuminate MIL	Extinguish MIL	Clear DTC Criteria	Applicable DTC
Continuous 1-trip monitor	(See note below) Input and output failure-rationally, functionally, electrically	3 consecutive pass trips	40 warm-up cycles	P0123

NOTE: The number of times the comprehensive component monitor must detect a fault depends on the vehicle manufacturer. On some vehicles, the comprehensive component monitor activates the MIL as soon as it detects a fault. On other vehicles, the comprehensive component monitor must fail two times in a row.

- Freeze-frame captured on first-trip failure.
- Enabling conditions: Many PCM sensors and output devices are tested at key-on or immediately after engine start-up. However, some devices (ECT, idle speed control) are only tested by the comprehensive component monitor after the engine meets particular engine conditions.
- Pending: No pending condition
- Conflict: No conflict conditions
- Suspend: No suspend conditions

GLOBAL OBD-II

All OBD-II vehicles must be able to display data on a global (also called *generic*) scan tool under nine different modes of operation. These modes include

Mode One	Current powertrain data (**parameter identification** display or **PID**)
Mode Two	Freeze-frame data
Mode Three	DTCs
Mode Four	Clear and reset DTCs, freeze-frame data, and readiness status monitors for noncontinuous monitors only
Mode Five	Oxygen sensor monitor test results
Mode Six	Onboard monitoring of test results for noncontinuously monitored systems
Mode Seven	Onboard monitoring of test results for continuously monitored systems
Mode Eight	Bidirectional control of onboard systems
Mode Nine	Module identification
Mode 10 ($0A)	Permanent DTCs

The global (generic) data is used by most state emission programs. Global OBD-II displays often use hexadecimal numbers, which use 16 numbers instead of 10. The numbers 0 to 9 (zero counts as a number) make up the first 10 and then capital letters A to F complete the 16 numbers. To help identify the number as being in a hexadecimal format, a dollar sign ($) is used in front of the number or letter. See the conversion chart below:

Decimal Number	Hexadecimal Code
0	$0
1	$1
2	$2
3	$3
4	$4
5	$5
6	$6
7	$7
8	$8
9	$9
10	$A
11	$B
12	$C
13	$D
14	$E
15	$F

Hexadecimal coding is also used to identify tests (**test identification [TID]** and **component identification [CID]**).

FREQUENTLY ASKED QUESTION

How Can You Tell Generic from Factory?

When using a scan tool on an OBD-II-equipped vehicle, if the display asks for make, model, and year, then the factory or enhanced part of the PCM is being accessed. If the generic or global part of the PCM is being scanned, then there is no need to know the vehicle identification details.

DIAGNOSING PROBLEMS USING MODE SIX

Mode six information can be used to diagnose faults by following three steps:

1. Check the monitor status before starting repairs. This step shows how the system failed.
2. Look at the component or parameter that triggered the fault. This step helps pin down the root cause of the failure.
3. Look to the monitor enable criteria, which shows what it takes to fail or pass the monitor.

REVIEW QUESTIONS

1. What does the PCM do during a trip to test emission-related components?
2. What is the difference between a type A and type B OBD-II DTC?
3. What is the difference between a trip and a warm-up cycle?
4. What could cause the MIL to flash?
5. What modes are available using Mode $06?

CHAPTER QUIZ

1. A freeze-frame is generated on an OBD-II vehicle __________.
   a. when a type C or D diagnostic trouble code is set
   b. when a type A or B diagnostic trouble code is set
   c. every other trip
   d. when the PCM detects a problem with the O2S
2. An ignition misfire or fuel mixture problem is an example of what type of DTC?
   a. Type A
   b. Type C
   c. Type B
   d. Type D

3. The comprehensive component monitor checks computer-controlled devices for __________.
   - **a.** opens
   - **b.** shorts-to-ground
   - **c.** rationality
   - **d.** All of the above

4. A freeze-frame is a __________ of all data at the instant an emission-related DTC is set.
   - **a.** comprehensive component monitor
   - **b.** failure record
   - **c.** snapshot
   - **d.** trip

5. Which is a continuous monitor?
   - **a.** Fuel system monitor
   - **b.** EGR monitor
   - **c.** Oxygen sensor monitor
   - **d.** Catalyst monitor

6. DTC P0302 is a(n) __________.
   - **a.** generic DTC
   - **b.** vehicle manufacturer-specific DTC
   - **c.** idle speed-related DTC
   - **d.** transmission/transaxle-related DTC

7. Enable criteria means __________.
   - **a.** the same thing as a trip
   - **b.** conditions for a particular test to be performed
   - **c.** a drive cycle
   - **d.** a warm-up cycle

8. By looking at the way diagnostic trouble codes are formatted, which DTC could indicate that the gas cap is loose or defective?
   - **a.** P0221
   - **b.** P1301
   - **c.** P0442
   - **d.** P1603

9. The computer automatically clears a DTC if there are no additional detected faults after __________.
   - **a.** forty consecutive warm-up cycles
   - **b.** eighty warm-up cycles
   - **c.** two consecutive trips
   - **d.** four key-on/key-off cycles

10. A global scan tool can display data under __________ modes of operation.
    - **a.** dual
    - **b.** nine
    - **c.** only three
    - **d.** fifteen

Chapter

84

MODULE REPROGRAMMING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- List the benefits of module reprogramming over previous methods of update.
- Describe the regulatory requirements of J2534.
- List the hardware used for programming.
- List the software used for programming.
- Describe the methods of module reprogramming.
- Explain the need for a battery maintainer during reprogramming.
- Describe the concerns of programming in the shop.
- Describe aftermarket reprogramming.

KEY TERMS:

Application programming interface (API) 980 • Battery maintainer 981 • PROM 978 • Electronically erasable programmable read only memory (EEPROM) 978 • Locksmith ID 980 • NASTF 980 • Over-the-air (OTA) 982 • Pass-through device 980 • SAE J2534 979 • SAE J2534-1 979 • SAE J2534-2 979 • SAE J2534 version 5.00 979

MODULE SOFTWARE UPDATE

HISTORY OF MODULE PROGRAMMING Software programming has been used by the engine control module to meet air quality and emission standards since fuel injection replaced carburetors. The method of updating the software calibration has changed as technology has evolved. On early fuel-injected vehicles, it was necessary to change the computer when the calibration needed to be updated. ● **SEE FIGURE 84–1**.

In the early 1980s, the replacement **PROM** (programmable read only memory) was introduced. Instead of replacing the entire module, the technician would remove the PROM and install a replacement chip. Several versions of replaceable PROMs were used. ● **SEE FIGURE 84–2A AND B**.

In 1990, General Motors introduced flash reprogramming. This process allowed the technician to download the replacement software calibration from the manufacturer and to install it in the vehicles computer **EEPROM** (electronically erasable programmable read only memory). This eliminated the need to stock any parts which decreased the cost and the time needed for the repair.

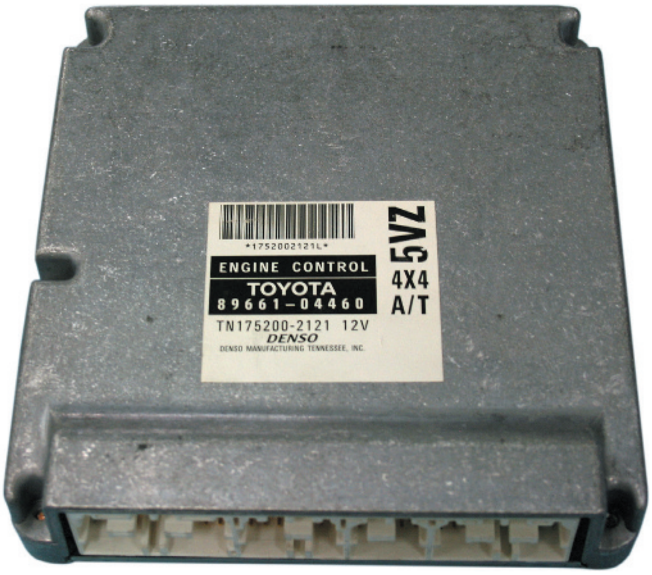


FIGURE 84–1 The Toyota engine control module pictured in the figure is an example of a module that must be replaced to update the programming memory.

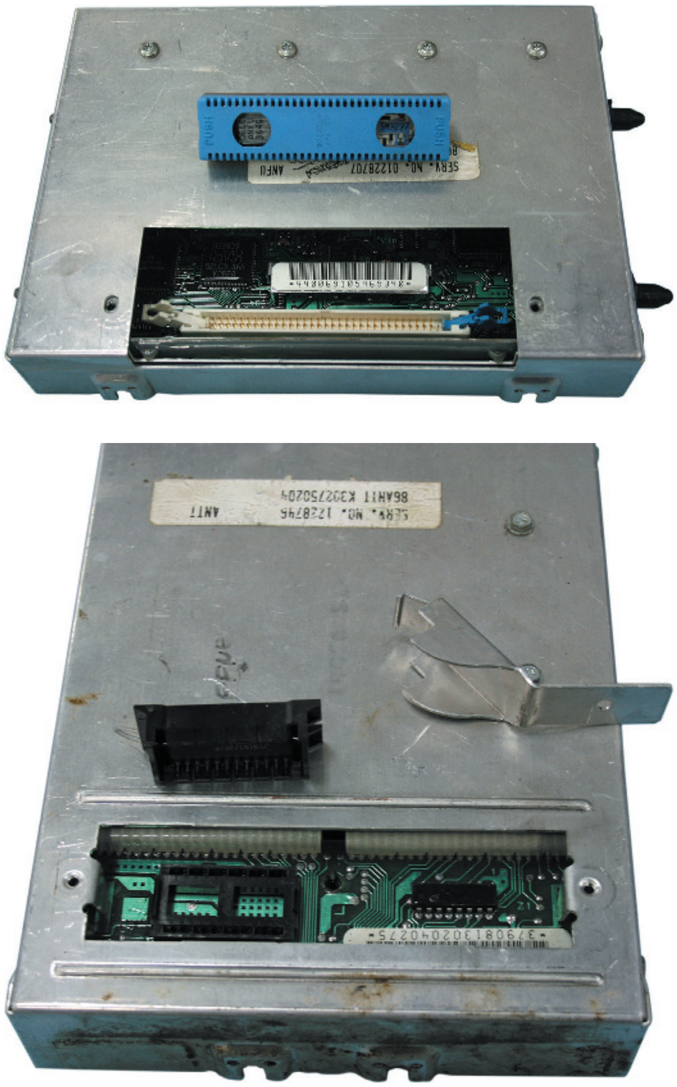


FIGURE 84–2A AND B The two General Motors engine control modules above are examples of two styles of removable PROMs used to update programmable memory.

In 1996 as part of the OBDII requirements, all modules that were responsible for emissions control were required to have EEPROM. The main purpose of this regulation was to make it more difficult for the technician to install a software calibration that would take the vehicle out of emission compliance. During this time period, module programming could typically only be performed by the dealer or by someone who had purchased manufacturer-specific tools. ● **SEE FIGURE 84–3**.

In 2004, it was mandated by CARB and the EPA that all vehicles manufactured after that point must be J2534 compliant, allowing for the reprogramming of emission-related modules. This mandate allowed for all individuals engaged in repair of emission-related failures the ability to update the software of these modules.

PURPOSE Designing a program that allows an engine to meet strict air quality and fuel economy standards while providing excellent performance is no small feat. However, this is only part of the challenge facing engineers assigned with the task of developing OBD-II software. The reason for this is the countless variables involved with running diagnostic monitors. Although programmers do their best to factor in any and all operating conditions when writing this complex code, periodic revisions are often required. Reprogramming consists of downloading new calibrations from the manufacturer into the PCM's electronically erasable programmable read only memory (EEPROM).

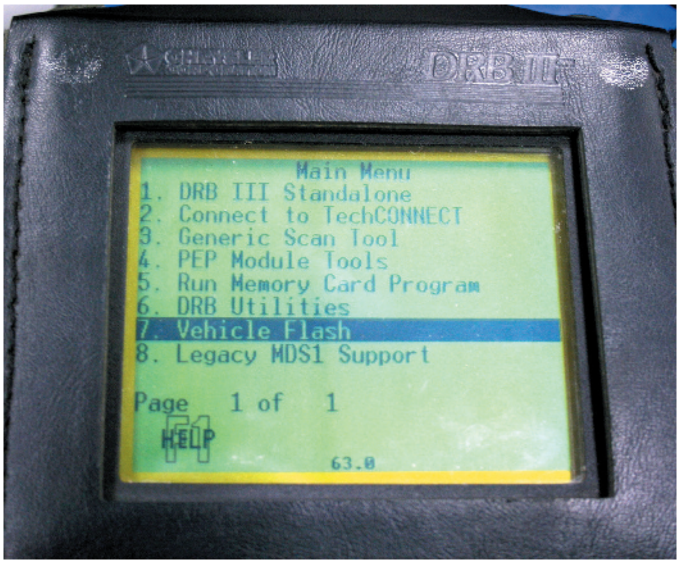


FIGURE 84–3 The manufacturer scan tool is being used to reprogram the engine control module via the data link connector.

SAE STANDARDS

J2534 SAE created the standard **SAE J2534** for communications between a computer and a vehicle. The original standard was introduced in February of 2002, and was identified as version 02.02. The EPA and CARB regulations require all automakers to provide a J2534 service to everyone in the United States for re-flashing emission-related controllers. If the technician has a SAE J2534 pass-through device, they can re-flash and, in some cases, diagnose vehicles with factory functionality. The EPA documentation requires OEMs to comply with SAE J2534 for pass-through reprogramming beginning with model year 2004. Reprogramming information also had to be made available within three months of vehicle introduction for new models. The original version of the standard was found to have some errors.

This original standard was updated in December of 2004. The new standard was identified as version 04.04 or more commonly as **SAE J2534-1**. The changes in the second version of the standard supported specific requirements of Ford and Chrysler that were not addressed in the first standard that related to J1850 class 2 communication protocols. It also defined specifics for the design of the vehicle communication interface device.

The standard was updated again and referred to as **SAE J2534-2**. These changes addressed issues related to single wire CAN BUS communication and issues related to the GM UART communication protocol. The new standard also provided a method for manufacturers to add optional features in a uniform way. An example of this is the ability to flash program modules that were not emission related.

The current standard is referred to as **SAE J2534 version 5.00**. The newest standard includes all the changes required in the previous updates and serves to improve the communication through the J1962 connector. It is important to have the most current equipment to ensure that that the flash reprogramming process will be completed without any malfunctions.

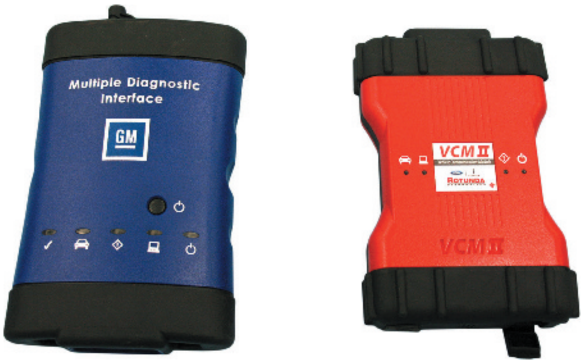

Multiple Diagnostic Interface
GM
VCM II
Rotunda
VCM II

FIGURE 84–4 The GM MDI and Ford VCI are examples of manufacturer-specific pass-through devices.

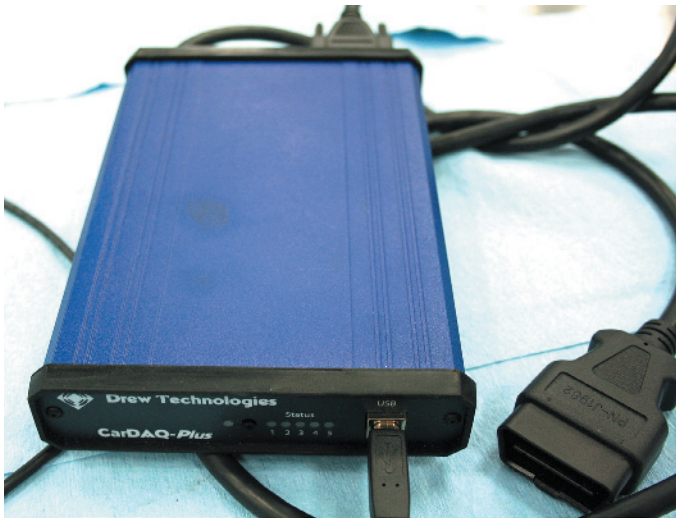
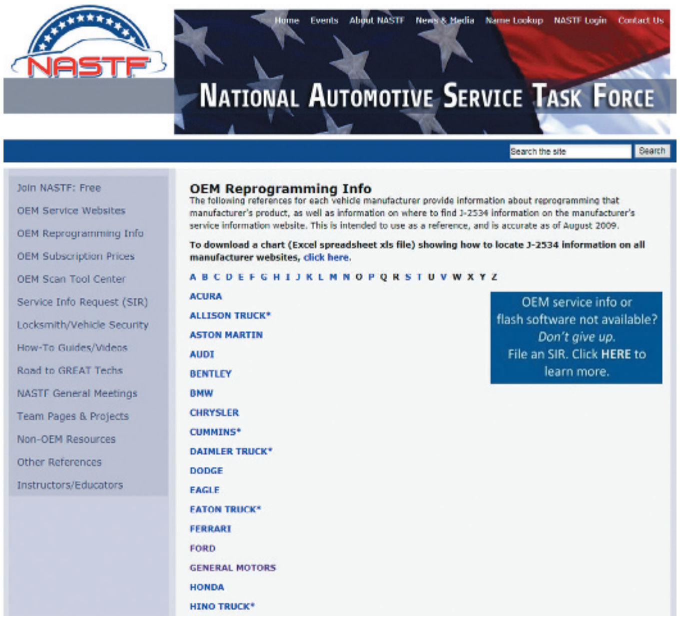

Drew Technologies
CarDAQ-Plus
Status
USB
PN-J1962

FIGURE 84–5 The CarDAQ Plus is a generic pass-through device.

PROGRAMMING HARDWARE

MANUFACTURER SPECIFIC Each manufacturer has developed their own J2534 **pass-through device** or **application programming interface (API)** that is specific to the brands the manufacturer sells. A pass-through device or API serves as a connection point that makes all the hardware look the same, and allows the computer with the reprogramming software to communicate with the vehicles control module through the data link connector (DLC). Generally, these tools are not designed with the functionality to support competitive brands. In many cases, these pass-through devices are designed to support the manufacturer scan tool in addition to providing reprogramming capabilities. The GM MDI and Ford VCI are both examples of this type of technology. ● **SEE FIGURE 84–4**.

GENERIC The generic J2534 pass-through device is designed to support multiple manufacturers. These tools typically do not have the same level of scan tool diagnostics as a manufacturer-specific tool. These tools are more often found outside of the dealership environment in the independent repair facilities. The Drew Technologies CarDAQ-Plus series of J2534 pass-through devices is an example of a generic tool. ● **SEE FIGURE 84–5**.


NASTF
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About NASTF
News & Media
Name Lookup
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National Automotive Service Task Force
Search the site
Search
Join NASTF: Free
OEM Service Websites
OEM Reprogramming Info
OEM Subscription Prices
OEM Scan Tool Center
Service Info Request (SIR)
Locksmith/Vehicle Security
How-To Guides/Videos
Road to GREAT Techs
NASTF General Meetings
Team Pages & Projects
Non-OEM Resources
Other References
Instructors/Educators
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

OEM Reprogramming Info

The following references for each vehicle manufacturer provide information about reprogramming that manufacturer's product, as well as information on where to find J-2534 information on the manufacturer's service information website. This is intended to use as a reference, and is accurate as of August 2009.

To download a chart (Excel spreadsheet xls file) showing how to locate J-2534 information on all manufacturer websites, click here.

ACURA
ALLISON TRUCK*
ASTON MARTIN
AUDI
BENTLEY
BMW
CHRYSLER
CUMMINS*
DAIMLER TRUCK*
DODGE
EAGLE
EATON TRUCK*
FERRARI
FORD
GENERAL MOTORS
HONDA
HINO TRUCK*

OEM service info or flash software not available? *Don't give up.* File an SIR. Click **HERE** to learn more.

FIGURE 84–6 The screenshot of the NASTF website provides an access point for the aftermarket automotive professional to obtain the needed reprogramming information.

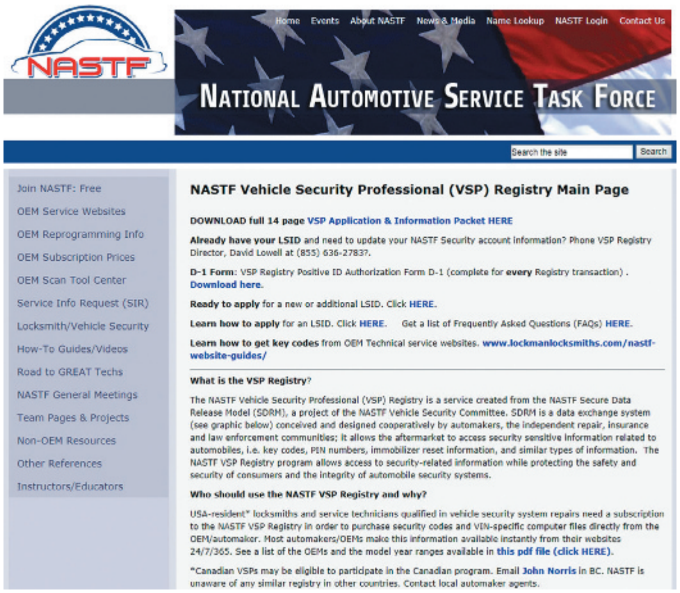
PROGRAMMING SOFTWARE

NASTF (NATIONAL AUTOMOTIVE SERVICE TASK FORCE) The **NASTF** is a cooperative effort of the automotive service industry, the tool industry, and the original equipment manufacturers to ensure that automotive professionals employed outside of the OEMs have all the information, training, and tools they need to diagnose and repair modern automobiles. The NASTF has created a portal for all automotive service professionals to access manufacturer-specific reprogramming information. This includes where to access the information, the tools needed, and in many cases a short video on how to complete the task. ● **SEE FIGURE 84–6**.

VEHICLE SECURITY PROFESSIONAL – LOCKSMITH ID Many times when a module must be reprogrammed or programmed upon replacement, the security codes or key specific information must be re-entered during the process. In order to obtain this information, the shop or service technician must be a registered vehicle security professional and have a **locksmith ID** number. The National Automotive Service Task Force (NASTF), in conjunction with automotive manufacturers, insurance industry, independent repair, and law enforcement communities, has developed this system to allow the aftermarket repair industry to access to this sensitive data. The forms and instructions needed to apply for this identification number can be found on the NASTF website (www.nasft.org) under Locksmith/Vehicle Security. ● **SEE FIGURE 84–7**.

REPROGRAMMING

ON-BOARD On-board reprogramming of the controller is defined as having the module connected to the vehicle during the process. The module uses its normal connection points to provide the power, ground, communication links, and any other needed support. This is the type of programming that typically occurs in a service facility. ● **SEE FIGURE 84–8**.


NASTF
Home
Events
About NASTF
News & Media
Name Lookup
NASTF Login
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Team Pages & Projects
Non-OEM Resources
Other References
Instructors/Educators

NASTF Vehicle Security Professional (VSP) Registry Main Page

DOWNLOAD full 14 page VSP Application & Information Packet HERE

Already have your LSID and need to update your NASTF Security account information? Phone VSP Registry Director, David Lowell at (855) 636-27837.

D-1 Form: VSP Registry Positive ID Authorization Form D-1 (complete for **every** Registry transaction) . Download here.

Ready to apply for a new or additional LSID. Click HERE.

Learn how to apply for an LSID. Click HERE. Get a list of Frequently Asked Questions (FAQs) HERE.

Learn how to get key codes from OEM Technical service websites. www.lockmanlocksmiths.com/nastf-website-guides/

What is the VSP Registry?

The NASTF Vehicle Security Professional (VSP) Registry is a service created from the NASTF Secure Data Release Model (SDRM), a project of the NASTF Vehicle Security Committee. SDRM is a data exchange system (see graphic below) conceived and designed cooperatively by automakers, the independent repair, insurance and law enforcement communities; it allows the aftermarket to access security sensitive information related to automobiles, i.e. key codes, PIN numbers, immobilizer reset information, and similar types of information. The NASTF VSP Registry program allows access to security-related information while protecting the safety and security of consumers and the integrity of automobile security systems.

Who should use the NASTF VSP Registry and why?

USA-resident* locksmiths and service technicians qualified in vehicle security system repairs need a subscription to the NASTF VSP Registry in order to purchase security codes and VIN-specific computer files directly from the OEM/automaker. Most automakers/OEMs make this information available instantly from their websites 24/7/365. See a list of the OEMs and the model year ranges available in this pdf file (click HERE).

*Canadian VSPs may be eligible to participate in the Canadian program. Email John Norris in BC. NASTF is unaware of any similar registry in other countries. Contact local automaker agents.

FIGURE 84–7 The screenshot from the NASTF website provides the resources for the technician to apply for a locksmith ID.

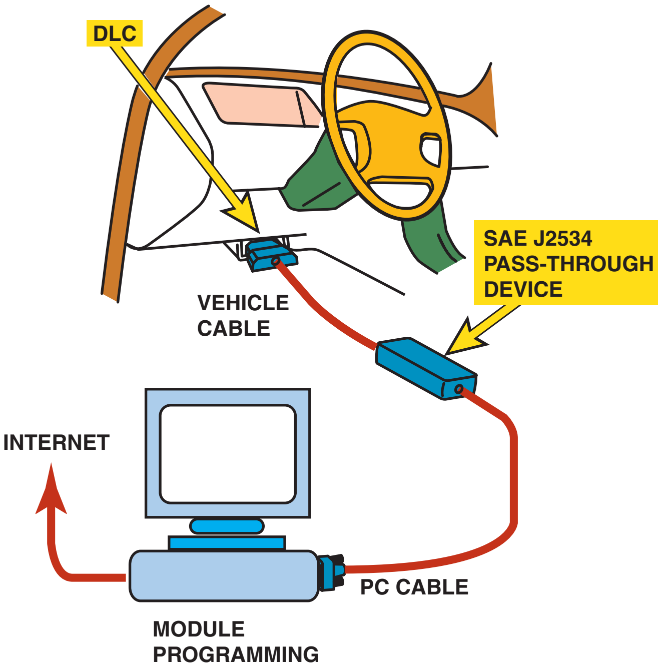

DLC
SAE J2534
PASS-THROUGH
DEVICE
VEHICLE
CABLE
INTERNET
PC CABLE
MODULE
PROGRAMMING

FIGURE 84–8 The J2534 device is being used to program the engine control module through the DLC.

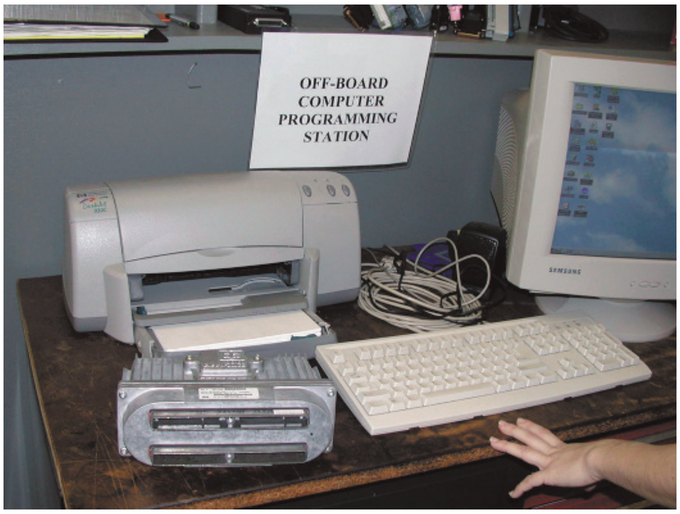

OFF-BOARD
COMPUTER
PROGRAMMING
STATION

FIGURE 84–9 The engine control module can be programmed at an off-board location.

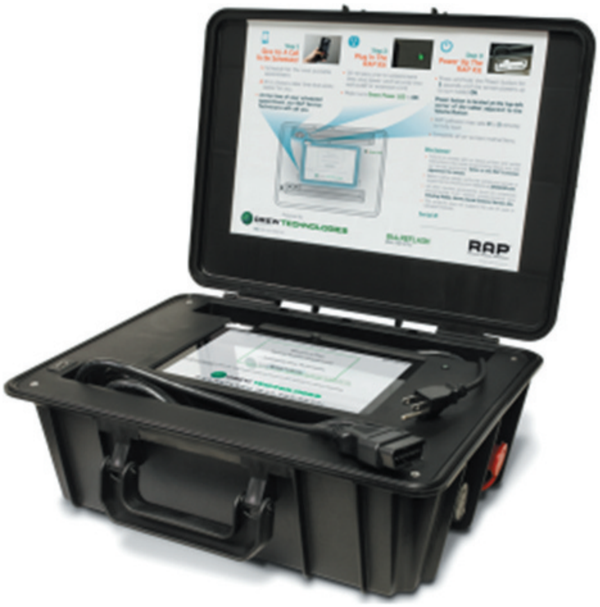


FIGURE 84–10 The Drew Technologies remote programming tool is an example of a tool that is connected to the vehicle and used remotely.

OFF-BOARD Off-board programming of the controller is defined as having the module programmed someplace other than in the vehicle. This could be anywhere that there is a computer and the needed power, ground and communication links. The purchase and programming of a module at a local parts store is an example of off-board programming. ● **SEE FIGURE 84–9**.

REMOTE Remote programming is a relatively new process. The servicing facility does not perform the reprogramming of the vehicle. Instead, the shop simply plugs in the equipment and follows the instructions of someone who is at a distant location. This process still requires an Internet connection and equipment. However, it relies on a third party who has the manufacturer subscription for the software. This option has become increasingly popular for shops that perform very few reprogramming events or lack the technical expertise to complete the task. ● **SEE FIGURE 84–10**.

BATTERY VOLTAGE

BATTERY MAINTAINER In order to provide a stable vehicle voltage throughout the reprogramming process, it is recommended that a **battery maintainer** be connected to the vehicle during the repair. A battery maintainer is designed to hold the vehicle at a specific voltage throughout the duration of the repair. A unique feature of the battery maintainer is that it accomplishes this task without wide fluctuations in voltage or amperage. ● **SEE FIGURES 84–11 AND 84–12**. Currently there are very few battery maintainers in the marketplace and they are more expensive than a battery charger. It is recommended that the maintainer be only used for the purpose of voltage stabilization during a reprogramming event, and they not be used for any other general shop use to ensure their proper operation.

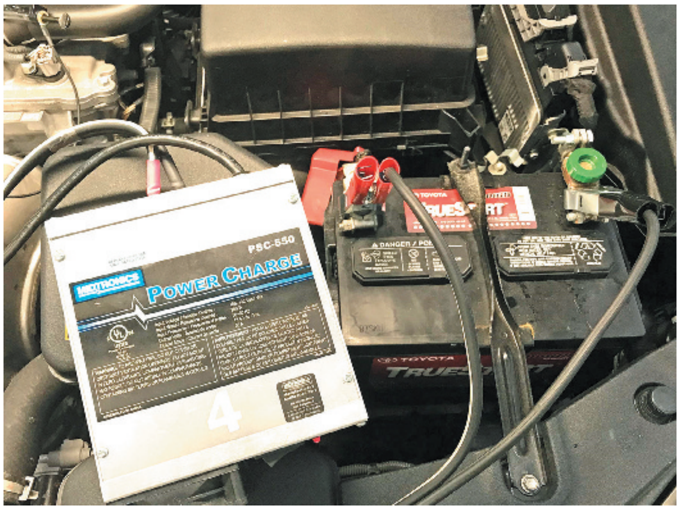


FIGURE 84–11 The Midtronics PSC-550 is an example of battery maintainer that meets the voltage and current requirements for reprogramming.

PROGRAMMING PROBLEMS AND CONCERNS

PROBLEMS AND CONCERNS IN THE FIELD The reprogramming of computers is relatively new to the automotive industry, and, as a result, there are many concerns related to the failure of the process and the damaging of the vehicle's module. The items listed below are some of the reasons some shops are hesitant to perform this type of repair.

- Are not plug-and-play technology.
- PC-based scan tools may host J2534 operations, but are not J2534 hardware.
- IT skills (owner or technician) will need to improve.
- Different OEMs use different interfaces and some tools can be difficult to use with some models.
- Software, Java, browser settings, and PC requirements are critical to proper operation.

AFTERMARKET REPROGRAMMING

COMPLIANCE CONCERNS There are many aftermarket programmers or "tuners" available in the marketplace today. The primary purpose of the programs is to increase torque and horsepower or to defeat emission control devices. These programs take the vehicle out of emission compliance because they do not meet the EPA/CARB requirements and are therefore illegal for on- or off-road use. It is likely that the change in torque and horsepower will lead to physical failures of the powertrain due to the increased numbers. The changes in software may also lead to a failure at the emission test lane due to monitor failures or omissions. ● **SEE FIGURE 84–13**.

FREQUENTLY ASKED QUESTION

How Does Over-The-Air Software Update Work?

Over-the-air (OTA) updates refers to the process of updating the software wirelessly by the manufacturer, eliminating the need to take the vehicle to the dealership. The vehicle is connected to the Internet via onboard cellular equipment (either 4G or 5G) or by Wi-Fi (if the owner allows access to their home Internet). The software is downloaded when the vehicle is updated while parked during a period of non-use. The process allows the manufacturer to update many vehicles in a very short period. ● **SEE FIGURE 84–14**.

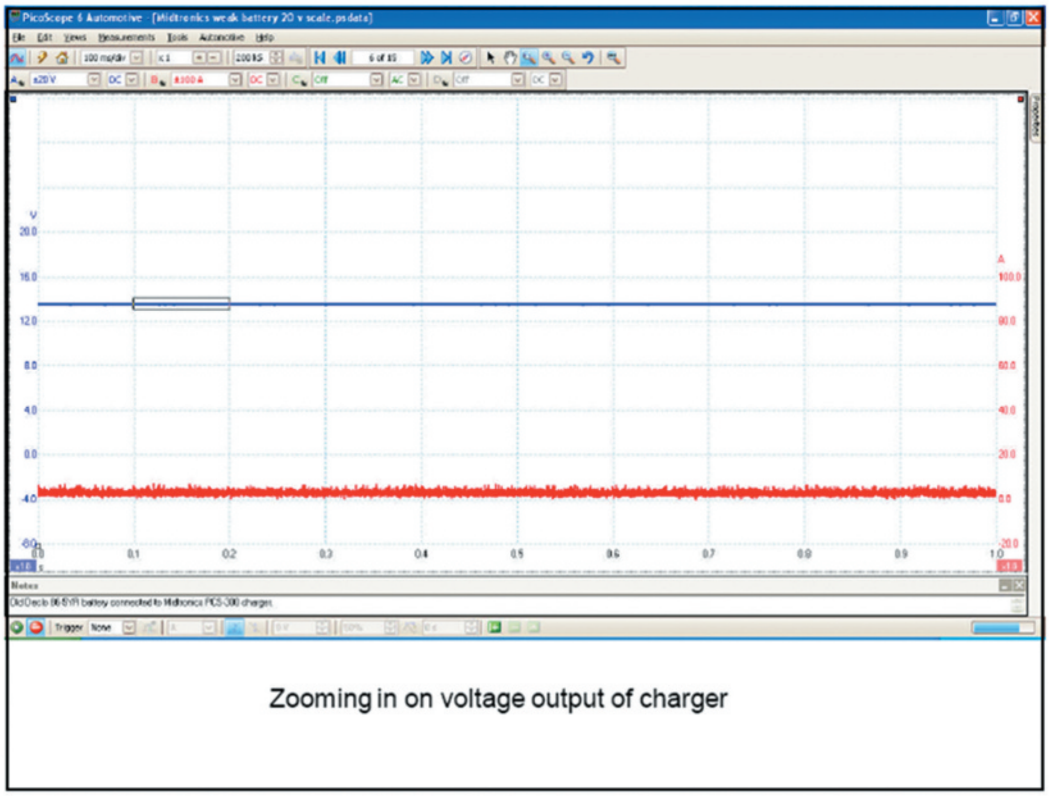


FIGURE 84–12 The scope patterns show stable voltage and current traces.

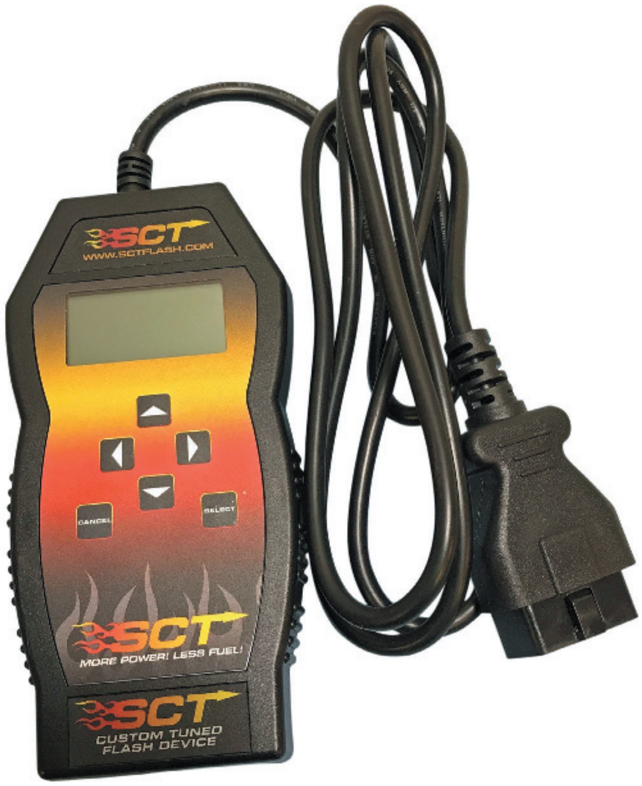
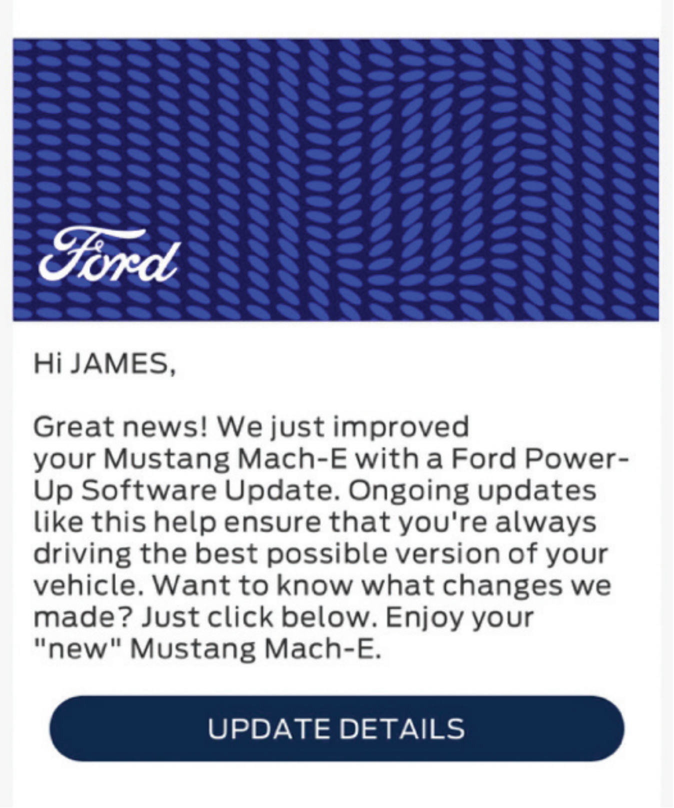


FIGURE 84–13 The SCT aftermarket tuner is an example of device that takes the vehicle out of compliance when reprogramming the module.



Hi JAMES,

Great news! We just improved your Mustang Mach-E with a Ford Power-Up Software Update. Ongoing updates like this help ensure that you're always driving the best possible version of your vehicle. Want to know what changes we made? Just click below. Enjoy your "new" Mustang Mach-E.

FIGURE 84–14 The vehicle owner receives a message from the manufacturer acknowledging the software update.

REVIEW QUESTIONS

1. Why did the manufacturers begin using EEPROM in 1996?
2. What is the SAE J2534 standard used for?
3. What are the differences between on-board, off-board, and remote programming?
4. Why is it important to use a battery maintainer when reprogramming a module?
5. Why do some aftermarket programmers or "tuners" cause a failure at the emission test lane?

CHAPTER QUIZ

1. Technician A says that reprogramming an engine control module using the J2534 system requires a factory scan tool. Technician B says that reprogramming an engine control module using the J2534 system requires Internet access. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Which method can be used to reprogram an engine control module?
   a. On-board
   b. Off-board
   c. Remote
   d. Any of the above
3. A battery maintainer is used during reprogramming to ______________.
   a. make sure the OBDII data is not lost
   b. make sure the customer's radio stations are not lost
   c. make sure the system voltage does not drop during the reprogramming event
   d. All of the above
4. What is *not* required to reprogram a vehicle's engine control module?
   a. A good Internet connection
   b. A manufacturer's scan tool
   c. A pass-through device
   d. A computer that meets the minimum specifications
5. SAE J2534 is a mandated specification to all automakers who sell vehicles in the United States after 2004 to ______________.
   a. have standard data link connectors
   b. support reprogramming of the EEPROM
   c. make service information available to all who service vehicle emissions
   d. All of the above
6. How was programming updated before 1996?
   a. A new computer had to be installed
   b. A replaceable PROM was used
   c. The control cable was replaced
   d. The instrument panel cluster (IPC) was updated

7. What type of battery charger is specified when reprogramming?
- **a.** Must be a low-voltage, high-amperage charger
- **b.** Must use a battery charger that produces little, if any, voltage fluctuations
- **c.** Must be able to communicate with the J2534 unit
- **d.** Needs to be OBD/CARB approved

8. What organization created the J2534 standard?
- **a.** EPA
- **b.** CARB
- **c.** SAE
- **d.** OBD

9. What does a pass-through device do?
- **a.** It is used between the vehicle and the scan tool.
- **b.** It passes data between the DLC and the computer used to program a vehicle.
- **c.** It is used only for off-board programming.
- **d.** It is used to monitor the data being transferred.

10. Aftermarket programmers may create an issue of ___________.
- **a.** noncompliance
- **b.** excessive cost to the vehicle owner
- **c.** not being certified by EPA/CARB
- **d.** Both a and c

Chapter 85

STRATEGY-BASED DIAGNOSIS

LEARNING OBJECTIVES:

After studying this chapter, the reader will be able to:

- List the steps of the diagnostic process.
- Discuss the types of scan tools that are used to assess vehicle components.
- Explain how to retrieve diagnostic information and how to use DTCs.
- Explain the troubleshooting procedures to follow if a diagnostic trouble code has been set.
- Explain manufacturer's diagnostic routines.
- Discuss completing system repairs, including resetting the PCM and road test (drive cycle).

KEY TERMS:

Data link connector (DLC) 988 • Drive cycle 994 • Pending code 988 • Smoke machine 988 • Technical service bulletins (TSBs) 988

THE EIGHT-STEP DIAGNOSTIC PROCEDURE

STRATEGY-BASED DIAGNOSIS The diagnostic process is a strategy that eliminates known good components or systems in order to find the root cause of automotive engine performance problems. All vehicle manufacturers recommend a diagnostic procedure, and the plan suggested in this chapter combines most of the features of these plans plus additional steps developed over years of real-world problem solving.

Many different things can cause an engine performance problem or concern. The service technician has to narrow the possibilities to find the cause of the problem and correct it. A funnel is a way of visualizing a diagnostic procedure. ● **SEE FIGURE 85–1**. At the wide top are the symptoms of the problem; the funnel narrows as possible causes are eliminated until the root cause is found and corrected at the bottom of the funnel.

All problem diagnosis deals with symptoms that could be the result of many different causes. The wide range of possible solutions must be narrowed to the most likely and these must eventually be further narrowed to the actual cause. The following section describes eight steps the service technician can take to narrow the possibilities to one cause. ● **SEE FIGURE 85–2**.

STEP 1—VERIFY THE PROBLEM (CONCERN) Before a minute is spent on diagnosis, be certain that a problem exists. If the problem cannot be verified, it cannot be solved or tested to verify that the repair was complete.

The driver of the vehicle knows much about the vehicle and how it is driven. *Before* diagnosis, always ask the following questions:

- Is the malfunction indicator light (check engine) on?
- What was the temperature outside?
- Was the engine warm or cold?
- Was the problem during starting, acceleration, cruise, or some other condition?
- How far had the vehicle been driven?
- Were any dash warning lights on? If so, which one(s)?
- Has there been any service or repair work performed on the vehicle lately?

NOTE: This last question is very important. Many engine performance faults are often the result of something being knocked loose or a hose falling off during repair work. Knowing that the vehicle was just serviced before the problem began may be an indicator as to where to look for the solution to a problem.

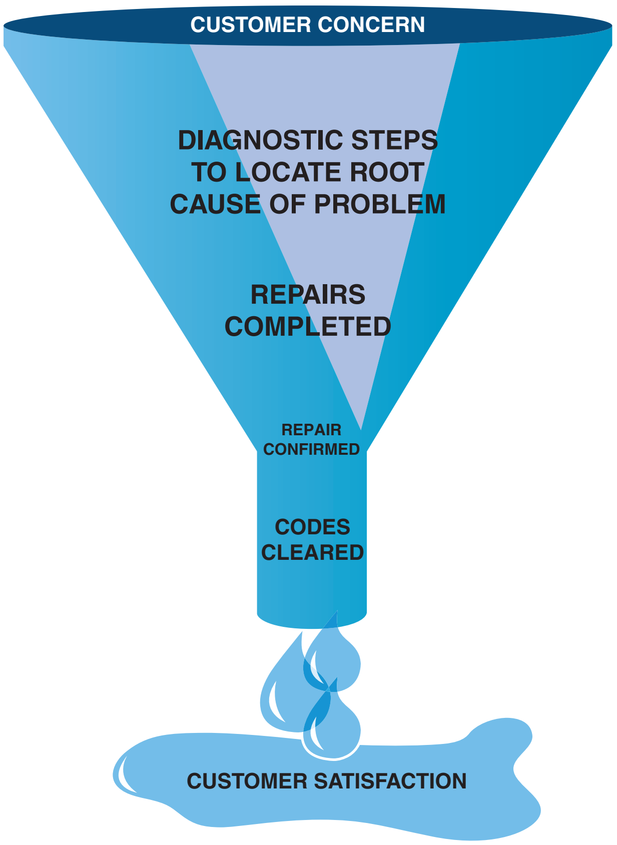

CUSTOMER CONCERN
DIAGNOSTIC STEPS TO LOCATE ROOT CAUSE OF PROBLEM
REPAIRS COMPLETED
REPAIR CONFIRMED
CODES CLEARED
CUSTOMER SATISFACTION

FIGURE 85–1 A funnel is one way to visualize the diagnostic process. The purpose is to narrow the possible causes of a concern until the root cause is determined and corrected.

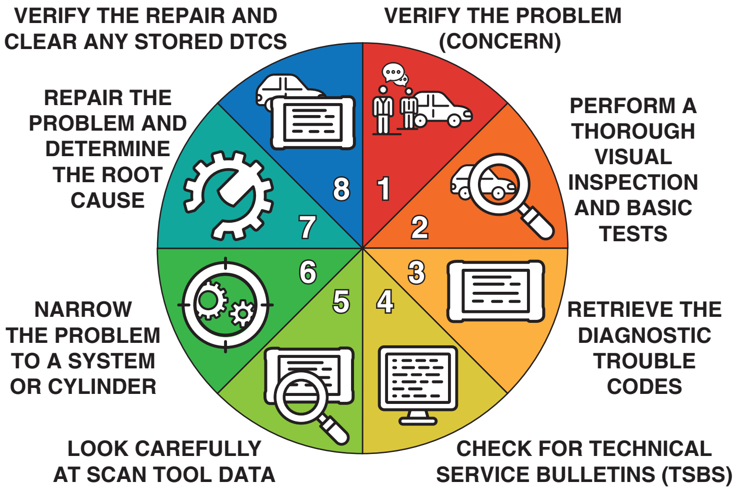

VERIFY THE REPAIR AND CLEAR ANY STORED DTCS
VERIFY THE PROBLEM (CONCERN)
REPAIR THE PROBLEM AND DETERMINE THE ROOT CAUSE
PERFORM A THOROUGH VISUAL INSPECTION AND BASIC TESTS
NARROW THE PROBLEM TO A SYSTEM OR CYLINDER
RETRIEVE THE DIAGNOSTIC TROUBLE CODES
LOOK CAREFULLY AT SCAN TOOL DATA
CHECK FOR TECHNICAL SERVICE BULLETINS (TSBS)
1
2
3
4
5
6
7
8

FIGURE 85–2 Another way to visualize the diagnostic process is in a circle.

After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed. A sample form that customers could fill out with details of the problem is shown in ● **FIGURE 85–3**.

NOTE: Because drivers differ, it is sometimes the best policy to take the customer on the test-drive to verify the concern.

STEP 2—PERFORM A THOROUGH VISUAL INSPECTION AND BASIC TESTS The visual inspection is the most important aspect of diagnosis! Most experts agree that between 10% and 30% of all engine performance, problems can be found simply by performing a *thorough* visual inspection. The inspection should include the following:

- **Check for obvious problems (basics, basics, basics).**
  Fuel leaks
  Vacuum hoses that are disconnected or split
  Corroded connectors
  Unusual noises, smoke, or smell
  Check the air cleaner and air duct (squirrels and other small animals can build nests or store dog food in them). ● **SEE FIGURE 85–4**.
- **Check everything that does and does not work.** This step involves turning things on and observing that everything is working properly.
- **Look for evidence of previous repairs.** Any time work is performed on a vehicle, there is always a risk that something will be disturbed, knocked off, or left disconnected.
- **Check oil level and condition.** Another area for visual inspection is oil level and condition.
  Oil level. Oil should be to the proper level.
  Oil condition. Using a match or lighter, try to light the oil on the dipstick; if the oil flames up, gasoline is present in the engine oil. Drip some engine oil from the dipstick onto the hot exhaust manifold. If the oil bubbles or boils, coolant (water) is present in the oil. Check for grittiness by rubbing the oil between your fingers.

NOTE: Gasoline in the oil will cause the engine to run rich by drawing fuel through the positive crankcase ventilation (PCV) system.

- **Check coolant level and condition.** Many mechanical engine problems are caused by overheating. The proper operation of the cooling system is critical to the life of any engine.

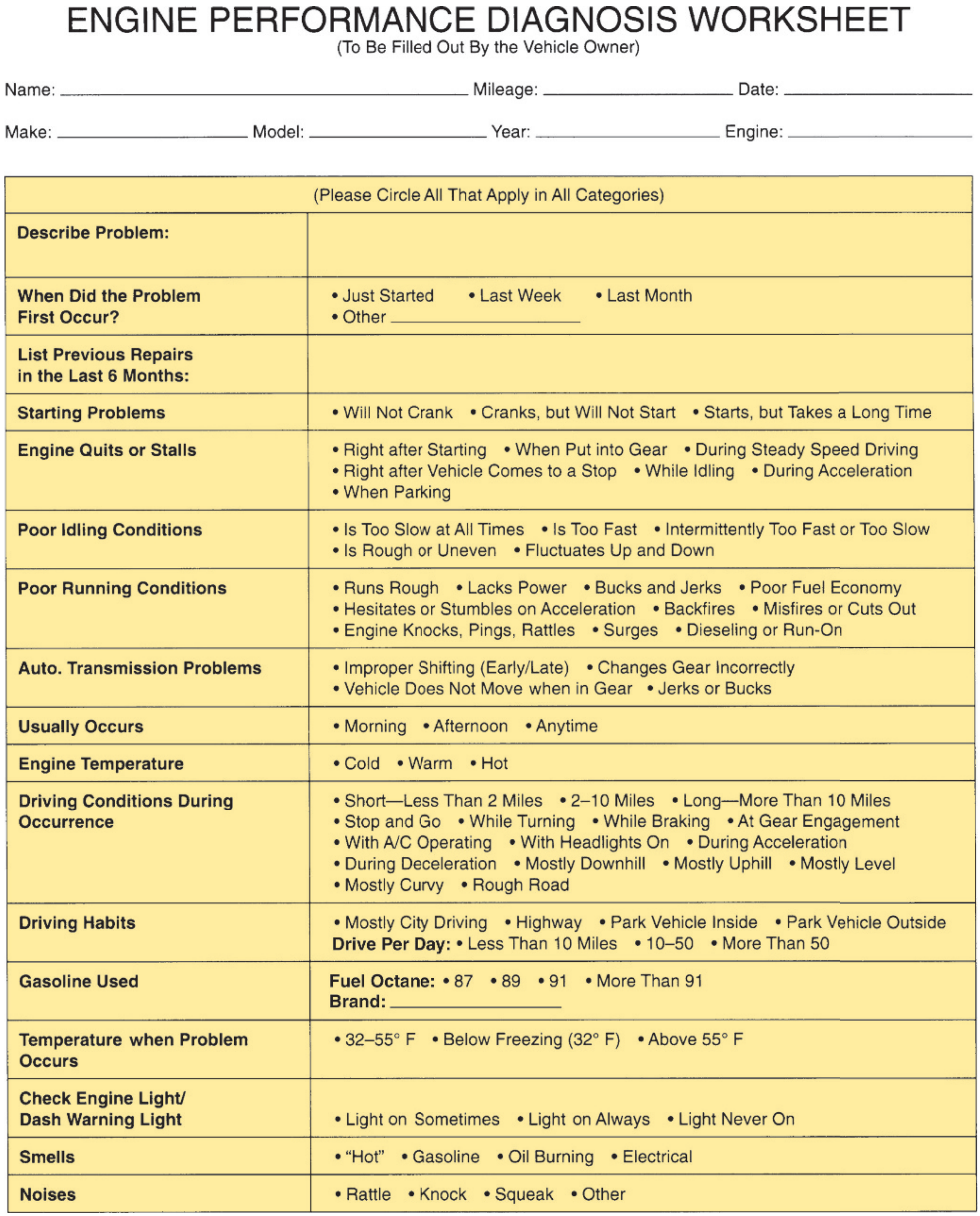
NOTE: Check the coolant level in the radiator only if the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately, which can cause severe burns because the coolant expands explosively upward and outward from the radiator opening.

TECH TIP

"Original Equipment" Is Not a Four-Letter Word

To many service technicians, an original-equipment part is considered to be only marginal, and to get the really "good stuff" an aftermarket (renewal market) part has to be purchased. However, many problems can be traced to the use of an aftermarket part that has failed early in its service life. Technicians who work at dealerships usually go immediately to an aftermarket part that is observed during a visual inspection. It has been their experience that simply replacing the aftermarket part with the factory original-equipment (OE) part often solves the problem.

Original equipment parts are *required* to pass quality and durability standards and tests at a level not required of aftermarket parts. The technician should be aware that the presence of a new part does not necessarily mean that the part is good.



ENGINE PERFORMANCE DIAGNOSIS WORKSHEET

(To Be Filled Out By the Vehicle Owner)

Name: ____________ Mileage: ____________ Date: ____________

Make: ____________ Model: ____________ Year: ____________ Engine: ____________

(Please Circle All That Apply in All Categories)

Describe Problem:	
When Did the Problem First Occur?	• Just Started • Last Week • Last Month • Other ____________
List Previous Repairs in the Last 6 Months:	
Starting Problems	• Will Not Crank • Cranks, but Will Not Start • Starts, but Takes a Long Time
Engine Quits or Stalls	• Right after Starting • When Put into Gear • During Steady Speed Driving • Right after Vehicle Comes to a Stop • While Idling • During Acceleration • When Parking
Poor Idling Conditions	• Is Too Slow at All Times • Is Too Fast • Intermittently Too Fast or Too Slow • Is Rough or Uneven • Fluctuates Up and Down
Poor Running Conditions	• Runs Rough • Lacks Power • Bucks and Jerks • Poor Fuel Economy • Hesitates or Stumbles on Acceleration • Backfires • Misfires or Cuts Out • Engine Knocks, Pings, Rattles • Surges • Dieseling or Run-On
Auto. Transmission Problems	• Improper Shifting (Early/Late) • Changes Gear Incorrectly • Vehicle Does Not Move when in Gear • Jerks or Bucks
Usually Occurs	• Morning • Afternoon • Anytime
Engine Temperature	• Cold • Warm • Hot
Driving Conditions During Occurrence	• Short—Less Than 2 Miles • 2–10 Miles • Long—More Than 10 Miles • Stop and Go • While Turning • While Braking • At Gear Engagement • With A/C Operating • With Headlights On • During Acceleration • During Deceleration • Mostly Downhill • Mostly Uphill • Mostly Level • Mostly Curvy • Rough Road
Driving Habits	• Mostly City Driving • Highway • Park Vehicle Inside • Park Vehicle Outside **Drive Per Day:** • Less Than 10 Miles • 10–50 • More Than 50
Gasoline Used	**Fuel Octane:** • 87 • 89 • 91 • More Than 91 **Brand:** ____________
Temperature when Problem Occurs	• 32–55° F • Below Freezing (32° F) • Above 55° F
Check Engine Light/ Dash Warning Light	• Light on Sometimes • Light on Always • Light Never On
Smells	• "Hot" • Gasoline • Oil Burning • Electrical
Noises	• Rattle • Knock • Squeak • Other

FIGURE 85–3 A form that the customer should fill out if there is a driveablilty concern to help the service technician more quickly find the root cause.

- **Ensure adequate fuel level.** Make certain that the fuel tank is at least one-fourth to one-half full; if the fuel level is low, it is possible that any water or alcohol at the bottom of the fuel tank is more concentrated and can be drawn into the fuel system.
- **Check the battery voltage.** The voltage of the battery should be at least 12.4 volts and the charging voltage (engine running) should be 13.5 to 15.0 volts at 2000 RPM. Low battery voltage can cause a variety of problems including reduced fuel economy and incorrect (usually too high) idle speed. Higher-than-normal battery voltage can also cause the PCM problems and could cause damage to electronic modules.
- **Check the spark using a spark tester.** Remove one spark plug wire and attach the removed plug wire to the spark tester. Attach the grounding clip of the spark tester to a

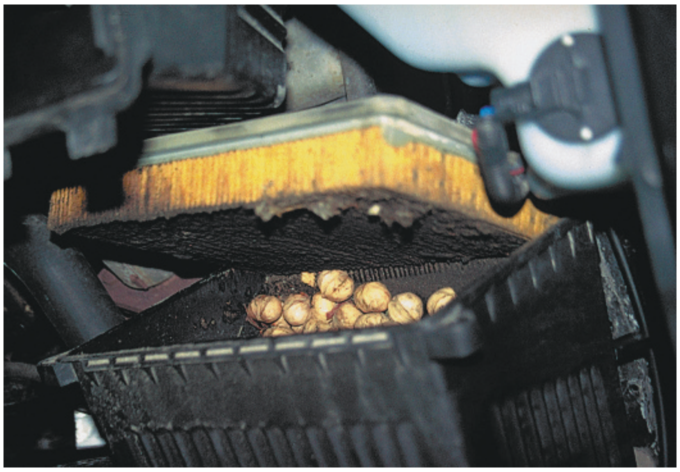


FIGURE 85–4 This is what was found when removing an air filter from a vehicle that had a lack-of-power concern. Obviously, the nuts were deposited by squirrels or some other animal, blocking a lot of the airflow into the engine.

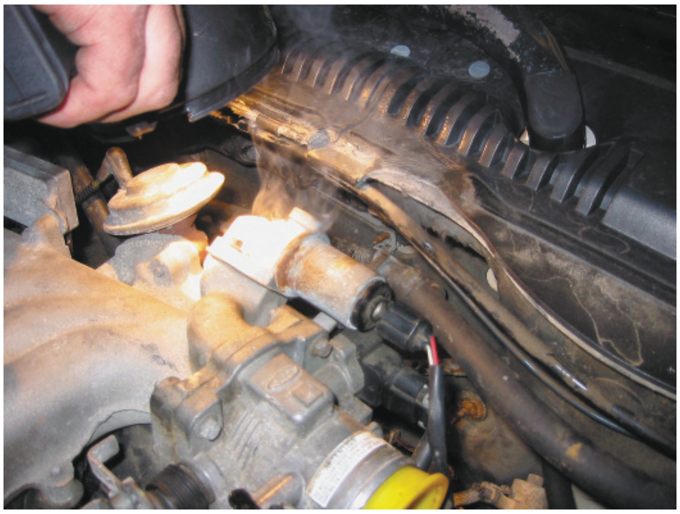


FIGURE 85–5 Using a bright light makes seeing where the smoke is coming from easier. In this case, smoke was added to the intake manifold with the inlet blocked with a yellow plastic cap and smoke was seen escaping past a gasket at the idle air control.

TECH TIP

Smoke Machine Testing

Vacuum (air) leaks can cause a variety of driveability problems and are often difficult to locate. One good method is to use a machine that generates a stream of smoke. Connecting the outlet of the **smoke machine** to the hose that was removed from the vacuum brake booster allows smoke to enter the intake manifold. Any vacuum leaks will be spotted by observing smoke coming out of the leak. ● **SEE FIGURE 85–5**.

good clean engine ground, start or crank the engine, and observe the spark tester. ● **SEE FIGURE 85–6**. The spark at the spark tester should be steady and consistent. If an intermittent spark occurs, then this condition should be treated as a no-spark condition. If this test does not show satisfactory spark, carefully inspect and test all components of the primary and secondary ignition systems.

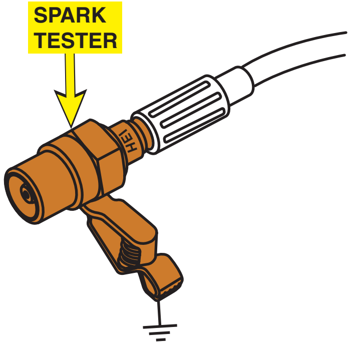


FIGURE 85–6 A spark tester connected to a spark plug wire or coil output. A typical spark tester will fire only if at least 25,000 volts is available from the coil, making a spark tester a useful tool. Do not use one that just lights when a spark is present, because it does not require more than about 2,000 volts to light.

NOTE: Do not use a standard spark plug to check for proper ignition system voltage. An electronic ignition spark tester is designed to force the spark to jump about 0.75 inch (19 mm). This amount of gap requires between 25,000 and 30,000 volts (25 to 30 kV) at atmospheric pressure, which is enough voltage to ensure that a spark can occur under compression inside an engine.

- **Check the fuel-pump pressure.** Checking the fuel-pump pressure is relatively easy on many port fuel-injected engines. Often the cause of intermittent engine performance is due to a weak electric fuel pump or clogged fuel filter. Checking fuel pump pressure early in the diagnostic process eliminates low fuel pressure as a possibility.

STEP 3—RETRIEVE THE DIAGNOSTIC TROUBLE CODES (DTCS)

If a diagnostic trouble code (DTC) is present in the computer memory, it may be signaled by illuminating a malfunction indicator lamp (MIL), commonly labeled “check engine” or “service engine soon.” ● **SEE FIGURE 85–7**. Any code(s) that is displayed when the MIL is *not* on is called a **pending code**. Because the MIL is not on, this indicates that the fault has not repeated to cause the PCM to turn on the MIL. Although this pending code is helpful to the technician to know that a fault has, in the past, been detected, further testing will be needed to find the root cause of the problem.

STEP 4—CHECK FOR TECHNICAL SERVICE BULLETINS (TSBS)

Check for corrections in **technical service bulletins (TSBs)** that match the symptoms. ● **SEE FIGURE 85–8**. According to studies performed by automobile manufacturers, as many as 30% of vehicles can be repaired following the information, suggestions, or replacement parts found in a service bulletin. DTCs must be known before searching for service bulletins, because bulletins often include information on solving problems that involve a stored diagnostic trouble code.

STEP 5—LOOK CAREFULLY AT SCAN TOOL DATA

Vehicle manufacturers have been giving the technician more and more data on a scan tool connected to the **data link connector (DLC)**. ● **SEE FIGURE 85–9**. Beginning technicians are often observed scrolling through scan data without a real clue about what they

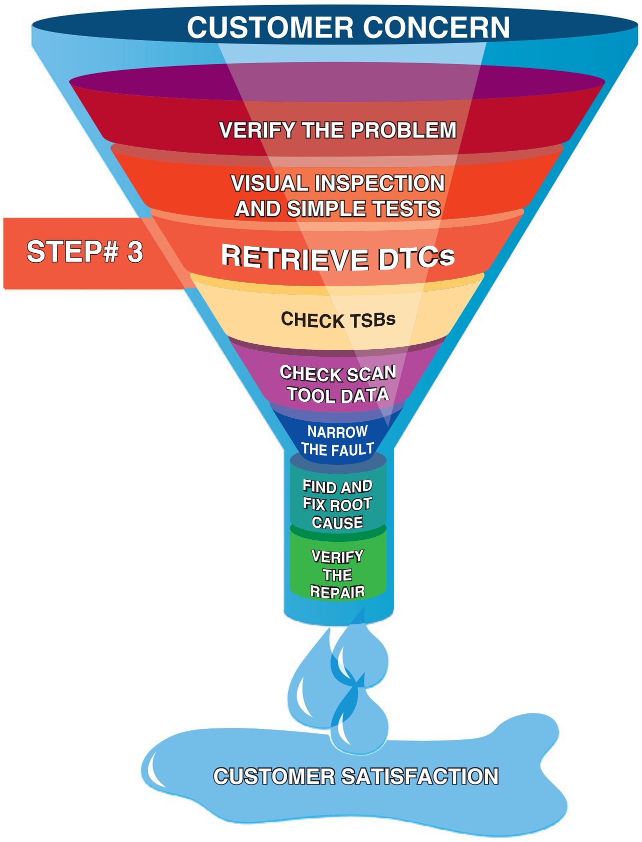

CUSTOMER CONCERN
VERIFY THE PROBLEM
VISUAL INSPECTION AND SIMPLE TESTS
STEP# 3
RETRIEVE DTCs
CHECK TSBs
CHECK SCAN TOOL DATA
NARROW THE FAULT
FIND AND FIX ROOT CAUSE
VERIFY THE REPAIR
CUSTOMER SATISFACTION

FIGURE 85–7 Step 3 in the diagnostic process is to retrieve any stored diagnostic trouble codes.

FIGURE 85–8 After checking for stored diagnostic trouble codes (DTCs), the wise technician checks service information for any technical service bulletins that may relate to the vehicle being serviced.

TECH TIP

Look at the Freeze Frame

Whenever a DTC is set, a freeze frame is stored. The freeze frame includes data showing how the engine was being operated at the time the code was set. The wise service technician saves the freeze frame information to help determine not only what might have caused the code to set but also to allow the technician to drive the vehicle under similar conditions to verify that the problem has been corrected.

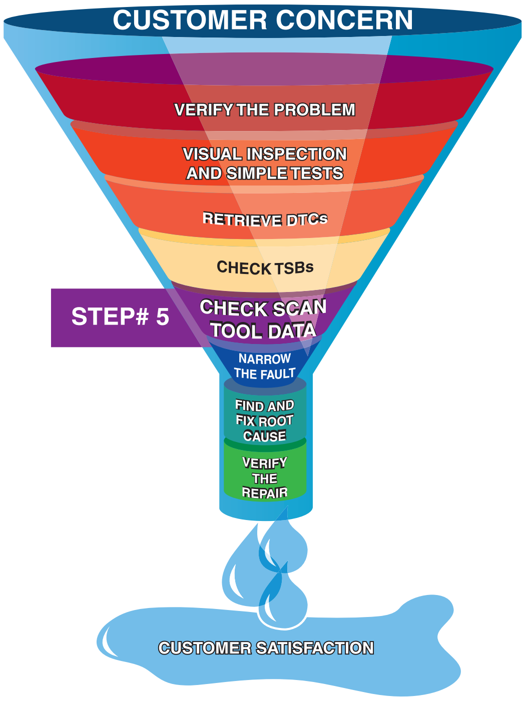

CUSTOMER CONCERN
VERIFY THE PROBLEM
VISUAL INSPECTION AND SIMPLE TESTS
RETRIEVE DTCs
CHECK TSBs
STEP# 5
CHECK SCAN TOOL DATA
NARROW THE FAULT
FIND AND FIX ROOT CAUSE
VERIFY THE REPAIR
CUSTOMER SATISFACTION

FIGURE 85–9 Looking carefully at the scan tool data is very helpful in locating the source of a problem.

are looking for. When asked, they usually reply that they are looking for something unusual, as if the screen will flash a big message "LOOK HERE—THIS IS NOT CORRECT." That statement does not appear on scan tool displays. The best way to look at scan data is in a definite sequence and with specific, selected bits of data that can tell the most about the operation of the engine, such as the following:

- Engine coolant temperature (ECT) is the same as intake air temperature (IAT) after the vehicle sits for several hours.
- Idle air control (IAC) valve is being commanded to an acceptable range.
- Oxygen sensor (O2S) is operating properly:
  1. Readings below 200 mV at times
  2. Readings above 800 mV at times
  3. Rapid transitions between rich and lean

The oxygen sensor data is used by the PCM to make any necessary adjustments to the fuel delivery to ensure that the catalytic converter is receiving an air–fuel ratio that can be most efficient not only for driveability but also for the lowest possible exhaust emissions. The correction is called fuel trim, and this represents the percentage of fuel either added or subtracted from the amount that was programmed as being the required. ● **SEE CHART 85–1**.

STEP 6—NARROW THE PROBLEM TO A SYSTEM OR CYLINDER

Narrowing the focus to a system or individual cylinder is the hardest part of the entire diagnostic process.

- Perform a cylinder power balance test.
- If a weak cylinder is detected, perform a compression test and a cylinder leakage test to determine the probable cause.

STEP 7—REPAIR THE PROBLEM AND DETERMINE THE ROOT CAUSE The repair or part replacement must be performed following vehicle manufacturer's recommendations and be certain

Rich/Lean Air–Fuel Ratio

TOTAL FUEL TRIM (LTFT + STFT) AT IDLE	2,500 RPM FUEL TRIM	LOADED FUEL TRIM	DRIVABILITY SYMPTOMS	POSSIBLE CAUSES
0–5%	0–5%	0–5%	No issues	Preferred fuel trim values
6–10%	6–10%	6–10%	No issues	Acceptable fuel trim valves
−10+%	−10+%	−10+%	Poor fuel economy	PCM is reducing fuel do to faults in the fuel system over-fueling the engine
+10%+	+10%+	+10%+	Low power, possible hesitation on acceleration	PCM is increasing fuel delivery do to faults in the air induction system

CHART 85–1

Normal short term fuel trim (STFT and long term fuel trim (LTFT) are considered to be less than +/− 10%.

that the root cause of the problem has been found. Also follow the manufacturer's recommended repair procedures and methods.

STEP 8—VERIFY THE REPAIR AND CLEAR ANY STORED DTCS

● **SEE FIGURE 85–10.**

- Test-drive to verify that the original problem (concern) is fixed.
- Verify that no additional problems have occurred during the repair process.
- Check for and then clear all diagnostic trouble codes. (This step ensures that the computer will not make any changes based on a stored DTC, but should not be performed if the vehicle is going to be tested for emissions because all of the monitors will need to be run and pass.)

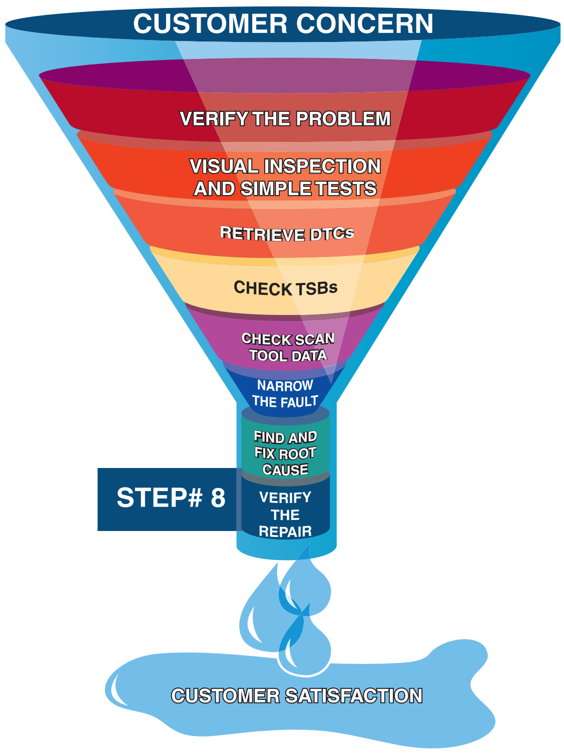


FIGURE 85–10 Step 8 is very important. Be sure that the customer's concern has been corrected.

- Return the vehicle to the customer and double-check the following:
  1. The vehicle is clean.
  2. The radio is turned off.
  3. The clock is set to the right time and the radio stations have been restored if the battery was disconnected during the repair procedure.

SCAN TOOLS

Scan tools are the workhorse for any diagnostic work on all vehicles. Scan tools can be divided into two basic groups

1. **Factory scan tools.** These are the scan tools required by all dealers that sell and service the brand of vehicle. Examples of factory scan tools include
   - **General Motors**—Tech 2, MDI (Multiple Diagnostic Interface), MDI 2, or GDS2 (global diagnostic system 2).
   - **Ford**—New Generation Star (NGS), IDS (Integrated Diagnostic System), VCM, VCM2, or VCM3.
   - **Chrysler**—DRB-III, Star Scan, wiTECH, or wiTECH 2.
   - **Honda**—HDS or Master Tech
   - **Toyota**—Master Tech, or Techstream ADVi.

TECH TIP

One Test Is Worth 1,000 "Expert" Opinions

Whenever any vehicle has an engine performance or driveability concern, certain people always say:

"Sounds like it's a bad injector."

"I'll bet you it's a bad computer."

"I had a problem just like yours yesterday and it was a bad EGR valve."

Regardless of the skills and talents of those people, it is still more accurate to perform tests on the vehicle than to rely on feelings or opinions of others who have not even seen the vehicle. Even your own opinion should not sway your thinking. Follow a plan, perform tests, and the test results will lead to the root cause.

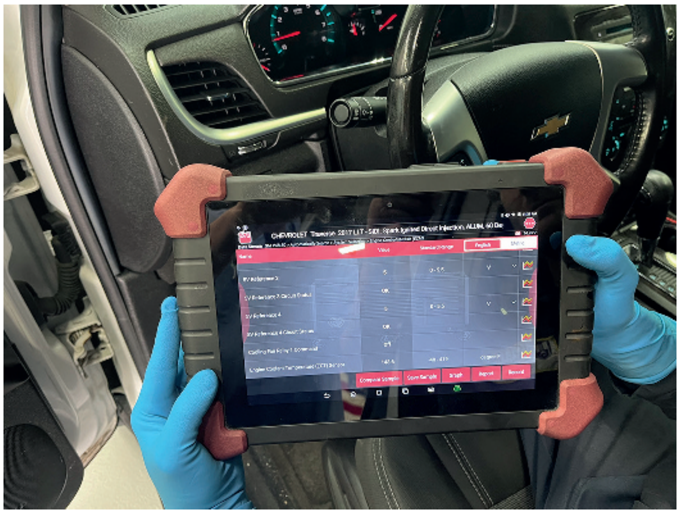


FIGURE 85–11 An enhanced aftermarket scan tool being used to diagnose an engine performance issue.

All factory scan tools are designed to provide bidirectional capability that allows the service technician the opportunity to operate components using the scan tool thereby confirming that the component is able to work when commanded. Also all factory scan tools are capable of displaying all factory parameters.

2. **Aftermarket scan tools.** These scan tools are designed to function on more than one brand of vehicle. Examples of aftermarket scan tools include

   - **Snap-on** (various models including the Solus and Vantage Ultra and Modis)
   - **OTC** (various models including Genisys and Task Master Evo and Evolve)
   - **Autel** (various models) ● **SEE FIGURE 85–11**.

While many aftermarket scan tools can display most if not all of the parameters of the factory scan tool, there can be a difference when trying to troubleshoot some faults. ● **SEE FIGURE 85–12**.

RETRIEVAL OF DIAGNOSTIC INFORMATION

To retrieve diagnostic information from the powertrain control module (PCM), a scan tool is needed. If a factory or factory-level scan tool is used, then all of the data can be retrieved. If a global (generic) only type scan tool is used, only the emissions-related data can be retrieved. To retrieve diagnostic information from the PCM, use the following steps:

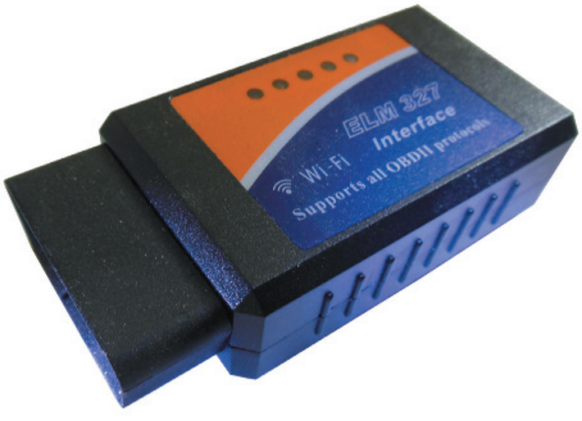


FIGURE 85–12 A Bluetooth adapter that plugs into the DLC and transmits global OBD II information to a smart phone that has a scan tool app installed.

STEP 1 Locate and gain access to the data link connector (DLC). ● **SEE FIGURES 85–13, 85–14, AND 85–15**.

STEP 2 Connect the scan tool to the DLC and establish communication.

NOTE: If no communication is established, follow the vehicle manufacturer's specified instructions.

STEP 3 Follow the on-screen instructions of the scan tool to correctly identify the vehicle.

STEP 4 Observe the scan data, as well as any diagnostic trouble codes.

STEP 5 Follow vehicle manufacturer's instructions if any DTCs are stored. If no DTCs are stored, compare all sensor values with a factory acceptable range chart to see if any sensor values are out of range. ● **SEE CHART 85–2**.

TROUBLESHOOTING USING DIAGNOSTIC TROUBLE CODES

Pinning down causes of the actual problem can be accomplished by trying to set the opposite code. For example, if a code indicates an open throttle position (TP) sensor (high resistance), clear the code and create a shorted (low-resistance) condition. This can be accomplished by using a jumper wire and connecting the signal terminal to the 5-volt reference terminal. This should set a diagnostic trouble code.

- **If the opposite code sets,** this indicates that the wiring and connector for the sensor is okay and the sensor itself is defective (open).
- **If the same code sets,** this indicates that the wiring or electrical connection is open (has high resistance) and is the cause of the setting of the DTC.

DIAGNOSING INTERMITTENT MALFUNCTIONS Of all the different types of conditions that you will see, the hardest to accurately diagnose and repair are intermittent malfunctions. These conditions may be temperature related (only occur when the vehicle is hot or cold), or humidity related (only occur when it is raining). Regardless of the conditions that will cause the malfunction to occur, you must diagnose and correct the condition.

When dealing with an intermittent concern, you should determine the conditions when the malfunction occurs, and then try to duplicate those conditions. If a cause is not readily apparent to you, ask the customer when the symptom occurs. Ask if there are any conditions that seem to be related to, or cause the concern.

Another consideration when working on an OBD-II-equipped, vehicle is whether a concern is intermittent, or if it only occurs when a specific diagnostic test is performed by the PCM. Since OBD-II systems conduct diagnostic tests only under very precise conditions, some tests may only be run once during an ignition cycle. Additionally, if the requirements needed to perform the

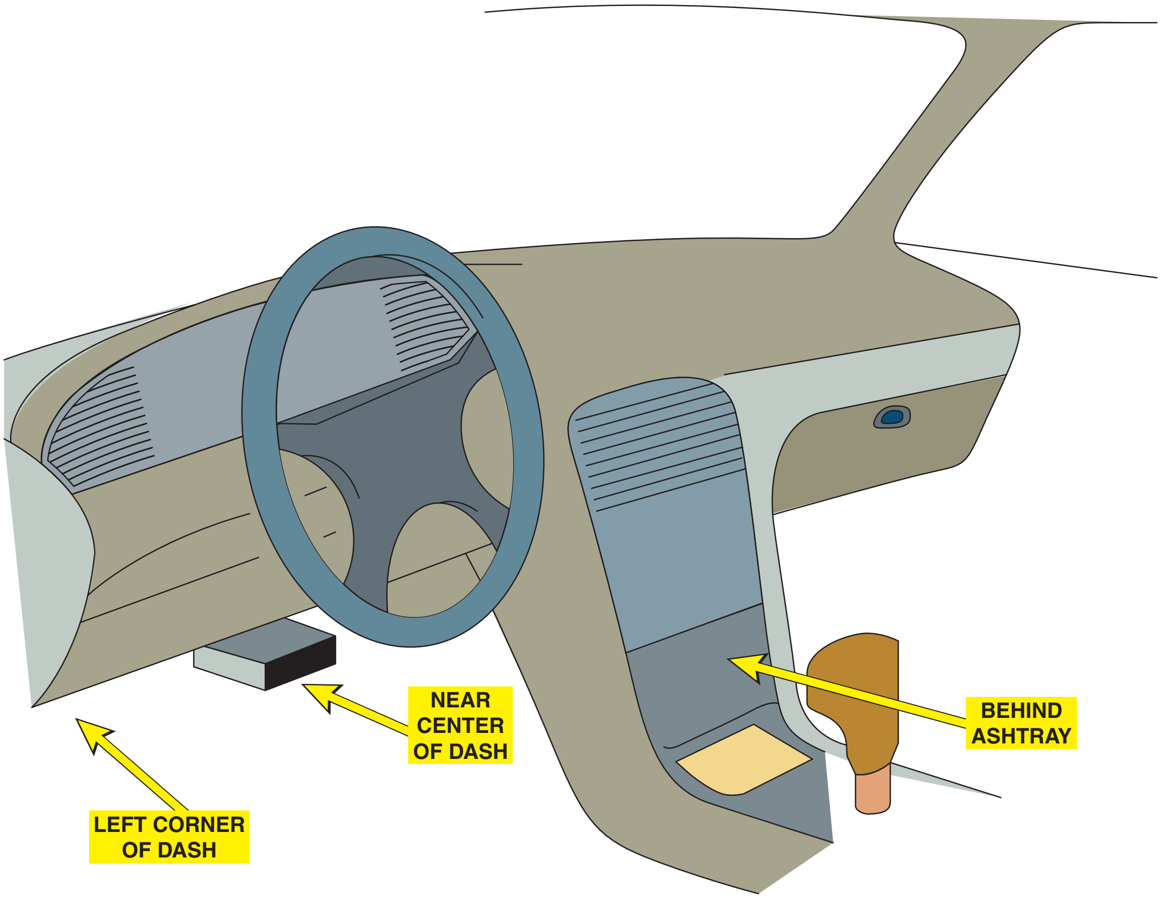


FIGURE 85–13 The data link connector (DLC) can be located in various locations.

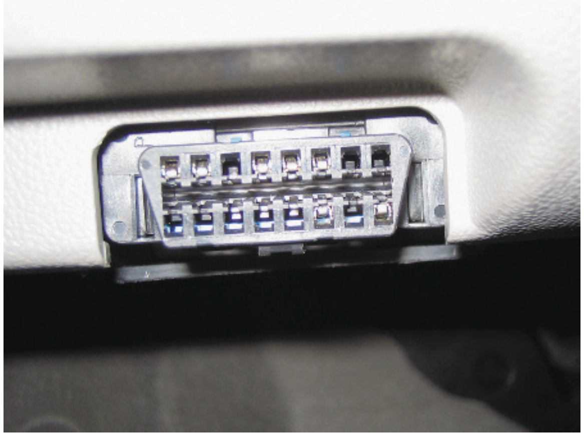


FIGURE 85–14 A typical OBD-II data link connector (DLC). The location varies with make and model and may even be covered, but a tool is not needed to gain access. Check service information for the exact location if needed.

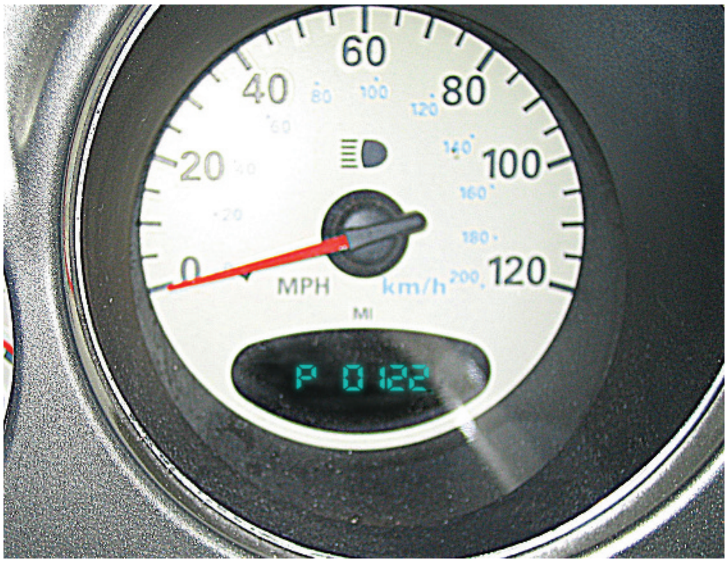


FIGURE 85–15 Diagnostic trouble codes (DTCs) from Chrysler and Dodge vehicles can be retrieved by turning the ignition switch to on and then off three times.

test are not met, the test will not run during an ignition cycle. This type of onboard diagnostics could be mistaken as "intermittent" when, in fact, the tests are only infrequent (depending on how the vehicle is driven). Examples of this type of diagnostic test are HO2S heaters, evaporative canister purge, catalyst efficiency, and EGR flow. When diagnosing intermittent concerns on an OBD-II-equipped vehicle, a logical diagnostic strategy is essential. The use of stored freeze-frame information can also be very useful when diagnosing an intermittent malfunction if a code has been stored.

MANUFACTURER'S DIAGNOSTIC ROUTINES

Each vehicle manufacturer has established their own diagnostic routines and they should be followed. Most include the following steps:

STEP 1 Retrieve diagnostic trouble codes.

Parameter Identification (PID)

Scan Tool Parameter	Units Displayed	Typical Data Value
Engine Idling/Radiator Hose Hot/Closed Throttle/ Park or Neutral/ Closed Loop/Accessories Off/ Brake Pedal Released		
3X Crank Sensor	RPM	Varies
24X Crank Sensor	RPM	Varies
Actual EGR Position	Percent	0
BARO	kPa/volts	65–110 kPa/3.5-4.5 volts
CMP Sensor Signal Present	Yes/No	Yes
Commanded Fuel Pump	On/Off	On
Cycles of Misfire Data	Counts	0–99
Desired EGR Position	Percent	0
ECT	°C/°F	Varies
EGR Duty Cycle	Percent	0
Engine Run Time	Hr: Min: Sec	Varies
EVAP Canister Purge	Percent	Low and Varying
EVAP Fault History	No Fault/ Excess Vacuum/ Purge Valve Leak/ Small Leak/ Weak Vacuum	No Fault
Fuel Tank Pressure	Inches of H_2O/volts	Varies
HO2S Sensor 1	Ready/ Not Ready	Ready
HO2S Sensor 1	Millivolts	0–1,000 and Varying
HO2S Sensor 2	Millivolts	0–1,000 and Varying
HO2S X Counts	Counts	Varies
IAC Position	Counts	15–25 preferred
IAT	°C/°F	Varies
Knock Retard	Degrees	0
Long-Term FT	Percent	0–10
MAF	Grams per second	3–7
MAF Frequency	Hz	1,200–3,000 (depends on altitude and engine load)
MAP	kPa/volts	20–48 kPa/0.75–2 volts (depends on altitude)
Misfire Current Cyl. 1–10	Counts	0
Misfire History Cyl. 1–10	Counts	0

CHART 85–2

Examples of observed scan tool data.

Scan Tool Parameter	Units Displayed	Typical Data Value
Short-Term FT	Percent	0–10
Start-Up ECT	°C/°F	Varies
Start-Up IAT	°C/°F	Varies
Total Misfire Current Count	Counts	0
Total Misfire Failures	Counts	0
Total Misfire Passes	Counts	0
TP Angle	Percent	0
TP Sensor	Volts	0.20–0.74
Vehicle Speed	mph/km/h	0

Note: Viewing the PID screen on the scanner is useful in determining if a problem is occurring at the present time.

CHART 85–2 continued

STEP 2 Check for all technical service bulletins that could be related to the stored DTC.

STEP 3 If there are multiple DTCs, the diagnostic routine may include checking different components or systems instead of when only one DTC was stored.

STEP 4 Perform system checks.

STEP 5 Perform a road test matching the parameters recorded in the freeze-frame to check that the repair has corrected the malfunction.

STEP 6 Repeat the road test to cause the MIL to be extinguished.

NOTE: Do not clear codes (DTCs) unless instructed by the service information.

Following the vehicle manufacturer's specific diagnostic routines will ensure that the root cause is found and the repair verified. This is important for customer satisfaction.

COMPLETING SYSTEM REPAIRS

After the repair has been successfully completed, the vehicle should be driven under similar conditions that caused the original concern. Verify that the problem has been corrected. To perform this test-drive, it is helpful to have a copy of the freeze-frame parameters that were present when the DTC was set. By driving under similar conditions, the PCM may perform a test of the system and automatically extinguish the MIL. This is the method preferred by most vehicle manufacturers. The DTC can be cleared using a scan tool, but then that means that monitors will have to be run and the vehicle may fail an emissions inspection if driven directly to the testing station.

PROCEDURES FOR RESETTING THE PCM The PCM can be reset or cleared of previously set DTCs and freeze-frame data in the following ways:

1. **Driving the Vehicle.** Drive the vehicle under similar conditions that were present when the fault occurred. If the

conditions are similar and the PCM performed the noncontinuous monitor test and it passed three times, then the PCM will extinguish the MIL. This is the method preferred by most vehicle manufacturers; however, this method could be time consuming. If three passes cannot be achieved, the owner of the vehicle will have to be told that even though the check engine light (MIL) is on, the problem has been corrected and the MIL should go out in a few days of normal driving.

2. **Clear DTCs Using a Scan Tool.** A scan tool can be used to clear the diagnostic trouble code (DTC), which will also delete all of the freeze-frame data. The advantage of using a scan tool is that the check engine (MIL) will be out and the customer will be happy that the problem (MIL on) has been corrected. Do not use a scan tool to clear a DTC if the vehicle is going to be checked soon at a test station for state-mandated emissions tests.
3. **Battery Disconnect.** Disconnecting the negative battery cable will clear the DTCs and freeze-frame on many vehicles but not all. Besides clearing the DTCs, disconnecting the battery for about 20 minutes will also erase radio station presets and other memory items in many cases. Most vehicle manufacturers do not recommend that the battery be disconnected to clear DTCs and it may not work on some vehicles.

ROAD TEST (DRIVE CYCLE)

Use the freeze-frame data and test-drive the vehicle so that the vehicle is driven to match the conditions displayed on the freeze-frame. If the battery has been disconnected, then the vehicle may have to be driven under conditions that allow the PCM to conduct monitor tests. This drive pattern is called a **drive cycle**. The drive cycle is different for each vehicle manufacturer but a universal drive cycle may work in many cases. In many cases, performing a universal drive cycle will reset most monitors in most vehicles.

UNIVERSAL DRIVE CYCLE

Preconditioning: Phase I.

MIL must be off.
No DTCs present.
Fuel fill between 15% and 85%.
Cold start–Preferred = eight – hour soak at 68°F to 86°F.
Alternative = ECT below 86°F.

1. With the ignition off, connect scan tool.
2. Start engine and drive between 20 and 30 mph for 22 minutes, allowing speed to vary.
3. Stop and idle for 40 seconds, gradually accelerate to 55 mph.
4. Maintain 55 mph for 4 minutes using a steady throttle input.
5. Stop and idle for 30 seconds, then accelerate to 30 mph.
6. Maintain 30 mph for 12 minutes.
7. Repeat steps 4 and 5 four times.

Using scan tool, check readiness. If insufficient readiness set, continue to universal drive trace phase II.

Important: (Do not shut off engine between phases). Phase II:

1. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 30 mph.
2. Maintain 30 mph for 22 minutes.
3. Repeat steps 1 and 2 three times.
4. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 35 mph.
5. Maintain speed between 30 and 35 mph for 4 minutes.
6. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 30 mph.
7. Maintain 30 mph for 22 minutes.
8. Repeat steps 6 and 7 five times.
9. Using scan tool, check readiness.

TECH TIP

The Brake Pedal Trick

If the vehicle manufacturer recommends that battery power be disconnected, first disconnect the negative battery cable and then depress the brake pedal. Because the brake lights are connected to battery power, depressing the brake pedal causes all of the capacitors in the electrical system and computer(s) to discharge through the brake lights.

TECH TIP

Drive the Light Out

If working on a vehicle that is subject to state emissions testing, it is best to not clear codes. When diagnostic trouble codes are cleared, all of the monitors have to be rerun and this can be a time-consuming job. Instead of clearing the code, simply drive the vehicle until the PCM clears the code. This will likely take less time compared to trying to drive the vehicle under varying conditions to run all of the monitors.

REVIEW QUESTIONS

1. Explain the procedure to follow when diagnosing a vehicle with stored DTCs using a scan tool.
2. Discuss what the PCM does during a drive cycle to test emissions-related components.
3. Where is the DLC typically located?
4. List three things that should be checked as part of a thorough visual inspection.
5. Explain why a bulletin search should be performed after stored DTCs are retrieved.

CHAPTER QUIZ

1. Technician A says that the first step in the diagnostic process is to verify the problem (concern). Technician B says the second step is to perform a thorough visual inspection. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. Which item is *not* important to know before starting the diagnosis of an engine performance problem?
   - **a.** List of previous repairs
   - **b.** The brand of engine oil used
   - **c.** The type of gasoline used
   - **d.** The temperature of the engine when the problem occurs
3. After completing repairs the technician should perform a ___________ to allow the PCM to conduct monitor tests.
   - **a.** battery disconnect
   - **b.** DTC survey
   - **c.** drive cycle
   - **d.** fuel mileage test
4. Which step should be performed *last* when diagnosing an engine performance problem?
   - **a.** Checking for any stored diagnostic trouble codes
   - **b.** Checking for any technical service bulletins (TSBs)
   - **c.** Performing a thorough visual inspection
   - **d.** Verifying the repair
5. Technician A says that if the opposite DTC can be set, the problem is the component itself. Technician B says if the opposite DTC cannot be set, the problem is with the wiring or grounds. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. The preferred method to clear diagnostic trouble codes (DTCs) is to ___________.
   - **a.** disconnect the negative battery cable for 10 seconds
   - **b.** use a scan tool
   - **c.** remove the computer (PCM) power feed fuse
   - **d.** cycle the ignition key on and off 40 times
7. Which is the factory scan tool for Chrysler brand vehicles?
   - **a.** wiTECH
   - **b.** Tech 2
   - **c.** NGS
   - **d.** Master Tech
8. Which of these is *not* part of a visual inspection?
   - **a.** Check oil level
   - **b.** Check coolant condition
   - **c.** Check battery voltage
   - **d.** Check DTCs
9. Technician A says that knowing if there are any stored diagnostic trouble codes (DTCs) may be helpful when checking for related technical service bulletins (TSBs). Technician B says that only a factory scan tool should be used to retrieve DTCs. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. To help the technician verify the customer's concern, a ___________ should be used.
    - **a.** scope
    - **b.** diagnosis worksheet
    - **c.** vibration monitor
    - **d.** digital camera

SECTION X

EV AND HEV (L3)

CHAPTERS

86 Hybrid and Electric Vehicle Safety
87 Introduction to Electric and Hybrid Electric Vehicles
88 Hybrid and Electric Vehicle Maintenance
89 EV And HEV High-Voltage Batteries
90 EV And PHEV Charging
91 Regenerative Brakes
92 Fuel Cells and Advanced Technologies

Chapter 86

HYBRID AND ELECTRIC VEHICLE SAFETY

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss high-voltage safety, electric shock potential, and EV/HEV service areas.
- Discuss electric shock potential.
- Discuss EV/HEV service areas.
- Describe the personal protective equipment (PPE) recommended for working on EV/HEV systems.
- Explain the tools and equipment needed for working on high-voltage electrical systems.
- Explain the purpose of the safety interlock system.
- Describe the process for depowering the high-voltage system.
- Discuss precautions that are needed when hoisting an EV/HEV in the shop.
- Discuss precautions that are needed when moving an EV/HEV in the shop.

KEY TERMS:

Acoustic vehicle alerting system (AVAS) 1003 • American National Standards Institute (ANSI) 999 • American Society for Testing and Materials (ASTM) 999 • Category three (CAT III) 1001 • Digital multimeter (DMM) 1001 • High voltage (HV) 996 • International Electrotechnical Commission (IEC) 1001 • Occupational Safety and Health Administration (OSHA) 999 • System main relays (SMRs) 998

HIGH-VOLTAGE SAFETY

NEED FOR CAUTION Electrical systems have been used on vehicles for more than a century. Technicians have been repairing vehicle electrical systems without fear of serious injury or electrocution. However, when working with electric or hybrid electric vehicles, this is no longer true. It is now possible to be seriously injured or electrocuted (killed) if proper safety procedures are not followed.

Electric and hybrid electric vehicles use **high-voltage (HV)** circuits that if touched with an unprotected hand could cause serious burns or even death.

PRECAUTIONS FOR ELECTRONIC MEDICAL DEVICES

- Electronic medical devices include cardiac pacemakers and cardioverter defibrillators.
- Technicians who rely on cardiac pacemakers should not service or repair electric or hybrid electric vehicles because of strong magnetic fields.
- Technicians who rely on implanted cardiac pacemakers or implanted cardioverter defibrillators should check with the manufacturer of the device before being in or around a charging vehicle.

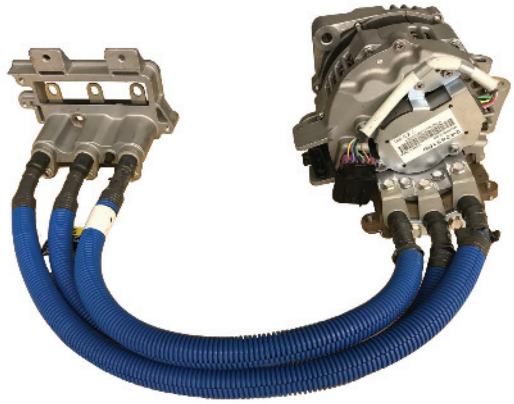


FIGURE 86–1A When the belt starter alternator assembly is installed, the three blue cables run between the inverter assembly and the alternator.

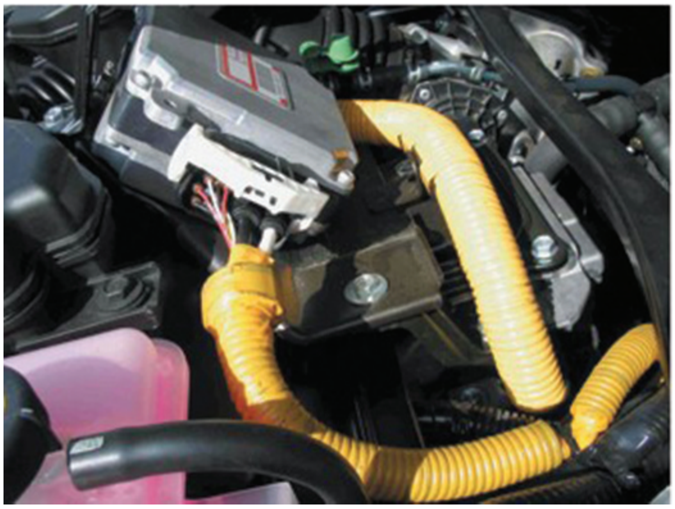


FIGURE 86–1B The yellow cable is part of the electric power steering system on a Toyota/Lexus vehicle.

IDENTIFYING HIGH-VOLTAGE CIRCUITS HV components are identified with warning labels. HV cables are identified by color of the plastic conduit and are indicated by the following colors:

- **Blue or yellow**—Up to 60 volts (not a shock hazard, but an arc will be maintained if a circuit is opened). ● **SEE FIGURE 86–1A AND 86–1B**.
- **Orange**—Above 60 volts. ● **SEE FIGURE 86–2**.

Follow all precautions when working on or near HV wiring or components.

ELECTRIC SHOCK POTENTIAL

LOCATIONS WHERE SHOCK CAN OCCUR Accidental and unprotected contact with any electrically charged ("hot" or "live") HV component can cause serious injury or death. However, receiving an electric shock from a hybrid vehicle is highly unlikely because of the following:

1. Contact with the battery module or other components inside the battery box can occur only if the box is damaged and the

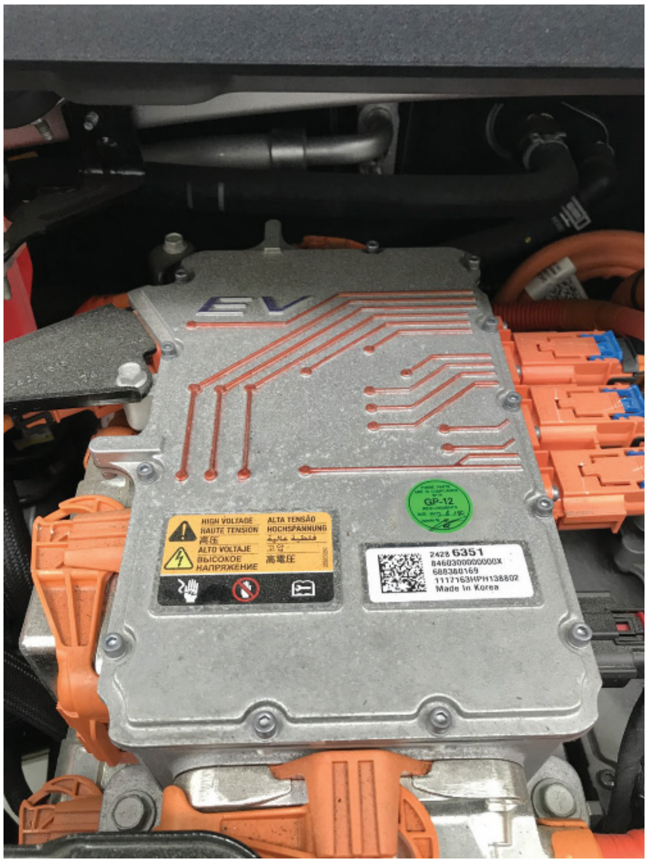


FIGURE 86–2 The orange cables connect to the high power distribution module (HPDM) on the Chevrolet Bolt.

FREQUENTLY ASKED QUESTION

How Much Current Is Too Much?

Low voltage, such as the 12–14 volts used in conventional vehicles, does not represent a shock hazard and it is safe to handle. The only concern would be a possible burn could occur if a 12-volt wire were to touch ground causing the wiring to overheat. Voltages between 14 and 60 volts do not present a shock hazard, but an arc can occur if a connector carrying current is opened. High voltage, over 60 volts, does create a shock hazard and all precautions must be adhered to prevent personal injury. Typical current and how it affects the body are given as follows:

- 1 milliamp—May be noticeable as a slight tingle.
- 2–5 milliamps—May be noticeable as a light shock forcing the technician to let go.
- 6–25 milliamps—Noticed by pain and the technician cannot let go of the wires or component.
- 26–150 milliamps—Severe pain and possibly fatal.
- 1,000 milliamps—One ampere across the heart can stop the heart (fatal).

Also, always wear HV gloves for protection whenever working on or near a potential HV circuit or component. To help prevent an electric current from flowing through the body, always place one hand in a pocket and use only one hand when measuring a potential HV circuit or disconnecting a potential HV circuit.

contents are exposed, or the box is opened without following proper precautions.

2. Contact with the electric motor can occur only after one or more components are removed.
3. The HV cables can be easily identified by their distinctive orange color, and contact with them can be avoided.
4. The **system main relays (SMRs)** or contactors disconnect power from the cables the moment the ignition is turned off.

ELECTRIC VEHICLES IN THE SERVICE AREA

For a safe working environment:

- Be sure the work area is clean and dry.
- Care should be taken that HV warnings and safety cones are posted.
- Additional precautions, such as a roof cone or warning tape, are also recommended.

They are used to establish a safety zone around the vehicles so that other technicians will know that a possible shock hazard may be present. ● **SEE FIGURE 86–3.**

TECH TIP

Silence Is NOT Golden

Never assume the vehicle is shut off just because the engine is off. When working with a hybrid electric vehicle, always look for the READY indicator status on the dash display. The vehicle is shut off when the READY indicator is off.

The vehicle may be powered by

1. The electric motor only.
2. The gasoline engine only.
3. A combination of both the electric motor and the gasoline engine.

The vehicle computer determines the mode in which the vehicle operates to improve fuel economy and reduce emissions. The driver cannot manually select the mode. ● **SEE FIGURE 86–4.**

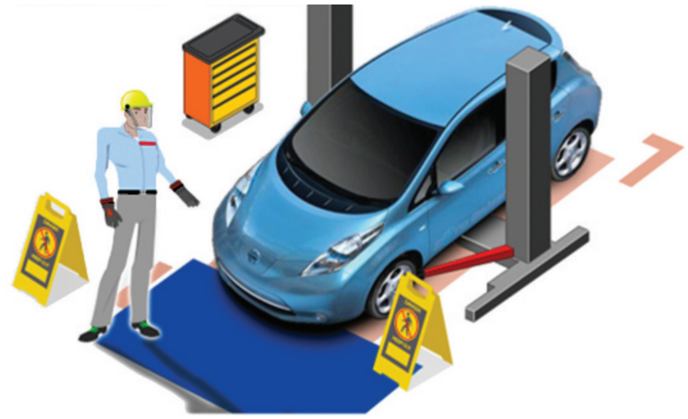


FIGURE 86–3 A clearly defined safety zone needs to be established in the area where a hybrid or electric vehicle is being repaired.

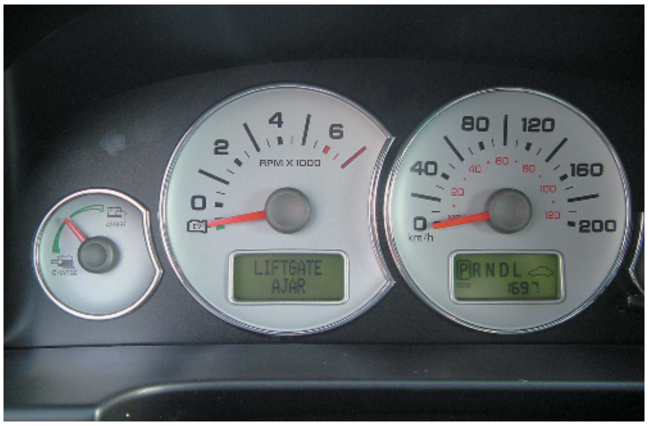


FIGURE 86–4 The Ford Escape Hybrid instrument panel showing the vehicle in park and the tachometer on "EV" instead of 0 RPM. This means the gasoline engine could start at any time depending on the state of charge of the HV battery and other factors.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

EYE PROTECTION Eye protection should be worn when testing for high voltage, which is considered by many experts to be over 60 volts. Eye protection should include the following features:

1. Plastic frames (Avoid metal frames as these are conductive and could cause a shock hazard.)
2. Side shields
3. Meet the standard ANSI Z87.1

NOTE: Some vehicle manufacturers specify that full-face shields be worn instead of safety glasses when working with HV circuits or components. ● **SEE FIGURE 86–5.**

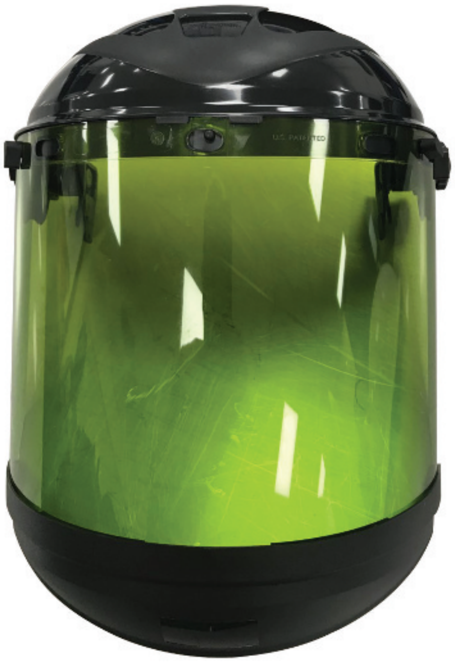


FIGURE 86–5 Safety glasses or a full-face shield similar to the items depicted must be worn when testing for the presence of high voltage.

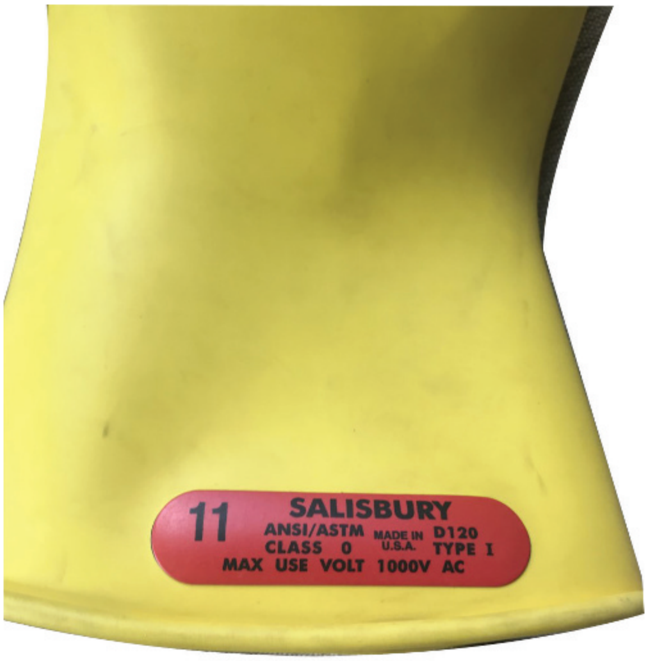


FIGURE 86–6 The gloves should be clearly marked indicating that they are class “0” and rated for 1,000 volts.

HIGH-VOLTAGE GLOVES Before working on the HV system of a hybrid electric vehicle, ensure that HV lineman’s gloves are available. Be sure that the gloves are rated at least 1,000 volts and class “0” by ANSI/ASTM. ● **SEE FIGURE 86–6**. The **American National Standards Institute (ANSI)** is a private, nonprofit organization that administers and coordinates the U.S. voluntary standardization and conformity assessment system. ANSI International, originally known as the **American Society for Testing and Materials (ASTM)**, was formed over a century ago to address the need for component testing in industry. The **Occupational Safety and Health Administration (OSHA)** requirements specify that the HV gloves get inspected every six months by a qualified glove inspection laboratory. Do not use gloves on which the expiration date has expired. Inspect the gloves carefully before each use. High voltage and current (amperes) in combination are fatal.

Before using the rubber gloves, they should be tested for leaks using the following procedure:

1. Roll the glove up from the open end until the lower portion of the glove begins to balloon from the resulting air pressure. Make sure to “lean” into the sealed glove to raise the internal air pressure. If the glove leaks any air, discard the gloves. ● **SEE FIGURE 86–7**.
2. An approved electric glove inflator can also be used to test the gloves before use. ● **SEE FIGURE 86–8**.
3. The gloves should not be used if they show any signs of wear and tear.

WARNING

Do not use shop air to test HV gloves. The high air pressure will damage the gloves and lead to a lack of personal protection against high voltage.

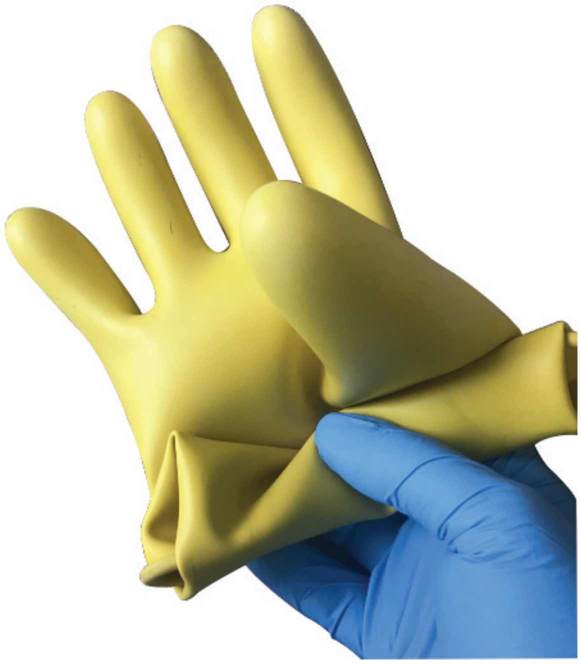


FIGURE 86–7 The glove is rolled up on the open end to check for air pressure and any air leakage.

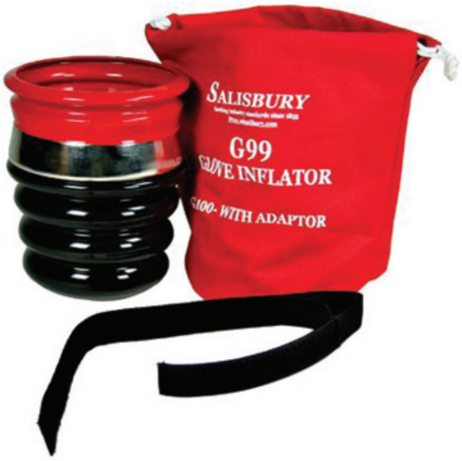


FIGURE 86–8 An electric glove inflator similar to this may be used for testing.

LEATHER PROTECTORS Use an outer leather glove to protect the HV rubber gloves. Be sure the rubber lineman’s glove extends at least 50 mm beyond the leather protector. The leather gloves should be clean and free of any material that might puncture the lineman’s glove or conduct electricity. ● **SEE FIGURE 86–9**.

SHOP UNIFORM Some manufacturers recommend arc flash clothing or long sleeve, 100% cotton clothing that is tucked into the gloves when working on HV components. Remove all jewelry, rings, watches, and bracelets before working on the vehicle.

INSULATED SHOES OR BOOTS Some manufacturers recommend the use of insulated boots or shoes to protect against exposure to high voltage. These are particularly useful in areas where water, oil, and other substances cannot be wiped off the floor. ● **SEE FIGURE 86–10**.

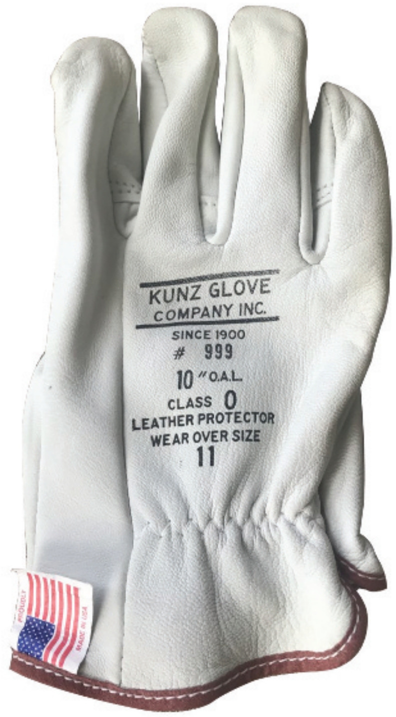

KUNZ GLOVE
COMPANY INC.
SINCE 1900
# 999
10" O.A.L.
CLASS 0
LEATHER PROTECTOR
WEAR OVER SIZE
11

FIGURE 86–9 Clean leather gloves must be used to protect the HV rubber gloves.

Insulated shoes
SAFETY SHOES

FIGURE 86–10 The sole of this shoe is designed to prevent the transfer of electrical current.

INSULATED RUBBER MATS AND BLANKETS Insulated rubber mats are placed on the floor when there is an exposure to high voltage. Insulated blankets are placed over the battery or other HV components after removal and during disassembly. ● **SEE FIGURE 86–11**.

FIRE EXTINGUISHERS Use ONLY a Class C fire extinguisher rated for electrical fires. An ABC-rated fire extinguisher may be used if a Class C is not available. ● **SEE FIGURE 86–12**.

OTHER PERSONAL PROTECTION EQUIPMENT Some manufacturers recommend that a 10-foot insulated fiberglass pole be available outside the safety zone to be used to pull a technician away from the vehicle in the unlikely event of an accident where the technician is shocked or electrocuted. Other manufacturers require a second set of safety equipment be available.

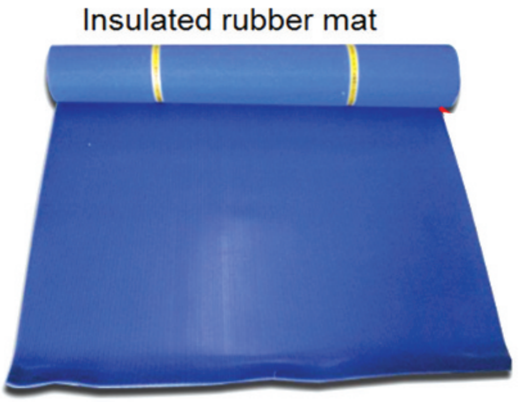

Insulated rubber mat

FIGURE 86–11 Some work locations require the use of insulated rubber mats in the work area.

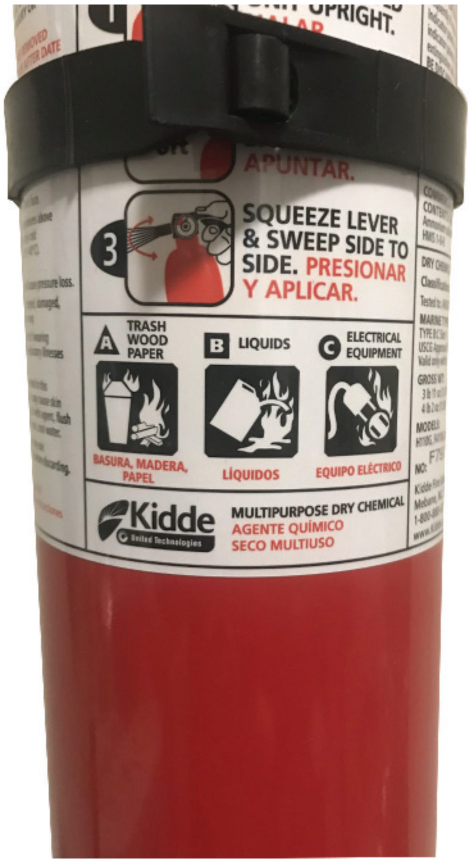

UPRIGHT.
APUNTAR.
3
SQUEEZE LEVER & SWEEP SIDE TO SIDE. PRESIONAR Y APLICAR.
A TRASH WOOD PAPER
B LIQUIDS
C ELECTRICAL EQUIPMENT
BASURA, MADERA, PAPEL
LÍQUIDOS
EQUIPO ELÉCTRICO
Kidde
MULTIPURPOSE DRY CHEMICAL
AGENTE QUÍMICO
SECO MULTIUSO

FIGURE 86–12 Make sure a proper fire extinguisher is available in the work area.

FREQUENTLY ASKED QUESTION

Is the Radiation from a Hybrid Dangerous?

No. While there is a changing magnetic field surrounding any wire carrying an electrical current, the amount of electromagnetic radiation is very low. ● **SEE FIGURE 86–13**.

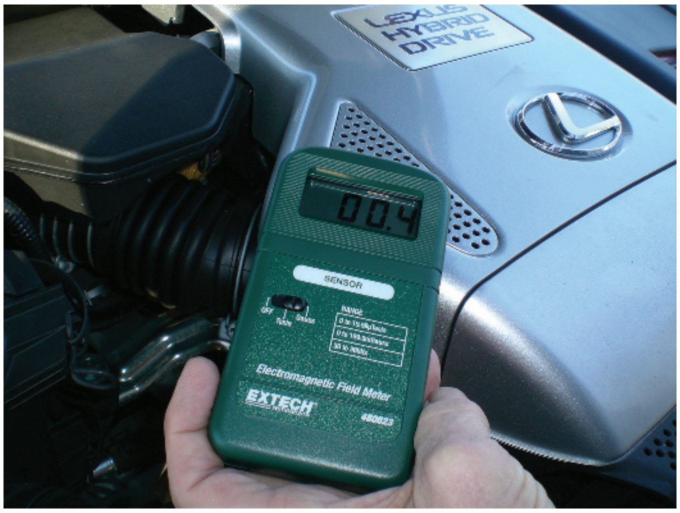


FIGURE 86–13 The radiation emitted from a hybrid electric vehicle is very low and is being measured in units of milligauss.

HIGH-VOLTAGE TOOLS AND EQUIPMENT

CAT-III RATED DIGITAL MULTIMETER Hybrid and electric vehicles are equipped with electrical systems whose voltages can exceed 600 volts DC. A **category three (CAT III)**-certified **digital multimeter (DMM)** is required for making measurements on these high-voltage systems.

The **International Electrotechnical Commission (IEC)** has several categories of voltage standards for meter and meter leads. These categories are ratings for over voltage protection and are rated CAT I, CAT II, CAT III, and CAT IV. The higher the category (CAT) rating of the meter, the greater the level of protection to the technician when measuring high-energy voltage. Under each category, there are various voltage ratings.

- **CAT I**—Typically a CAT I meter is used for low-voltage (LV) measurements, such as voltage measurements at wall outlets in the home. Meters with a CAT I rating are usually rated at 300–800 volts. CAT I is for relatively low-energy levels. While the voltage level is high enough for use when working on a hybrid electric vehicle, the protective energy level is lower than what is needed.
- **CAT II**—A CAT II meter is a higher-rated meter that would be typically used for checking voltages at the circuit-breaker panel in the home. Meters with a CAT II rating are usually rated at 300–600 volts. CAT II-rated meters have similar voltage ratings as the other CAT ratings, but the energy level of protection is higher with a CAT II compared to a CAT I.
- **CAT III**—CAT III is the minimum-rated meter that should be used for hybrid and electric vehicles. Meters with a CAT III rating are usually rated at 600–1,000 volts and the highest energy level that is needed to protect the service technician. ● **SEE FIGURES 86–14 AND 86–15.**
- **CAT IV**—CAT IV meters are for clamp-on meters only. A clamp-on meter is used to measure current (amperes) in a circuit by placing the clamp around the wire carrying the current. If a clamp-on meter also has meter leads for voltage measurements, that part of the meter will be rated as CAT III.

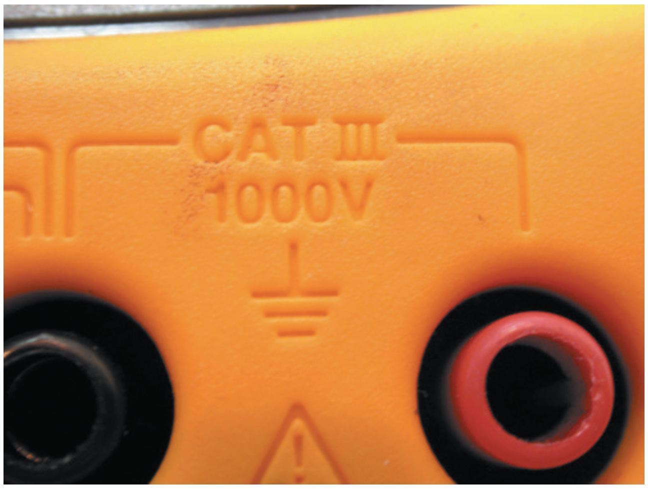


FIGURE 86–14 Use only a meter that is CAT III rated when making electrical measurements on an electric or hybrid electric vehicle.

FIGURE 86–15 The meter leads should also be CAT III rated when checking voltages on an electric or hybrid electric vehicle.

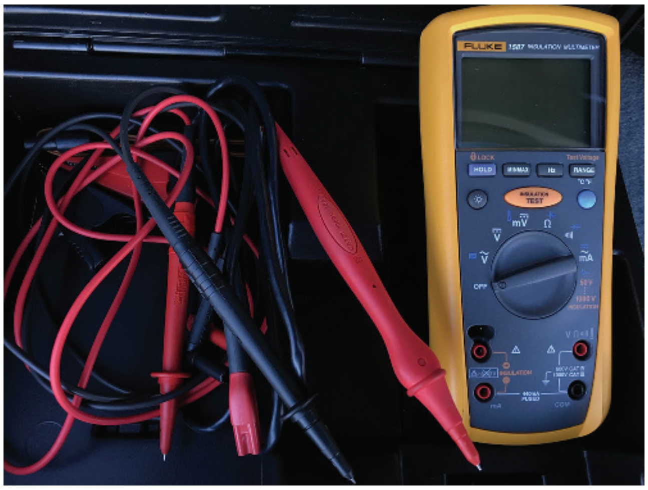


FIGURE 86–16 The Fluke 1587 is an example of an insulation tester that is able to test the HV circuit insulation to 1,000 volts. The resistance between the HV circuit and ground should be higher than one million ohms (1.0–22.2 MΩ).

MEGOHMMETER (INSULATION TESTER) A megohmmeteror insulation tester is used to check for continuity between the HV cables and the vehicle chassis. It contains an internal DC–DC converter that allows for the continuity test to occur at a much higher voltage than a conventional ohmmeter. ● **SEE FIGURE 86–16.**

INSULATED HAND TOOLS Although they are not required by all manufacturers, insulated tools such as a ratchets, extensions, sockets, pliers, and screwdrivers provide an additional margin of safety to the service technician when working around HV components and systems. ● **SEE FIGURE 86–17.**

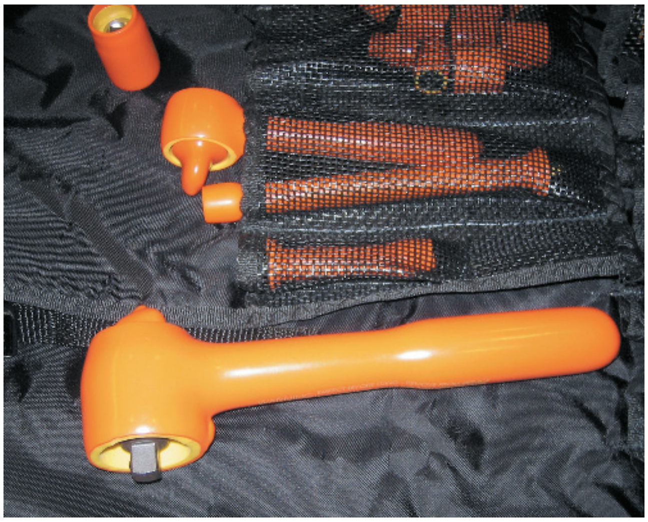


FIGURE 86–17 Insulated tools, such as this socket set, provide an additional margin of safety to the service technician when working around HV components and systems.

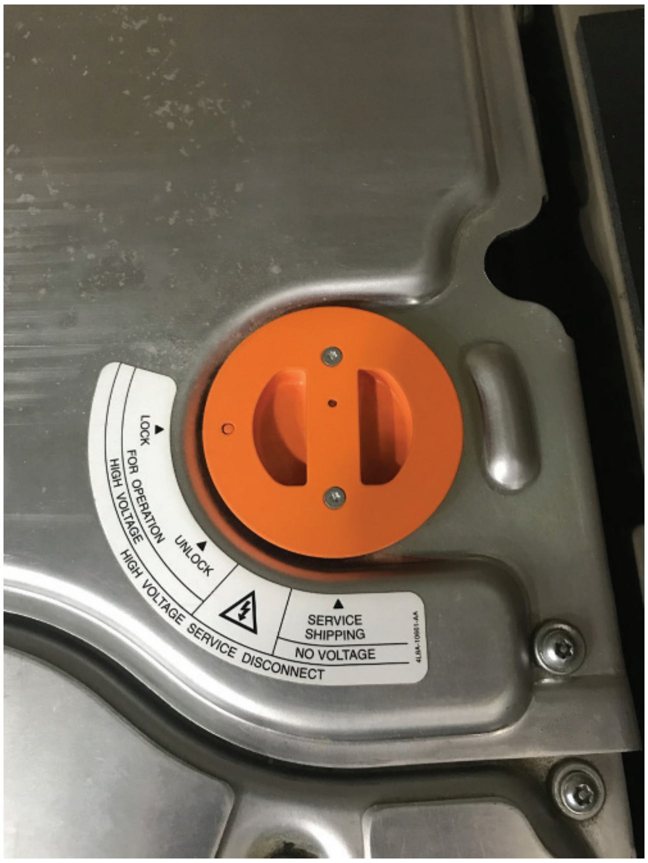


FIGURE 86–18 The manual disconnect on this Ford battery contains a fuse and safety interlock.

SAFETY INTERLOCK SYSTEM

PURPOSE AND FUNCTION The HV system uses contactors or heavy-duty relays to detect opens in the HV circuits.

This is a safety system that keeps the power circuits from closing with an open HV circuit. The manual safety disconnect switch protects the HV battery pack, and it includes a safety interlock switch that uses two small terminals. With an open detected, the HV controller does the following to keep the vehicle safe. ● **SEE FIGURE 86–18.**

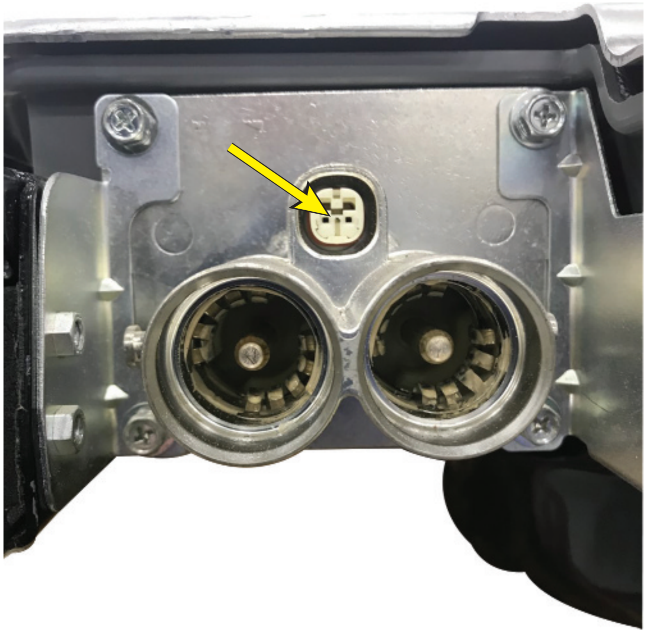


FIGURE 86–19 The small white connector is the local interlock on the HV connection to the battery.

- On a hybrid vehicle, if the engine is running, it will detect a fault and set a diagnostic trouble code (DTC). It also opens the power relays, turning off the “ready” light.
- If the hybrid vehicle is moving, it will allow it to continue until a stop, and will disable the internal combustion engine (ICE).
- If the hybrid vehicle is not moving, it will disable the ICE immediately.
- On an electric vehicle, the HV system will be depowered.

LOCAL INTERLOCK A local interlock is an LV circuit that uses separate switches and contacts to detect when there has been an open in LV circuits or components that are associated with the HV system. The local interlock can detect the removal of items such as covers, battery disconnects, air-conditioning compressors, or any other component that is associated with an HV circuit. ● **SEE FIGURE 86–19**. If an open has been detected, the controller (ECM) signals the hybrid controller to open the contactors or power relays and discharge the HV capacitors.

DEPOWERING THE HIGH-VOLTAGE SYSTEM

THE NEED TO DEPOWER THE HIGH-VOLTAGE SYSTEM During routine vehicle service work, there is no need to go through any procedures needed to depower or shut off the HV circuits. However, if work is going to be performed on any of the following components, service information procedures must be followed to prevent possible electrical shock and personal injury:

- The HV battery pack
- Any of the electronic controllers that use orange cables, such as the inverter and converters
- The air-conditioning compressor, if electrically driven, and has orange cables attached

ABUS
SAFETY REDBOX™
FOR LOCKOUT

FIGURE 86–20 A lock box is a safe location to keep the ignition keys of a hybrid or electric vehicle while it is being worked on.

To safely depower the vehicle, always follow the instructions found in service information for the exact vehicle being serviced. The steps usually include the following:

STEP 1 Turn the ignition off and remove the key (if equipped) from the ignition and store it in a lock box to prevent accidental starting. ● **SEE FIGURE 86–20**.

CAUTION: If a push-button start is used, remove the key fob at least 15 feet (5 meters) from the vehicle to prevent the vehicle from being powered on. With the key fob out of the vehicle, attempt to start the vehicle to confirm no other key fobs are present in the vehicle.

STEP 2 Remove the 12-volt power source to the HV controller and wait 10 minutes for all capacitors to discharge. This step could involve

- Removing a fuse or a relay
- Disconnecting the negative battery cable from the auxiliary 12-volt battery

STEP 3 Remove the HV fuse or service plug or switch.

STEP 4 Confirm there is no HV power present before beginning the repair.

HOISTING A HYBRID OR ELECTRIC VEHICLE

When hoisting or using a floor jack, refer to the manufacturer's service information for proper lift points. ● **SEE FIGURE 86–21**. Orange cables run under the vehicle just inside the frame rails on most hybrid and electric vehicles. The battery for many electric vehicles is underneath the vehicle and can be easily damaged by a hoist. In addition to the electrical circuits, many electric vehicles use coolant or refrigerant to maintain the temperature of the battery. Caution should be used to avoid damaging these lines. Some Honda hybrid vehicles use an aluminum pipe painted orange that includes three HV cables for the starter/generator and also three more cables for the HV air-conditioning compressor. If any damage occurs to any HV cables, the malfunction indicator Lamp (MIL) will light up and a no-start will result if the powertrain control module (PCM) senses a fault. The cables are not repairable and are expensive. The cables can be identified by an orange outer casing, but in some cases, the orange casing is not exposed until a black plastic underbelly shield is removed first.

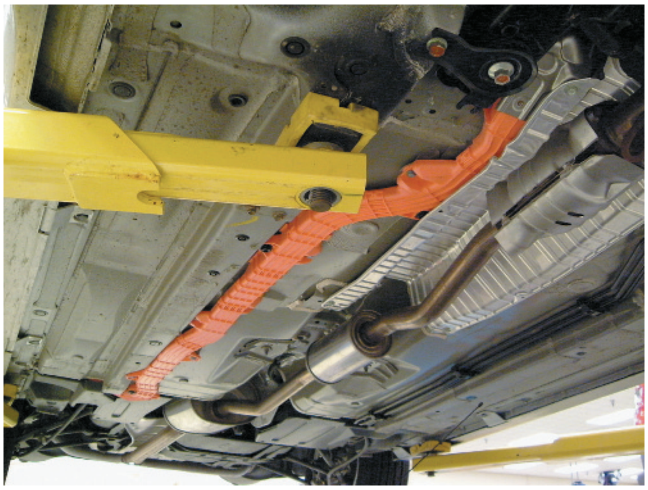


FIGURE 86–21 The HV wiring on this Honda hybrid is colored orange for easy identification.

MOVING A HYBRID OR ELECTRIC VEHICLE AROUND THE SHOP

After a hybrid or electric vehicle has been serviced, it may be necessary to push the vehicle to another part of the shop or outside as parts are ordered. Make sure to tape any orange HV cable ends that were disconnected during the repair procedure. Permanent magnets are used in all the drive motors and generators and it is possible that an HV arc could occur as the wheels turn and produce voltage. Another way to prevent this is to use wheel dollies. A sign that says "HIGH VOLTAGE–DO NOT TOUCH" could also be added to the roof of the vehicle or across the steering wheel. Remove the keys from the vehicle and keep in a safe location.

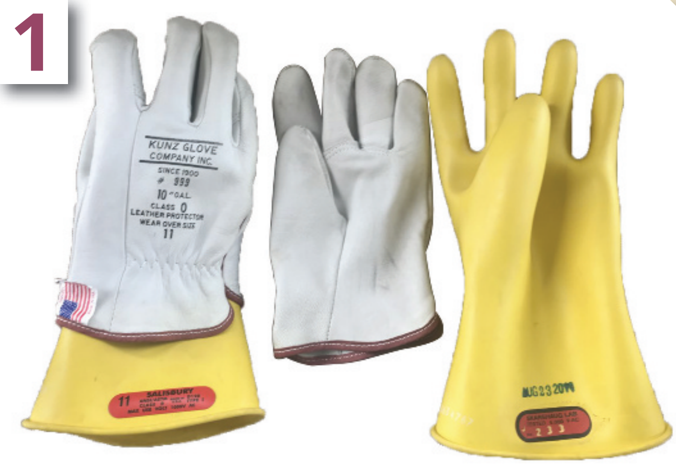
FREQUENTLY ASKED QUESTION

What Is That Sound?

Electric vehicles and most hybrid electric vehicles emit a sound through a speaker in the front at low speeds to warn pedestrians that a moving vehicle is nearby. This system is called **acoustic vehicle alerting system (AVAS)**. It creates the sound whenever the vehicle is traveling at low speed. The U.S. National Highway Traffic Safety Administration (NHTSA) requires the device to emit warning sounds when travelling at speeds less than 19 MPH (30 km/h) with compliance by September 2020. While easily heard from outside the vehicle, it is usually not heard inside the vehicle unless the windows are down. Some customers ask their service technician to disable this system, but it is a safety device and could help prevent personal injury if someone were to step in front or back of a moving vehicle that is almost silent.

HIGH-VOLTAGE GLOVE PHOTO SEQUENCE

1

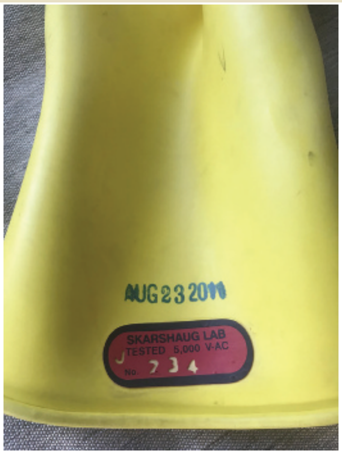

KUNZ GLOVE
COMPANY INC.
SINCE 1900
# 999
10" GAL.
CLASS 0
LEATHER PROTECTOR
WEAR OVER SIZE
11

The cuff of the rubber glove should extend at least 1/2 inch beyond the cuff of the leather protector.

2

To determine the correct glove size, use a soft tape measure around the palm of the hand. A measurement of 9 inches would correspond with a glove size of 9.

3

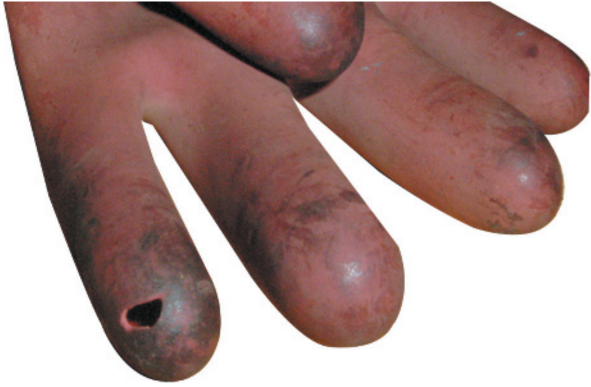

SKARSHAUG LAB
TESTED 5,000 V-AC
No. 2 3 4

The glove rating and the date of the last test should be stamped on the glove cuff.

4

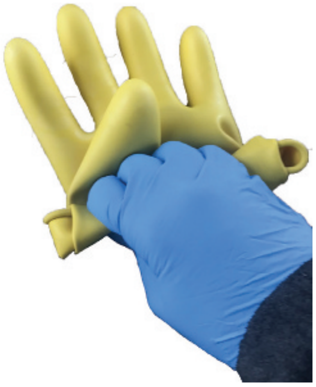
Start a visual inspection of the glove fingertips, making sure that no cuts or other damages are present.

5



The damage on this glove was easily detected with a simple visual inspection. Note that the rubber glove material can be damaged by petroleum products, detergents, certain hand soaps, and talcum powder.

6



Manually inflate the glove to inspect for pinhole leaks. Starting at the cuff, roll up the glove and trap air in the finger end. Listen and carefully watch for deflation of the glove. If a leak is detected, the glove must be discarded.

STEP BY STEP

7

Petroleum on the leather protector’s surface will damage the rubber glove underneath.

8

TEN-FOUR®
GLOVE
DUST
SALISBURY

Glove powder (glove dust) should be used to absorb moisture and reduce friction.

9

Put on the gloves and tighten the straps on the back of the leather protectors (if equipped).

10

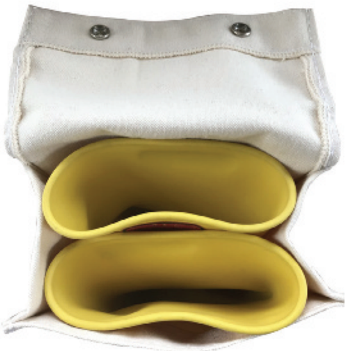
Technicians MUST wear HV gloves whenever working around the HV areas of a hybrid or electric vehicle.

11

ALWAYS
WEAR
YOUR

HV gloves should be placed in a canvas storage bag when not in use. Note the ventilation hole at the bottom of this bag.

12



Make sure the rubber gloves are not folded when placed in the canvas bag. Folding increases mechanical stress on the rubber and can lead to premature failure of the glove material.

REVIEW QUESTIONS

1. What actions are needed to disable the high-voltage (HV) circuit?
2. What are the personal safety precautions that service technicians should adhere to when servicing hybrid or electric vehicles?
3. What are the recommended tools and equipment that should be used when working on the HV circuits of a hybrid or electric vehicle?
4. What precautions should be taken when hoisting a hybrid or electric vehicle?
5. When should the HV system be depowered?

CHAPTER QUIZ

1. Rubber gloves should be worn whenever working on or near the HV circuits or components of a hybrid electric vehicle. Technician A says that the rubber gloves should be rated at 1,000 volts or higher. Technician B says that leather gloves should be worn over the HV rubber gloves. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. A CAT III-certified DMM should be used whenever measuring HV circuits or components. The CAT III rating relates to __________.
   - **a.** high voltage
   - **b.** high energy
   - **c.** high electrical resistance
   - **d.** both high energy and high voltage
3. All of the following will shut off the high voltage to components and circuits *except* __________.
   - **a.** opening the driver's door
   - **b.** turning off the ignition
   - **c.** disconnecting the auxiliary 12-volt battery
   - **d.** removing the main fuse, relay, or HV plug
4. What can occur if a hybrid electric vehicle is pushed in the shop?
   - **a.** The HV battery pack can be damaged.
   - **b.** The tires will be locked unless the ignition is on.
   - **c.** Damage to the electric control will occur.
   - **d.** High voltage will be generated by the motor/generator as the wheels turn.
5. When hoisting a hybrid or electric vehicle, what precautions must the technician follow to ensure personal safety and avoid damage to the vehicle?
   - **a.** Make sure the lift points do not contact HV cables.
   - **b.** Do not lift the vehicle by the battery case.
   - **c.** Ensure the lift points are clear of battery cooling and refrigeration lines.
   - **d.** All of the above are correct.
6. When does the HV system *not* need to be depowered?
   - **a.** When removing the HV battery pack
   - **b.** When performing routine service
   - **c.** When replacing the HV cables
   - **d.** When replacing the HV air-conditioning compressor
7. What will occur if the safety interlock system detects an open circuit on a hybrid vehicle?
   - **a.** If the engine is running, it will detect a fault and set a DTC. It also opens the power relays, turning off the "ready" light.
   - **b.** If the vehicle is moving, it will allow it to continue until a stop, and will disable the ICE.
   - **c.** If the vehicle is not moving, it will disable the ICE immediately.
   - **d.** All of the above are correct.
8. What precautions need to be taken to ensure the hybrid or electric vehicle work area is safe?
   - **a.** The area should be clean and dry.
   - **b.** The work area should be clearly marked.
   - **c.** No special precautions are needed.
   - **d.** The area should be clean and dry and clearly marked.
9. What is the purpose of a megohmmeter or insulation tester?
   - **a.** To check for continuity between the HV cables and the vehicle chassis
   - **b.** To measure the resistance of connections in the LV system
   - **c.** To measure the current flow through the HV cables
   - **d.** None of the above is correct.
10. What should be done if the HV rubber gloves inspection dates are found to be expired?
    - **a.** Use them anyway if they look ok.
    - **b.** Use them if they pass the air test.
    - **c.** Send them to a qualified inspection laboratory.
    - **d.** Throw the gloves away.

Chapter

87

INTRODUCTION TO ELECTRIC AND HYBRID ELECTRIC VEHICLES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Define terms related to hybrid electric vehicles.
- Define terms related to electric vehicles.
- Explain the history of hybrid and electric vehicles.
- Compare the efficiency of electric motors to internal combustion engines.
- Describe the unique characteristics of owning or driving a hybrid or electric vehicle.
- Discuss the levels of hybrid vehicles.
- Describe the different powertrain configurations in a hybrid vehicle.
- Explain the differences between one-, two-, and three-motor systems.
- Compare the advantages and disadvantages of electric vehicles.

KEY TERMS:

Battery electric vehicles (BEV) 1008 • Electric vehicle (EV) 1007 • Hybrid electric vehicle (HEV) 1007 • Internal combustion engine (ICE) 1007 • Medium hybrid 1012 • Micro hybrid 1011 • Mild hybrid 1011 • One-pedal driving 1010 • Phone as a Key (PAAK) 1007 • Plug-in hybrid electric vehicle (PHEV) 1007 • Range anxiety 1010 • Strong hybrid 1012

HYBRID ELECTRIC VEHICLES

DEFINITION OF TERMS A hybrid vehicle is one that uses two different methods to propel the vehicle. A **hybrid electric vehicle (HEV)** uses both an internal combustion engine and an electric motor to propel the vehicle. Most hybrid vehicles use a high-voltage battery pack and a combination electric motor and generator to help or assist a gasoline engine. The **internal combustion engine (ICE)** used in a hybrid vehicle can be either gasoline or diesel, although only gasoline-powered engines are currently used in hybrid vehicles. An electric motor is used to help propel the vehicle, and in some designs, it is capable of propelling the vehicle alone without having to start the ICE.

FREQUENTLY ASKED QUESTION

What Is Meant by "Phone as a Key (PAAK)"?

Many hybrid electric and electric vehicles, as well as some regular (ICE) vehicles, can be controlled using a smart phone application (app). This control of the vehicle, including remote start from the smart phone, is referred to as **Phone as a Key (PAAK)**. There are apps for using a smart watch as a key, which makes it very convenient to start and unlock a vehicle using just the smart watch.

A **plug-in hybrid electric vehicle (PHEV)** is an HEV with a larger capacity battery that can be recharged by the ICE or by plugging it into an AC power source or charging station. A PHEV can drive in electric-only mode for up to 40 miles on some vehicles.

ELECTRIC VEHICLES

DEFINITION OF TERMS An **electric vehicle (EV)**, also referred to as an electric drive vehicle, uses one or more electric motors to propel the vehicle. Electricity is used as the transportation fuel to power the EV. The electrical energy is typically stored in an energy storage device, such as a battery. The electrical energy is replenished by connecting to an electrical source, usually stationary. The Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) define an EV as a zero-emission vehicle. ● **SEE FIGURE 87–1**.

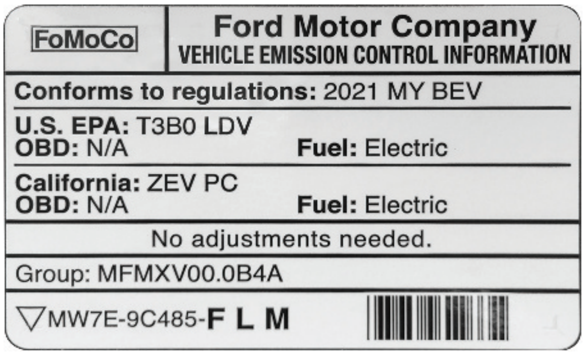

FoMoCo
Ford Motor Company
VEHICLE EMISSION CONTROL INFORMATION
Conforms to regulations: 2021 MY BEV
U.S. EPA: T3B0 LDV
OBD: N/A **Fuel:** Electric
California: ZEV PC
OBD: N/A **Fuel:** Electric
No adjustments needed.
Group: MFMXV00.0B4A
▽MW7E-9C485-**F L M**

FIGURE 87–1 The official emission sticker lists the vehicle as electric and producing zero emissions. The EPA rating is Tier 3, Bin 0 and a light-duty vehicle (T3B90, LDV). The California standards is listed as a zero emission vehicle and a passenger vehicle (ZEV PC).

HISTORY

EARLY ELECTRIC VEHICLES Early EVs, also called **battery electric vehicles (BEVs)**, were first used in the late 1800s, and it was not until the early 1900s that EVs were practically possible using rechargeable lead–acid batteries.

- One of the first was the 1903 Baker Electric Car, produced by the Baker Motor Vehicle Company in Cleveland, Ohio.
- The Detroit Electric Car Company (1907–1939) produced very practical fully EVs.

The old EV mechanical controller was able to switch all six batteries in various combinations of series and parallel configurations to achieve lower voltage for slow speeds and higher voltages for higher speeds. EVs did not have a long range and needed to have the batteries charged regularly, which meant that EVs could only be used for short distances. In fact, EVs were almost more popular than steam-powered vehicles in 1900—while steam-powered vehicles had 40% of the sales, EVs had 38% of the sales. The gasoline-powered cars represented only 22% of the vehicles sold.

EARLY HYBRID VEHICLES In 1901, Ferdinand Porsche developed the Lohner-Porsche Mixte Hybrid, the first gasoline-electric hybrid automobile in the world. It was originally an electric-powered vehicle and then a gasoline engine was added to recharge the battery. One of the first hybrid electric cars was produced by the Owen Magnetic Motor Car Corporation, manufactured in New York City and then in Wilkes-Barre, Pennsylvania, from 1915 until 1922. It failed because the fuel economy was about the same as a conventional gasoline-powered vehicle, yet cost more. Another vehicle that used both a gasoline engine and an electric motor to power the vehicle was built by Woods Motor Company of Chicago, Illinois, and was called the "Woods Dual Power" (1915–1918).

NOTE: Due to the oil embargo of 1973 and an increased demand for alternative energy sources, Congress enacted Public Law 94-413, the *Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976*, which was designed to promote new technologies.

The hybrid electric vehicle did not become widely available until the release of the Toyota Prius in Japan in 1997, followed by the Honda Insight sold in the United States starting in 1999. In 2001, the first Toyota Prius was introduced in the United States.

EFFICIENCIES OF ELECTRIC MOTORS AND ICEs

Electric motors are more efficient compared to any ICE and have just one moving part compared to hundreds of moving parts in a typical gasoline-powered or diesel-powered ICE.

- An electric motor can have efficiency (including controller) of over 90%, while a gasoline engine has efficiency of only 35% or less.
- An ICE does not have the overload capability of an electric motor. That is why the rated power of an ICE is usually much higher than that required for highway cruising. Operating smoothly at idle speed produces a much lower efficiency than while operating at a higher speed.
- Maximum torque of an ICE is reached at intermediate speed and the torque declines as speed increases further.
- There is a maximum fuel efficiency point in the speed range for the ICE, and this speed is optimized by many hybrid vehicle manufacturers by using a transmission that keeps the engine speed within the most efficient range. ● **SEE FIGURE 87–2**.

Electric motors offer ideal characteristics for use in a vehicle because of the following factors:

- Constant power over all speed ranges
- Constant torque at low speeds needed for acceleration and hill-climbing capability
- Constant torque below base speed
- Constant power above base speed
- Only single gear or fixed gear is needed in the electric motor transmission

DRIVING A HYBRID OR ELECTRIC VEHICLE

DRIVING A HYBRID VEHICLE Driving a hybrid electric vehicle (HEV) is the same as driving any other conventional vehicle. In fact, many drivers and passengers are often not aware that they are driving or riding in a hybrid electric vehicle. Some unique characteristics that the driver may or may not notice include the following:

- After the ICE has achieved normal operating temperature and other conditions are met, the engine will stop when the vehicle slows down and stops. This condition may cause a concern to some drivers who may think that the engine has stalled and may try to restart it.
- The brake pedal may feel different, especially at slow speeds of about 5 MPH and 15 MPH when slowing to a stop. It is at about these speeds that the brake system switches from regenerative braking to actually applying brake force to the mechanical brakes. A slight surge or pulsation may be felt at this time. This may or may not be felt and is often not a concern to drivers.
- The power steering works even when the engine stops because all HEV and PHEV use an electric power steering system.

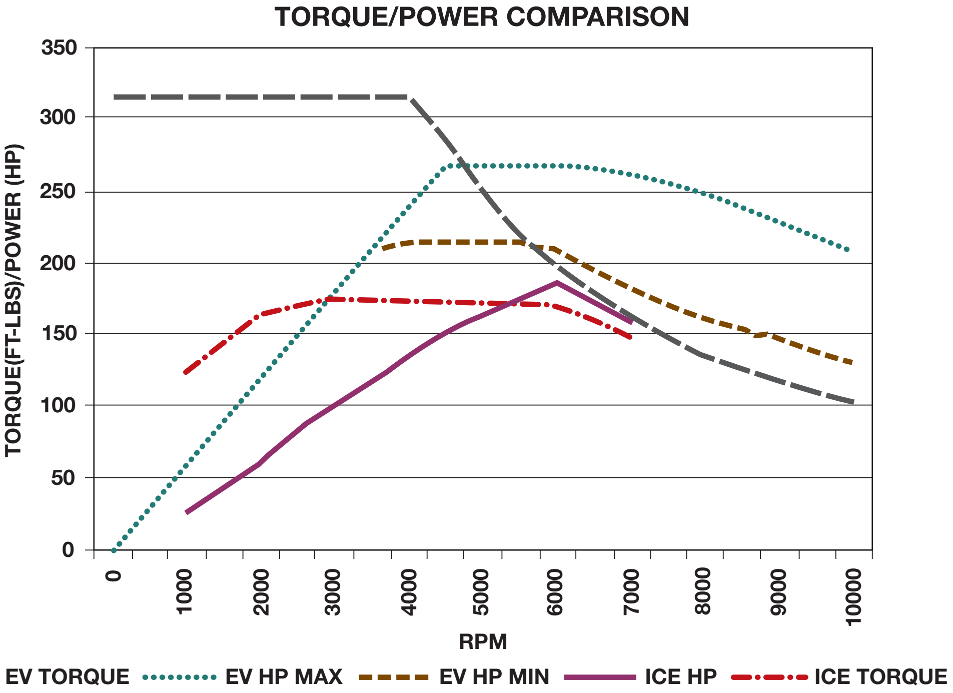


FIGURE 87–2 The graph shows a comparison of torque and power between an electric vehicle and a vehicle with an ICE.

- Some HEVs and all PHEVs are able to propel the vehicle using the electric motor alone, resulting in quiet, almost eerie operation.
- If an HEV is being driven aggressively and at a high rate of acceleration, there is often a feeling that the vehicle is not going to slow down when the accelerator pedal is first released. This is caused by two factors:
    1. The inertia of the rotor of the electric motor attached to the crankshaft of the ICE results in the engine continuing to rotate after the throttle has been closed.
    2. The slight delay that occurs when the system switches the electric motor from powering the vehicle to generating (regenerative braking). While this delay would rarely be experienced, it is not at all dangerous. For a fraction of a second, it gives a feeling that the accelerator pedal did not react to a closed throttle.

DRIVING AN ELECTRIC VEHICLE Driving an EV is a very different driving experience than a conventional vehicle. Some of the unique characteristics include the following:

- The startup and shutdown procedures are enough different than a conventional vehicle that many drivers need to be retrained on the processes.
- The lack of an ICE results in a much quieter ride. In many cases, the most predominate noise heard is the tires on the various road surfaces. Most electric vehicles come from the factory with tires that have acoustical foam inside of the tire to reduce the tire noise by up to 9 db. ● **SEE FIGURE 87–3**.

NOTE: The EV may be silent when in park or neutral. When put in drive or reverse, an artificial "running engine" sound is generated at the front of the vehicle through a speaker behind the front bodywork. Some vehicles have a second speaker mounted in the rear of the vehicle. Typically, the sound is present until the vehicle reaches approximately 20 MPH. ● **SEE FIGURE 87–4**.

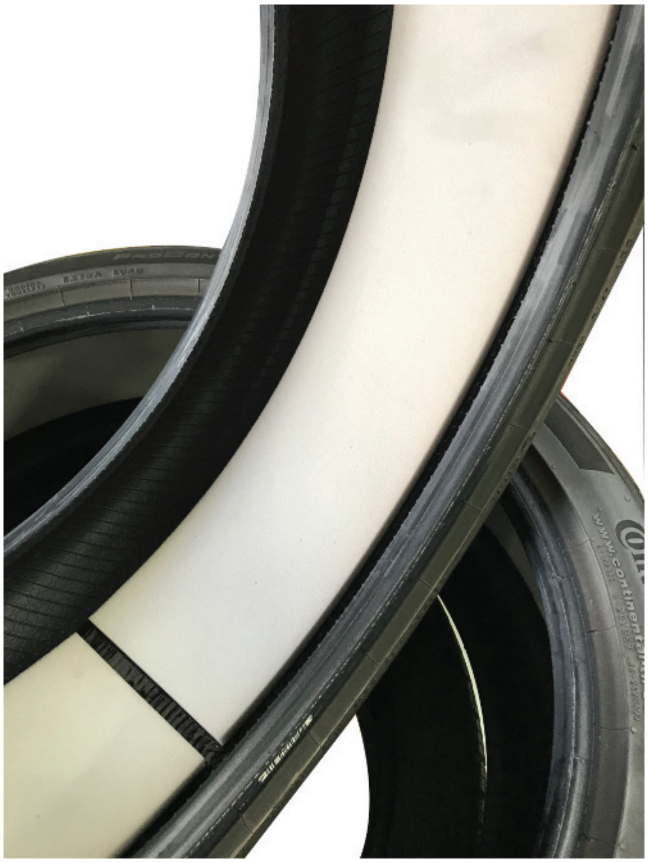


FIGURE 87–3 This Continental tire with acoustical foam on the inside is from a Tesla Model 3.

- The electric motors that propel the vehicle provide exceptional torque and responsiveness.
- The regenerative braking systems tend to slow the vehicle more aggressively than a conventional vehicle. Often the system can be set so that the brake pedal is not used during normal driving except to keep the vehicle

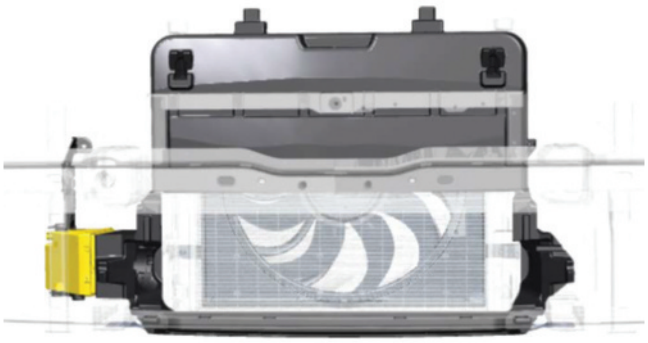


FIGURE 87–4 The sound generator on this 2021 VW ID.4 is located behind the front bumper assembly.

FREQUENTLY ASKED QUESTION

How Fast Does the Motor-Generator Turn the Engine When Starting?

The typical starter motor used on a conventional gasoline or diesel engine rotates the engine from 100 to 300 revolutions per minute (RPM). Because the typical engine idles at about 600 to 700 RPM, the starter motor is rotating the engine at a speed slower than it operates. This makes it very noticeable when starting because the sound is different when cranking compared to when the engine actually starts and runs.

However, when the motor-generator of an HEV rotates the engine to start it, the engine is rotated about 1000 RPM, which is about the same speed as when it is running. As a result, engine cranking is just barely heard or felt. The engine is either running or not running, which is a truly unique sensation to those not familiar with the operation of hybrid electric vehicles.

stationary when stopped. This feature is usually called **one-pedal driving**.

- Seasonal temperature changes, weather, and driving style will affect the battery range.
- Careful mapping of charging stations will be required when traveling a distance beyond the battery range capacity.
- **Range anxiety** is the fear that many potential owners of EV have that the vehicle will have insufficient range to reach their destination, and therefore could get stuck with a dead vehicle on the road. According to owners of EV, this fear tends to go away after about two weeks of ownership after seeing that the range and the charging can be easily controlled.

OWNING A HYBRID OR ELECTRIC VEHICLE

A hybrid or electric vehicle will cost and weigh more than a conventional vehicle. The increased initial purchase price is due to the batteries, electric motor(s), and controllers used plus the additional components needed to allow operation of the heating and air-conditioning systems during idle stop periods. The cost is offset, in part, by improved fuel economy as well as state and national government energy credits awarded at the time of purchase for some new technology vehicles.

Plug-in hybrid and electric vehicle owners will save money at the gasoline pump; however, they will experience a higher electric bill, depending on the amount of electricity these use. The increase in the cost of the electricity will vary based on the electrical providers' purchase plan. Some providers offer discounted rates when the electricity is consumed during off-peak hours.

ROUTINE MAINTENANCE

Most hybrid and electric vehicles have a different maintenance schedule than a conventional vehicle. In the case of an EV, most of these costs are eliminated. A typical EV requires just the following as part of routine maintenance:

- Windshield washer fluid
- Windshield wiper blades
- Cabin filter
- Tire rotation

● **SEE FIGURE 87–5**.

FREQUENTLY ASKED QUESTION

Can the Nissan Leaf Be Taken through a Car Wash?

Yes, the Nissan Leaf, and all hybrid and electric vehicles, can be taken through the car wash. All the high-voltage components, including the battery, that are outside of the passenger compartment are sealed from outside water entry. If there has been no damage to protective coverings, the components will not be damaged and there is no chance of electrical shock.

FIGURE 87–5 Adding windshield washer fluid to an EV is the item that requires most frequent maintenance depending on driving conditions.

CASE STUDY

The Case of the Vibrating Tesla

An owner of a Tesla Model Y visited a tire shop complaining of a vibration in the steering wheel at highway speeds. A local tire shop balanced both front tires. The right front only needed a quarter ounce whereas the left front required over four ounces to balance. After leaving the shop, the owner immediately noticed that the vibration was much worse. The owner returned to the shop and this time the tire was removed from the rim. It became apparent that the vibration issue was caused by the foam inside the tire. This foam that generally played the role of reducing noise had separated and was loose inside the tire. The shop removed the foam and did not try to reinstall it. The wheel was balanced, which solved the vibration concern. The driver did not notice any increase in noise. ● **SEE FIGURE 87–6**.

Summary:

Complaint—A Tesla owner complained of a vibration in the steering wheel at highway speeds.
Cause—The acoustical foam inside a tire that is supposed to reduce noise had separated from the inner liner of the left front tire.
Correction—The foam was removed from the tire and the tire/wheel assembly was balanced, which corrected the vibration concern.

FREQUENTLY ASKED QUESTION

Why Are EVs and PHEVs Taxed in Some States?

Recently some states have added fees to the cost of the license plate on hybrid and electric vehicles to recover loss fuel taxes. Typically, these fees have been in the $100 to $200 range. Depending on the number of miles driven per year, these fees may have a negative impact on the cost of ownership.

In the case of a hybrid vehicle, certain costs may actually increase because of materials used because a hybrid vehicle typically uses full-synthetic motor oil, which is more expensive than conventional motor oil. Additionally, the owner of a plug-in vehicle will need to make an investment in a recharging network for the home.

All of these factors must be considered when making an informed decision to purchase a hybrid or electric vehicle. It may take many years of operation before the extra cost is offset by cost savings from the improved fuel economy. However, many owners purchase a hybrid or electric vehicle for other reasons besides fuel savings, including a feeling that they are helping the environment and the love of the high technology involved.

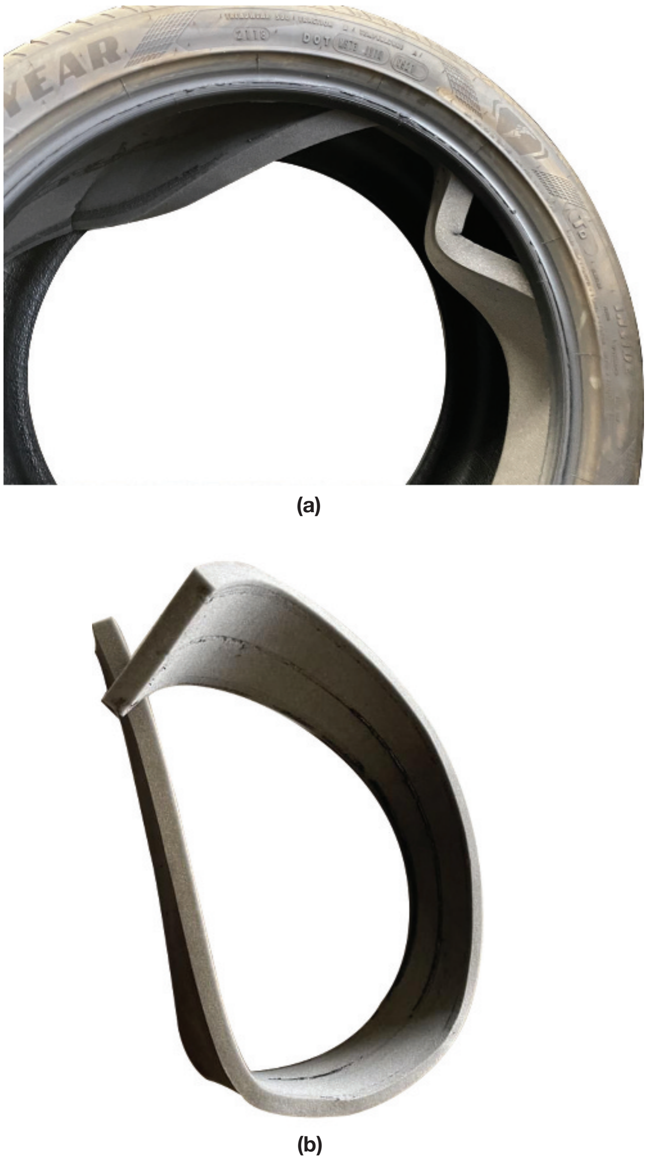


FIGURE 87–6 (a) The dismounted tire shows where the foam had become detached. (b) The foam removed in its entirety.

LEVELS OF HYBRID VEHICLES

MICRO HYBRID A **micro hybrid** will incorporate idle stop, but is not capable of propelling the vehicle without starting the ICE. A micro-hybrid system has the advantage of costing less, but saves less fuel compared to a full hybrid vehicle. The micro hybrid usually uses a second 12-volt battery and a heavy-duty starter motor and flywheel to restart the ICE when accelerating from a stop.

MILD HYBRID A **mild hybrid** will incorporate idle stop and regenerative braking, but is not capable of using the electric motor to propel the vehicle on its own without help from the ICE. A mild-hybrid system has the advantage of costing less, but saves less fuel compared to a full hybrid vehicle and usually uses a 42-volt electrical motor and battery package (36-volt batteries, 42-volt charging). An example of this type of hybrid is the 2004–2007 General Motors Silverado pickup truck and the 2007 Saturn VUE. The fuel savings for a mild type of hybrid design are about 8% to 15%.

FREQUENTLY ASKED QUESTION

Is a Diesel-Hybrid Electric Vehicle Possible?

Yes, using a diesel engine instead of a gasoline engine in an HEV is possible. While the increased efficiency of a diesel engine would increase fuel economy, the extra cost of the diesel engine is the major reason this combination is not currently in production.

FREQUENTLY ASKED QUESTION

What Is an Assist Hybrid?

An assist hybrid-electric vehicle is a term used to describe a vehicle where the electric motor is not able to start moving the vehicle on electric power alone. This type of hybrid would include micro hybrids (12 volt), all mild hybrids (36 to 42 volts), as well as the medium hybrids that use 144- to 158-volt systems.

MEDIUM HYBRID A **medium hybrid** uses 144- to 158-volt batteries that provide for engine stop/start, regenerative braking, and power assist. Like a mild hybrid, a typical medium hybrid is not capable of propelling the vehicle from a stop using battery power alone. Examples of a medium-hybrid vehicle include the Honda Insight, Civic, and Accord. The fuel economy savings are about 20% to 25% for medium-hybrid systems.

FULL HYBRID A **strong hybrid**, also called a *full hybrid*, uses idle stop, regenerative braking, and is able to propel the vehicle using the electric motor(s) alone. Each vehicle manufacturer has made its decision on which hybrid type to implement based on its assessment of the market niche for a particular model. Examples of a full or strong hybrid include the General Motors Silverado/Sierra (two-mode hybrid), Ford Escape SUV, Toyota Highlander, Lexus RX400h, Lexus GS450h, Toyota Prius, and Toyota Camry. The fuel economy savings are about 30% to 50% for full-hybrid systems.

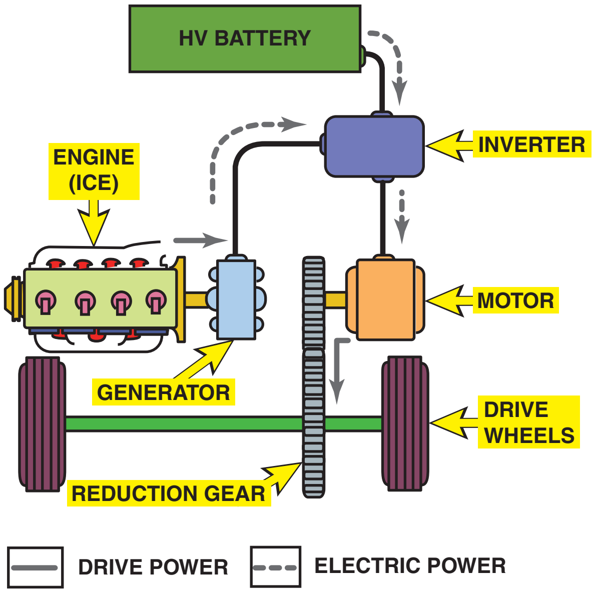


FIGURE 87–7 A drawing of the power flow in a typical series-hybrid vehicle.

CLASSIFICATIONS OF HYBRID VEHICLE POWERTRAIN

SERIES HYBRID POWERTRAIN In a series-hybrid design, sole propulsion is by a battery-powered electric motor, but the electric energy for the batteries comes from another onboard energy source, such as an ICE. In this design, the engine turns a generator and the generator can either charge the batteries or power an electric motor that drives the transmission. The ICE never powers the vehicle directly. ● **SEE FIGURES 87–7 AND 87–8.**

The engine is operated only to keep the batteries charged. Therefore, the vehicle could be moving with or without the ICE running. Series-hybrid vehicles also use regeneration braking to help keep the batteries charged. The Chevrolet Volt is an example of a series-hybrid design. The engine is designed to just keep the batteries charged, and, therefore, is designed to operate at its most efficient speed and load.

An advantage of a series-hybrid design is that no transmission, clutch, or torque converter is needed.

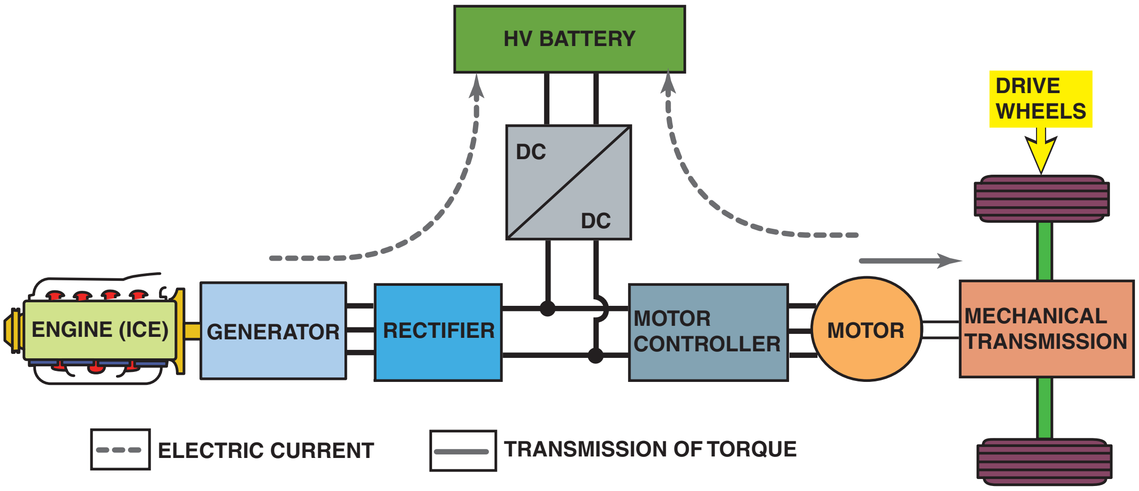


FIGURE 87–8 This diagram shows the components included in a typical series-hybrid design. The solid line arrow indicates the transmission of the torque to the drive wheels. The dotted line arrows indicate the flow of the electrical current.

A disadvantage of a series-hybrid design is the added weight of the ICE to what is basically an EV. The engine is actually a heavy on-board battery charger. Also, the electric motor and battery capacity have to be large enough to power the vehicle under all operating conditions, including climbing hills.

All power needed for heating and cooling must also come from the batteries, so using the air conditioning in hot weather and the heater in cold weather reduces the range that the vehicle can travel on battery power alone.

PARALLEL HYBRID POWERTRAIN In a parallel-hybrid design, multiple propulsion sources can be combined, or one of the energy sources alone can drive the vehicle. In this design, the battery and engine are both connected to the transmission.

The vehicle using a parallel-hybrid design can be powered by the ICE alone, by the electric motor alone (full hybrids only), or by a combination of engine and electric motor propulsion. In most cases, the electric motor is used to assist the ICE. ● **SEE FIGURES 87–9 AND 87–10**.

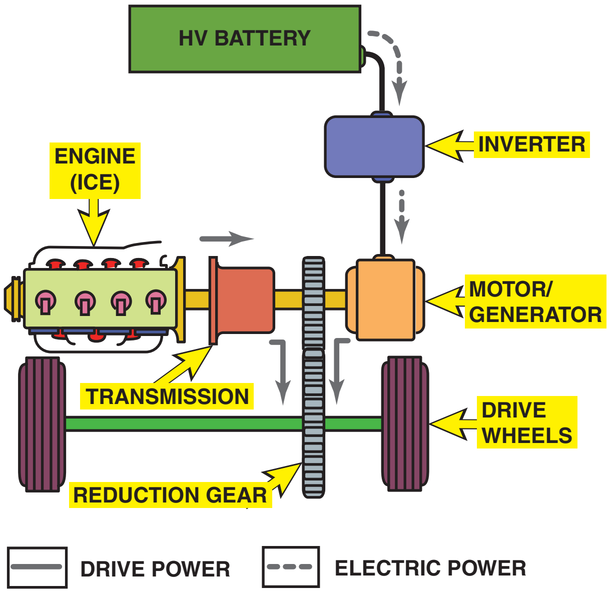


FIGURE 87–9 The power flow in a typical parallel-hybrid vehicle.

One of the advantages of using a parallel-hybrid design is that by using an electric motor or motors to assist the ICE, the engine itself can be smaller than would normally be needed.

NOTE: A parallel-hybrid design could include additional batteries to allow for plug-in capability, which could extend the distance the vehicle can travel using battery power alone.

One disadvantage of a parallel-hybrid design is that complex software is needed to seamlessly blend electric and ICE power. Another concern about the parallel-hybrid design is that it has to be engineered to provide proper heating and air-conditioning system operation when the ICE stops at idle.

SERIES-PARALLEL HYBRID POWERTRAIN The Toyota and Ford hybrids are classified as series-parallel hybrids because they can operate using electric motor power alone or with the assist of the ICE. Series-parallel hybrids combine the functions of both a series and a parallel design. The ICE may be operating even though the vehicle is stopped if the electronic controller has detected that the batteries need to be charged. ● **SEE FIGURE 87–11**.

NOTE: The ICE may or may not start when the driver starts the vehicle, depending on the temperature of the engine and other conditions. This can be confusing to some who are driving an HEV for the first time and sense that the engine did not start when they tried to start the engine.

ONE-, TWO-, AND THREE-MOTOR HYBRID SYSTEMS

ONE-MOTOR HYBRID SYSTEMS HEVs that use one electric motor include VW, Nissan, Honda, and General Motors. In these units, an electric motor is attached to the ICE (engine) crankshaft, which is used to perform two functions:

1. Start the ICE engine
2. Act as a generator to charge the high-voltage batteries

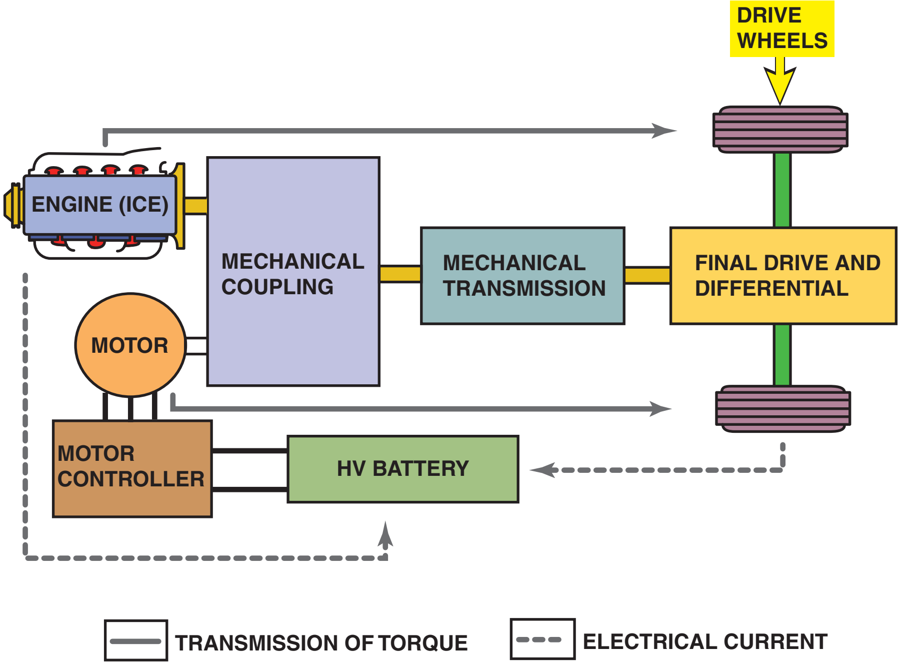


FIGURE 87–10 Diagram showing the components involved in a typical parallel-hybrid vehicle. The solid line arrows indicate the transmission of torque to the drive wheels, and the dotted line arrows indicate the flow of electrical current.

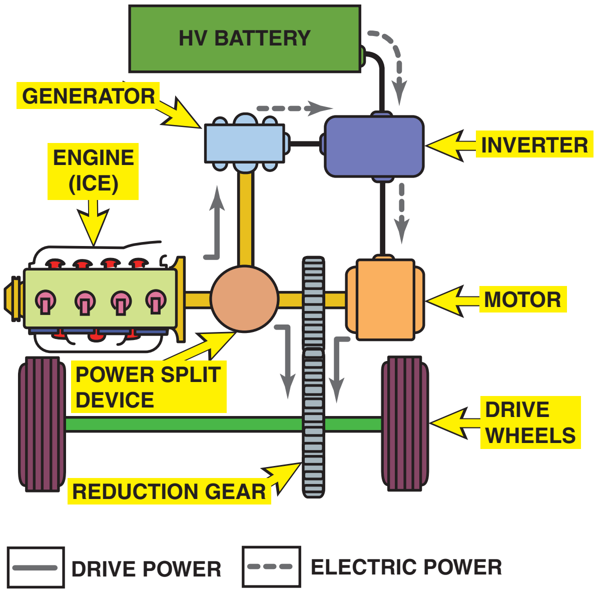


FIGURE 87–11 A series-parallel hybrid design allows the vehicle to operate in electric motor mode only or in combination with the ICE.

Hybrids that use one motor are often called mild hybrids, and usually are not able to power the vehicle using electric power alone. ● **SEE FIGURE 87–12**.

TWO-MOTOR HYBRID SYSTEMS HEVs that use two motors are the most commonly used hybrids by Toyota, Ford, and General Motors in their full-size two-mode trucks. Each electric motor serves two purposes:

- The motor/generator attached to the engine, usually labeled M/G1 or M/G A, is used to start the gasoline engine and to charge the high-voltage batteries.
- The motor/generator that is connected to the drive wheels, usually labeled M/G2 or M/G B, is used to propel the vehicle and to recharge the high-voltage battery during deceleration (regenerative braking).

Two-motor HEVs are full (strong) hybrids and are capable of propelling the vehicle using electric motor power alone for short distances. ● **SEE FIGURE 87–13**.

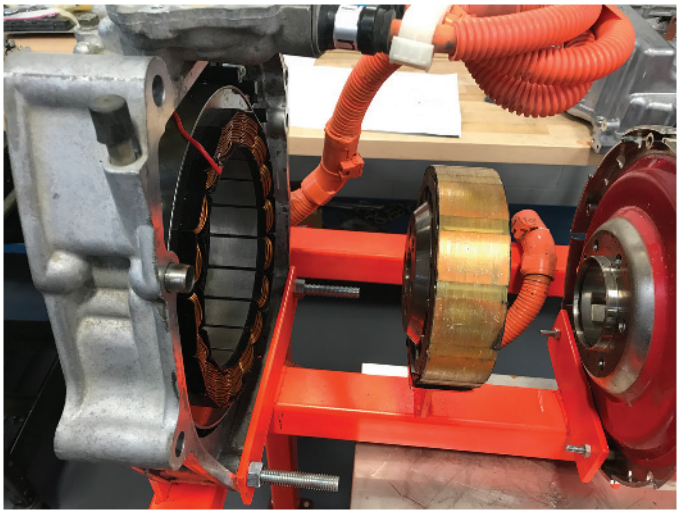


FIGURE 87–12 The exploded view of this Honda IMA motor assembly is an example of a one-motor hybrid system.

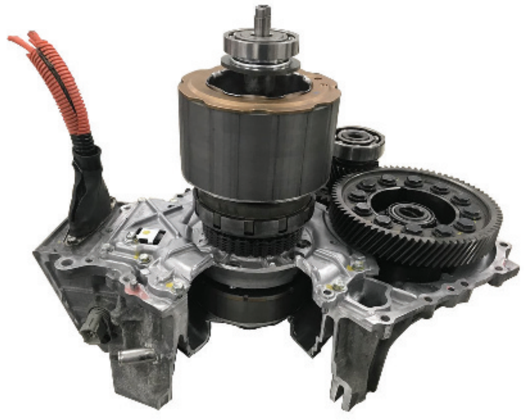


FIGURE 87–13 The cutaway of a second-generation Prius transmission (P112) shows two electric motors (MG1 and MG2). The vehicle can drive a short distance using just the electric motors.

THREE-MOTOR HYBRID SYSTEMS Three-motor HEVs are usually two-motor hybrids that use an additional electric motor to propel the rear wheels for all-wheel-drive capability. HEVs that use three electric motors include the Toyota Highlander and Lexus RX400h/450h SUVs.

ADVANTAGES AND DISADVANTAGES OF ELECTRIC VEHICLES

ADVANTAGES There are many advantages of an EV compared to a vehicle powered by an ICE, which include the following:

- **Initial torque**—Electric vehicles have high torque at the starting from a stop and can provide a rapid acceleration experience to the driver. ● **SEE FIGURE 87–14**.
- **Better handling and stability**—The high-voltage battery in an EV, being the heaviest electric component, is placed very low, on the body floor, resulting in a very low center of mass. This gives the vehicle more stability, resulting in better handling for the vehicle.

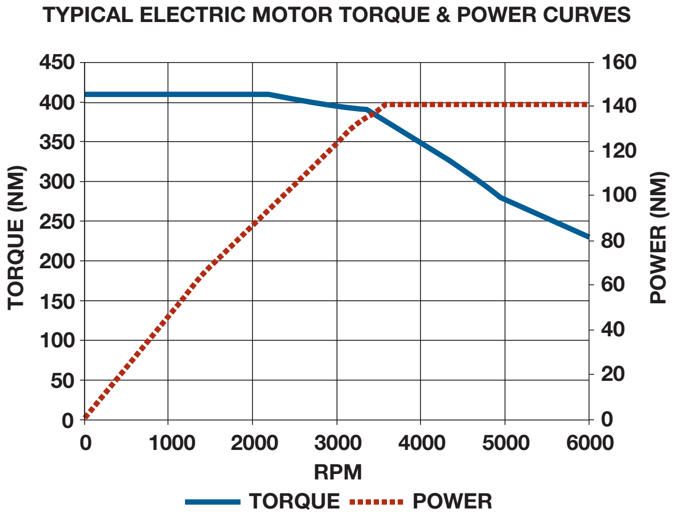


FIGURE 87–14 The graph shows how high the initial torque is in an electric motor and how quickly it generates power.

- **Maximum traction**—Electric motors are independently controlled, thereby providing precise control on each wheel for maximum traction in all-wheel-drive EVs.
- **More efficient than gasoline vehicles**—An EV is more efficient than a gasoline vehicle in converting stored energy into energy of motion. The efficiency of an electric motor is around 85% to 90%, whereas that of an ICE-powered vehicle is 35% to 40%.
- **Less cost of operation**—Cost of operation of an EV is less when compared to gasoline vehicle because the cost of electricity is less when compared to fossil fuels, as well as the high efficiency of the electric motor.
- **Less maintenance**—Fewer moving parts are included in EVs so the maintenance required is reduced. There is no need for oil changes and the brakes may last the life of the vehicle because of the regenerative braking technology. Only some items require periodical maintenance, which include tire rotation, changing the cabin filter, adding windshield washer fluid, and replacing the windshield wiper blades.
- **EVs are quiet and ecofriendly**—EVs are very quiet and do not make any sound while operating. So EVs will be more suitable for big cities where noise pollution is a concern. Also due to zero emission, it is considered ecofriendly.
- **Charge from your house**—Most of the EVs can be charged from the household itself.

DISADVANTAGES There are several disadvantages of an EV compared to an ICE vehicle including

- **Limited range**—While range is increasing due to improved battery designs, range is still a concern for many people. Early EVs had a range of up to 80 miles, but

FREQUENTLY ASKED QUESTION

Can an Electric Vehicle Be Towed?

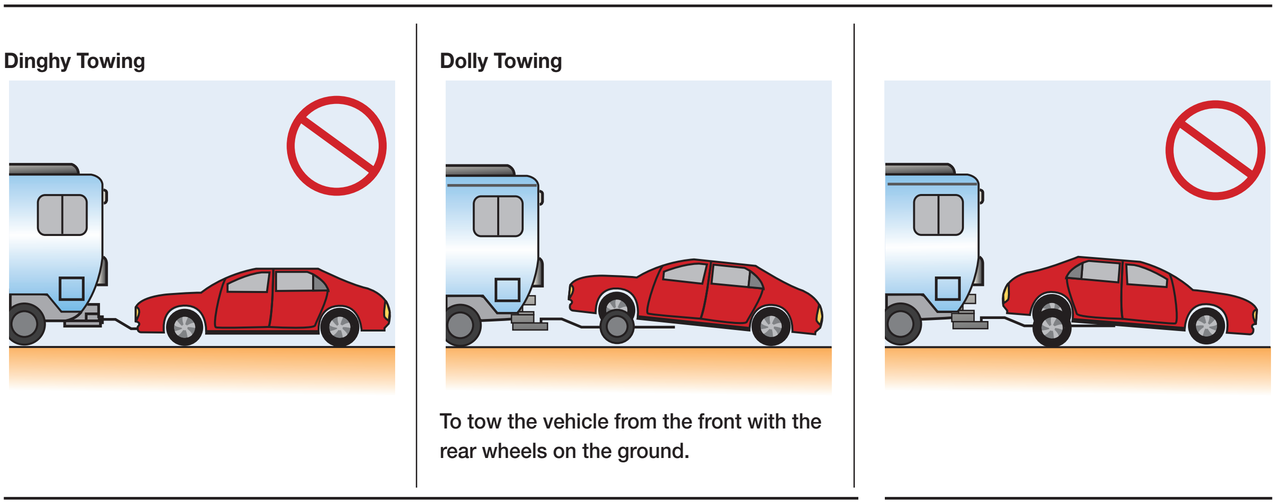
Yes, with some precautions to prevent damage to the vehicle. Most vehicle manufacturers recommended towing any vehicle with all four wheels off the ground. ● **SEE FIGURE 87–15**. The manual for a Chevrolet Bolt includes the following steps:

- Place the front wheels on a dolly.
- Place the shift lever in P (Park).
- Secure the vehicle to the dolly.

However, under "Electric Parking Brake" the owner's manual says that the electric parking brake (EPB) may automatically apply in some situations when the vehicle is not moving to check the correct operation of the EPB system. Some Bolt owners have reported that the EPB has engaged while being towed with the rear wheels on the ground, which ruined the rear tires. If any front-wheel-drive vehicle is being towed with the rear wheels on the ground, many experts recommend the following precautions:

- Disconnect the 12-volt battery to prevent the possibility of the electric parking brake being applied.
- Listen carefully to ensure that the car does not automatically apply the EPB between the time that the car is turned off and the time that the battery is disconnected.
- Make sure to keep the driver's door open until after the battery is disconnected, otherwise the car may automatically lock the doors requiring the use of the physical key to unlock the door.
- Always make sure to test that the wheels are rolling freely before departure.

Obviously, all the aforementioned precautions are not necessary if the vehicle is towed with all four wheels off the ground.


Dinghy Towing

Dolly Towing

To tow the vehicle from the front with the rear wheels on the ground.

FIGURE 87–15 How a front-wheel-drive EV should be towed as per the vehicle manufacture's instructions.

newer models are now reaching a range of 240 to 300 miles or more.

- **Electrical needs at home**—Most EVs are charged at home, and this usually means that the electric service needs to be installed or upgraded to provide a 220–240-volt outlet near the vehicle to allow overnight charging.
- **High initial cost**—Because the cost of the high-voltage batteries is high, the cost of an EV is higher than an ICE vehicle of the same type and size.

TIPS FOR RANGE INCREASE

- Accelerate slowly.
- Avoid high-speed driving because as the speed increases, the aerodynamic drag is increased by the square of the speed.
- Avoid using the air-conditioning unless absolutely needed.
- Check tire pressure. The door placard pressure offers the best compromise in terms of tire rolling resistance, braking distance, comfort, lateral dynamics, and wear.
- Pre condition the vehicle. As long as the vehicle is attached to the charging station, it makes sense to pre condition the interior and to specify the departure time in winter because the battery is only fully charged at the time of departure and is already at operating temperature.
- Reduce weight by removing unnecessary additional weight and roof structures, such as bike racks unless being used.

REVIEW QUESTIONS

1. What are the advantages and disadvantages of a series-hybrid design?
2. What are the advantages and disadvantages of micro, mild, medium, and full hybrids?
3. What are some of the advantages and disadvantages of owning an electric vehicle (EV)?
4. What is the purpose of the third motor in a three-motor hybrid system?
5. What are the items that will affect the range of an electric vehicle?

CHAPTER QUIZ

1. What is the difference between a mild hybrid and a full hybrid?
   a. A mild hybrid will propel the vehicle in electric mode.
   b. A full hybrid will propel the vehicle in electric mode.
   c. There are no differences between mild and full hybrid vehicles.
   d. None of the answers are correct.
2. What is the difference between a hybrid electric vehicle (HEV) and plug-in hybrid electric vehicle (PHEV)?
   a. Both an HEV and PHEV have to be plugged in.
   b. Only the PHEV needs to be plugged in to achieve maximum range.
   c. A PHEV does not use an ICE.
   d. An HEV uses a high-voltage battery that has a higher capacity than a PHEV.
3. One-pedal driving means ___________.
   a. the vehicle only has one pedal
   b. the vehicle has the ability to slow and often stop using just the accelerator pedal
   c. the vehicle does not use regenerative brakes but just friction brakes
   d. the vehicle uses the accelerator pedal to accelerate and the parking brake level to slow and stop
4. An electric vehicle (EV) is also called a ___________.
   a. self-driving vehicle
   b. battery electric vehicle (BEV)
   c. hybrid electric vehicle (HEV)
   d. plug-in hybrid electric vehicle (PHEV)
5. An electric motor is ___________ an internal combustion engine (ICE).
   a. less efficient than
   b. just as efficient as
   c. more efficient than
   d. None of the above
6. Range anxiety is ___________.
   a. the fear of running out of electrical battery charge and being left stranded
   b. the fear of having to recharge on the way to work if the distance is greater than 5 miles
   c. normal anxiety when first owning an EV
   d. Both a and c
7. In a series hybrid powertrain, the source of propulsion is the ___________.
   a. ICE
   b. electric motor
   c. three-speed transmission
   d. ICE or electric motor
8. In a three-motor hybrid vehicle, the third motor drives the ___________ wheels.
   a. rear
   b. front
   c. both front and rear
   d. None of the above
9. A full hybrid uses ___________.
   a. a 12-volt battery and a 144-volt battery
   b. two 12-volt batteries
   c. a 12-volt battery and a 42-volt battery
   d. a 12-volt battery and a 300-volt battery
10. What is NOT an advantage of an EV?
   a. Higher cost
   b. Lack of required oil changes and other services that an ICE requires
   c. More economical to operate on a cost per mile basis
   d. All of the above

Chapter

88

HYBRID AND ELECTRIC VEHICLE MAINTENANCE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe routine service procedures for both hybrid and electric vehicles.
- Explain how to place a hybrid vehicle in maintenance mode.
- Describe an oil and filter change and engine maintenance on a hybrid vehicle.
- Explain how to service the base brake system on a hybrid or electric vehicle.
- Discuss related maintenance items including battery air filter, A/C service, tires, auxiliary battery, and steering systems.
- List diagnostic procedures for hybrid and electric vehicles.

KEY TERM:

Noise-reducing tire 1021

ROUTINE SERVICE PROCEDURES

CUSTOMER PERCEPTION Many customers love their hybrid and electric vehicle; however, routine maintenance is frequently overlooked because it is different from a vehicle with just an internal combustion engine (ICE). Over time, the customer begins to notice a decrease in the fuel economy. The perception is that the decrease is a result of a failing high-voltage battery. In many cases the decrease in fuel economy or performance is a result of a lack of routine maintenance. ● **SEE CHART 88–1**.

HEV/PHEV MAINTENANCE ITEMS	EV MAINTENANCE ITEMS
Oil changes (once or a year or when the OLM indicates)	NA
Engine air filter (every 2–3 years)	NA
Cabin filter (every 2–3 years)	Cabin filter (every 2–3 years)
Tire rotation (every 7,500 miles)	Tire rotation (every 7,500 miles)
Windshield washer fluid (as needed)	Windshield washer fluid (as needed)
Windshield wiper blades (as needed)	Windshield wiper blades (as needed)

CHART 88–1

Routine maintenance service.

INSTRUMENT CLUSTER WARNING MESSAGES As part of correctly diagnosing a hybrid or electric vehicle, the technician must understand what the indicators in the instrument cluster and message center mean. These indicators will help to confirm the customer's concern and provide a clue as to what may be wrong with the vehicle. The failure to understand these symbols may lead to unnecessary or incorrect initial diagnostic assumptions. ● **SEE FIGURE 88–1**.

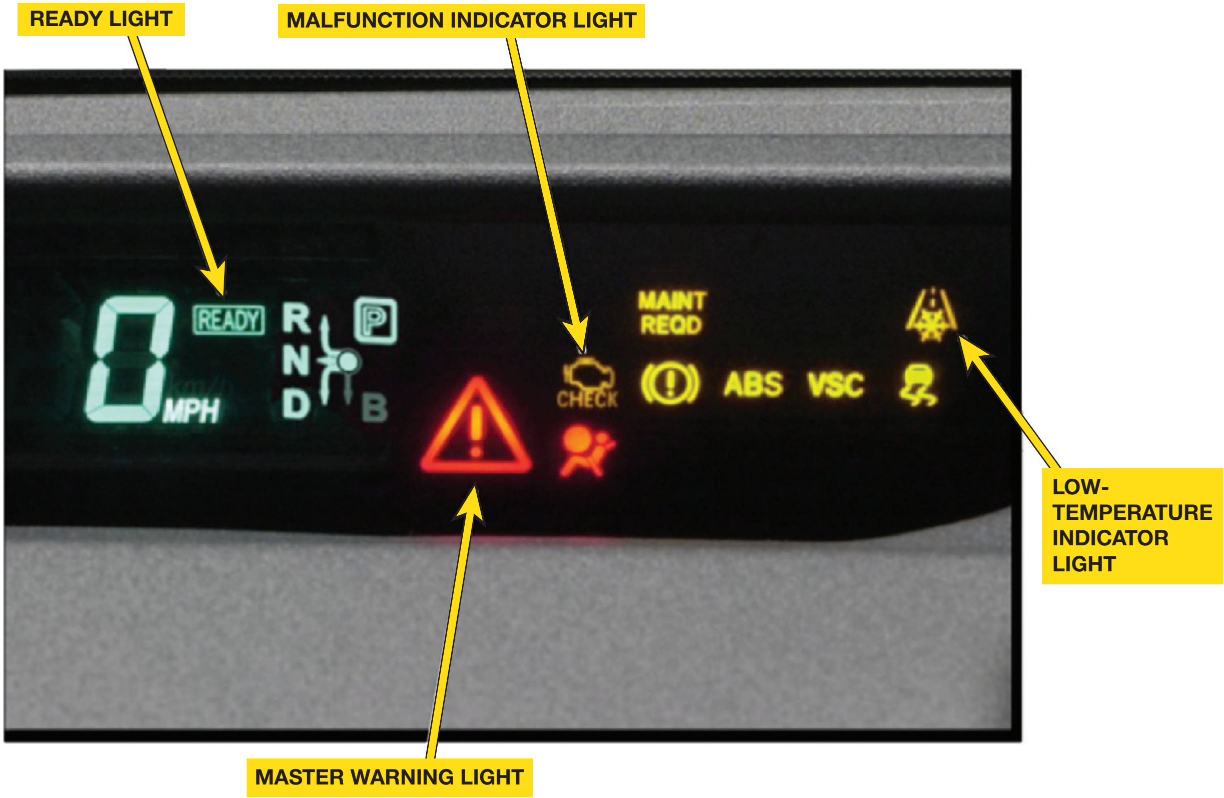


FIGURE 88–1 An example message screen from a Generation 2 Toyota Prius provides a wealth of information for the driver and the service technician.

NON-HIGH-VOLTAGE COMPONENTS THAT IMPACT FUEL ECONOMY When performing a vehicle inspection, it is important to notice the absence or change in any of the following components as it may affect the vehicles' fuel economy:

- Low rolling resistance tires
- Low-mass wheels
- Spoilers
- Underbody trays
- Aerodynamic assist steps

PLACING THE HYBRID VEHICLE IN MAINTENANCE MODE

There are times when the service technician needs to bypass the idle-stop feature and keep the engine running. These conditions can include the following:

- Checking air-conditioning pressures
- Bringing the engine to operating temperature
- Safety inspection of the exhaust system

Depending on the manufacturer, this mode is called any of the following:

- Service mode
- Maintenance mode
- Inspection mode

The vehicle can be placed in this mode either with a scan tool or through a specific sequence of steps inside the vehicle. Most vehicle manufacturers warn not to drive the vehicle while in this mode because torque limiting factors are disabled and damage to powertrain components could occur.

LIFTING AN ELECTRIC VEHICLE Most electric vehicle chassis are developed using a "skateboard design." In this configuration, the high-voltage battery and its covers fill a large portion of the underside of the vehicle. As a result, some vehicles require special adapters for lifting so that the battery and its covers are not damaged by the lift pads. Always follow the manufacturer's specific instructions to ensure the vehicle is safely lifted and damage does not occur. ● **SEE FIGURE 88–2**.

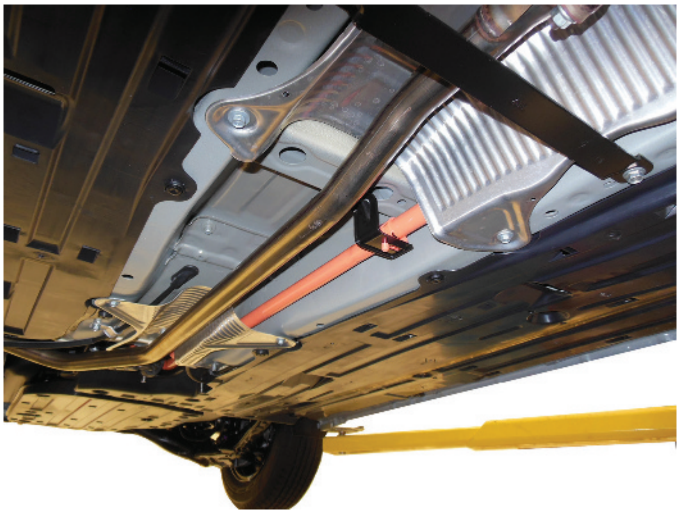


FIGURE 88–2 When positioning the lift, make sure the arms and contact points are clear of any high-voltage cables.

OIL AND FILTER CHANGE AND ENGINE MAINTENANCE

OIL AND FILTER SERVICE Performing an oil change in a hybrid vehicle is similar to changing oil in any vehicle equipped with an ICE. However, there are several items to know when changing oil in a hybrid electric vehicle (HEV).

Always use the specified oil viscosity. Most HEVs require either SAE 0W-20, SAE 0W-16, or SAE 5W-20.

Most hybrid vehicles use a full synthetic oil. Using the specified oil viscosity is important because the engine stops and starts many times and using the incorrect viscosity not only can cause a decrease in fuel economy, but also could cause engine damage. ● **SEE FIGURE 88–3**.

When replacing the oil filter, make sure it meets the manufacturer's original equipment specifications and it is correctly installed. A Honda Civic hybrid service procedure requires the oil filter to be prefilled upon installation to avoid a potential P1021 DTC.

Always follow the specified procedures. Be sure that the ICE is off and that the "READY" lamp is off. If there is a smart key or the vehicle has a push-button start, be sure that the key fob is at least 15 feet (5 meters) away from the vehicle to help prevent the engine from starting accidentally.

ENGINE MAINTENANCE Hybrid vehicles may have specific engine maintenance requirements. These may include the following:

- Honda Insight requires the indexing of spark plugs.
- Some Honda engines require mechanical valve lash adjustments.
- Atkinson cycle engines may require more frequent throttle body service.

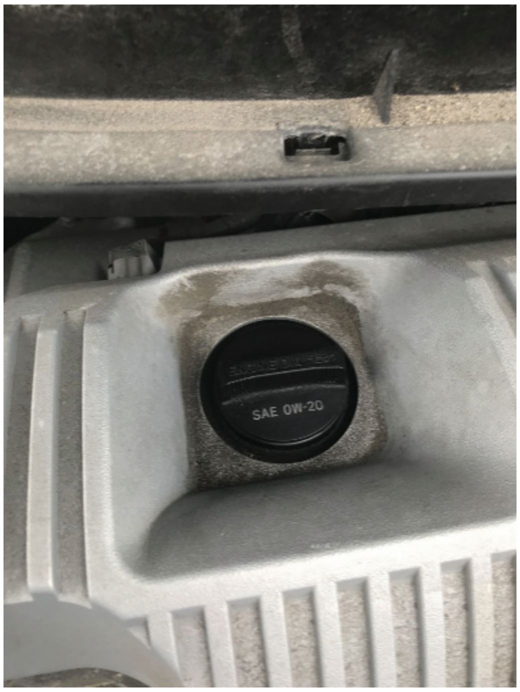


FIGURE 88–3 This Toyota Prius uses SAE 0W-20 as indicated by the oil filler cap.

FREQUENTLY ASKED QUESTION

When Do I Need to Depower the High-Voltage System?

During routine service work, there is no need for a technician to depower the high-voltage system. The only time when this process is needed is if service repairs or testing is being performed on any circuit that has an orange cable attached. These include

- AC compressor if electrically powered
- High-voltage battery pack or electronic controllers

The electric power steering system usually operates on 12 volts or 42 volts and neither is a shock hazard. However, an arc will be maintained if a 42-volt circuit is opened. Always refer to service information if servicing the electric power steering system, or any other system that may contain high voltage.

COOLING SYSTEM SERVICE Performing cooling system service is similar to performing this service in any vehicle equipped with an ICE. However, there are several items to know when servicing the cooling system on a hybrid and electric vehicle, including there may be two or three systems that require service. Always check service information for the exact procedure to follow. The procedure will include the following:

1. The specified coolant. Most vehicle manufacturers will recommend using premixed coolant because using tap water (half of the coolant) that has minerals could cause corrosion issues.

CASE STUDY

A No-Start Prius after a Routine Oil Change

A technician went to start a Toyota Prius after completing a routine oil and filter service. The technician discovered the engine would crank over briefly and then fail to start. A visual inspection was performed and no components were found to be damaged or disconnected as a result of the oil service. Further diagnosis revealed the engine crankcase was significantly overfilled. When motor generator 1 (MG1) turned over the crankshaft on startup, it was unable to achieve the desired engine RPM as a result of the extra resistance created by the excess oil in the crank case. The fail-safe or limp-in operation was a no-start condition. After the engine oil level was lowered to the correct level, the vehicle started and operated normally.

Summary:

The vehicle failed to start due to a crankcase overfill condition that caused MG1 to go into a fail-safe or limp-in condition.

Concern—The vehicle would not start.
Cause—An over-full engine crank case was observed.
Correction—Lowered the engine oil to the correct level.

2. The specified coolant replacement interval. While this may be similar to the coolant replacement interval for a conventional vehicle, always check to be sure that this service is being performed at the specified time or mileage interval.
3. The specified precautions. Some Toyota Prius HEVs use a coolant storage bottle that keeps the coolant hot for up to three days. Opening a coolant hose could cause the release of this hot coolant and can cause serious burns to the technician.
4. Always read, understand, and follow all of the service information instructions when servicing the cooling system on a hybrid or electric vehicle. In many cases a vacuum lift or evacuation system will be needed in order to get all the air out of the system and the system completely full of the coolant mixture. A failure to get the system completely full may result in an overheat condition and possible component failure.
5. When replacing the coolant bottle caps, make sure the cap goes back onto the correct bottle. Some hybrid vehicles use a different pressure cap on the engine as compared to the electronics cooling systems. ● **SEE FIGURES 88–4 AND 88–5**.

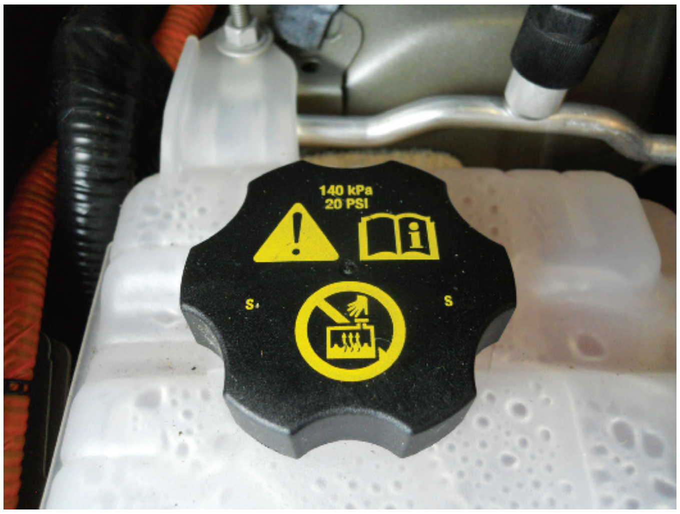


FIGURE 88–4 Chevrolet Volt engine cooling system with a 20 PSI-rated reservoir cap.

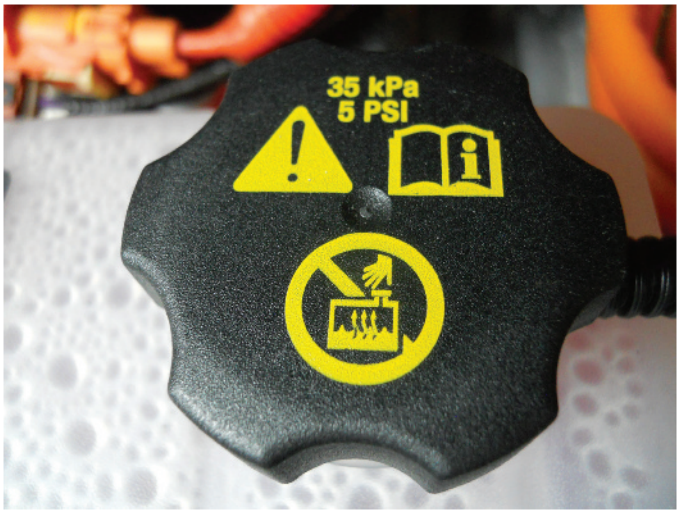


FIGURE 88–5 Chevrolet Volt electronic cooling system with a 5 PSI-rated reservoir cap.

BRAKING SYSTEM SERVICE

Performing braking system service is similar to performing this service in any vehicle equipped with an ICE. However, there are several items to know when servicing the braking system on a hybrid or electric vehicle. They are as follows:

1. Check service information for any precautions that are specified to be followed when servicing the braking system on a hybrid or electric vehicle.
2. Before beginning any base brake service on a hybrid or electric vehicle, make sure to have the needed scan tools, pressure bleeders, and other required tools to properly disable, bleed, and re-enable system.
3. All hybrid and electric vehicles use a regenerative braking system, which captures the kinetic energy of the moving vehicle and converts it to electrical energy and is sent to the high-voltage battery pack. The amount of current produced during hard braking can exceed 100 amperes. This current is stored in the high-voltage battery pack and is used as needed to help power the vehicle.
4. The base brakes used on HEVs are the same as any other conventional vehicle except for the master cylinder and related control systems. There are no high-voltage circuits associated with the braking system as the regeneration occurs inside the electric drive (traction) motors and is controlled by the motor controller.
5. The base brakes on many hybrid and electric vehicles are often found to be stuck or not functioning correctly because the brakes are not doing much work and can rust. The use of regenerative braking decreases the amount of heat generated at the brake assembly and reduces the amount of evaporation of moisture. This is a very common occurrence in the part of the country that the auto manufacturers refer to as the “salt belt.” ● **SEE FIGURE 88–6**.

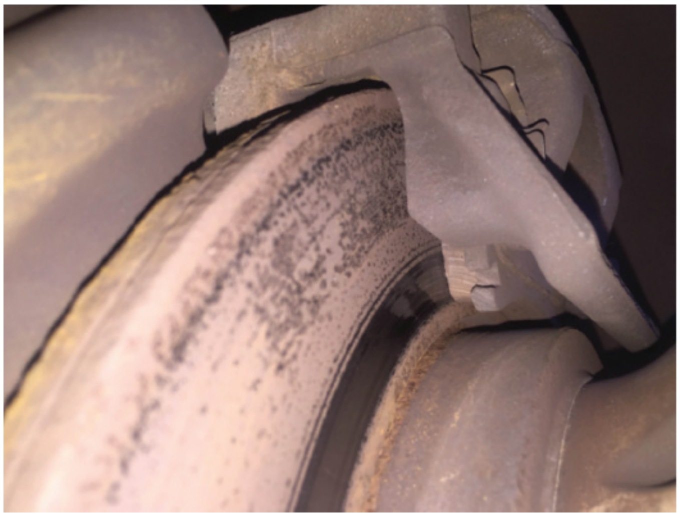


FIGURE 88–6 The brake rotor on this Audi Q5 hybrid is rusted and has very little pad contact due to a seized brake caliper pin.

RELATED MAINTENANCE ITEMS

HIGH-VOLTAGE BATTERY AIR FILTER Many hybrid vehicles rely on the air that is heated and cooled for the passenger compartment to regulate the temperature of the high-voltage battery. To prevent the intrusion of passenger compartment debris from the entering the high-voltage battery cooling system, a filter is placed in the air-intake system. These filters must be replaced at specific service intervals to ensure proper cooling. ● **SEE FIGURE 88–7**.

AIR-CONDITIONING SERVICE Performing air-conditioning system service is similar to performing this service in any vehicle equipped with an ICE. However, there are several items to know when servicing the air-conditioning system on a hybrid or electric vehicle. They are as follows:

- Many hybrid and electric vehicles use an air-conditioning compressor that uses high voltage from the high-voltage battery pack to operate the compressor.
- Make sure the high-voltage system has been properly depowered before removing the compressor for service.
- If the system is electrically driven, special refrigerant oil, POE oil, is used that is nonconductive and will not degrade the insulation on the electric motor windings. This means that a separate recovery machine should be used to avoid the possibility of mixing regular refrigerant oils with the oil used in hybrid and electric systems. ● **SEE FIGURE 88–8**.

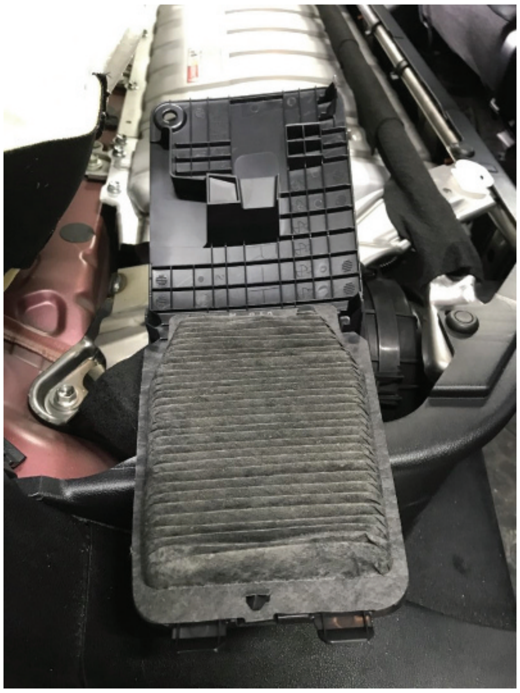


FIGURE 88–7 This Toyota Prius has a high-voltage battery air filter that must be replaced at the documented time or mileage to prevent the battery from overheating.

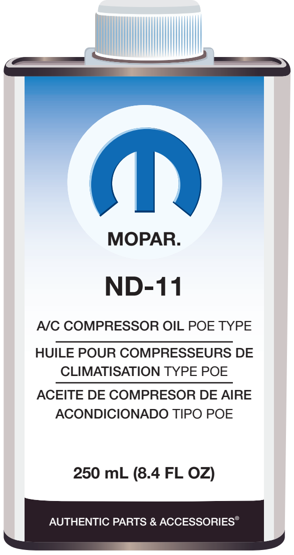

MOPAR.
ND-11
A/C COMPRESSOR OIL POE TYPE
HUILE POUR COMPRESSEURS DE CLIMATISATION TYPE POE
ACEITE DE COMPRESOR DE AIRE ACONDICIONADO TIPO POE
250 mL (8.4 FL OZ)
AUTHENTIC PARTS & ACCESSORIES®

FIGURE 88–8 This POE refrigerant oil is specific to FCA brand products.

TIRE SERVICE Performing tire-related service is similar to performing this service in any vehicle equipped with an ICE. However, there are several items to know when servicing tires on a hybrid or electric vehicle. They are as follows:

1. Tire pressure is very important not only to the fuel economy but also to the life of the tire. Lower inflation pressure increases rolling resistance and reduces load-carrying capacity and tire life. Always inflate the tires to the pressure indicated on the door jamb sticker or found in service information or the owner's manual.
2. All tires create less rolling resistance as they wear. Even if the same identical tire is used as a replacement, the owner may experience a drop in fuel economy.
3. Tires can have a big effect on fuel economy. It is best to warn the owner that replacement of the tires can and often will cause a drop in fuel economy, even if low rolling resistance tires are selected.
4. Try to avoid using tires that are larger than used from the factory. The larger the tire, the heavier it is, and it takes more energy to rotate, resulting in a decrease in fuel economy.
5. Follow normal tire inspections and tire rotation intervals as specified by the vehicle manufacturer.

NOISE-REDUCING TIRES The purpose of a **noise-reducing tire** is to eliminate noise in the 130–240 Hz range that would be normally covered up by normal engine noise in a vehicle with an ICE. The noise reduction is accomplished by adding acoustical foam to the inside of a tire. The sound is created within the structure of the tire itself and is not transmitted through the air, but rather through the chassis of the vehicle. The sound is similar to the sound heard when blowing across a partially filled glass Coke bottle. As result, this sound is often referred to a "Coke bottle resonance." This sound is most noticeable with electric vehicles (EVs) because there is no drivetrain noise to drown out the resonance. ● **SEE FIGURE 88–9**.

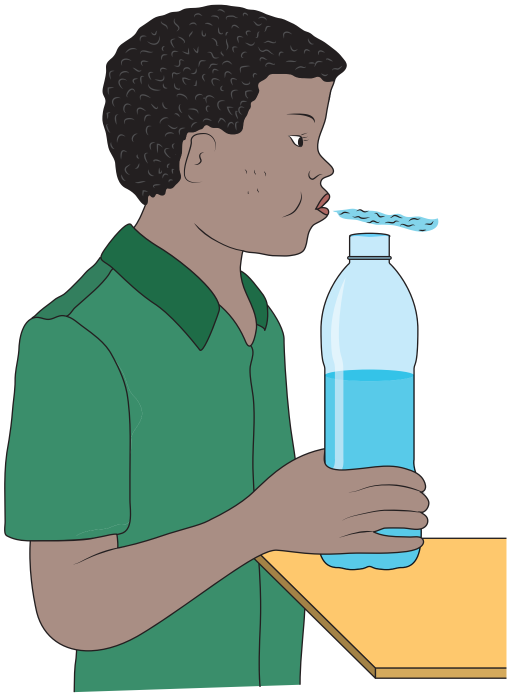


FIGURE 88–9 Blowing across the top of an empty “Coke” bottle creates a noise similar to a vehicle without noise-reducing tires.

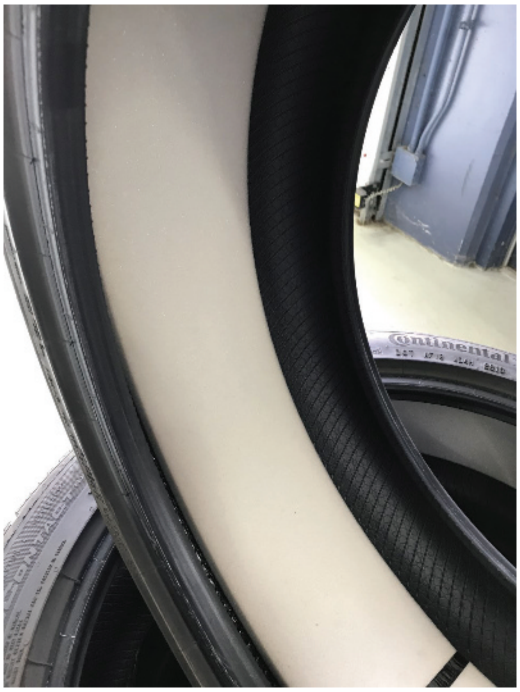


FIGURE 88–10 A tire off a Tesla Model 3 with acoustical foam.

The tire repair process is different on many noise-reducing tires because of the use of acoustical foam. In most instances, the acoustical foam must be carefully cut from the area of the wound and after the repair is complete it must be reattached. ● **SEE FIGURE 88–10**.

AUXILIARY BATTERY TESTING AND SERVICE

Performing auxiliary battery service is similar to performing this service in any vehicle equipped with an ICE. However, there are several items to know when servicing the auxiliary battery on a HEV. They are as follows:

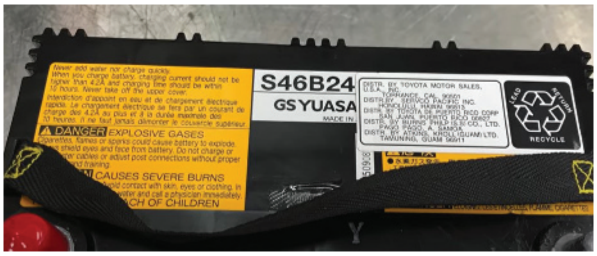


FIGURE 88–11 This Toyota battery is rated using the Japanese Industrial Standard (JIS) rather than cold-cranking amperes.

1. Auxiliary 12-volt batteries used in hybrid or electric vehicles are located in one of two general locations.
    - Under the hood—If the 12-volt auxiliary battery is under the hood, it is generally a flooded-type lead–acid battery and should be serviced the same as any conventional battery.
    - In the passenger or trunk area—If the battery is located in the passenger or trunk area of the vehicle, it is usually of the absorbed glass mat (AGM) design. This type of battery requires that a special battery charger that limits the charging voltage be used.
2. The auxiliary 12-volt battery is usually smaller than a battery used in a conventional vehicle because it is not used to start the engine.
3. The 12-volt auxiliary battery can be tested and serviced the same as any battery used in a conventional vehicle.
4. Some micro hybrids with the stop-start feature will have two 12-volt batteries. The batteries must be isolated during testing to obtain accurate results.
5. Always read, understand, and follow all of the service information instructions when servicing the auxiliary battery on a hybrid or electric vehicle. ● **SEE FIGURE 88–11**.

STEERING SYSTEM SERVICE

Performing steering system service is similar to performing this service in any vehicle equipped with an ICE. However, there are several items to know when servicing the steering system on a hybrid or electric vehicle, which include the following:

1. Check service information for any precautions that are specified to be followed when servicing the steering system on a hybrid or electric vehicle.
2. Most hybrid or electric vehicles use an electric power steering system. These can be powered by one of two voltages:
    - 12 volts—These systems can be identified by the red or black wiring conduit and often use an inverter that increases the voltage to operate the actuator motor (usually to 42 volts). While this higher voltage is contained in the controller and should not create a shock hazard, always follow the specified safety precautions and wear protective high-voltage gloves as needed.
    - 42 volts—These systems use a yellow or blue plastic conduit over the wires to help identify the possible hazards from this voltage level. This voltage level is not a

shock hazard, but can maintain an arc if a circuit carrying 42 volts is opened.

- Many electric power steering systems contain capacitors that provide additional voltage to the system under heavy operating loads. When depowering the power steering system to make repairs, it is important to follow the specific wait times to ensure the capacitors are completely discharged. ● **SEE FIGURE 88–12**.

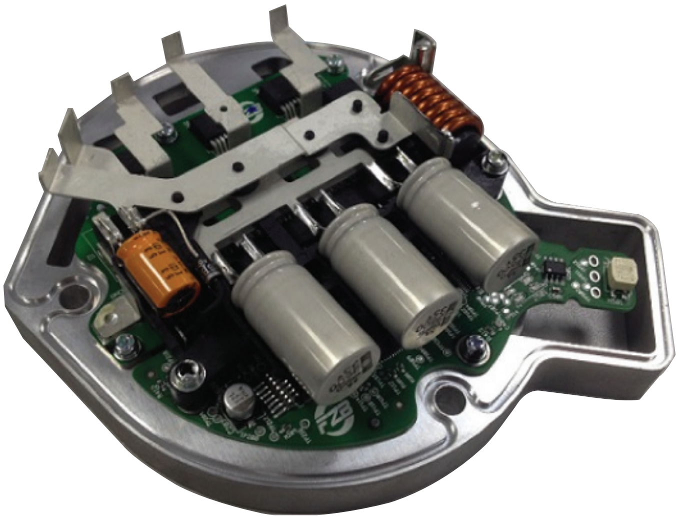


FIGURE 88–12 The capacitors in the power steering assist unit provide additional power when needed but must be allowed to discharge before service work begins.

DIAGNOSIS PROCEDURES

Hybrid and electric vehicles should be diagnosed the same as any other type of vehicle. This means following a diagnostic routine, which usually includes the following steps:

STEP 1 Verify the customer concern.

STEP 2 Check for diagnostic trouble codes (DTCs). An enhanced or factory level scan tool may be needed to get access to codes and sub codes.

STEP 3 Perform a thorough visual inspection. If a DTC is stored, carefully inspect those areas that might be the cause of the trouble code.

STEP 4 Check for technical service bulletins (TSBs) that may relate to the customer concern.

STEP 5 Follow service information specified steps and procedures. This could include checking scan tool data for sensors or values that are not within normal range.

STEP 6 Determine and repair the root cause of the problem.

STEP 7 Verify the repair and clear any stored DTCs unless in an emission testing area. If in an emission test area, drive the vehicle until the powertrain control module (PCM) passes the fault and turns off the malfunction indicator lamp, thereby allowing the vehicle to pass the inspection.

STEP 8 Complete the work order and record the “three Cs” (complaint, cause, and correction).

REVIEW QUESTIONS

1. What is the purpose of the hybrid vehicle maintenance mode?
2. Why do most manufacturers of hybrid vehicles use full synthetic engine oil.
3. Why do most manufacturers recommend premixed coolant when servicing the hybrid or electric vehicle cooling systems?
4. Why does the base brake system require more frequent maintenance in the “salt belt” portion of the country?
5. What is the purpose of the acoustical foam in the noise-reducing tire?

CHAPTER QUIZ

1. The purpose of the hybrid vehicle maintenance mode is to ___________.
   a. bypass the idle stop feature
   b. service the base brake system
   c. change the oil and filter
   d. service the cooling system
2. Why do most hybrid vehicles use a full synthetic engine oil?
   a. The engine stops and starts more frequently.
   b. It helps to reduce engine damage.
   c. It helps to improve fuel economy.
   d. All of the above are correct.
3. Why do most manufacturers recommend using a premixed replacement coolant when servicing a hybrid or electric vehicle cooling system?
   a. The minerals in tap water can cause corrosion issues.
   b. It is difficult to get the mixture ratio correct.
   c. Both a and b are correct.
   d. Neither a nor b is correct.
4. Why do base brake systems require more frequent maintenance in the “salt belt” portion of the country?
   a. Salt causes the brake pads to separate from their backing.
   b. The use of regenerative brakes causes less heat at the brake rotor and leads to a decrease in the evaporation rate of moisture on the brake system.
   c. Corrosion causes the brake pins and sliders to stick.
   d. All of the above are correct.
5. What special procedures may be needed when repairing a puncture on a noise-reducing tire?
   a. The tire cannot be repaired, it must be replaced.
   b. The acoustical foam in the area of the leak will need to be removed prior to repairing the wound.
   c. The acoustical foam will need to be reattached after the repair is complete.
   d. Both b and c are correct.

6. Lack of proper maintenance could cause ____________, leading the customer to think the HV battery is failing.
    - **a.** noises
    - **b.** dim headlights
    - **c.** decreased fuel economy
    - **d.** None of the above

7. Electric power steering systems operate at what voltage level?
    - **a.** 12 volts
    - **b.** 42 volts
    - **c.** 60 volts
    - **d.** Both a and b are correct

8. What cautions should be observed when servicing an electric air-conditioning compressor?
    - **a.** Make sure the high-voltage system has been properly depowered.
    - **b.** Make sure the proper refrigerant oil is used in the repair.
    - **c.** Use the appropriate refrigerant recovery machine.
    - **d.** All of the above are correct.

9. What is the purpose of the high-voltage battery cabin filter?
    - **a.** To prevent the intrusion of passenger compartment debris
    - **b.** To help regulate the temperature of the battery
    - **c.** Both a and b are correct.
    - **d.** Neither a nor b is correct.

10. Why is the eight-step diagnostic procedure used when diagnosing a hybrid or electric vehicle?
    - **a.** To ensure a problem is not overlooked
    - **b.** To ensure the vehicle is repaired as efficiently as possible
    - **c.** To make sure the repair is properly documented
    - **d.** All of the above are correct.

Chapter 89

EV AND HEV HIGH-VOLTAGE BATTERIES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss hybrid and electric vehicle high-voltage batteries.
- Describe nickel-metal hydride batteries and designs used in hybrid electric vehicles.
- Explain the operation of lithium-ion high-voltage batteries.
- Describe the designs of lithium-ion cells.
- Describe the types of lithium-ion batteries.
- Explain HEV/EV electronics cooling.
- Explain high-voltage battery cooling and heating.
- Discuss battery capacity versus vehicle range.
- Discuss the high-voltage battery control components.
- Discuss the factory authorized lithium-ion battery repair procedure.
- Describe battery degradation and balancing.

KEY TERMS:

Active balancing 1038 • Battery density 1030 • Battery control module (BCM) 1034 • Battery management system (BMS) 1035 • Electrical Distribution System (EDS) 1035 • Guess-O-Meter (GOM) 1033 • Lithium iron phosphate ($LiFePO_4$) 1030 • Nickel, cobalt, and aluminum (NCA) 1030 • Nickel, manganese, and cobalt (NMC) 1030 • Nickel-metal hydride (NiMH) 1026 • MPGe 1033 • Passive balancing 1038 • Pouch cell 1029 • System Main Relays (SMRs) 1034 • Worldwide harmonized Light vehicles Test Procedure (WLTP) 1033

HYBRID AND ELECTRIC VEHICLE HIGH-VOLTAGE BATTERIES

PURPOSE AND FUNCTION Hybrid electric vehicles (HEVs) use a dual-voltage electrical system:

- The high-voltage (HV) system is used to power the electric drive (traction) motor.
- A conventional 12-volt system is used to power all other aspects of vehicle operation.

One advantage to using this system is that the vehicle can use any conventional electrical accessories in its design.

NOTE: It is possible for an HEV to have three separate voltage systems. The Toyota Highlander HEV, for example, has a 12-volt auxiliary system, a 42-volt system for the electric power assist steering, and a 288-volt system for the hybrid drive.

ELECTRIC MOTOR REQUIREMENTS EVs and HEVs use high-output electric motors to drive and assist vehicle movement. These motors are rated anywhere from 10 to 50 kW for HEVs and as much as 450 kW for some EVs, so they consume large amounts of electrical power during operation. If a conventional 12-volt electrical system was used to power these motors, the amount of current flow required would be extremely large and the cables used to transmit this energy would also be so large as to be impractical. Also, the motors used in these systems would have large gauge windings and would be big and heavy relative to their power output. Automotive engineers overcome this problem by increasing the voltage provided to the motors, thus decreasing the amount of current that must flow to meet the motor's wattage requirements (see Frequently Asked Question, "Why Do Higher Voltage Motors Draw Less Current?"). Smaller amounts of current flowing in the cables mean that the cables can be sized smaller, making it much more practical to place a battery in the rear of the vehicle and run cables from there to the drive motor in the engine compartment. ● **SEE FIGURE 89–1**.

The motors can also be made much smaller and more powerful when they are designed to operate on higher voltages.

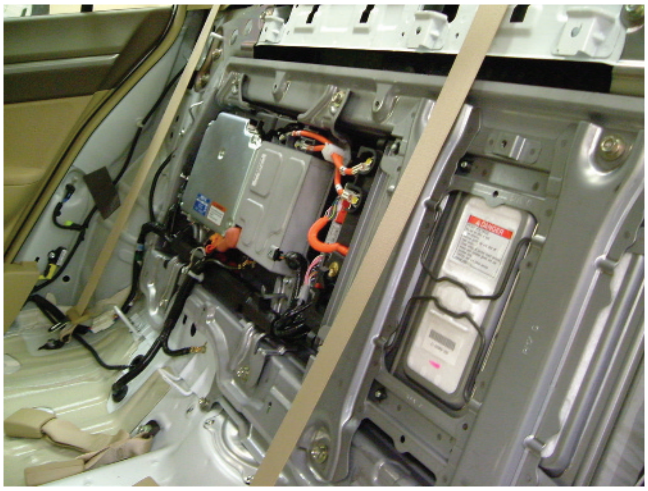


FIGURE 89–1 The high-voltage battery and motor controls are located behind the rear passenger's seat in a Honda.

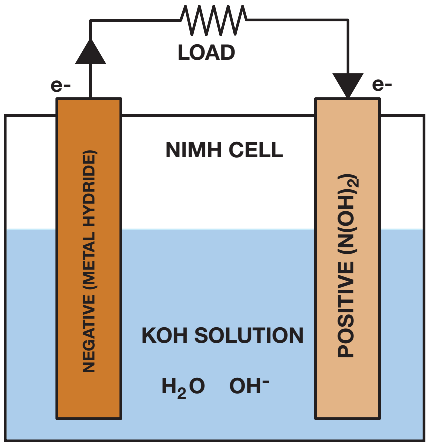


FIGURE 89–2 An NiMH cell. The unique element in a nickel-metal hydride cell is the negative electrode, which is a hydrogen-absorbing alloy. The positive electrode is nickel hydroxide. The electrolyte does not enter into the chemical reaction and is able to maintain a constant conductivity regardless of the state-of-charge of the cell.

NICKEL-METAL HYDRIDE BATTERIES

USES Many HEVs use **nickel-metal hydride (NiMH)** battery technology for the high-voltage battery. NiMH batteries are being used for these applications because of their performance characteristics, such as specific energy, cycle life, and safety. From a manufacturing perspective, the NiMH battery is attractive because the materials used in its construction are plentiful and recyclable.

DESCRIPTION AND OPERATION NiMH batteries have a positive electrode made of nickel hydroxide. The negative electrode is unique, in that it is a hydrogen-absorbing alloy, also known as a metal hydride. The electrolyte is an alkaline, usually potassium hydroxide. The nominal voltage of an NiMH battery cell is 1.2 volts.

ELECTROLYTE NiMH batteries are known as alkaline batteries due to the alkaline (pH greater than 7) nature of the electrolyte. The electrolyte is aqueous potassium hydroxide. Potassium hydroxide works well for this application because it does not corrode the other parts of the battery and can be housed in a sealed steel container. Also, potassium hydroxide does not take part in the chemical reaction of the battery, so the electrolyte concentration stays constant at any given state-of-charge. These factors help the NiMH battery achieve high-power performance and excellent cycle life. ● **SEE FIGURE 89–2**.

OPERATION DURING CHARGING During battery charging, hydrogen ions (protons) travel from the positive electrode to the negative electrode, where they are absorbed into the metal hydride material. The electrolyte does not participate in the reaction and acts only as a medium for the hydrogen ions to travel through.

OPERATION DURING DISCHARGING When the battery is discharged, this process reverses, with the hydrogen ions (protons) traveling from the negative electrode back to the positive electrode. The density of the electrodes changes somewhat during the charge/discharge process, but this is kept to a minimum as only protons are exchanged during battery cycling. Electrode stability due to minimal density changes is one of the reasons why the NiMH battery has a very good cycle life. ● **SEE FIGURE 89–3**.

FREQUENTLY ASKED QUESTION

Why Do Higher Voltage Motors Draw Less Current?

Keep in mind that an electric motor is powered by wattage. Every electric motor is rated according to the amount of power (in watts) it consumes. Power is calculated using the following formula:

$$P = I \times E$$

or

$$\text{Power in watts} = \text{Current (in amperes)} \times \text{Voltage (in volts)}$$

An electric motor rated at 144 watts will consume 12 amperes at 12 volts of applied voltage (12 volts × 12 amperes = 144 watts). If this same motor was powered with 6 volts, it would draw 24 amperes to achieve the same power output. This increase in current draw would require a much bigger cable to efficiently transmit the electric current and minimize voltage drop. The motor windings would also have to be much heavier to handle this increased current. Imagine that we power this same motor with a 144-volt battery. Now we require only 1 ampere of electrical current to operate the motor (144 volts × 1 ampere = 144 watts). The cable required to transmit this current could be sized much smaller and it will now be much easier to run the cables over the length of the car without significant power loss. Also, the electric motor can be made much smaller and more efficient when less current is needed to power it. Some hybrid systems have motors that operate at up to 650 volts in an effort to increase system efficiency.

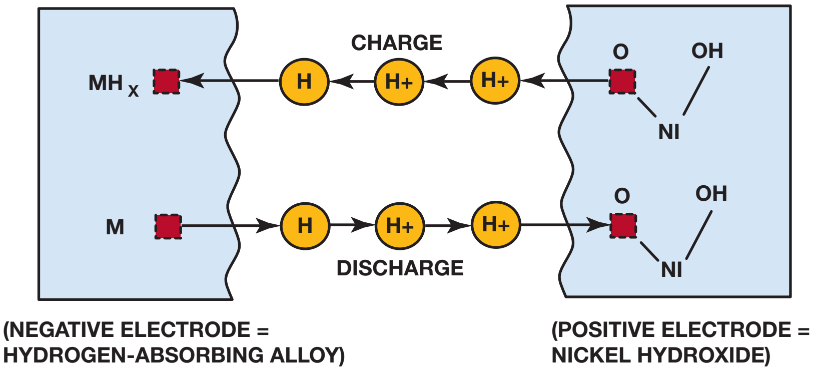


FIGURE 89–3 Chemical reactions inside an NiMH cell. Charging and discharging both involve an exchange of hydrogen ions (protons) between the two electrodes.

ADVANTAGES Nickel-based alkaline batteries have a number of advantages over other battery designs. These include the following:

- High specific energy.
- The nickel electrode can be manufactured with large surface areas, which increase the overall battery capacity.
- The electrolyte does not react with steel, so NiMH batteries can be housed in sealed steel containers that transfer heat reasonably well.
- The materials used in NiMH batteries are environmentally friendly and can be recycled.
- Excellent cycle life.
- Durable and safe.

DISADVANTAGES Disadvantages of the NiMH battery include the following:

- High rate of self-discharge, especially at elevated temperatures.
- Moderate levels of memory effect, although this seems to be less prominent in newer designs.
- Moderate to high cost.

FREQUENTLY ASKED QUESTION

How Is an Alkaline Battery Different from a Lead–Acid Battery?

Lead–acid batteries use sulfuric acid as the electrolyte, which acts as the medium between the battery's positive and negative electrodes. Acids have a pH that is below 7, and pure water has a pH of exactly 7. If electrolyte from a lead–acid battery is spilled, it can be neutralized using a solution of baking soda and water (an alkaline solution). Alkaline batteries use an electrolyte such as potassium hydroxide, which has a pH greater than 7. This means that the electrolyte solution is basic, which is the opposite of acidic. If an alkaline battery electrolyte is spilled, it can be neutralized using a solution of vinegar and water (vinegar is acidic). Both nickel-cadmium (Ni-Cd) and nickel-metal hydride (NiMH) batteries are alkaline battery designs.

NiMH BATTERY DESIGNS There are two primary designs for an NiMH battery cell. These are:

1. **Cylindrical type.** The cylindrical type has the active materials made in long ribbons and arranged in a spiral fashion inside a steel cylinder (case). The negative electrode is wound alongside the positive electrode, and the separator material holding the electrolyte is placed between them. The negative electrode is attached to the steel battery case, while the positive electrode attached to the (–) terminal at the top of the battery. There is a self-resealing safety vent located at the top of the battery case, which will relieve internal pressure in case of overcharge, short circuiting, reverse charge, or other abuse. Cylindrical cells are often constructed very similar to a conventional "D" cell. Cylindrical cells are most often incorporated into modules with a group of six cells connected in series. This creates a single battery module with a 7.2-volt output. Groups of these modules can then be connected in series to create higher voltage battery packs. ● **SEE FIGURE 89–4**.
2. **Prismatic type.** The prismatic type is a rectangular or box-like design with the active materials formed into flat plates, much like a conventional lead–acid battery. The positive and negative plates are placed alternately in the battery case, with tabs used to connect the plate groups. Separator material is placed between the plates to prevent them from touching, but still allow electrolyte to circulate freely. ● **SEE FIGURE 89–5**.

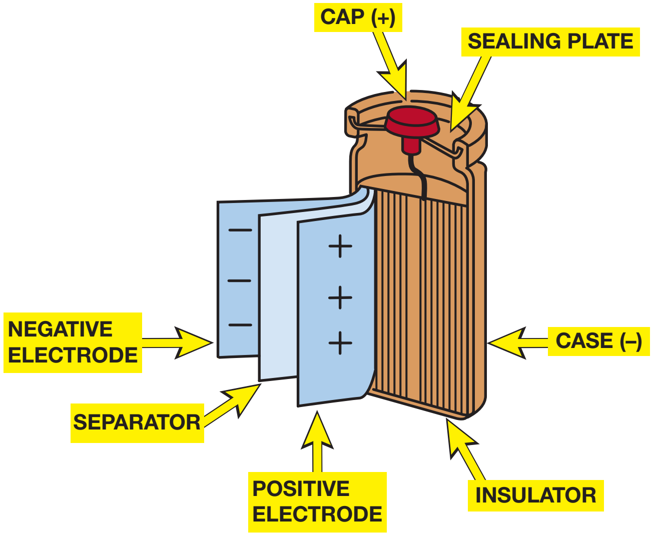


FIGURE 89–4 Cylindrical-type NiMH batteries are made with a stainless-steel housing.

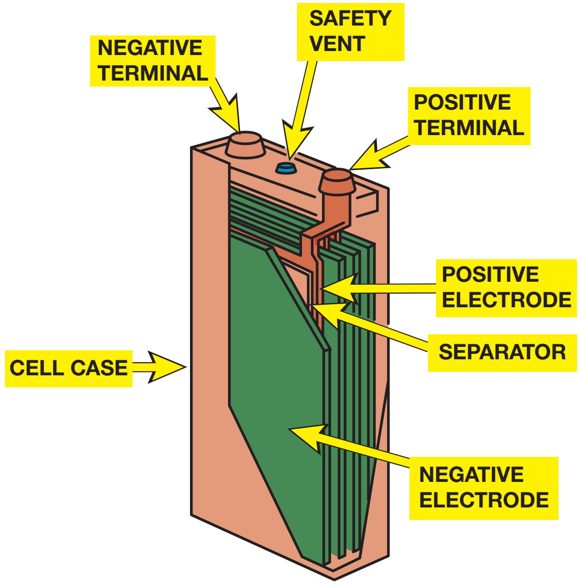

SAFETY VENT
NEGATIVE TERMINAL
POSITIVE TERMINAL
POSITIVE ELECTRODE
SEPARATOR
CELL CASE
NEGATIVE ELECTRODE

FIGURE 89–5 A prismatic NiMH cell. Prismatic cells are built with flat plates and separators similar to conventional lead–acid batteries.

BATTERY CELLS ARE CONNECTED IN SERIES Battery designers are limited by the nominal cell voltage of the battery technology. In the case of NiMH batteries, each cell is capable of producing only 1.2 volts. A high-voltage battery based on NiMH technology must be built using multiples of 1.2 volts. In order to build a 144-volt battery, 114 individual NiMH cells must be connected together in series (144 × 1.2 volts). Obviously, the higher the voltage output of the battery, the greater the number of individual battery cells that must be used to achieve the necessary voltage. ● **SEE FIGURES 89–6, 89–7, AND 89–8.**

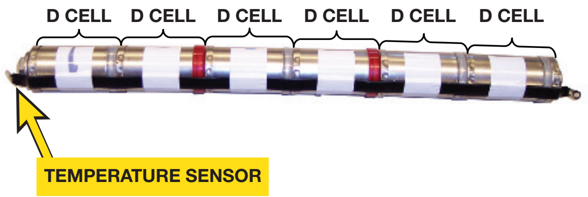

D CELL
D CELL
D CELL
D CELL
D CELL
D CELL
TEMPERATURE SENSOR

FIGURE 89–6 Each cell has 1.25 volts and a group of six as shown has 7.5 volts. These sections are connected to other sections to create the HV battery pack.

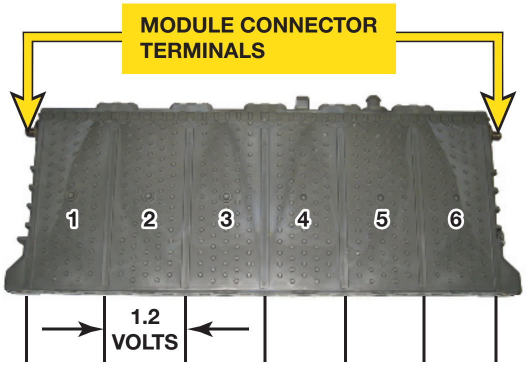

MODULE CONNECTOR TERMINALS
1
2
3
4
5
6
1.2 VOLTS

FIGURE 89–7 A prismatic NiMH module from a Toyota Prius HV battery pack. The battery posts are located on the left and right sides of the module. A self-resealing vent is located on the top right for venting hydrogen gas if the module overheats.

FIGURE 89–8 A Toyota Camry Hybrid HV battery pack.

LITHIUM-ION HIGH-VOLTAGE BATTERIES

USES A battery design that shows a great deal of promise for electric vehicles (EV) and hybrid electric vehicles (HEV) applications is lithium-ion (Li-ion) technology. Lithium-ion batteries have been used extensively in consumer electronics since the early 1990s and are currently used in most electric and plug-in hybrid electric vehicles (PHEVs).

DESCRIPTION A lithium-ion cell is named because during battery cycling, lithium ions move back and forth between the positive and negative electrodes. Lithium-ion has approximately twice the specific energy of nickel-metal hydride.

CONSTRUCTION The positive electrode in a conventional lithium-ion battery has lithium cobalt oxide as its main ingredient, with the negative electrode being made from a specialty carbon. The electrolyte is an organic solvent, and this is held in a separator layer between the two electrode plates. To prevent battery rupture and ensure safety, a pressure release valve is built into the battery housing that will release gas if the internal pressure rises above a preset point. ● **SEE FIGURE 89–9.**

OPERATION The lithium-ion cell is designed so that lithium ions can pass back and forth between the electrodes when the battery is in operation.

1. During battery discharge, lithium ions leave the anode (negative electrode) and enter the cathode (positive electrode) through the electrolyte and across the separator.

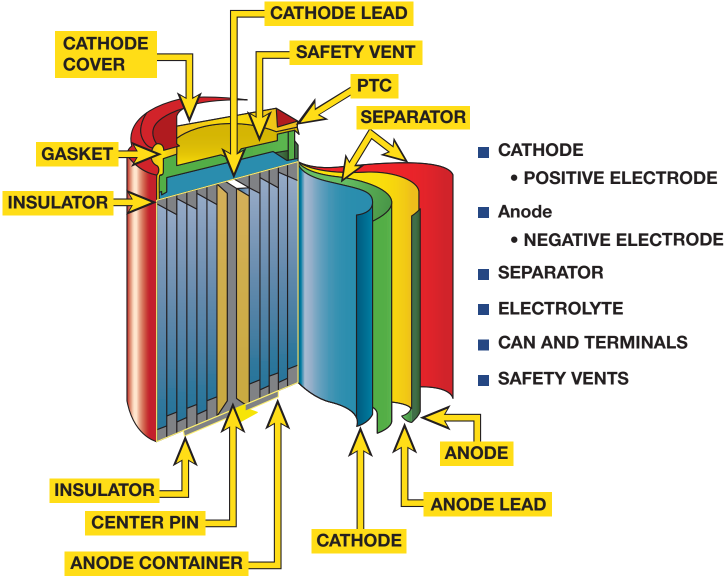

CATHODE LEAD
CATHODE COVER
SAFETY VENT
PTC
SEPARATOR
GASKET
INSULATOR
CATHODE
• POSITIVE ELECTRODE
Anode
• NEGATIVE ELECTRODE
SEPARATOR
ELECTROLYTE
CAN AND TERMINALS
SAFETY VENTS
ANODE
INSULATOR
ANODE LEAD
CENTER PIN
CATHODE
ANODE CONTAINER

FIGURE 89–9 Construction of a cylindrical lithium-ion cell. Note the pressure relief valve and exhaust gas hole that will relieve internal battery pressure if it gets too hot.

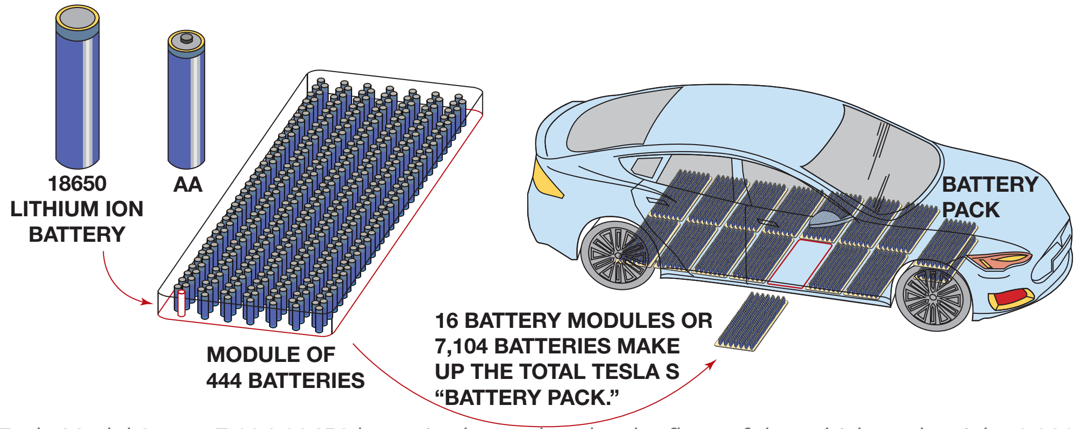


FIGURE 89–10 A Tesla Model S uses 7,104 18650 batteries located under the floor of the vehicle and weighs 1,200 pounds (544 kg).

FREQUENTLY ASKED QUESTION

How Much Lithium Is There in a Typical Li-Ion High-Voltage EV Battery?

In a typical electric vehicle, such as the Tesla Model S, it is estimated that there is a total of about 15 pounds (7 kg) of lithium used in all of the cells. This is about the weight of a bowling ball.

2. Lithium ions leave the cathode and move through the electrolyte into the anode.

ADVANTAGES Lithium-ion batteries have the following advantages:

- High specific energy
- Good high-temperature performance
- Low self-discharge
- Minimal memory effect
- High nominal cell voltage. The nominal voltage of a lithium-ion cell is 3.6 volts, which is three times that of nickel-based alkaline batteries. This allows for fewer battery cells being required to produce high voltage from an HV battery.

DISADVANTAGES Disadvantages of the lithium-ion battery include

- High cost
- Issues related to battery overheating

NOTE: Early lithium-ion battery designs have experienced problems with thermal runaway, which has led to fire and even explosions. Lithium-ion battery packs in automotive applications are designed with cooling and safety systems that prevent overheating and isolate cell failures.

DESIGNS OF LITHIUM-ION CELLS

CYLINDRICAL A cylindrical cell has high specific energy, good mechanical stability, and lends itself to automated manufacturing. Cylindrical cell design cycles well, offers a long life and is low cost, but it has less than ideal packaging density. The cylindrical cell design is used by many electric vehicle manufacturers such as Tesla.

Tesla, for example, uses several sizes of cylindrical cells including

- 18650 cells manufactured by Panasonic in the Models S and X cars since 2012. These are small battery cells, slightly larger than the standard AA cells. The Tesla cylindrical cells are 18 mm in diameter and 65 mm tall. ● **SEE FIGURE 89–10**.
- Tesla Model 3 and Y use 2170 batteries, which are 21 mm in diameter and 70 mm tall.
- Tesla Cyber Truck uses 4680 cells, which are 46 mm in diameter and 80 mm tall.

PRISMATIC—HARD CASE The prismatic type is a rectangular or boxlike design with the active materials formed into flat plates, much like a conventional lead–acid battery. The positive and negative plates are placed alternately in the battery case, with tabs used to connect the plate groups. Separator material is placed between the plates to prevent them from touching, but still allow electrolyte to circulate freely. ● **SEE FIGURE 89–11**.

PRISMATIC—POUCH TYPE Pouch design HV battery uses laminated architecture in a bag referred to as **pouch cell**. It is light and cost-effective, but exposure to humidity and high temperature can shorten its life. The pouch cell offers a simple, flexible, and lightweight battery design. The pouch cell makes most efficient use of space and achieves 90–95% packaging efficiency, the highest among battery packs.

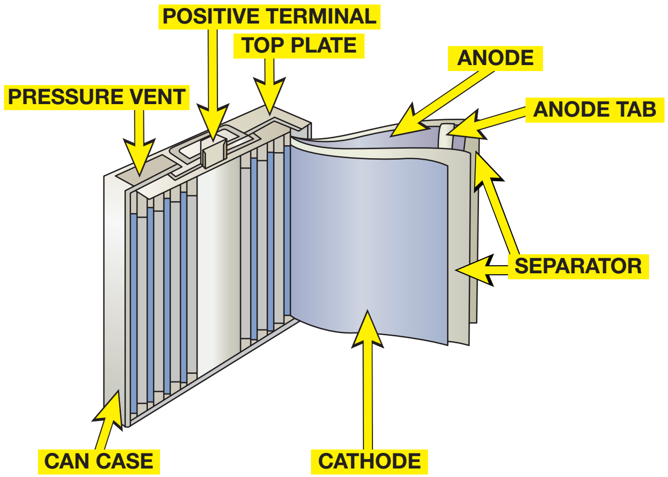


FIGURE 89–11 The prismatic type is a rectangular or boxlike design that allows them to be stacked close together to create a HV battery pack.

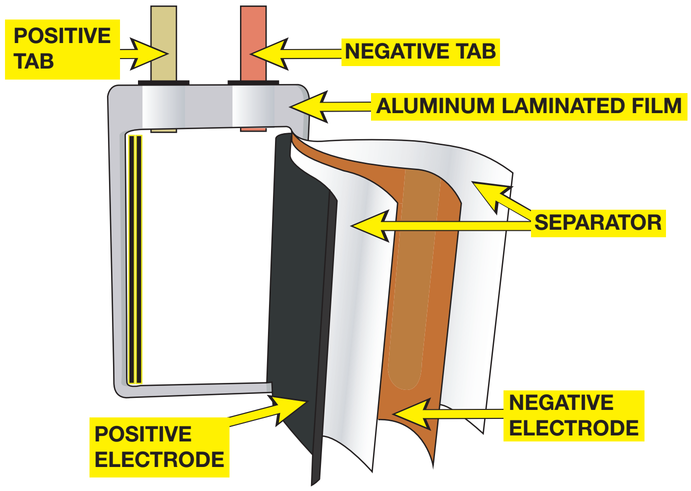


FIGURE 89–12 The pouch design uses a flexible outer container that is able to expand when being charged without damaging the battery.

Eliminating the metal enclosure reduces weight, but the cell needs support and allowance to expand in the battery compartment. The pouch packs are used in consumer, military and automotive applications, and are used in the Jaguar I-Pace, Mustang Mach E, and the GMC Hummer EV electric vehicles. The General Motor's Ultium batteries are unique because of their large-format, pouch-style cells, which can be stacked vertically or horizontally inside the battery pack. No standardized pouch cells exist as each manufacturer designs its own. ● **SEE FIGURE 89–12**.

TYPES OF LITHIUM-ION BATTERIES

NUMEROUS MATERIALS There are numerous types of lithium-ion batteries, and the list is growing. While every component of the battery is under development, the primary difference between the various designs is the materials used for the positive electrode or cathode. The original Li-ion cell design used lithium cobalt oxide for its cathode, which has good energy storage characteristics, but suffers chemical breakdown at relatively low temperatures. This failure results in the release of heat and oxygen, which often leads to a fire or explosion as the electrolyte ignites. In order to make lithium-ion batteries safer and more durable, a number of alternative cathode materials have been formulated.

CATHODE MATERIAL Vehicle manufacturers use several different cathode materials:

- A combination of **nickel, manganese, and cobalt (NMC)** for the cathode material. This cathode material results in slightly lower energy, but is less volatile and can withstand variation in temperature.

  NOTE: This design of battery is used in the 48-volt mild-hybrid Ram truck.

- Tesla uses **nickel, cobalt, and aluminum (NCA)** cathode material, which results in a long battery life and faster charging capability.
- Another cathode design for automotive applications includes **lithium iron phosphate ($LiFePO_4$)**, which is stable at higher temperatures and does not contain cobalt, which is in limited supply worldwide.

The lithium iron phosphate battery is the most promising future battery and is constructed using lithium iron phosphate as the cathode, and a graphitic carbon electrode with a metallic backing as the anode. The lithium iron phosphate battery offers a longer life cycle, low cost, low toxicity, well-defined performance, and long-term stability making it a likely battery for use in future electric vehicles. ● **SEE CHART 89–1**.

CHEMICAL NAME	MATERIAL	ABBREVIATION
Lithium Cobalt Oxide	$LiCoO_2$	LCO
Lithium Nickel Cobalt Oxide	$LiNi_xCOyAl_zO_2$	LNCO
Lithium Nickel Manganese Cobalt Oxide	$LiNiMnCoO_2$	NMC
Lithium Manganese Oxide	$LiMn_2O_4$	LMO
Lithium Iron Phosphate	$LiFePO_4$	LFP
Lithium Nickel Cobalt Aluminum Oxide	$LiNiCoAlO_2$	NCA

CHART 89–1

Chart of the most commonly used Li-ion batteries.

FREQUENTLY ASKED QUESTION

What Is "Battery Density"?

Battery density refers to the amount of energy in kilowatt-hours (kWh) that a battery can store per kilogram of mass (kWh per kilograms) or volume (kWh per liter) of volume. The higher the number, the higher the energy density of the battery. ● **SEE CHART 89–2**.

BATTERY TYPE	ENERGY DENSITY (kWh/kg)	ENERGY DENSITY (kWh/L)
Lead–Acid	0.11–0.14	0.22–0.27
Nickel-Metal Hydride	0.36	1.44
Lithium Cobalt Oxide	0.70	2.0

CHART 89–2

The higher the number, the higher the energy density of the battery. Notice that the lithium-ion battery has the highest energy density compared to lead–acid and nickel-metal hydride batteries.

FREQUENTLY ASKED QUESTION

What Is a "Solid State" Battery?

Many manufacturers including Toyota are working on a solid-state battery that does not use a liquid or gel electrolyte. A prototype solid-state battery is said to use a lithium-nickel-manganese-cobalt cathode and a flexible ceramic separator. The lithium ions from the cathode create a metal film on the collector when charging. The advantages of a solid-state battery include a faster charging rate, lower weight, and higher capacity.

HEV/EV ELECTRONICS COOLING

NEED FOR COOLING Hybrid electric vehicles are unique in that they have electric motors and electronic controls that are not found in vehicles with conventional drivetrains. These components are designed to operate under heavy load with high current and voltage demands, so they tend to generate excessive heat during vehicle operation. Special auxiliary cooling systems are incorporated into hybrid electric vehicles to prevent overheating of these critical components and keep those components at efficient operating temperatures.

EFFECTS OF HEAT ON THE ELECTRICAL/ELECTRONIC SYSTEM Electronic components operate more efficiently as their temperature decreases, but can suffer permanent damage if they overheat. All hybrid electric vehicles have cooling systems for their motors and motor controls, and some use air-cooling to remove excess heat from these components. ● **SEE FIGURE 89–13**.

For example, a Chevrolet Bolt electric vehicle has two expansion valves in the A/C system. One is used to cool the passenger compartment and the other is used to cool the electronics and the high-voltage battery.

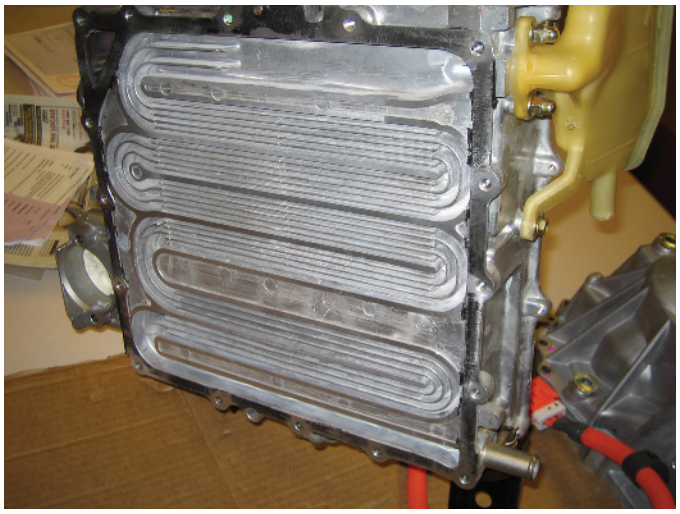


FIGURE 89–13 The underside of the Toyota Prius controller showing the coolant passages used to cool the electronic control unit.

Many hybrid electric vehicles use a liquid cooling system for their motors and motor controls. These systems are often separate from the ICE's cooling system and typically operate at lower temperatures.

SYSTEM CONSTRUCTION The liquid cooling systems used for the motors and motor controls on hybrid electric vehicles have much in common with conventional ICE cooling systems. There is a separate expansion tank that acts as a coolant reservoir for the system, and the coolant is often the same type that is used for the ICE cooling system. A radiator is used to dissipate excess heat and is located at the front of the vehicle. Some designs may have the radiator incorporated into the ICE radiator, or it may be separate. ● **SEE FIGURE 89–14**.

A low-voltage electric water pump is used to circulate the coolant, and it is often configured to run whenever the vehicle is in operation. The coolant is circulated through the various components in the system, which could include the following:

- Electric motor-generator(s)
- DC–DC converter
- Inverter
- Transmission oil cooler
- Other high-load control modules

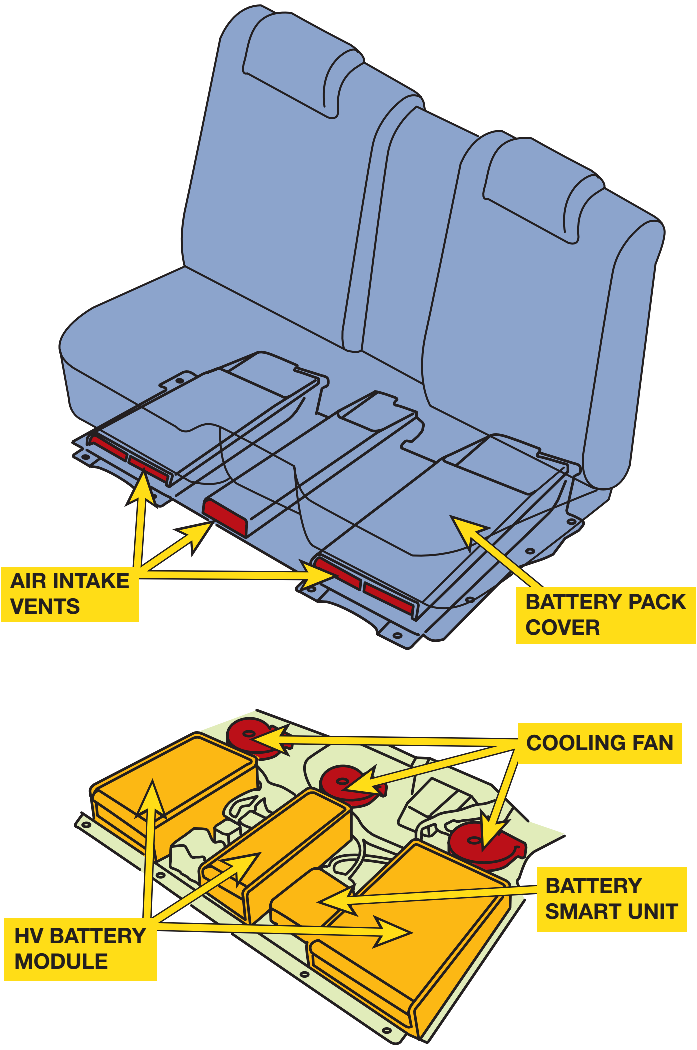


FIGURE 89–14 The motor and HV battery electronics on Toyota hybrid SUV.

FREQUENTLY ASKED QUESTION

Why Isn't the ICE Cooling System Used to Cool HEV Motors and Motor Controls?

Most ICE cooling systems operate at over 200 degrees F (93 degrees C). For maximum efficiency, it is important that the ICE operate at close to this temperature at all times. Electric motors and the motor controls, however, tend to operate more efficiently at lower temperatures. The ICE cooling system runs too hot to allow these components to operate at peak efficiency, so a separate low-temperature system is often used.

NOTE: The first- and second-generation Ford Escape Hybrid also uses a cabin filter in the auxiliary climate control (battery zone) system to prevent particulate matter from collecting on the traction battery cooling passages. ● SEE FIGURE 89–15.

HIGH-VOLTAGE BATTERY COOLING AND HEATING

THE NEED TO HEAT/COOL HV BATTERIES High operating temperatures can lower performance and cause damage to an NiMH or lithium battery pack. The cooling systems can be categorized as either air or liquid cooling systems. Most current production HEVs use air cooling to control HV battery pack temperature. Cabin air is circulated over the battery cells using an electric fan and ducting inside the vehicle. ● **SEE FIGURE 89–16**.

In some cases, the air-conditioning system has an extra zone that cools the air being circulated over the HV battery pack. The first- and second-generation Ford Escape Hybrid is an example of this type of system. ● **SEE FIGURE 89–17**.

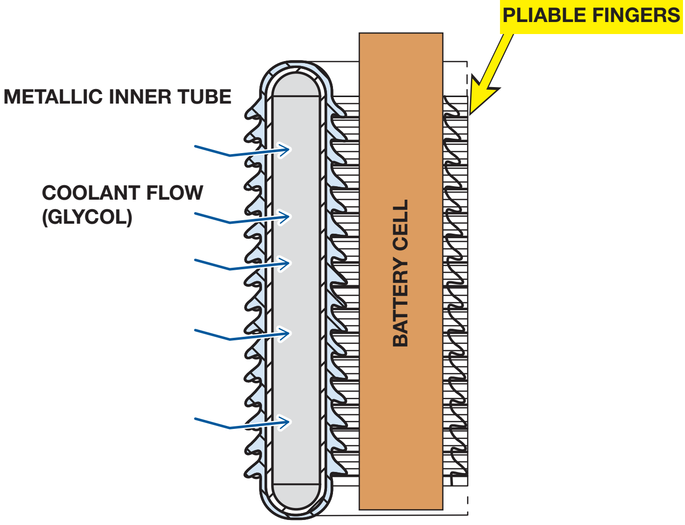


FIGURE 89–15 The electric motors and the motor controls are cooled using a separate cooling system. This Toyota Hybrid Synergy Drive (HSD) system uses a radiator that is integral with the ICE cooling system radiator.

Most current electric vehicles use a liquid cooling system. Coolant is circulated through a dedicated system that transfers battery heat to the outside air through a dedicated radiator. In a battery using prismatic cells, there is an aluminum cooling plate inserted between each pair of cells. A battery using cylindrical cells uses a ribbon-type tube between the cells.

Temperature sensors (thermistors) are mounted in various locations in the battery pack housing to send data to the module responsible for controlling battery temperature. These inputs are used to help determine battery charge rate and cooling system operation.

HIGH-VOLTAGE BATTERY COOLING SYSTEM SERVICE The service of high-voltage battery cooling systems falls into two main categories:

1. Service of the air distribution system
2. Service of the liquid system

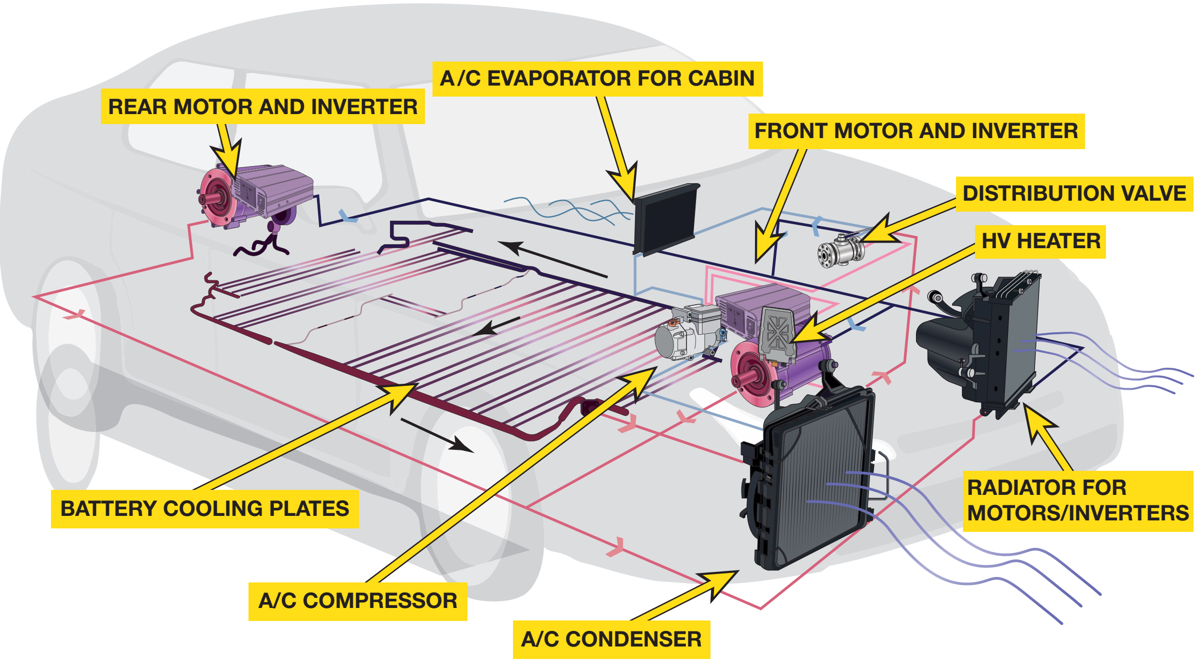


FIGURE 89–16 The battery and electronics are included as part of the temperature control system.

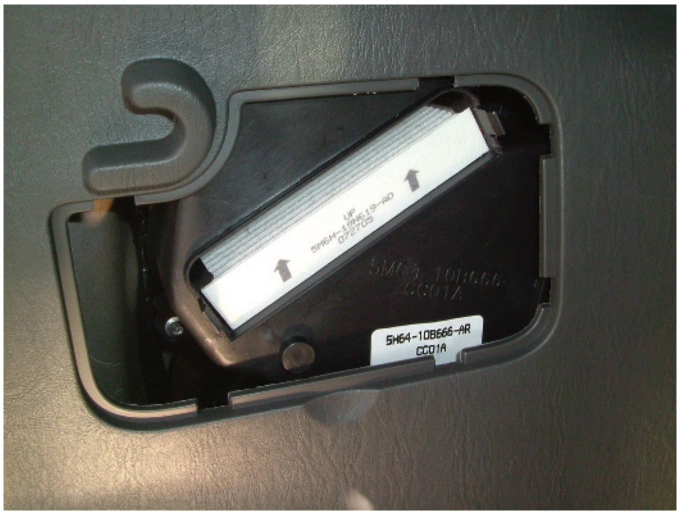


FIGURE 89–17 The HV battery cooling system from a Ford Escape Hybrid. Ford uses outside air to cool the battery pack, then increases cooling with a separate zone in the A/C system when necessary. The battery zone filter was only used on a first generation Ford Escape Hybrid.

The service of the air distribution system is similar to HVAC systems. The blower motor must be operational and the fan must be free of debris. The air intake inlets must be inspected and found to be free of anything that would restrict airflow. If the system has a dedicated cabin filter, it must be replaced at the specified interval.

The service of the liquid cooling system is similar to a conventional cooling system. On a regular basis the cooling system level must be checked to ensure there are no leaks and the freeze protection and pH level should be checked with a refractometer or test strip. The coolant should be replaced at the specified service interval using the recommended replacement coolant. The electric water pump must be inspected for proper operation. This is verified by actuating the pump with a factory-level scan tool. The dedicated radiator needs to be checked for airflow obstructions and for proper cooling fan operation.

EV BATTERY HEATER The electric vehicle battery heating methods include heater pads that are typically 0.011 inch (0.28 mm) thick and can be applied between cells, wrapped around cells, or modules bonded to the surface of a cold plate directly under a module. The pads ensure quicker time to temperature while achieving better uniformity from cell to cell, and function as a dielectric barrier between cells/modules/plates with minimal impact on cooling performance.

NOTE: A water-cooling system for Hyundai and Kia's EV battery packs, rather than air cooling, have yielded further increases in range because water-cooling channels take up less space than air-cooling channels, increasing battery density by up to 35%.

BATTERY CAPACITY VS VEHICLE RANGE

ICE VEHICLE MILEAGE In the United States, fuel economy for an internal combustion engine (ICE) vehicle is expressed in miles per gallon (MPG). Outside of the United States, fuel economy is measured in the number of liters of fuel needed to travel 100 kilometers (62 miles), abbreviated L/100 km. This means that as the number increases, the fuel economy decreases. In the metric system, the fuel is measured; in the United States, the miles are measured.

EPA VS WLTP In the United States, the Environmental Protection Agency (EPA) estimates electric vehicle range, while in Europe electric vehicle range uses the **Worldwide harmonized Light vehicles Test Procedure (WLTP)**. When the range is expressed using the WLTP standard, drivers can convert it to approximate EPA range estimates by dividing the WLTP value by 1.12. However, the EPA range is in fact just an estimate and real-world range can be different.

EV EQUIVALENT ECONOMY A kilowatt (kW) is a rate of energy flow similar to the gallons per minute that a water hose or pump can deliver. A kilowatt-hour (kWh) is a quantity of electricity, similar to what a gallon is with water. A bigger battery pack with a higher number of kWh will hold more electricity, just as a bigger bucket will hold more gallons of water.

With an electric vehicle, how far it can travel is measured in *miles per kilowatt-hours.* A typical electric vehicle can travel about 3 to 4 miles per kilowatt-hour of battery capacity. The larger the battery in kWh, the greater the range, like an ICE vehicle that has a larger fuel tank capacity.

To help consumers compare the energy consumption of electric vehicles with those that run on fossil fuel, the EPA created a miles-per-gallon measurement, called **MPGe**. This is calculated based on a conversion factor of 33.705 kilowatt-hours of electricity equaling one gallon of gasoline. Therefore, a battery that has a capacity of 100 kWh is equal to the energy of about three gallons of gasoline.

FREQUENTLY ASKED QUESTION

What Is a "Guess-O-Meter"?

The dash display that shows the miles per kWh is often called a **Guess-O-Meter (GOM)** because it is often not accurate. Good numbers for miles per kWh are 4.3 to 4.9 miles of travel for each kWh consumed. It can be used to help plan a trip. For example, if the GOM indicates the battery capacity is 60 kWh in the battery, this usually means the vehicle can travel about 235 miles, so plan on charging at about 200 miles. ● **SEE FIGURE 89–18**.

TECH TIP

The Rule of Thumb Is 3

To help estimate the range of an electric vehicle (EV), multiply the battery capacity in kilowatt-hours (kWh) by three to get a good idea as to the range of the vehicle. For example, a Tesla Model 3 has a battery capacity of 75 kWh and when multiplied by 3 equals 225 miles ($75 \times 3 = 225$).

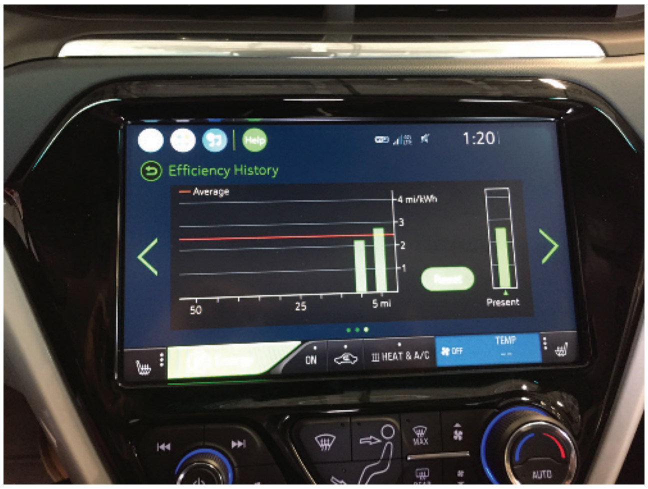


FIGURE 89–18 The dash display on a Chevrolet Bolt indicates the miles per kWh, which may or may not be accurate. Because the displayed estimated range varies, it is often referred to as "Guess-O-Meter."

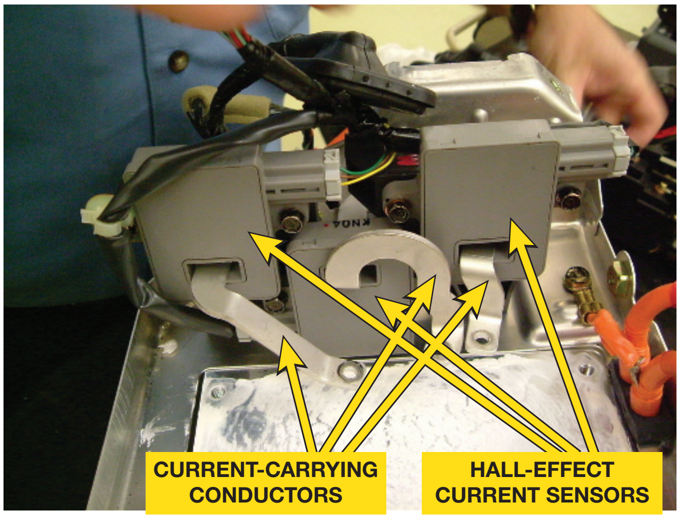


FIGURE 89–19 The three legs of the brushless motor run through three Hall-effect-type current sensors. The conductors used in the Honda unit are flat aluminum and attach to the motor controller terminals.

HIGH-VOLTAGE BATTERY CONTROL COMPONENTS

BATTERY CONTROL MODULE

The **battery control module (BCM)** is responsible for controlling the operation of the high-voltage battery based on the requests from the hybrid control module. The BCM monitors the voltage blocks, the current sensor, and temperature sensors to determine the need for charging. The BCM communicates with the other vehicle modules on the CAN BUS network and its data is accessible with a scan tool.

SYSTEM MAIN RELAYS (SMRs)

System Main Relays (SMRs) are heavy duty relays that control the high-voltage circuit between the battery and the other components of the high-voltage system. SMRs are often referred to as contactors. Depending on the design of the battery control system, the battery will contain one to three SMRs. The battery control module controls the low-voltage side of the SMR. When the load side of the SMR closes, high-voltage current is allowed to flow from the battery. In a three SMR system design, one SMR controls the positive circuit and two SMRs control the negative circuit. On the negative side, one SMR is in-series with a high-wattage resistor that pre-charges the system capacitors. To allow current to flow:

- The BCM will first close the SMR for the positive cable.
- The BCM will close the SMR with the resistor on the negative cable. This will reduce the initial current flow to the system capacitors and also reduce the possibility of arcing across the high-current SMR contacts.
- The BCM will then close the second SMR on the ground cable and open the SMR in-series with the resistor. This will allow for full current flow.

CURRENT SENSORS

The current sensor is used to measure the current flowing into the battery during charging and is used to measure current flowing out of the battery when it is discharging. The sensor may be mounted on the positive or the negative cable based on design. This data is combined with individual cell temperature and voltage to provide an overall state-of-charge (SOC) of the battery. The sensor will be either a Hall-effect design or a shunt, depending on the manufacturer and the design of the system. The BCM will set a fault code if the senor becomes open, shorted, or if the current running through the sensor becomes abnormally high or low. ● **SEE FIGURE 89–19**.

VOLTAGE BLOCK MONITORING CIRCUITS

Each cell block, which consists of multiple battery cells, is monitored by the BCM for voltage level. These are low-voltage circuits that allow the BCM to flag a group of cells that are out of range when compared to the cell groups in the battery. A variance of 0.3 volts between cell groups is allowed. Any variance of measured voltage that is greater than 0.3 volts will set a fault code. This condition could be as a result of a bad cell or an imbalance condition.

TEMPERATURE SENSORS

Temperature sensors are used to measure the temperature of the battery cells and temperature of the air entering the pack if a forced air system is used to cool the battery. The primary use of this data is to control the fan speed of the blower used to cool the battery. The data is also used in the calculation of the battery state-of-charge (SOC). The sensors are PTC thermistors so the higher the battery temperature, the lower the resistance of the sensor. ● **SEE FIGURE 89–20**.

NOTE: The General Motors electric vehicles using the Ultium batteries incorporate a wireless transmitter connected to the battery cells. Instead of running wires from each battery cell to the battery control module, the wireless system reduces the number of wires and connections.

HV DISCONNECT

The purpose of the HV battery disconnect switch is to remove power from the high-voltage system prior to repairs. When removing the HV disconnect switch, personal protective equipment (PPE) must be worn to protect against electrocution. Many HV disconnect switches contain a high-voltage fuse. Most HV disconnect switches also contain a low-voltage monitoring circuit. Failure to properly install and latch the HV disconnect switch will result in a no-start or failure to power-up condition. ● **SEE FIGURE 89–21**.

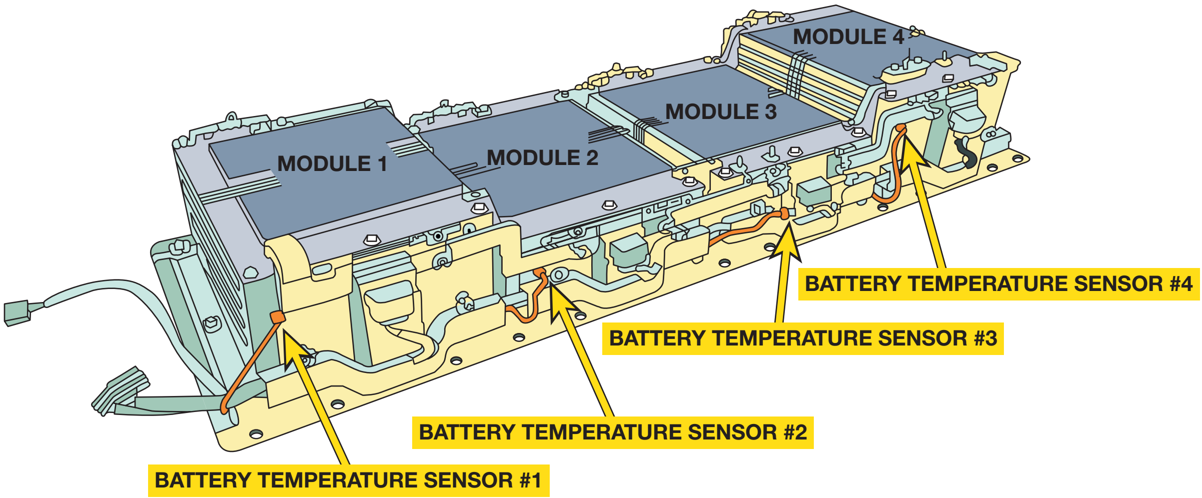

MODULE 1
MODULE 2
MODULE 3
MODULE 4
BATTERY TEMPERATURE SENSOR #4
BATTERY TEMPERATURE SENSOR #3
BATTERY TEMPERATURE SENSOR #2
BATTERY TEMPERATURE SENSOR #1

FIGURE 89–20 Temperature sensors are located throughout a HV battery pack.

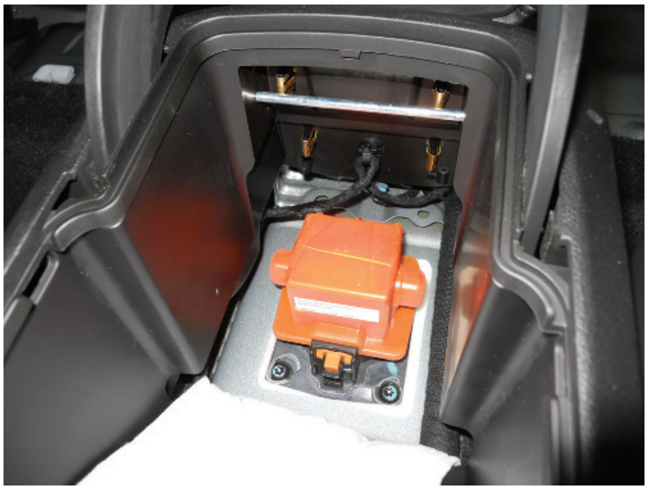


FIGURE 89–21 The battery disconnect on a Chevrolet Volt is located under the center console.

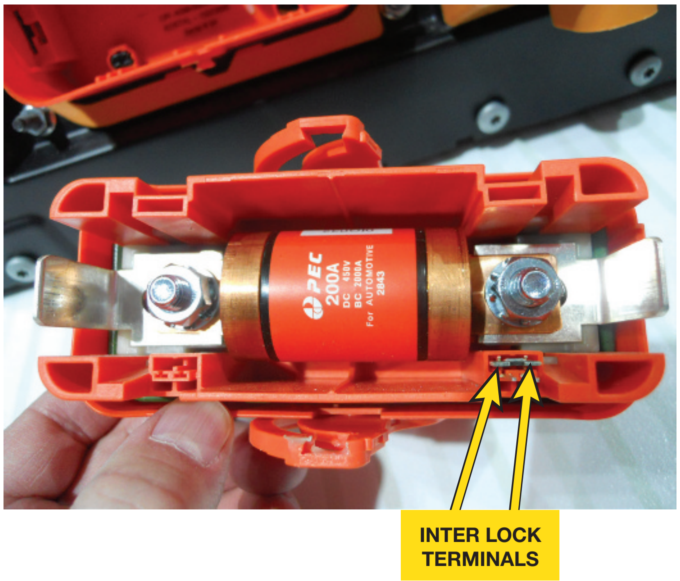


FIGURE 89–22 The HV disconnect plug has two small terminals used to signal the HV controller that the safety/service plug has been removed.

BATTERY MANAGEMENT SYSTEM (BMS) The battery cells or modules need to be monitored and controlled for temperature and voltage. The **battery management system (BMS)** is an electronic system that manages cells in a battery pack. The BMS monitors and controls

- State-of-charge (SOC)
- State of health (SOH)
- State of function (SOF)
- Safety and critical safeguards
- Temperature
- Load balancing/individual cell efficiency

The BMS receives inputs from voltage and temperature sensors in the modules. In some packs, the BMS may also provide outputs to drive other components, such as fans, pumps, or valves for the battery cooling system. External connectors enable robust and safe connection between the battery pack and other vehicle systems.

ELECTRICAL DISTRIBUTION SYSTEM (EDS) The primary function of the **Electrical Distribution System (EDS)** is to provide the electrical conduction path through the battery pack and includes the following features:

- Isolates the conduction path
- Measures current and voltage in the high-voltage (HV) line
- Provides pre-charge function when energizing the HV line
- Fuses the HV line in case of over-current
- Provides manual disconnect of the HV line for vehicle servicing
- Monitors effectiveness of the electrical insulation

The low-voltage (LV) wiring provides power for the battery control functions and allows communication between the battery and vehicle (CAN protocol). The LV wiring is also used to confirm all external connectors are correctly in place, and to ensure that HV conductors cannot be contacted externally. ● **SEE FIGURE 89–22**.

ISOLATION TESTING The high-voltage system is completely isolated from the vehicle. A loss of isolation in the high-voltage system will result in a vehicle that will not power-up to the ready mode and set a series of diagnostic trouble codes. Some vehicles will set additional information codes that will help to identify the area where the loss of isolation has occurred.

To verify the loss of isolation has occurred, a meg ohm meter is used to perform the isolation test. The use of class 0 high-voltage safety gloves is required when performing this

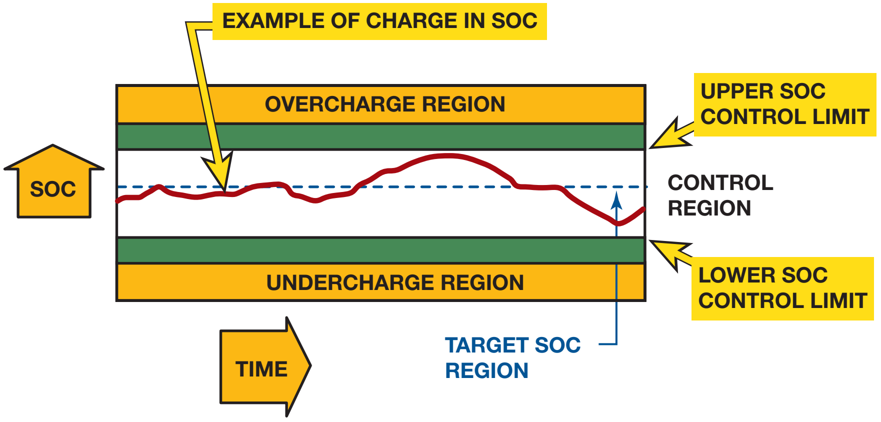


FIGURE 89–23 The HV battery pack SOC is maintained in a relatively narrow range to prevent overheating and maximize service life.

test. With the high-voltage battery disconnected, the meg ohm meter is connected between the high-voltage system and chassis ground. During the test, the meter will charge its internal capacitor to up to 1,000 volts and measure the resistance between the high-voltage system and chassis ground. If continuity is detected, the loss of isolation needs to be identified and repaired. The system should be tested again after the repair is complete to verify the repair was successful.

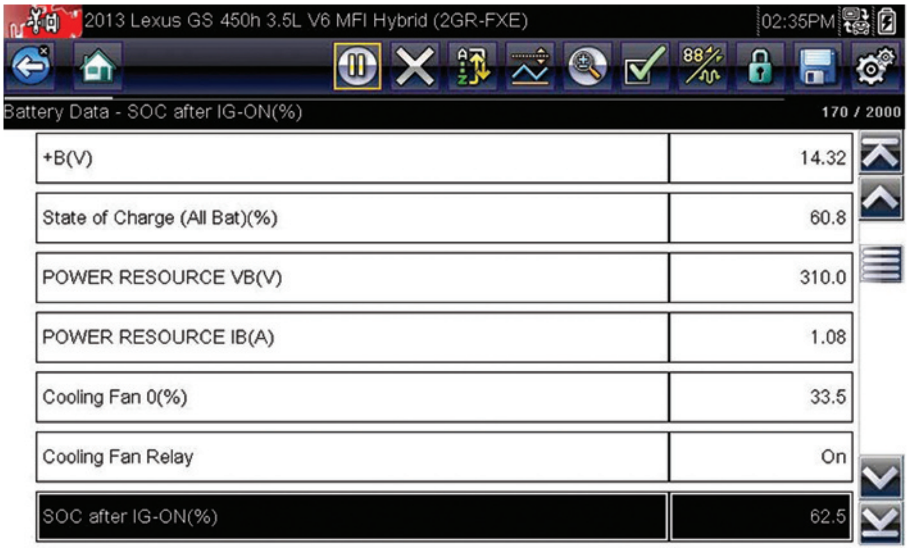
STATE-OF-CHARGE MANAGEMENT The HV battery in a hybrid electric vehicle (HEV) is subjected to constant charging and discharging during normal operation. The battery can overheat under the following conditions:

- The battery state-of-charge rises above 80%.
- The battery is placed under a load when its SOC is below 20%. In order to prevent overheating and maximize service life, the battery SOC must be carefully managed. In most hybrid-electric vehicle applications, a target SOC of 60% is used, and the battery is then cycled so its SOC varies no more than 20% higher or lower than the target. ● **SEE FIGURE 89–23**.

NOTE: The Chevrolet Volt is designed to allow the state-of-charge to drop to 25–35% before the gasoline engine is started to maintain that level of state-of-charge. The cooling system and software are designed to allow this reduced SOC so that the vehicle can be driven for an extended distance without having to start the engine.

HEV HIGH-VOLTAGE BATTERY MONITOR The HV battery pack controller monitors the state-of-charge.

- During acceleration, the battery pack state-of-charge (SOC) may drop slightly, and rise when the vehicle decelerates as a result of regenerative braking, which charges the HV battery.
- Scan data displays charge and discharge levels. Normal operating HV battery SOC range for most hybrid electric vehicles is within 52–68%.
- When the SOC drops to 50%, the ICE starts to recharge the HV batteries. This means that the idle stop (start-stop) function is disabled if the SOC is at or below 50%, and will resume after it reaches 52% or higher in most cases. ● **SEE FIGURE 89–24**.
- If the SOC reaches 80% or higher, the regenerative braking stops. This means that during vehicle braking when the SOC is high, a harder than normal brake pedal effort is often noticed.
- Reduction of electric traction motor power occurs when the state-of-charge falls to 40%. If the ICE does start, there will be little or no electric assist from the electric traction motor. This will likely only occur if the vehicle runs out of fuel for the ICE and the vehicle operates on electric power alone. However, the main warning light will be on and the system will set and store multiple diagnostic trouble codes (DTCs) if this happens.

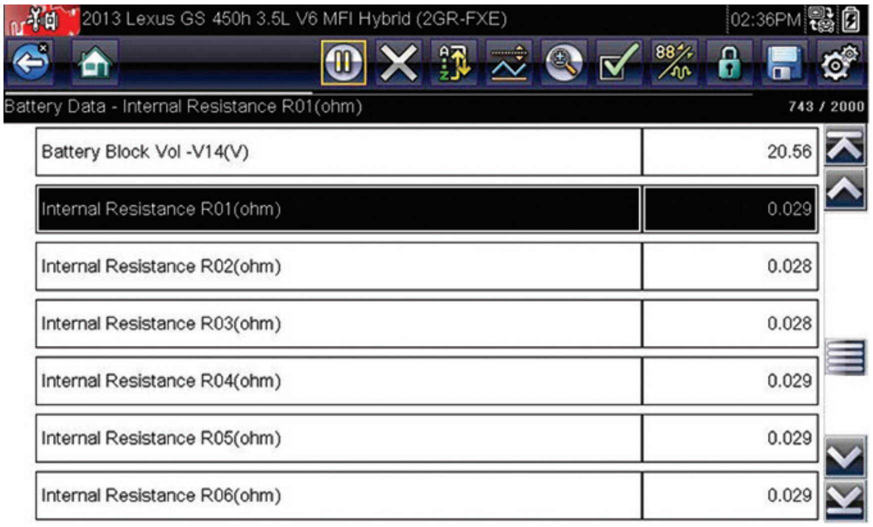


2013 Lexus GS 450h 3.5L V6 MFI Hybrid (2GR-FXE) 02:35PM

Battery Data - SOC after IG-ON(%) 170 / 2000

+B(V)	14.32
State of Charge (All Bat)(%)	60.8
POWER RESOURCE VB(V)	310.0
POWER RESOURCE IB(A)	1.08
Cooling Fan 0(%)	33.5
Cooling Fan Relay	On
SOC after IG-ON(%)	62.5

FIGURE 89–24 A Snap-on Solus scan tool displays the state-of-change of the high-voltage battery under the heading of "HV ECM."


2013 Lexus GS 450h 3.5L V6 MFI Hybrid (2GR-FXE) 02:36PM

Battery Data - Internal Resistance R01(ohm) 743 / 2000

Battery Block Vol -V14(V)	20.56
Internal Resistance R01(ohm)	0.029
Internal Resistance R02(ohm)	0.028
Internal Resistance R03(ohm)	0.028
Internal Resistance R04(ohm)	0.029
Internal Resistance R05(ohm)	0.029
Internal Resistance R06(ohm)	0.029

FIGURE 89–25 The internal resistances of the battery blocks are available on the data stream as shown using an aftermarket scan tool. The internal resistance should be between 15 and 40 milliohms (0.015 to 0.040 ohms).

TECH TIP

Check State-of-Charge First

If a hybrid vehicle owner complains of a lack of power on acceleration, check the state-of-charge (SOC) first. There may be nothing wrong with the traction motor or its controller. It may be simply that the HV battery pack is not within a normal state-of-charge, usually due to a fault with the battery pack or related electrical connections.

SCAN DATA TEST PROCEDURE Connect the scan tool and select the vehicle, and then select the following parameter identification (PID) items:

- State-of-charge
- Battery temperature
- Battery voltage
- Battery current draw
- Check the battery block internal resistance as displayed on a scan tool for Toyota/Lexus HEVs. Normal internal resistance is 15 to 40 milliohms (0.015 to 0.040 ohms).

  ● **SEE FIGURE 89–25**.

LITHIUM-ION BATTERY REPAIR

PURPOSE Some original equipment manufacturers (OEMs) are replacing defective high-voltage battery components rather than replacing the entire battery. This reduces the amount of time the vehicle is in a non-drivable condition and it reduces the cost of the repair. Included in the list of replaceable components is the high-voltage battery module.

PROCEDURE A typical example of a factory-authorized procedure that addresses failed high-voltage battery modules used by Nissan/Infinity on specific hybrid and electric vehicles includes a battery cell replacement as determined by a diagnostic trouble code. A P3374 DTC indicates that a cell is more than 100 mV lower than other cells. The scan tool data indicates that cell #27 was more than 100 mV lower than the rest of the cells. ● **SEE FIGURE 89–26**.

Before the battery is removed, it is essential that all the required tools are available. The specified tools include the required PPE, insulated tools, and the module balance adjuster tool. The procedure includes the following steps:

STEP 1 Following the service procedures and observing all high-voltage cautions, the battery should be removed from the vehicle and made ready for repair.

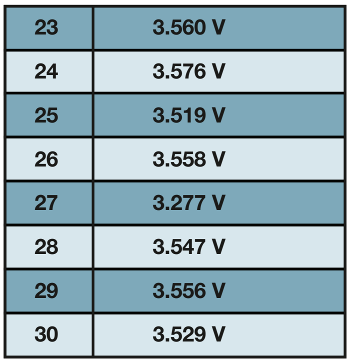
STEP 2 Using the service information, identify the location of the defective module within the pack.

STEP 3 Remove the battery covers, the controller, and other components needed to access the battery modules as described in the service procedures. ● **SEE FIGURE 89–27**.

STEP 4 Prior to completing the final disassembly of the battery, all module voltages must be measured using a digital multimeter to determine the module charge balance of the battery. This data will be used to determine the adjustment voltage for the replacement module.

STEP 5 The new replacement battery module must be installed in the module charge balancer, and the adjustment voltage must be entered into the charger. This will allow the charge to be adjusted to match the rest of the battery.

STEP 6 The defective module can now be removed and the new module installed.



23	3.560 V
24	3.576 V
25	3.519 V
26	3.558 V
27	3.277 V
28	3.547 V
29	3.556 V
30	3.529 V

FIGURE 89–26 The scan tool data indicates that cell #27 was a lot lower than the rest of the cells, which indicates a problem and the reason for the diagnostic trouble code to be set.

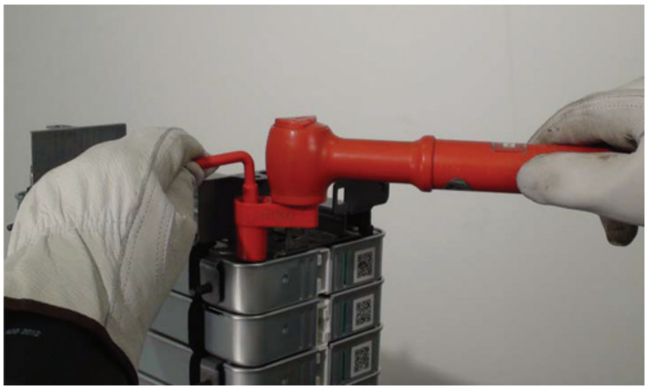


FIGURE 89–27 Whenever working on any potential high-voltage components, always follow the recommended safety procedures including using insulated tools and rubber gloves.

STEP 7 Reinstall all parts that have been removed during the disassembly process and make the battery ready for reinstallation.

BATTERY DEGRADATION AND BALANCING

RATE OF DEGRADATION Most HV batteries will outlast the usable life of the vehicle. However, some factors that affect battery life and the rate of degradation include the following:

- The average decline in energy storage is 2.3% per year.
- EV batteries decline in a non linear fashion, which means that at the beginning of the battery life, there is an early drop, but the rate of decline slows down in subsequent years.
- Liquid-cooled batteries decline slower than air-cooled packs. For example, a liquid-cooled EV has an average annual degradation rate of 2.3%, compared to an air-cooled EV rate of 4.2%.
- Higher vehicle use does not necessarily equal higher battery degradation.
- Vehicles driven in hot temperatures show a faster decline in battery health.
- The use of DC fast-chargers speeds up the process of degradation, but there is not much difference in battery health based on frequent use of Level 1 versus Level 2 charging. Losses that happen with frequent DC charging are made worse in hot climate conditions.

PASSIVE AND ACTIVE CELL BALANCING Long battery life requires that the electronics in the vehicle perform passive and active battery cell balancing.

- **Passive balancing** is achieved by having energy drawn from the most charged cell and dissipated as heat, usually through resistors. Passive balancing allows the stack to act as if every cell has the same capacity as the weakest cell. Using a relatively low current, it drains a small amount of energy from high SOC cells during the charging cycle so that all cells charge to their maximum state-of-charge (SOC).
- **Active balancing** is achieved when energy is drawn from the most charged cell and transferred to the least charged cells, usually through DC–DC converters.

NORMAL OPERATION During normal vehicle operation, the charge and discharge cycles of the high-voltage battery in an HEV are monitored and controlled by the battery management system (BMS). This module monitors battery temperature, current, and voltage to calculate SOC and determine at what rate the battery should be charged. While dealerships sometimes have a special high-voltage battery charger for recharging HEV battery packs, the best charger is the vehicle itself. If the HV battery in an HEV becomes discharged, the first step should be getting the vehicle started to recharge the battery pack. The procedure will vary depending on the model in question. Always follow the manufacturer's specified procedures when starting a disabled hybrid vehicle.

CASE STUDY

The Case of the Broken Prius

The owner of a Prius complained that "the engine never shuts off" and fuel economy has dropped to as low as 25 MPG instead of the normal 40+ MPG. By "never shuts off," the customer means that the idle stop (auto start/stop function) is suspended. The master warning light was also on, indicating a serious problem has been detected. The technician used a scan tool and retrieved the following diagnostic trouble codes (DTCs):

- P0A80—The difference in voltage between two of the blocks in the battery pack is too high.
- P3006—Uneven state-of-charge.

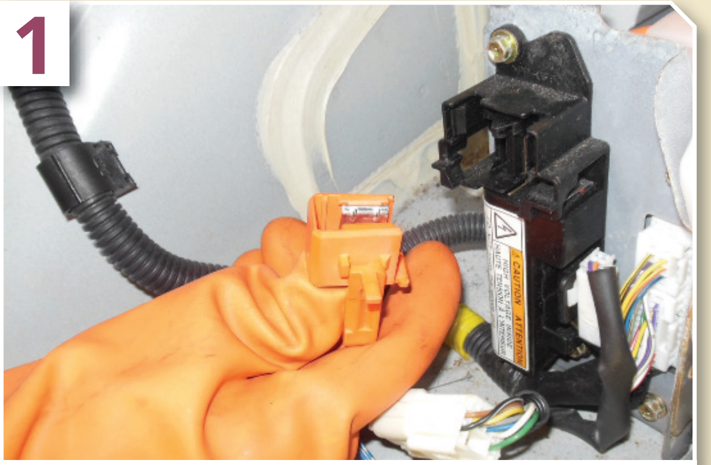
Scan tool data showed battery block voltages reading ranging from 4.65 to 15.01 volts. Generally, if a battery block is under 7.5 volts, it cannot be restored to useful service. Even if it can be charged, the module will have a short service life. The shop recommended, and the customer approved, a replacement reconditioned battery pack supplied by a nationally known company. The battery pack was replaced and the vehicle was restored to normal operation and fuel economy.

Summary:

Complaint—The owner of a Prius complained of reduced fuel economy.
Cause—The difference in voltage between two of the blocks in the battery pack is too high.
Correction—The battery pack was replaced and the vehicle was restored to normal operation and fuel economy.

PHOTO SEQUENCE HEV-HV BATTERY INSPECTION AND TESTING STEP BY STEP

1

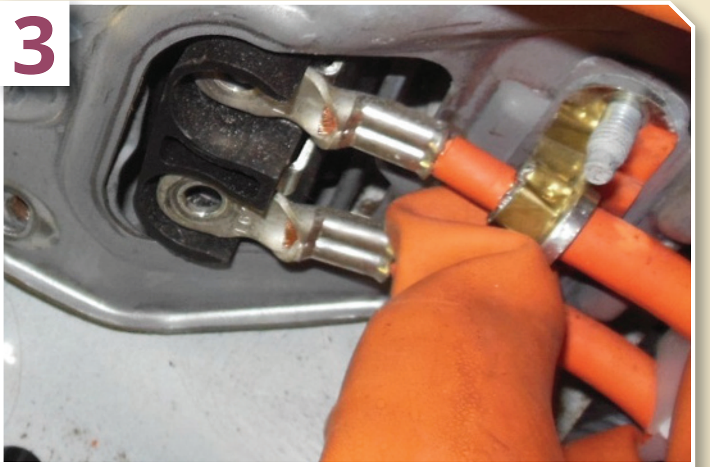


To depower the high-voltage system, the ignition was off and the negative battery cable was disconnected from the 12-volt auxiliary battery, then the HV battery safety plug was removed.

2

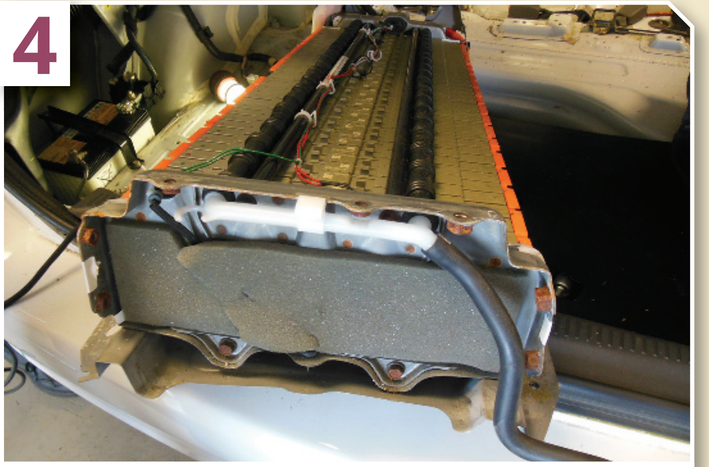
After checking that the voltage level is safe, the rear seat and HV battery cover were removed. Always follow the safety procedures specified by the manufacturer for the vehicle being serviced and adhere to all safety warning and precautions.

3



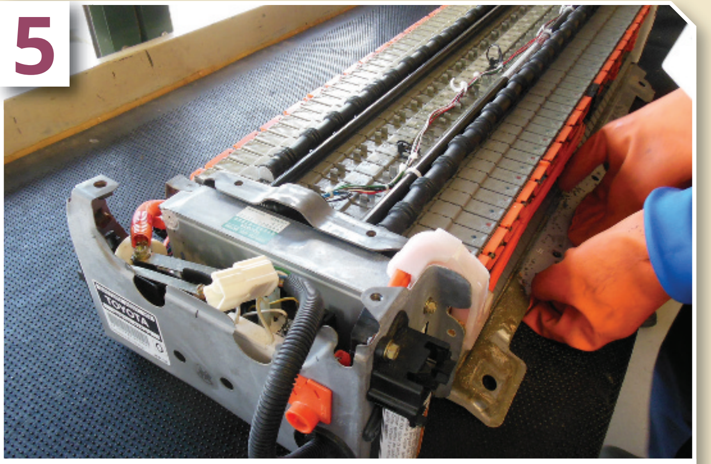
The high-voltage wires were removed from the battery pack while wearing HV gloves.

4



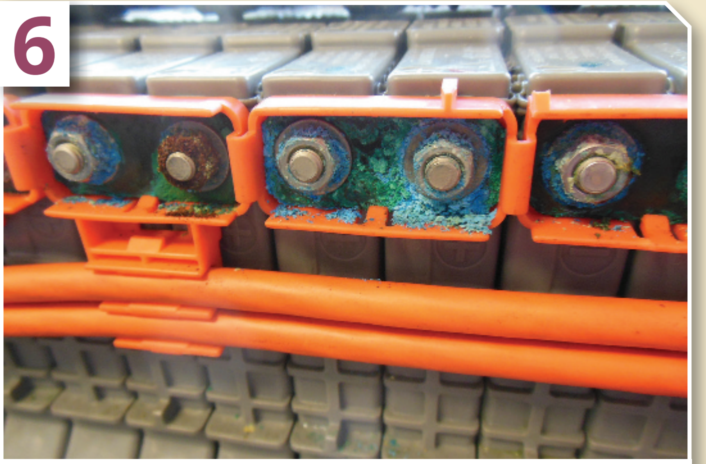
The HV battery pack is being removed through the rear of the vehicle.

5



The HV battery pack is placed on a workbench that is covered with a thick rubber (insulating) mat. A wood top bench can also be used.

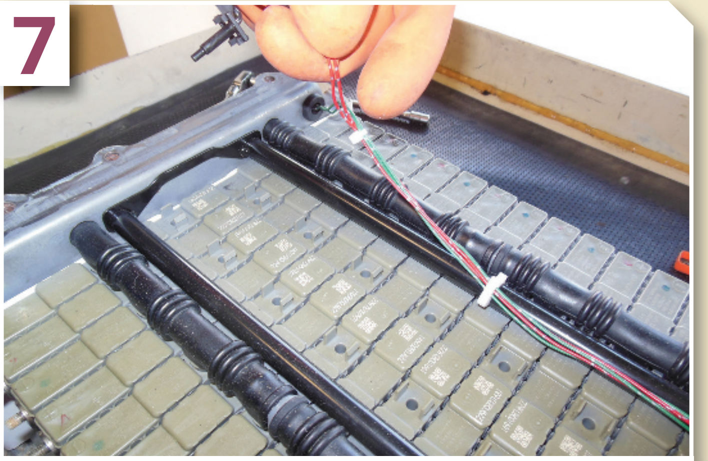
6



A visual inspection shows that many electrical connections between battery modules are corroded.

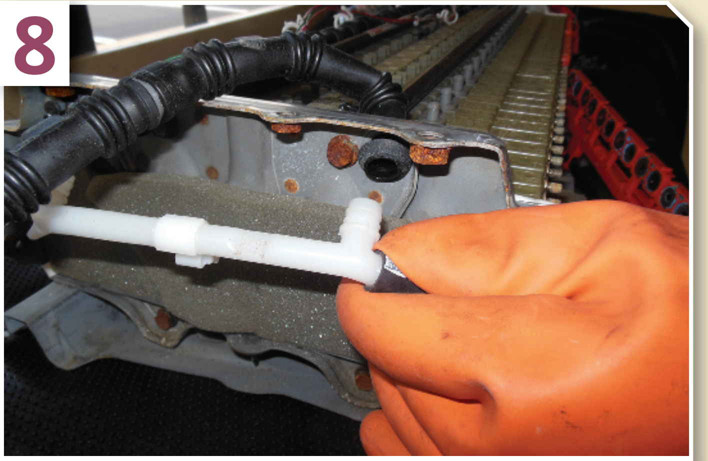
PHOTO SEQUENCE HEV-HV BATTERY INSPECTION AND TESTING

7



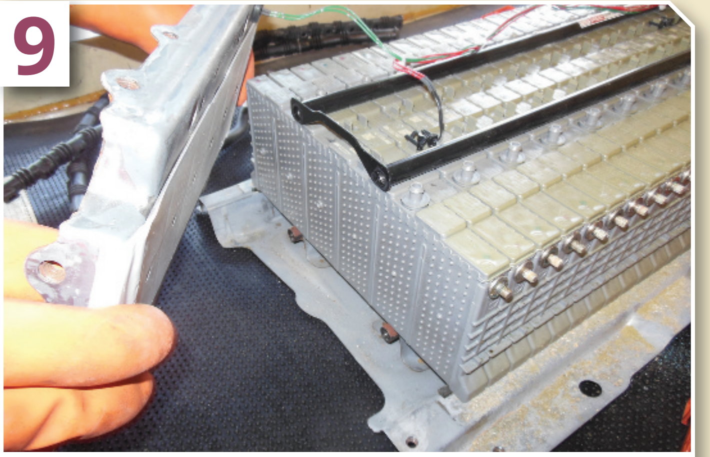
The HV battery pack temperature sensors are removed.

8



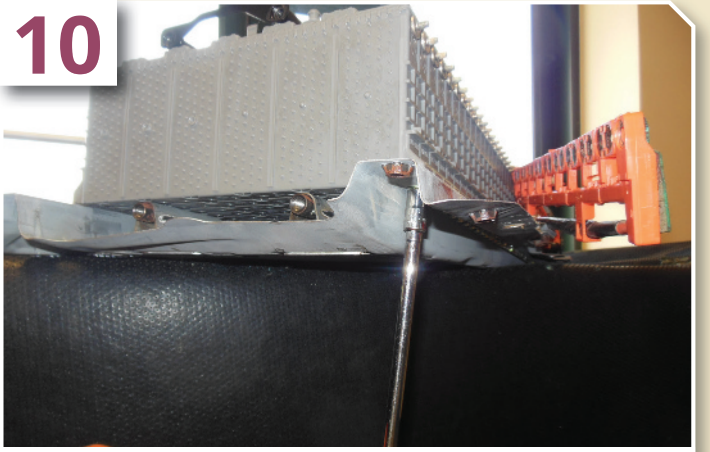
The HV battery vent tubes are removed from the battery pack.

9



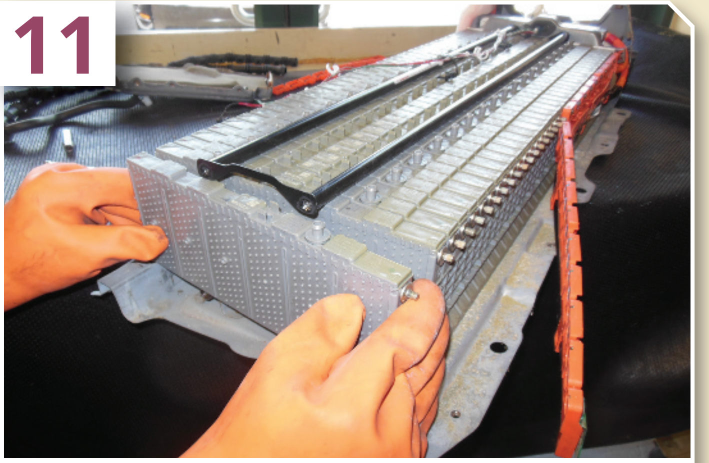
The end caps are removed from the battery pack.

10



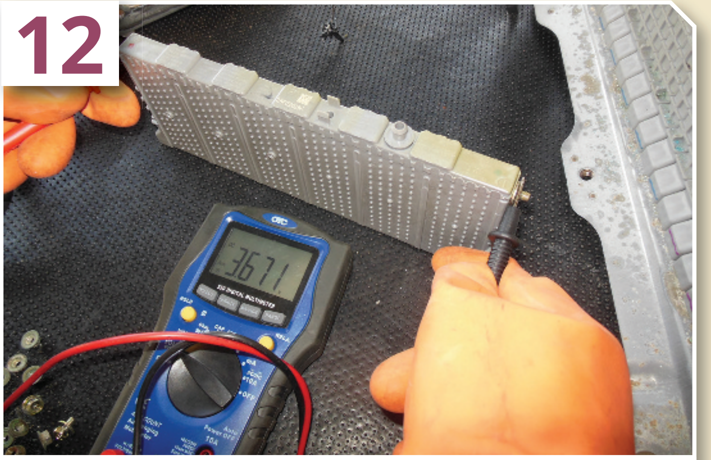
The fasteners that hold the battery modules to the base of the battery pack are removed.

11



The end module is being removed from the battery pack.

12



The individual modules were measured using a voltmeter and most modules were found to be about 3.6 volts, which is far below the minimum of 5.4 volts that most experts think can be restored by charging.

REVIEW QUESTIONS

1. Why do high-voltage batteries need to be heated if cold or cooled if hot?
2. What advantages do lithium-ion batteries have comparted to NiMH batteries?
3. What is the primary function of the Electrical Distribution System (EDS)?
4. What are the steps involved to address failed high-voltage battery modules?
5. What occurs if the state-of-charge exceeds 80%?

CHAPTER QUIZ

1. High-voltage batteries are used in ___________
   - **a.** hybrid electric vehicles
   - **b.** battery electric vehicles
   - **c.** ICE vehicles
   - **d.** Both a and b
2. The nominal voltage of an NiMH battery cell is ___________.
   - **a.** 1.2 volts
   - **b.** 3.2 volts
   - **c.** 3.6 volts
   - **d.** 4.8 volts
3. A lithium-ion cell produces ___________ per cell.
   - **a.** 1.2 volts
   - **b.** 3.2 volts
   - **c.** 3.6 volts
   - **d.** 4.8 volts
4. Electronic components operate more efficiently as their temperature ___________.
   - **a.** increases
   - **b.** decreases
   - **c.** remains constant
   - **d.** changes from hot to cold rapidly
5. Lithium-ion cells can be ___________.
   - **a.** cylindrical cell
   - **b.** prismatic—hard case
   - **c.** prismatic—pouch type
   - **d.** Any of the above
6. An electric vehicle can travel ___________ miles per killowatt-hour.
   - **a.** about 10 to 12
   - **b.** about 3 to 4
   - **c.** about 100 or more
   - **d.** less than 2
7. In most hybrid electric vehicle applications, a target SOC of ___________ is used, and the battery is then cycled so its SOC varies no more than ___________ higher or lower than the target.
   - **a.** 100%; 50%
   - **b.** 80%; 20%
   - **c.** 70%; 50%
   - **d.** 80%; 40%
8. In a three SMR system design, one SMR controls the positive circuit and two SMRs control the negative circuit. On the negative side an SMR is in-series with a(n) ___________.
   - **a.** capacitor
   - **b.** resistor
   - **c.** diode
   - **d.** inductor (coil)
9. Some HV batteries can be repaired by ___________.
   - **a.** replacing the electrolyte
   - **b.** adding water
   - **c.** replacing cooling fins
   - **d.** replacing battery modules
10. HV batteries that are air-cooled degrade at ___________ liquid-cooled HV batteries.
    - **a.** the same rate as
    - **b.** a slower rate than
    - **c.** a faster rate than
    - **d.** None of the above

Chapter 90

EV AND PHEV CHARGING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe plug-in hybrid electric vehicles (PHEVs).
- Explain how the high-voltage batteries are recharged in an electric vehicle (EV), including battery capacity, and range correlation.
- Discuss Level 1 charging.
- Discuss Level 2 charging.
- Discuss Level 3 charging.
- Discuss owning and charging an electric vehicle (EV).

KEY TERMS:

Always Be Charging (ABC) 1047 • Battery electric vehicle (BEV) 1044 • Combo Charging System (CCS) 1048 • DCFC (DC Fast Charge) 1047 • Destination charging 1050 • Electric vehicle (EV) 1044 • EV range 1042 • kilowatt-hour (kWh) 1042 • kWh/100 mi 1045 • Miles per hour (MPH) 1046 • Public Charging Stations (PCS) 1049 • Plug-in hybrid electric vehicle (PHEV) 1042 • Range per hour (RPH) 1046 • Range anxiety 1045 • State-of-charge (SOC) 1043 • Time-of-use (TOU) 1049 • Work place charging (WPC) 1049 • Zero-emission vehicles (ZEVs) 1044

PLUG-IN HYBRID ELECTRIC VEHICLES

TERMINOLOGY A **plug-in hybrid electric vehicle (PHEV)** is a vehicle that is designed to be plugged into an electrical outlet at home, at work, or when traveling to charge the batteries. By charging the batteries in the vehicle, it can operate using electric power alone (stealth mode) for a longer time, thereby reducing the use of the internal combustion engine (ICE). The less the ICE is operating, the less fuel is consumed, which lowers the emissions of the vehicle. Some PHEVs offer the driver an option to use the ICE first and switch to EV mode (electric only) later in the trip. This option is commonly used where the driver is first traveling on the highway and uses the ICE to propel the vehicle, saving the energy in the battery to be used when arriving in the city.

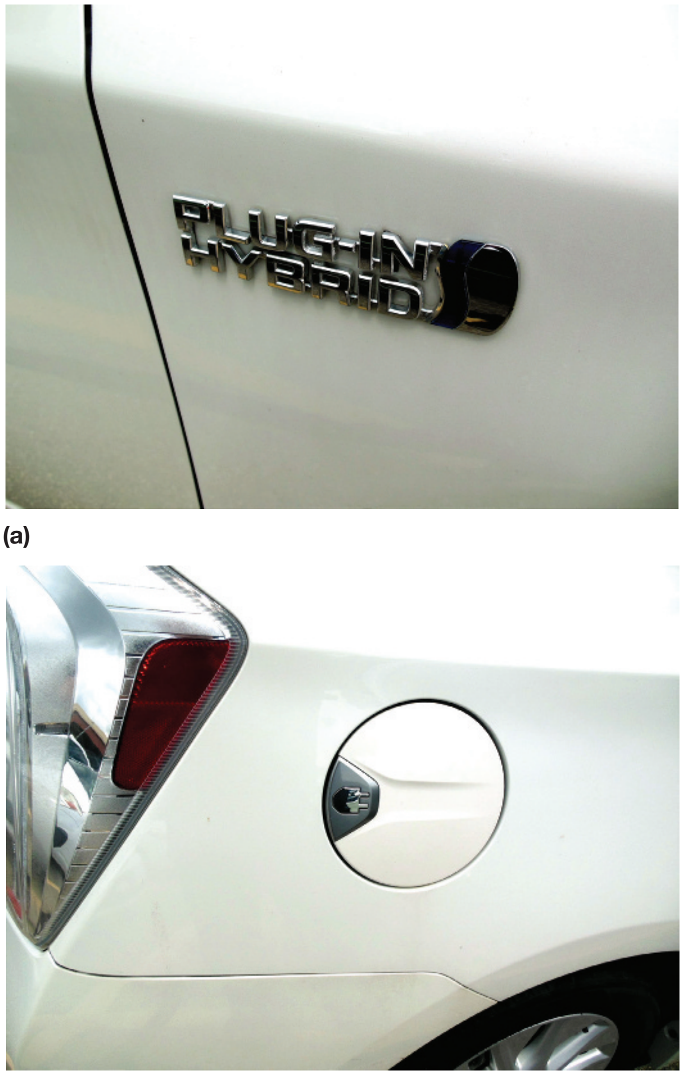
IDENTIFYING A PHEV Many PHEV are built using a conventional or a hybrid-electric vehicle (HEV) configuration with just added battery capacity. As a result, some PHEVs may be difficult to pick out, such as the plug-in version of the Toyota Prius. Features that identify a plug-in version of an HEV include the following:

- Different badges (usually stating that it is a PHEV, sometimes including PHEV on the badge).
- An access door for the charging cable in addition to the normal ICE fueling door.
- A different instrument panel cluster.

● **SEE FIGURE 90–1**.

The operation of the plug-in version is the same as the HEV version of the same vehicle, so from a service or maintenance point of view, it does not really matter whether it is a PHEV or an HEV.

PHEV BATTERY CAPACITY The size or capacity of the battery pack used determines how far that the vehicle can travel without using the ICE, commonly called the **EV range**. Battery capacity is measured in **kilowatt-hour (kWh)**. A kilowatt is 1,000 watts and a watt is a volt times an ampere, which is a measurement of electrical power. The higher the kWh rating of the battery, the more electrical energy it can store.



(a)

(b)

FIGURE 90–1 (a) About the only way to tell a plug-in Prius from a regular Prius is from the badge on the sides or (b) by the charge port door on the passenger side at the rear.

- A lower kilowatt-hour (kWh)-rated battery weighs less and is less expensive, but the range that the vehicle can travel on battery power alone is limited.
- A higher kWh rating battery means that the battery is capable of propelling the vehicle for a greater distance before the ICE is used. This reduces the fuel used, but the larger battery weighs and costs more.
- The high-voltage battery is continuously checked for state-of-charge. The **state-of-charge (SOC)** is the percentage of the available capacity that can be stored in a battery. A battery that has a state-of-charge of 100% is fully charged.

Therefore, a plug-in vehicle is a compromise between cost and weight of the battery.

PHEV EXAMPLES A standard Toyota Prius has a 1.3 kWh battery pack, whereas the plug-in version has a larger 4.4 kWh battery, allowing electric-only travel of about 10 miles before the ICE is used. When the battery pack state-of-charge has been depleted, the vehicle operates as a standard HEV with the ICE and electric motor both used to propel the vehicle.

RESERVED FOR
CHARGING
ONLY

FIGURE 90–2 Chevrolet Volt extended range electric vehicle (EREV), also called a plug-in hybrid electric vehicle (PHEV), being charged at a row of charging stations at the Corvette assembly plant in Blowing Green, KY.

VEHICLE MAKE AND MODEL	BATTERY CAPACITY
BMW i8	11 kWh
Chevrolet Volt	16 kWh
Ford C-Max Energi	7.6 kWh
Ford Fusion Energi	7.6 kWh
Honda Accord PHEV	6.7 kWh
Porsche Cayenne PHEV	9.4 kWh
Porsche Panamera S PHEV	9.4 kWh
Toyota Prius PHEV	4.4 kWh
Toyota RAV4	8.1 kWh
Volvo XC60/XC90	11.6 kWh
VW Golf PHEV	8.8 kWh

CHART 90–1

The higher the capacity of the HV battery, the further the vehicle can travel using electric power only; it takes longer to be fully charged when plugged into a charger.

A Chevrolet Volt has a larger 16 kWh battery pack and, as a result, can travel about 40 miles on electric power alone, without using the ICE until the battery has been discharged to about 25% to 35%. At this stage, the ICE is operated to keep the battery pack at a level high enough to keep propelling the vehicle. ● **SEE FIGURE 90–2**.

● **SEE CHART 90–1** for a comparison of many of the current PHEVs.

CHARGING A PHEV After the battery pack has been discharged propelling the vehicle, the ICE is used to keep the battery charged enough to propel the vehicle, but it does not fully recharge the battery pack. To fully charge the high-voltage battery pack in a plug-in hybrid electric vehicle, it should be plugged into either a 110/120-volt or a 220/240-volt outlet. ● **SEE FIGURE 90–3**.

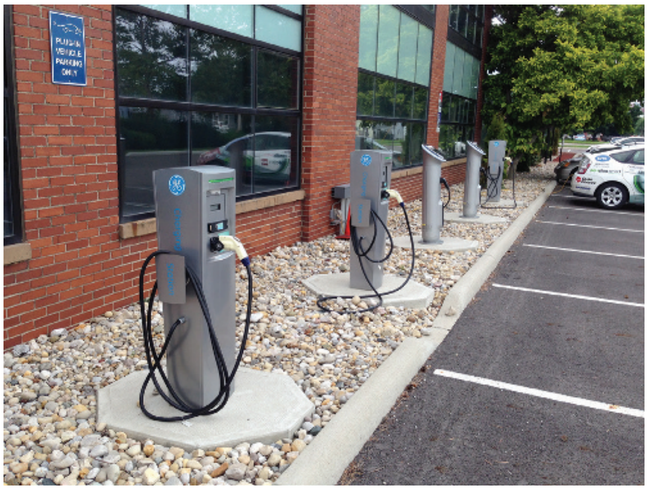


FIGURE 90–3 Charging stations that are equipped with SAE standard J1772 chargers are often found at large companies, colleges, universities, and shopping malls in many parts of the country.

TECH TIP

Turn on Heat or A/C While Still Connected

If charging a plug-in hybrid or an electric vehicle, use a smartphone app to access the vehicle to turn on the air conditioning (A/C) or heat 15 minutes before leaving from work. For example, an owner of a Nissan Leaf, who works in Phoenix, AZ, uses the phone app to start the A/C while it is still connected to the charging station at work. The interior is nice and cool when the owner is ready to leave work, even though the vehicle has been sitting in the hot sun on a 100-degree day. Because the operation of the A/C is occurring while still plugged into the charging station, the range of the Leaf is not affected, and the ride home is done in comfort. The same can be done to heat the interior in cold weather, too.

ELECTRIC VEHICLES

EV BATTERY CAPACITY An **electric vehicle (EV)**, also called a **battery electric vehicle (BEV)**, uses a high-voltage battery pack to supply electrical energy to an electric motor(s) to propel the vehicle under all driving conditions. Electric vehicles that use battery power alone to propel the vehicle are called **zero-emission vehicles (ZEVs)**. The capacity of the battery pack, in kilowatt-hours, determines the range of the vehicle. It has to be plugged in to recharge the battery before it can be driven further. The time it takes to charge an electric vehicle can be as little as 30 minutes or more than 12 hours, depending on the size of the battery and the speed of the charging station.

TECH TIP

Batteries Like the Same Temperature Range as Humans

Batteries work best when they are kept within a temperature range that is also the most comfortable for humans. Most people are comfortable when the temperature is between 68°F and 78°F (20°C and 26°C).

- Below 68°F (20°C), most people want heat.
- Above 78°F (26°C), most people want cooling.

Batteries perform best when they are exposed to the same temperature range. Therefore, a proper heating and cooling system must be used to keep the batteries within this fairly narrow temperature range for best performance.

COLD-WEATHER CONCERNS Past models of electric vehicles, such as the General Motors electric vehicle (EV1), were restricted to locations such as Arizona and southern California that had a warm climate. Cold weather is a major disadvantage to the use of electric vehicles for the following reasons:

- Cold temperatures reduce battery efficiency.
- Additional electrical power from the batteries is needed to heat the batteries themselves to be able to achieve reasonable performance.
- Passenger compartment heating is a concern for an electric vehicle because it requires the use of resistance units or other technology that reduces the range of the vehicle.

HOT-WEATHER CONCERNS Batteries do not function well at high temperatures, and therefore, some type of battery cooling must be added to the vehicle to allow for maximum battery performance. This results in a reduction of vehicle range due to the use of battery power needed just to keep the batteries working properly. Besides battery concerns, the batteries also have to supply the power needed to keep the interior cool, as well as all of the other accessories. These combined electrical loads represent additional battery drain and reduce the range of the vehicle.

RANGE How far an electric vehicle can travel on a full battery charge is called **range**. The range of an electric vehicle depends on many factors, including

- Battery energy storage capacity
- Vehicle weight
- Outside temperature
- Terrain (driving in hilly or mountainous areas requires more energy from the battery)
- Use of heating or air-conditioning systems and other electrical devices
- Driving style or habits

EVs have a shorter driving range than most conventional vehicles although EV driving ranges are improving. Many early EVs could travel less than 100 miles on a charge, but now typical range for an electric vehicle is in excess of 200 miles, depending on the make and model. A typical electric vehicle will consume about 30 kW per 100 miles (62 km). ● **SEE FIGURE 90–4**.

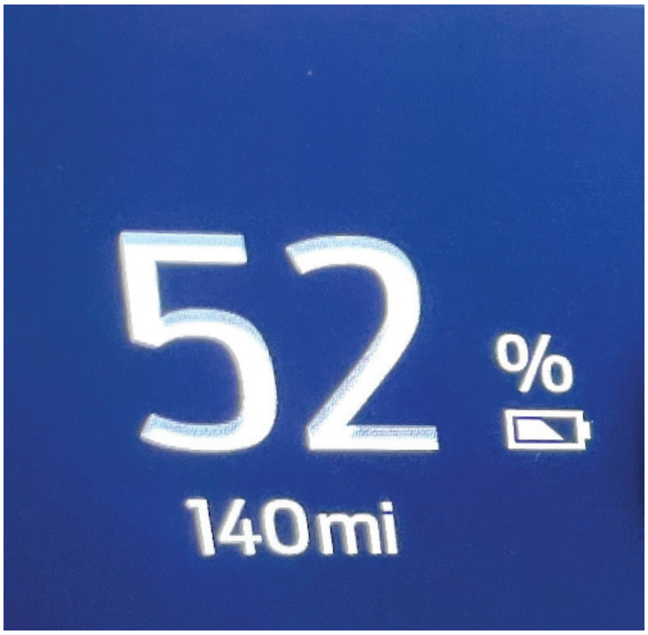


FIGURE 90–4 The "gas gauge" on an electric vehicle is the miles remaining and the state-of-charge. According to those who have owned an electric vehicle, range anxiety lasts only about 10 days after they see that their travel distance can be easily achieved after being charged.

TECH TIP

Use Phone App to Turn on Seat and Steering Wheel Heaters

If not plugged into a charging station on a cold day, most experts recommend that just the steering wheel and seat warmers be turned on to help conserve electrical power. Heating the seats and steering wheel will give the driver a sense of warmth without draining the HV batteries in an effort to heat the air in the entire passenger compartment.

COST OF CHARGING The national average for electricity is about $0.11 per kilowatt-hour. Charging an all-electric vehicle with a 250-mile range (assuming a fully depleted 96 kWh battery) will cost about $10.56 to reach a full charge. This cost is about the same as operating an average central air conditioner for about 6 hours. General Motors estimates the annual energy use of the Chevy Volt is about 2,520 kilowatt-hours, which is less energy than is required to power a typical water heater or central air conditioning.

FREQUENTLY ASKED QUESTION

What Is Range Anxiety?

Range anxiety is a feeling that many drivers experience when driving an electric vehicle because they fear running out of electric battery energy before they reach their destination. This condition is very common, but according to studies, this feeling lasts about two weeks after first getting an electric vehicle. Within those first two weeks, the driver develops experience regarding how far the vehicle can travel on a full charge and knows that their regular trip can be completed without any issues.

KILOWATTS PER 100 MILES The EPA also expresses an EV's energy consumption in terms of the number of kilowatts per hour needed to run the vehicle for 100 miles shortened to **kWh/100 mi**. For example, a Tesla Model 3 uses about 28 KW per 100 miles.

LEVEL 1 CHARGING

20-AMPERE CIRCUIT Level 1 charging uses 110/120-volt standard electric outlet (20-ampere circuit). The maximum power with a Level 1 charging is 1.9 kW. This low rate of charging means that it is best to charge the vehicle overnight, so it is ready to go the next morning. The advantage is that there is little, if any, installation cost because many houses are equipped with 110/120-volt outlets and can supply up to 16 amperes protected by a 20-ampere circuit breaker. ● **SEE FIGURE 90–5**.

Level 1 charging results in 2 to 5 miles of range for each hour of charging. Before plugging an EV into any outlet, be sure that the circuit does not supply other appliances, such as refrigerators or lights. For the connector, nearly all EVs come with a portable Level 1 cord set, which has a standard three-prong household plug on one end for the outlet and a standard J1772 connector for the vehicle. For Level 1 charging when plugged into regular 120-VAC outlet, a lot of vehicles will limit the rate 12 A which is 1.4 kW, while the peak allowed by the standard (and typical household wiring) is 16 A (1.9 kW). ● **SEE FIGURE 90–6**.

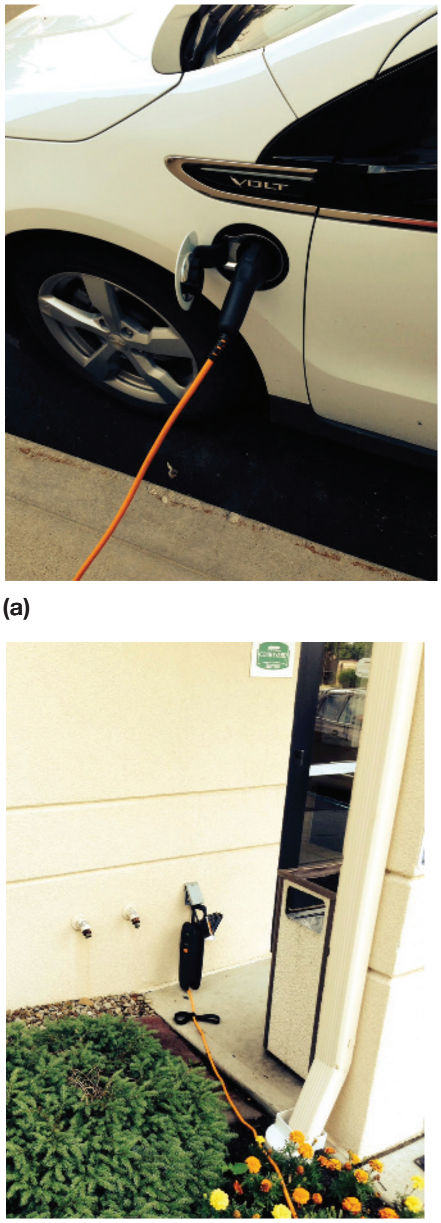
PRECAUTIONS USING A LEVEL 1 CHARGING When using the 110/120-volt plug of the charging cord that comes with the

TECH TIP

Tip on Using Some Generators

If trying to use a gasoline-powered generator to charge an electric vehicle, the neutral and ground have to be tied together or the charger errors out. For example, an owner of a Honda EU 2000i generator got a plug with the two lead (neutral and ground) tied together that it can be plugged into the other socket if needed to charge the vehicle. The electric vehicle needs to see 120 volts on the hot lead and 0 volt on neutral when referenced to ground. Some generators will show 60 volts and 60 volts, and then the vehicle may display a ground fault error.

NOTE: The neutral and ground *must* be electrically isolated. This is also true for any remote panel and all receptacles. The only place they can be connected together is in the main panel where the service ground (ground rod) is located. Some early generators combined them, which led to a whole host of problems, especially with household electronic equipment.



(a)

(b)

FIGURE 90–5 (a) A Chevrolet Volt being charged using the supplied 120-volt charger. (b) Always lay out the entire length of the charging cord before plugging the vehicle into the outlet. If the cord is not kept straight, the current flow can not only create a coil, but the flow of current can overheat the wires and, in some cases, can actually cause the insulation to melt.

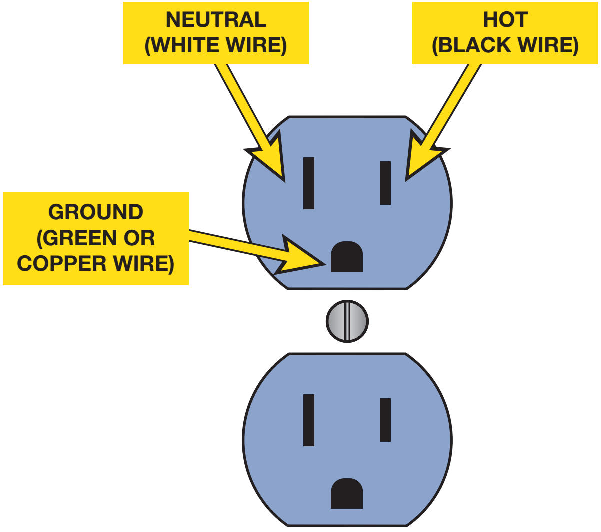


FIGURE 90–6 The electrical outlet must be wired correctly to the house wiring to avoid the possibility of an electrical shock and for proper charging of the vehicle.

CASE STUDY

The Case of the Older House

The owner of a Chevrolet Bolt was visiting a relative who lives in an older home. When visiting, the owner thought that they might as well charge their car even though it was at Level 1 (110/120-volt outlet). At least this could add some range added during the visit. Unfortunately, the house was so old that the electrical outlets did not have a separate ground wire and instead used just a neutral and power (hot) wire. The car knew that the connection did not have a proper ground and the connection was not completed. In this case, the car was smarter than the house.

Summary:

Complaint—A Chevrolet Bolt would not charge when connected to a 110-volt outlet.
Cause—The outlet did not have a ground terminal.
Correction—The vehicle did not allow charging because of the missing ground terminal. This is normal operation and a safety feature of electric vehicles and no correction was needed.

vehicle, the following safety precautions should be adhered to preventing personal injury or property damage:

- Uncoil the cord before connecting the plug to an electrical outlet. If the cord is kept on the charger reel, heat can build up during charging that can cause the insulation to melt. Always unroll the entire length of the charge cord before charging.
- Plug the charging cord directly into a dedicated 110/120-volt, 20-ampere outlet. Do not use an extension cord.

LEVEL 2 CHARGING

HIGHER VOLTAGE EQUALS FASTER CHARGING Level 2 chargers uses 208/240 volts to charge the same vehicle in about 4 hours. Level 2 chargers can be added to most houses, making recharging faster (up to 80 amperes) when at home, and are the most commonly used charging stations available at stores and colleges. A 208/240-volt Level 2 charger rated at 30 amperes will deliver 7.2 kW (240 × 30/1000). In one hour, that will send 7.2 kWh of electricity to a plug-in vehicle, so it will be fine to service vehicles with onboard chargers rated at 7.2 kW or less. Adding a Level 2 charging outlet to the garage or parking location can cost from $500 to $2,000 or more, depending on the location and the wiring of the house or condo. Level 2 charging adds about 25 miles of **range per hour (RPH)**, labeled as **miles per hour (MPH)** on the dash display of a Nissan Leaf. For Level 2 (220/240VAC) charging, vehicles have between a 3 kW and 10 kW onboard chargers, which is usually the limiting factors as to how many kWh of charging is actually achieved. ● **SEE FIGURE 90–7**.

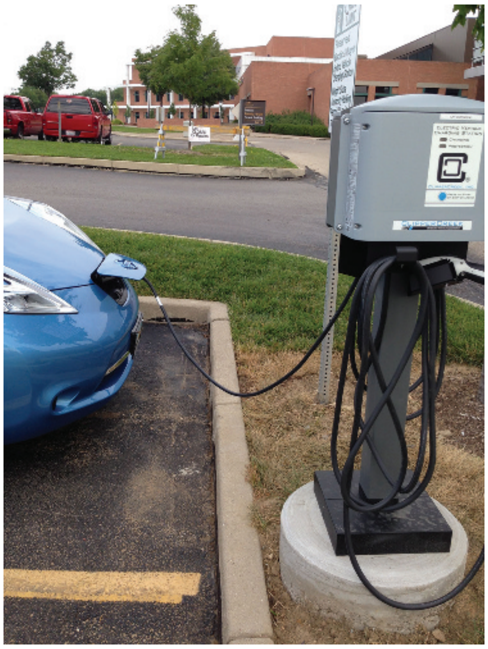


FIGURE 90–7 Nissan Leaf plugged into a Level 2 charging station at a college.

ONBOARD CHARGERS The Level 1 and 2 AC charging is done by the onboard charger. The charging station tells the vehicle the voltage and the maximum current available, and the vehicle will limit itself to no more than that current. Following that handshake (communications between the charging station and the vehicle), the charging station just switches on the power.

NOTE: For Level 3, the vehicle tells the charger how much voltage it can handle, and the external charger will limit the voltage and then the vehicle will take as much current as it can, up to the max the charger can provide.

FREQUENTLY ASKED QUESTION

What Is That Sound?

Many electric vehicle owners say that they hear their vehicle making humming sounds while parked in the garage like the climate control fans running. Checking the smartphone app indicated that the climate control was off. While this can cause some concerns to first time owner of electric vehicle, the noise is usually caused by one of the following:

- The fan, which keeps the battery cool, will run especially if charging or having just finished driving.
- A Chevrolet Volt, for example, often makes gurgling noises due to the A/C running to help cool the battery down in the garage on a hot sunny day.

Because these systems are working when the vehicle is stopped and not operating, many experts recommend that the vehicle is plugged in all the time when it is at home. This is what is often referred to as **Always Be Charging (ABC)**.

LEVEL 3 CHARGING

DC FAST CHARGING Level 3 charging stations use 440/480 volts AC input and outputs DC to charge most electric vehicles to 80% charge in less than 30 minutes. This high-charge rate may be harmful to battery life. Always follow the charging instructions and recommendations as stated in the owner's manual of the vehicle being charged. Level 3 chargers charge the vehicle using direct current (DC) at a rate up to 125 amperes. Level 3 chargers are often called a **DCFC (DC Fast Charge)** or *DC Quick Charge (DCQC)*. ● **SEE FIGURE 90–8**.

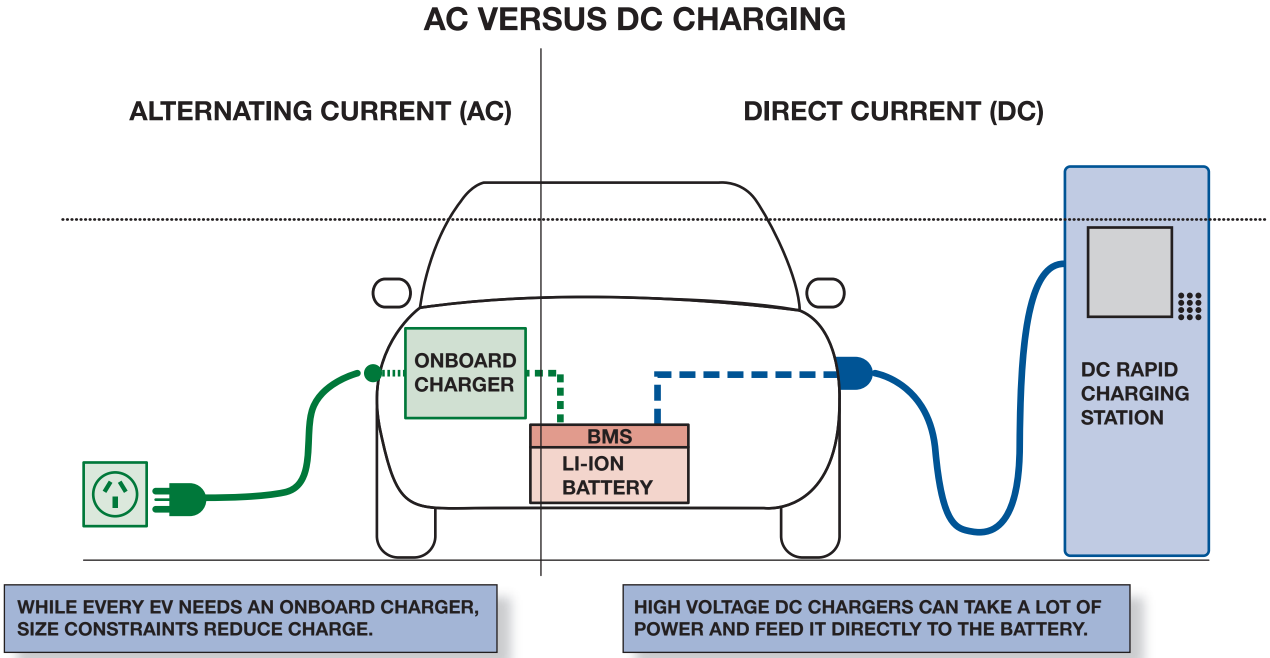

AC VERSUS DC CHARGING
ALTERNATING CURRENT (AC)
DIRECT CURRENT (DC)
ONBOARD CHARGER
BMS
LI-ION BATTERY
DC RAPID CHARGING STATION
WHILE EVERY EV NEEDS AN ONBOARD CHARGER, SIZE CONSTRAINTS REDUCE CHARGE.
HIGH VOLTAGE DC CHARGERS CAN TAKE A LOT OF POWER AND FEED IT DIRECTLY TO THE BATTERY.

FIGURE 90–8 The difference between Level 1, 2, and 3 charging is that by using AC (Levels 1 and 2) the onboard charger has to convert the alternating current (AC) to direct current (DC) in order to charge the high-voltage battery; using direct current (Level 3) this conversion is not needed so that the DC can be used directly to charge the battery.

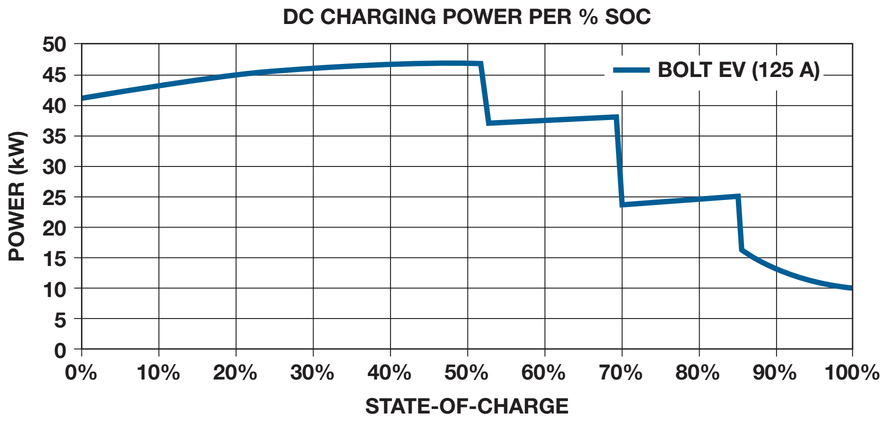


FIGURE 90–9 A chart showing a typical charging rate, which is decreased once the state-of-charge reaches about 70%.

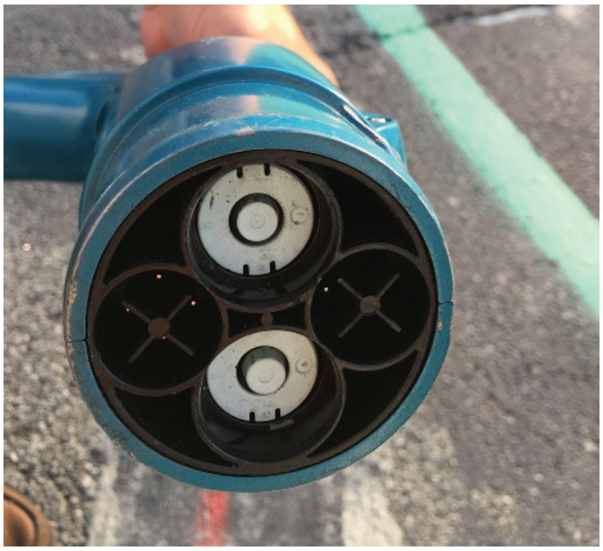


FIGURE 90–10 A close-up view of CHAdeMO Level 3 charging plug.

A Level 3 charger station can cost $50,000 or more, making this type of charger most suitable where facilities will be selling the service of rapidly charging the vehicle. For example, DCFC can provide 60 to 80 miles of range in as little as 20 minutes of charging time. ● **SEE FIGURE 90–9**.

LEVEL 3 ELECTRICAL CONNECTORS There are four different DCFC connectors currently being used by electric vehicle manufacturers all over the world.

- **CHAdeMO**—Nissan and other Japanese companies such as Mitsubishi. ● **SEE FIGURE 90–10**.
- **SAE Combo Charging System (CCS)**—(BMW, Ford, GM, VW, and other vehicle makers). ● **SEE FIGURE 90–11**.
- **Tesla Supercharger**—Tesla standard connector. The Tesla “superchargers” are Level 3 chargers and are free to use by some Tesla owners. Tesla electric vehicles use their own unique plug and supply adaptors if the vehicle is going to be connected to a standard SAE J1772 charging station plug or a 110/120-volt electrical outlet. ● **SEE FIGURE 90–12**.
  ● **SEE CHART 90–2**.

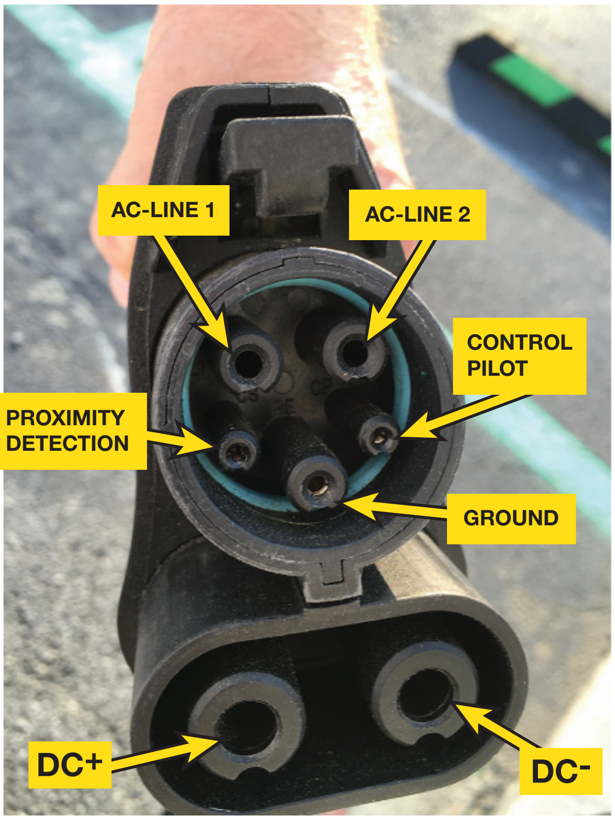


FIGURE 90–11 The SAE Combo Charging System (CCS) is a DCFC connector standard used by BMW, Ford, GM, VW, and other vehicle makers.

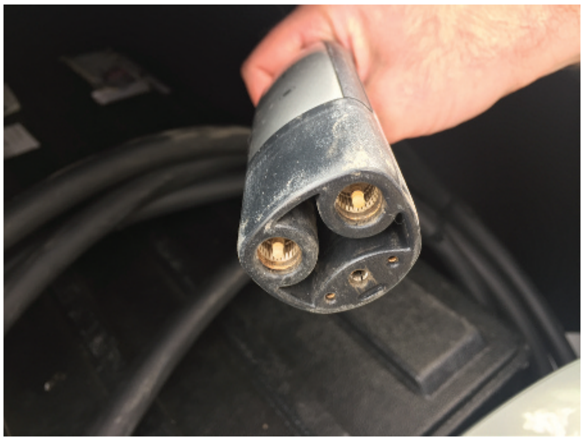


FIGURE 90–12 Tesla vehicles use a unique changing connector that is only used by Tesla.

SUMMARY CHARGING CHART

Level (voltage)	Rate	Time to Fully Charge	Miles per Hour (MPH) Range per Hour (RPH)
Level 1 (110/120 volts)	16 amperes (1.4 to 1.7 kW)	16 hours for 32 kWh battery 40 hours for 80 kWh battery	5 miles per hour
Level 2 (208/210/220 volts)	32–48 amperes (7 to 13 kW)	3.5 hours for 32 kWh battery 8 hours for 80 kWh battery	12 miles per hour with 3.7 kW onboard charger. 25 miles per hour with 6.6 kW onboard charger
Level 3 (440/480 volts DC)	24 kW to 250 kW	Depends, but generally 80% charge in 30 minutes	Up to 200 miles per hour

CHART 90–2

The charge time and range per mile depend upon the voltage and current available during charging.

OWNING AND CHARGING AN EV

TIME-OF-USE For almost all EV owners, choosing a **time-of-use (TOU)** electric rate plan is needed to achieve the largest savings for charging. A TOU plan offers lower electric rates during off-peak periods (usually 11 PM until 5 AM), with higher rates for using electricity during high-demand times. Because most EVs are parked at home overnight, TOU rates are a wise choice for most EV owners.

PUBLIC CHARGING STATIONS (PCS) **Public Charging Stations (PCS)** are available at many locations and most commercial Level 2 charging stations come with added features, which include the following:

- Authentication
- Integrated payment gateways
- Software for remote monitoring

The electric power consumed needs to be billed and payment needs to be collected. The power utilities may also want to manage power drawn by these chargers over time.

NOTE: Some commercial charging stations will stop charging at 80%, whereas others may stop after 30, 45, or 1 hour while others have no limits. Use the website for the charging system being used to check for locations and the charging limits.

WORK PLACE AND DESTINATION CHARGING **Work place charging (WPC)** is very popular because the vehicle owner can

TECH TIP

Speak the Language of Electricity

Most people understand units like inches and feet, meters and kilometers, cups and gallons, milliliters and liters, kilobytes and megabytes and gigabytes, but never learned the basic units of electricity. Many home appliances, such as hair dryers and microwave ovens, have the wattage printed right on the front. There are some people who think electricity is just too complicated. So, when it comes to EVs, manufacturers and charging station operators try to help by stating the miles of range you can get per minute or hour of charging instead of the actual power rating of a charging station. Also, vehicle manufacturers tend to mention just the range that the vehicle can achieve instead of the kWh capacity of the battery. The first battery electric vehicles were equipped with chargers rated at 3.3 kW. They could only accept a maximum of 3.3 kW of electricity each hour they were connected to a 240-volt, or Level 2, power supply. A watt is the basic unit of electricity, and a kilowatt is 1,000 watts. A charging station that could send only 1 kilowatt of electricity to the battery pack in an hour would be a 1 kilowatt-hour (kWh) device. The basic charging capacity of a Tesla, for instance, is 10 kWh, and buyers can order a second onboard charger that doubles the charging speed to 20 kWh. To compute how much electrical current will be delivered to a plugged-in vehicle through any properly installed EVSE, multiply the amperes by the volts and divide by 1,000. Typically, most EVs on a Level 2 charging station can achieve about 25 miles per charging hour.

FREQUENTLY ASKED QUESTION

What Is Plug & Charge?

"Plug & Charge" uses the ISO 15118 international standard, which specifies the secured communication protocol that an EV and the charging stations should use. Plug & charge improves the public charging experience for electric vehicle owners. Until now, networked public EV charging stations required the use of

- an RFID card,
- a smartphone app, and
- a credit card.

Some owners of EV find using a public charging station a frustrating experience. This is because the station often fails to communicate properly and the session either takes a couple of attempts to initiate. Using the plug & charge will simplify public charging and is available for use by many EV makes and models, except Tesla that have their own network.

charge their vehicle while at work and usually for free. Hotels and motels often provide charging stations known as **destination charging**. Hotels are adding chargers to their properties to help attract EV drivers traveling on long trips.

Other charging locations include the following:

- Large factories
- Small businesses
- Museums
- Colleges and universities
- Shopping centers

The usual charging station at these locations is a Level 2 (220/240 volt).

LOCATING A CHARGING STATION Most electric vehicles will display where to charge if a trip is entered into the navigation system. Plus, there are numerous smartphone apps that can be used to locate charging stations. Some of them are as follows:

- Charge Point
- Charge Way
- Electrify America
- Drive the Arc
- EV Match
- Plug Share
- Pod Point

COST TO CHARGE Some businesses provide chargers at no cost to their customers as a way to add value to the service they provide and to help alleviate range anxiety, while others charge a fee. This can either be on a pay-as-you-go basis using a credit card, or via an account with a charging network like ChargePoint or Blink. Blink charges between $0.04 and $0.06 per minute or from $0.39 to $0.79 per kWh, in states where permitted. ● **SEE FIGURE 90–13**.

TECH TIP

Charge to 80% Unless Traveling

Batteries do not have a long service life if the **state-of-charge (SOC)** is above 80% or below 20%. To help protect the high-voltage battery and extend its life, use the menu in the vehicle display main screen to charge to 80% and input the charging stations at work or a free charger used frequently. Usually at 80% SOC, the charging rate drops and then holds steady until 95% where it tapers again. Even when charged to 80%, the display may say fully charged and needs to be manually changed to indicate charge capacity closer to 100%. The only difference will be the number of miles to zero. The two ways that batteries can degrade are as follows:

1. Over discharging starts eating copper once no more lithium is left to move and this action will destroy the battery.
2. Heat created by a high-charge level can cause acid to eat the battery more rapidly.
3. Once the charging station has been inputted, the vehicle will start to precondition the battery in preparation to being charged. Try to charge to 100% only for trips and charge to 80% for daily runs to help protect the battery life.

FREQUENTLY ASKED QUESTION

Why Doesn't My EV Charge at the Rated Output of the Charging Station?

The Bolt owner's manual states to use at least 80 kW to get a full charge in 30 minutes. However, trying to locate a DCFC unit that does in fact supply 80 kW may be a challenge. For example, one Chevrolet Bolt owner was able to locate a DCFC rated at 50 kW, but when using it, the charger was only supplying 35 kW. Other EV owners report the same situation where the rated charger output is not what is actually being supplied to the vehicle. The reasons for this apparent reduced charger include that the vehicle battery may be limiting the amount of current that is be used to charge the battery. This could be the result of the state-of-charge, the battery temperature, or other parameters. As a result of the many factors involved, it is difficult to know what the charging rate will be. Best to use the smartphone app for the vehicle, which will provide the information on charging status.

FREQUENTLY ASKED QUESTION

Can a Solar Panel on the Roof Charge My EV?

While this sounds like a neat idea, it is not practical. If a vehicle's surface was covered with solar panels, they might be able to produce 50-watt hours of electricity. A standard 110/120-volt electrical outlet that takes 8 hours to charge a Chevrolet Volt by supplying about 1,400 watts per hour. A full solar charge would roughly take 350 hours. To answer the question . . . , probably not.

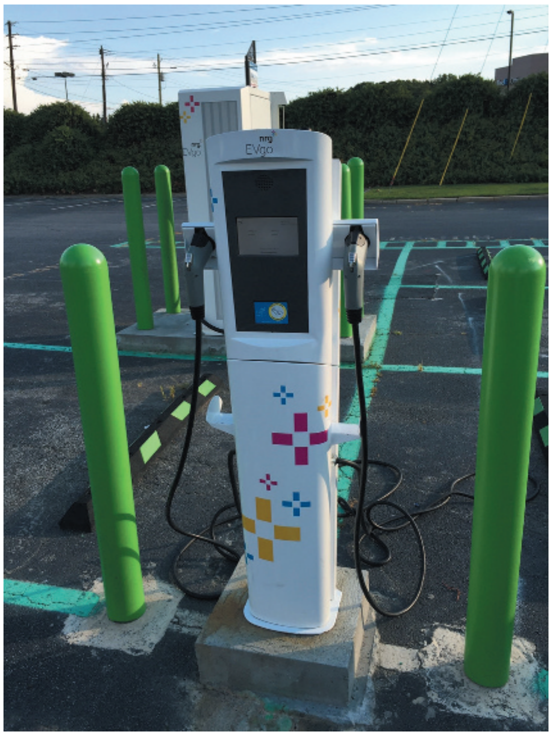
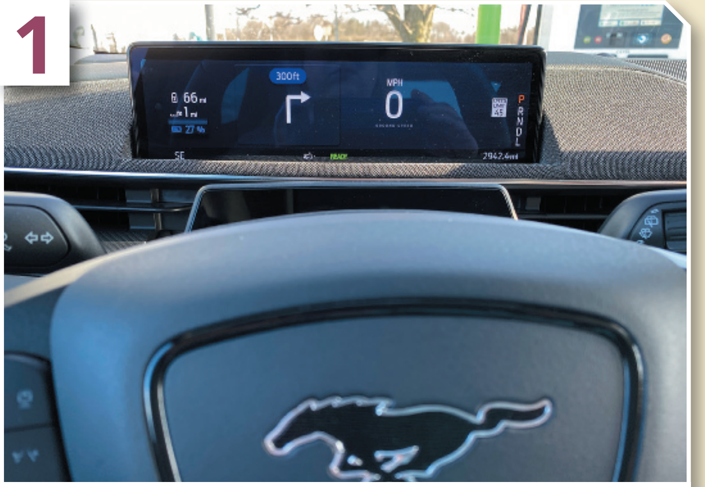


FIGURE 90–13 Commercial charging stations are often located in shopping areas and while most charge a fee, either by the minute of the kWh, some, such as some businesses and schools, are free to use.

COMMERCIAL HIGH-SPEED CHARGING

1


66 mi
300ft
MPH
0
27 %
2942.6mi

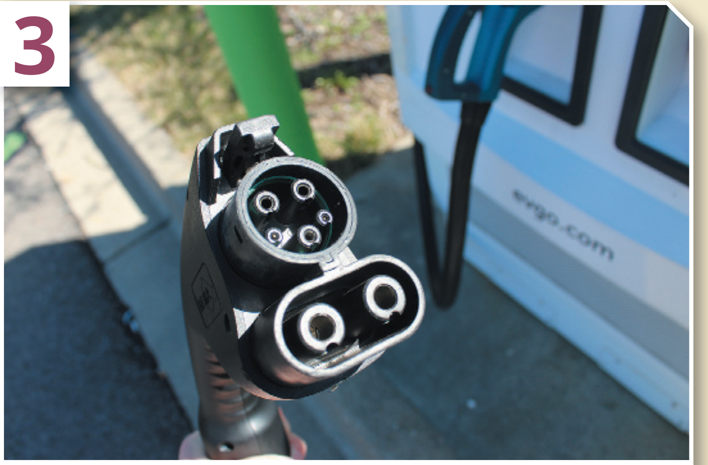
A Mustang Mach E electric SUV is showing 66 miles (27%) of charge remaining.

2

EVgo
FAST CHARGING

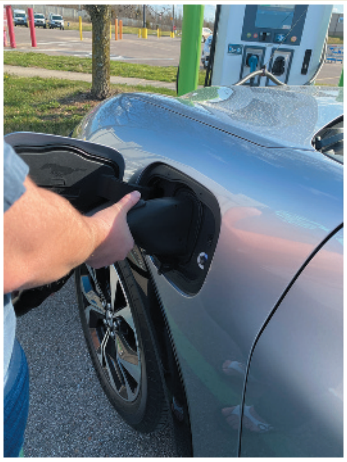
Using a smartphone app, Plug Share in this case, the driver located a Level 3 charging station.

3



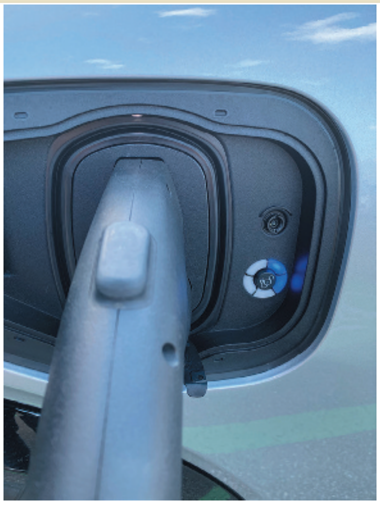
After using a credit card to gain access, the driver removed the SAE CCS charge plug from the charging station.

4



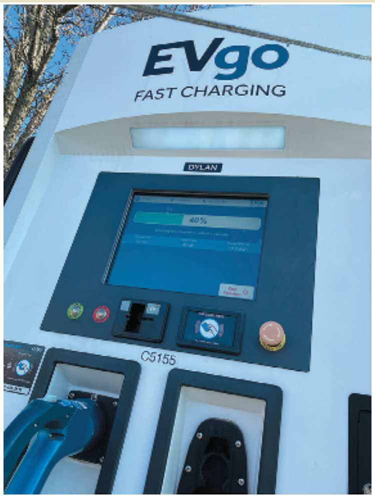
The charge post on the Mustang Mach E is located on the left front fender.

5



During charging, the Mach E lights a series of lights around the charge receptible to let the driver know the level of charge. When all lights are on, the vehicle has been fully charged.

6


EVgo
FAST CHARGING
DYLAN
40%
C5155

The charging station also shows the state-of-change on the display. Most experts recommend only charging to 80% unless traveling when the extra range is required to help protect the HV battery.

REVIEW QUESTIONS

1. What is the difference between a hybrid electric vehicle (HEV) and a plug-in hybrid vehicle (PHEV)?
2. What precautions are needed when charging a vehicle using a Level 1 charging cable that comes with the vehicle?
3. What are the voltage and amperage used to power a Level 2 charger at home?
4. What are the typical charging rates for Level 3 (DCFC) chargers?
5. What are some of the smartphone apps that can be used to locate charging stations?

CHAPTER QUIZ

1. What identifies a plug-in version of a hybrid electric vehicle?
   - **a.** Different badges
   - **b.** An access door for the charging cable in addition to the normal ICE fueling door
   - **c.** Different instrument panel cluster
   - **d.** Any of the above
2. What is true about Level 1 charging?
   - **a.** Uses 110/120 volts
   - **b.** Can supply 2–5 miles per hour of range per hour of charging
   - **c.** Can supply 1.4 to 1.9 kW
   - **d.** All of the above
3. Level 2 charging ___________.
   - **a.** uses J1772 connector
   - **b.** uses 110/120-volt outlet
   - **c.** can supply 1.4 to 1.9 kW
   - **d.** does not need EVSE
4. Level 3 charging ___________.
   - **a.** charges the high-voltage battery using DC
   - **b.** uses 110/120-volt outlet
   - **c.** uses the SAE J1772 connector
   - **d.** Both a and c
5. A typical electric vehicle will consume about ___________ per 100 miles (62 km).
   - **a.** 10 kWh
   - **b.** 20 kWh
   - **c.** 30 kWh
   - **d.** 50 kWh
6. Level 3 chargers use what type of connector?
   - **a.** SAE J1772
   - **b.** SAE Combo Charging System (CCS)
   - **c.** NEMA 14-50
   - **d.** NEMA 6-50
7. Destination charging means ___________.
   - **a.** charging at home
   - **b.** charging at the workplace
   - **c.** charging at a hotel/motel
   - **d.** Any of the above
8. Using a J1772 plug ___________.
   - **a.** can charge most PHEV and EVs
   - **b.** can use 110/120 volts
   - **c.** can use 220/240 volts
   - **d.** All of the above
9. Public Charging Stations (PCS) often charge ___________.
   - **a.** by the hour of usage
   - **b.** by the kWh
   - **c.** by the level of voltage required
   - **d.** Either a or b
10. Charging at 7.2 kW rate is achieved using ___________.
    - **a.** Level 1 charger
    - **b.** Level 2 charger
    - **c.** Level 3 charger
    - **d.** None of the above

Chapter 91

REGENERATIVE BRAKES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the principles and operation of regenerative brake systems.
- Discuss the different types of regenerative brake systems, including the components of the system.
- Discuss one-pedal driving.
- Discuss deceleration rates.
- Describe the servicing precautions involved with regenerative brakes.

KEY TERMS:

Inertia 1053 • Kinetic energy 1053 • One-pedal driving 1057 • Regeneration 1054

REGENERATIVE BRAKING IN VEHICLES

INERTIA, FORCE, AND MASS If a moving object has a mass, it has inertia. **Inertia** is the resistance of an object to change its state of motion. In other words, as Newton's first law of motion states: "An object in motion tends to stay in motion, and an object at rest tends to stay at rest unless acted on by an outside force." An electric vehicle (EV) or hybrid electric vehicle (HEV) can reclaim energy by converting the energy of a moving object, called **kinetic energy**, into electric energy. According to basic physics:

A force applied to move an object results in the equation:

$$F = ma$$

where F = force

m = mass

a = acceleration

The faster an object is accelerated, the more force that has to be applied. Energy from the battery (watts) is applied to the coil windings in the motor. These windings produce a magnetic force on the rotor of the motor, which produces torque on the output shaft. This torque is applied to the wheels of the vehicle by use of a coupling of gears and shafts. When the wheel turns, it applies a force to the ground, which, due to friction between the wheel and the ground, causes the vehicle to move along the surface. ● **SEE FIGURE 91–1**.

All vehicles generate torque to move the wheels to drive the vehicle down the road. During this time, it is generating friction and losses. When standard brakes are applied, it is just another friction device that has specially designed material to handle the heat from friction. This friction is applied to the drums and rotors that stop the wheel from turning. The friction between the wheel and the ground actually stops the vehicle. However, the energy absorbed by the braking system is lost in the form of heat and cannot be recovered or stored for use later to help propel the vehicle. The kinetic energy increases with the square of the speed. In other words, if the speed of a vehicle doubles, the kinetic energy is four times higher (speed is doubled (times 2) and the kinetic energy is squared (2 times 2 equals 4)). ● **SEE FIGURE 91–2**.

TRANSFERRING ENERGY BACK TO THE MOTOR Inertia is the fundamental property of physics that is used to reclaim energy from the vehicle. Instead of using 100% friction brakes (base brakes), the braking torque is transferred from the wheels back into the motor shaft. One of the unique things about most electric motors is that electrical energy can be converted into mechanical energy, and mechanical energy can be converted back into

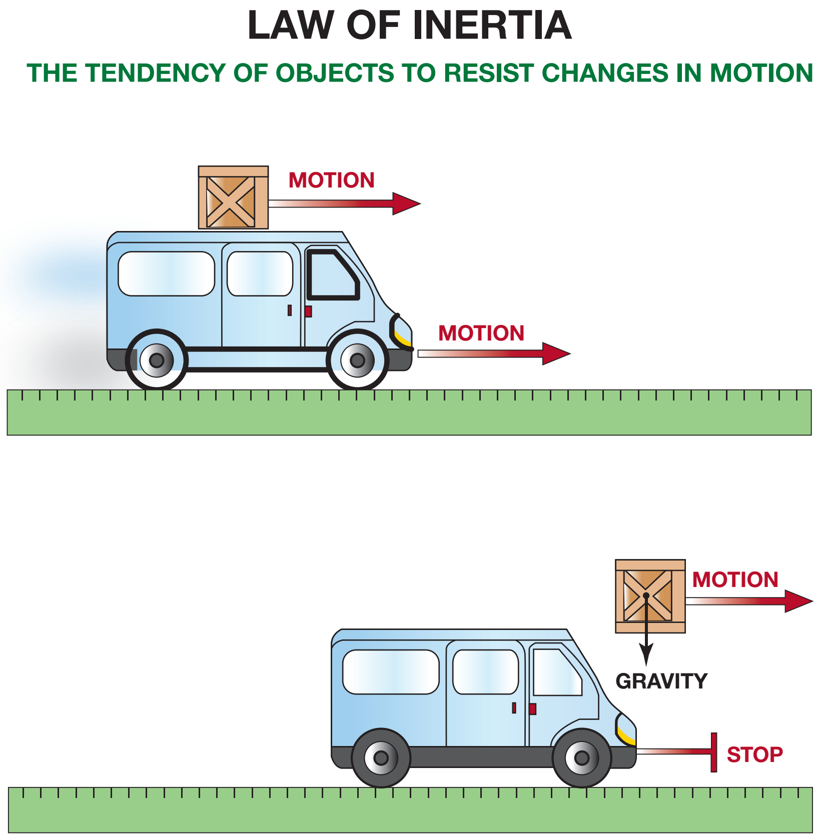

LAW OF INERTIA
THE TENDENCY OF OBJECTS TO RESIST CHANGES IN MOTION
MOTION
MOTION
MOTION
GRAVITY
STOP

FIGURE 91–1 Any object tends to stay in motion unless acted on by an outside force.

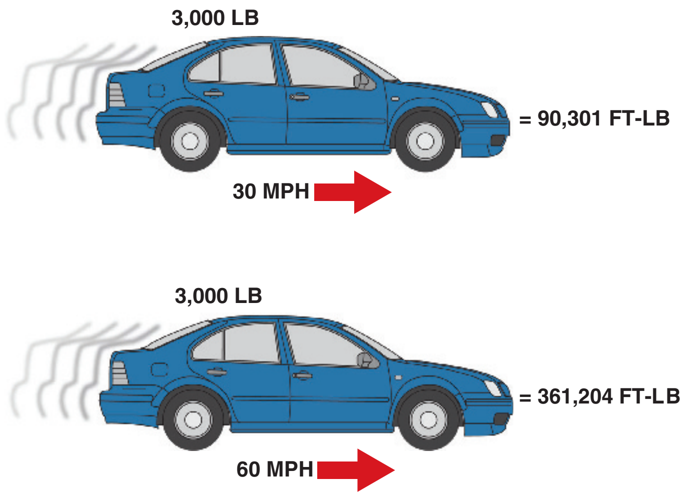


FIGURE 91–2 Kinetic energy increases as the square of any increase in vehicle speed.

FREQUENTLY ASKED QUESTION

What Is the Difference between Mass and Weight?

Mass is the amount of matter in an object. One of the properties of mass is inertia. Inertia is the resistance of an object to being put in motion, and the tendency to remain in motion once it is set in motion. The weight of an object is the force of gravity on the object and may be defined as the mass times the acceleration of gravity. Therefore, mass means the property of an object and weight is a force.

electrical energy. In both cases, this can be done very efficiently. Through the use of the motor and motor controller, the force at the wheels transfers torque to the electric motor shaft. The magnets on the shaft of the motor (called the rotor—the moving part of the motor) move past the electric coils on the stator (the stationary part of the motor), passing the magnetic fields of the magnets through the coils, producing electricity. This electricity is electrical energy, which is directed to and recharges the high-voltage battery. This process is called **regeneration**, *regen*, or simply "reclaiming energy."

LIMITATIONS OF REGENERATIVE BRAKES There are some limitations that will always affect even the best regenerative braking systems, which include the following:

- It only acts on the driven wheels.
- The system has to be designed to allow for proper use of the antilock braking system (ABS).

FREQUENTLY ASKED QUESTION

Are the Friction Brakes Used during Regenerative Braking?

Yes. Most hybrid vehicles make use of the base (friction) brakes during stopping. The amount of regenerative braking compared to the amount of friction braking is determined by the electronic brake controller. It is important that the base brakes be used regularly to keep the rotors free from rust and ready to be used to stop the vehicle. A typical curve showing the relative proportion of brake usage is shown in ● **FIGURE 91–3**.

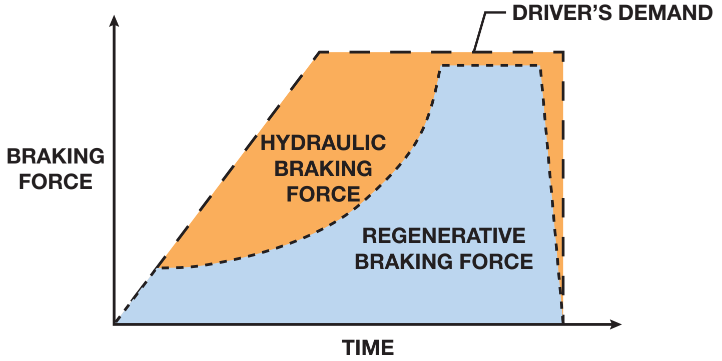


FIGURE 91–3 The regenerative braking system works with the mechanical and hydraulic brake system to provide the necessary braking force to slow and stop the vehicle. Regenerative brakes seldom work at speeds below 10 MPH (16 km/h).

- The batteries are commanded to be kept at a maximum of about 60%, plus or minus 20%, which is best for long battery life and to allow for energy to be stored in the batteries during regenerative braking. If the batteries were allowed to be fully charged, there would be no place for the electrical current to be stored and the conventional friction brakes alone have to be used to slow and stop the vehicle. Charging the batteries over 80% would also overheat the batteries.

BENEFITS OF REGENERATIVE BRAKING SYSTEMS Depending on the type of vehicle, this would reduce fuel consumption by 10% to 25%.

Regenerative braking can be extremely powerful and can recover about 20% of the energy normally wasted as brake heat. Regenerative braking has the following advantages:

- Reduces the drawdown of the battery charge.
- Extends the overall life of the battery pack.
- Reduces fuel consumption.

All production EVs and HEVs use regenerative braking as a method to improve vehicle efficiency, and this feature alone provides the most fuel economy savings. How much energy is reclaimed depends on many factors, including the weight of the vehicle, speed, and the rate of deceleration. ● **SEE FIGURE 91–4.**

FREQUENTLY ASKED QUESTION

When Does Regenerative Braking Not Work?

There is one unusual situation where regenerative braking will not occur. What happens if, for example, the vehicle is at the top of a long hill and the battery charge level is high? In this situation, the controller can only overcharge the batteries. Overcharging is not good for the batteries, so the controller will disable regenerative braking and use the base brakes only. This is one reason why the SOC of the batteries is kept below 80% so regenerative braking can occur.

TYPES OF REGENERATIVE BRAKE SYSTEMS

SERIES REGENERATION In series regenerative braking systems, the amount of regeneration is proportional to the brake pedal position. As the brake pedal is depressed further, the controller that regulates the regenerative braking system computes the torque needed to slow the vehicle, as would occur in normal braking. As the brake pedal is depressed even further, the service brakes are blended into the regenerative braking to achieve the desired braking performance based on brake pedal force and travel. Series regenerative braking requires active brake management to achieve total braking to all four wheels. This braking is more difficult to achieve if the hybrid electric vehicle uses just the front or rear wheels to power the vehicle. This means that the other axle must use the base brakes alone, whereas the drive wheels can be slowed and stopped using a combination of regenerative braking and base brake action. All series regenerative braking systems use an electrohydraulic brake (eHb) system, which includes the hydraulic control unit (ABS modulator) that manages the brake system pressures, as well as the front–rear axle brake balance. Most hybrid vehicles use this type of regenerative braking system. The regenerative braking system mainly uses the regenerative capability, especially at higher vehicle speeds, and gradually increases the amount of the base braking force at low vehicle speeds. ● **SEE FIGURE 91–5.**

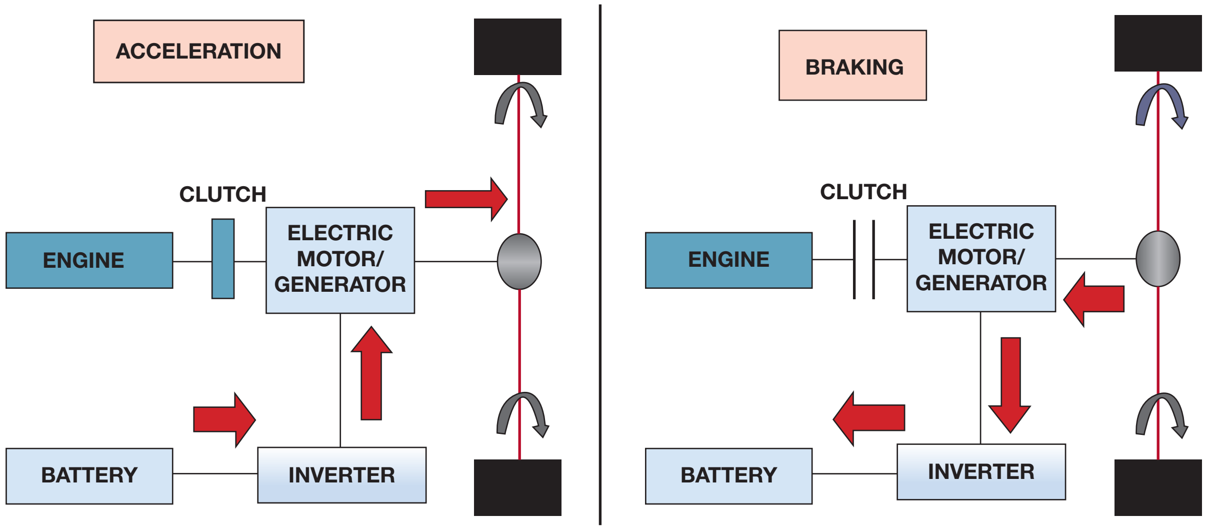


FIGURE 91–4 During acceleration, the ICE and motor/generator are used to propel the vehicle. During deceleration, the energy is returned to the HV battery through the inverter that changes the AC created in the motor/generator to DC to charge the battery.

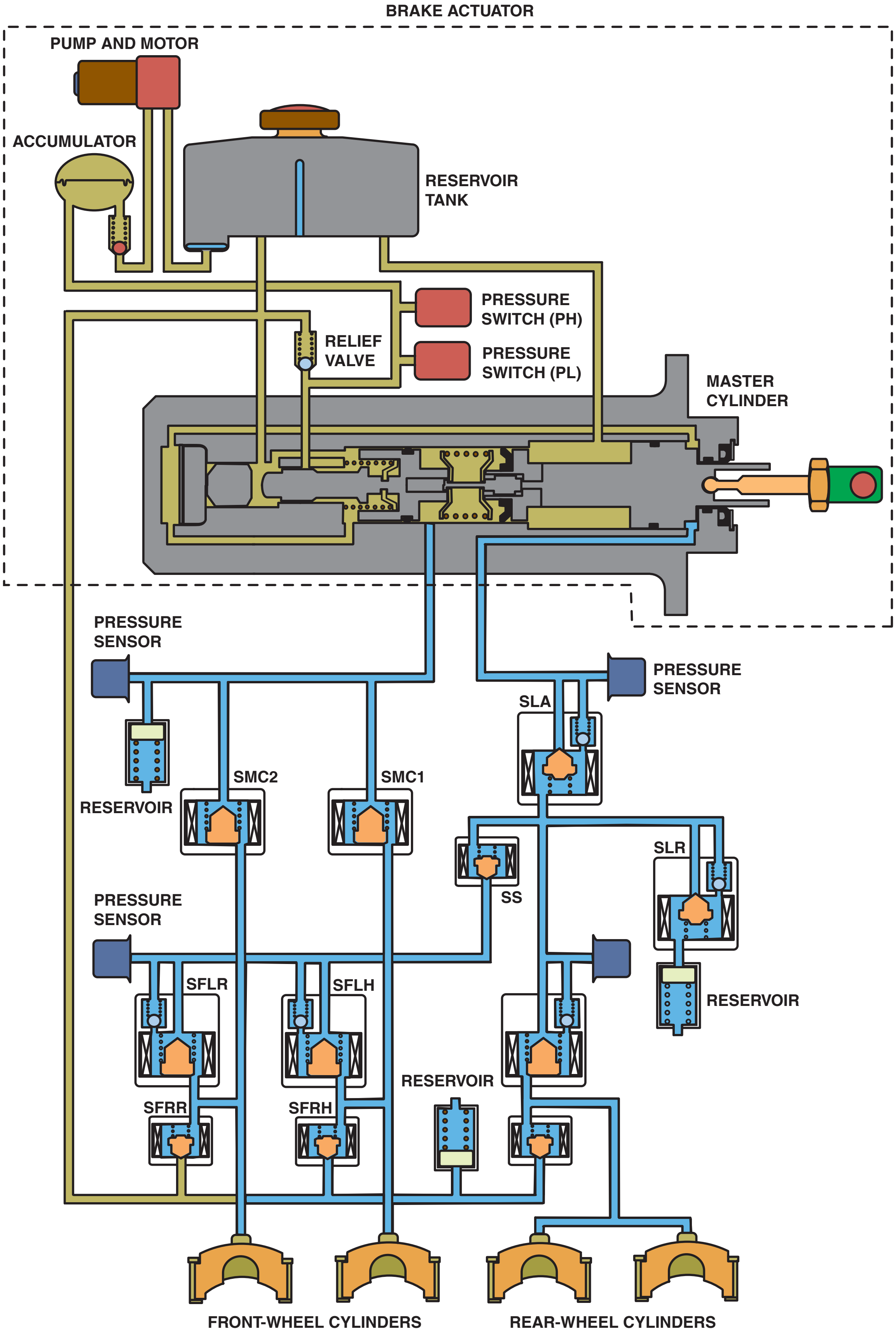

BRAKE ACTUATOR
PUMP AND MOTOR
ACCUMULATOR
RESERVOIR TANK
PRESSURE SWITCH (PH)
PRESSURE SWITCH (PL)
RELIEF VALVE
MASTER CYLINDER
PRESSURE SENSOR
PRESSURE SENSOR
SLA
RESERVOIR
SMC2
SMC1
SLR
SS
PRESSURE SENSOR
SFLR
SFLH
RESERVOIR
RESERVOIR
SFRR
SFRH
FRONT-WHEEL CYLINDERS
REAR-WHEEL CYLINDERS

FIGURE 91–5 The Toyota Prius regenerative braking system component showing the master cylinder and pressure switches.

PARALLEL REGENERATION A parallel regenerative braking system is less complex because the base (friction) brakes are used along with energy recovery by the motors, becoming generators. The controller for the regenerative braking system determines the amount of regeneration that can be achieved based on the vehicle speed. Front and rear brake balance is retained because the base brakes are in use during the entire braking event. The amount of energy captured by a parallel regenerative braking system is less than from a series system. As a result, the fuel economy gains are less.

REGENERATIVE BRAKE COMPONENTS It is the ABS ECU that handles regenerative braking, as well as ABS functions, sending a signal to the hybrid ECU how much regeneration to impose. But how does the ABS ECU know what to do?

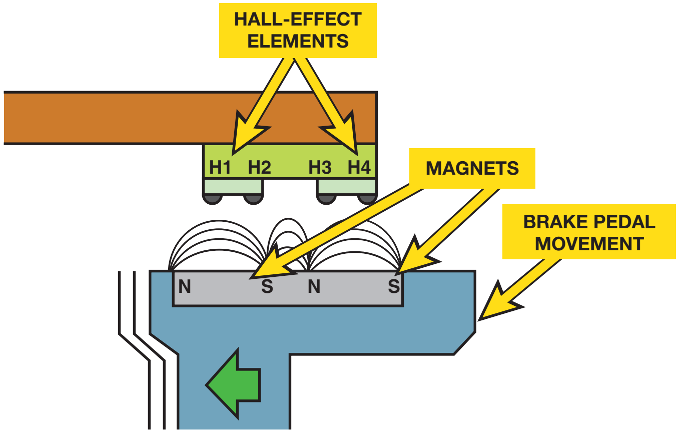


FIGURE 91–6 A contactless BPP sensor uses two Hall-effect elements and magnets to determine not only the position of the brake pedal, but also the speed that the driver is depressing the brake pedal.

Rather than measuring brake pedal travel, which could vary with pad wear, the system uses pressure measuring sensors to detect master cylinder pressure. Some systems use a brake pedal position (BPP) sensor as an input signal to the brake ECU. A typical BBP sensor has two Hall-effect sensor elements on the vacuum booster body and a slide connected to the brake pedal with four Hall magnets. ● **SEE FIGURE 91–6**. The operation includes the following:

- The magnets are connected to the input push rod.
- When the driver presses the brake pedal, the Hall magnets move over the Hall sensors.

This movement (speed and position) is interpreted as a braking request by the brake control system.

The higher the master cylinder pressure, the harder the driver is pushing on the brake pedal. If the driver is pushing only gently, the master cylinder piston displacement will be small and the hydraulic brakes will be only gently applied. In this situation, the ECU knows that the driver wants only gentle deceleration and instructs the hybrid ECU to apply only a small amount of regeneration. However, as master cylinder pressure increases, so does the amount of regeneration that can automatically be applied.

If the electromechanical brake servo and ESC fail at the same time, purely mechanical braking is still possible.

There are four pressure sensors in the braking system and two pressure switches. However, it is the master cylinder pressure sensor that is most important. ● **SEE FIGURE 91–7**.

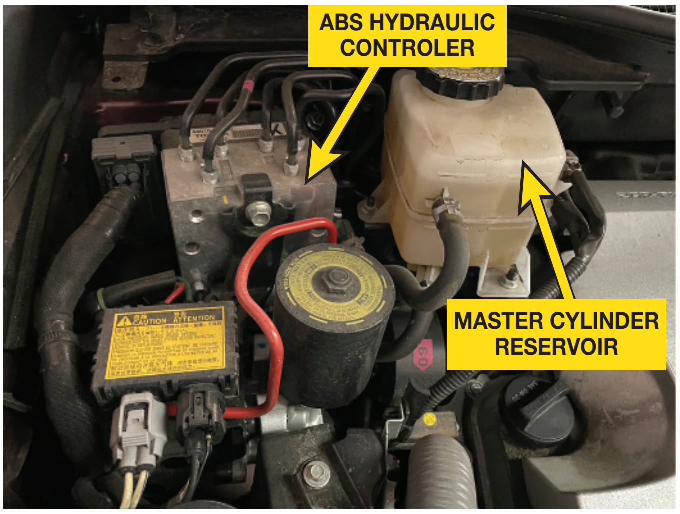


FIGURE 91–7 The components under the hood of a Toyota Highlander hybrid electric vehicle showing the master cylinder reservoir and the ABS controller.

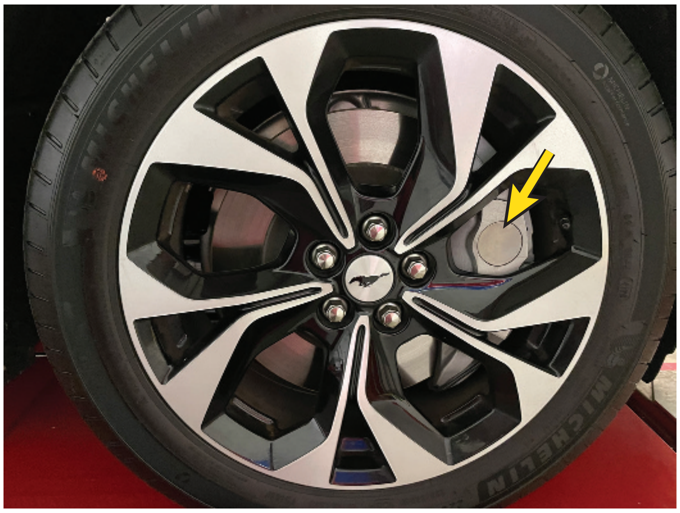


FIGURE 91–8 The front disc brakes on a Mustang Mach E electric vehicle look like most multi-piston front disc brakes used on conventional vehicles.

FREQUENTLY ASKED QUESTION

What Do Regenerative Brakes Look Like?

Regenerative brakes use the rotation of the wheels applied to the electric traction (drive) motor to create electricity. Therefore, the brakes themselves look the same as conventional brakes because the hydraulic brakes are still in place and work the same as conventional brakes. The major difference is that the standard wheel brakes work mostly at low vehicle speeds, whereas conventional brakes work at all speeds. As a result, the brakes on a hybrid electric vehicle should last many times longer than the brakes on a conventional vehicle. ● **SEE FIGURE 91–8**.

FREQUENTLY ASKED QUESTION

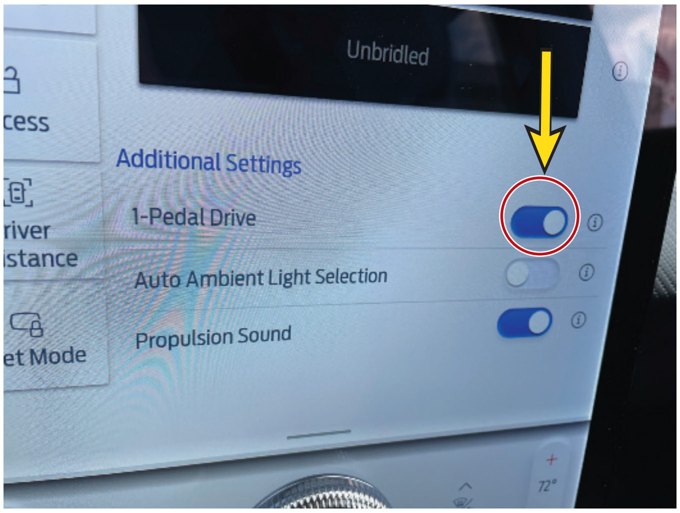
Can an On-Vehicle Brake Lathe Be Used on a Hybrid Electric Vehicle?

Yes. When a brake rotor needs to be machined on a hybrid electric vehicle, the rotor is being rotated. On most hybrids, the front wheels are also connected to the traction motor that can propel the vehicle and generate electricity during deceleration and braking. When the drive wheels are being rotated, the motor/generator is producing electricity. However, unless the high-voltage circuit wiring has been disconnected, no harm will occur.

ONE-PEDAL DRIVING

DEFINITION **One-pedal driving** means that for normal driving, the driver only needs to use the accelerator pedal to accelerate and decelerate. Tesla started using one-pedal driving in 2012 with the Tesla Model S. The brakes on a Tesla are stand alone and are not tied in and blended with the regenerative braking system. One-pedal driving involves the following:

- To accelerate, the driver depresses the accelerator pedal. To accelerate faster, the accelerator pedal is depressed further.



Additional Settings

1-Pedal Drive

Auto Ambient Light Selection

Propulsion Sound

FIGURE 91–9 The display on the dash display of an electric vehicle shows where the one pedal feature can be turned on or off.

- To decelerate (slow down), the driver releases the accelerator pedal and the vehicle speed slows. The faster the driver lets up on the accelerator pedal, the more regenerative braking is achieved and the faster the vehicle slows down. If the deceleration rate is greater than 0.2 Gs, the brake lights come on to warn the driver behind that the vehicle is braking, just as if the driver depressed the brake pedal.

Drivers still have to use the brake pedal to come to a complete stop below 5 to 7 MPH (8 to 11 km/h). In a Nissan Leaf, the car can come to a complete stop in its "e-Pedal" mode. When the car stops totally, it engages the hydraulic brakes to hold it in place. This is not the case with most other vehicles that require the driver to depress the brake pedal to hold the vehicle from moving. ● **SEE FIGURE 91–9**.

EXAMPLES

- The Nissan Leaf has an "L" setting for its drive selector that increases the strength of the regeneration. But it is not strong enough to permit proper one-pedal driving under many circumstances.
- The Volkswagen eGolf and the Chevrolet Bolt EV offer options for one-pedal driving or not depending on the driver needs and desires.
- The Bolt's default "D" position operates like an automatic-transmission car, while the "L" position provides strong regen, eliminating the idle creep, and allows one-pedal driving right down to 0 MPH.
- Audi, while it offers one-pedal driving, the feature has to be selected by the driver. The normal operation of an Audi EV is to allow the vehicle to coast, thereby maintaining the kinetic energy of the moving vehicle without converting that energy back into electrical energy to be stored in the HV battery.
- One-pedal driving seems strange at first, but getting used to it occurs quickly and becomes easy to control the vehicle. The only time that the brake pedal is depressed is for emergency situations or to hold the vehicle from moving, and at very low speeds where regenerative braking is not active.

FREQUENTLY ASKED QUESTION

Is One-Pedal Driving an Advantage?

Some dealers are recommending that their customers do not use one-pedal driving to maximized range. Some electric vehicle manufactures also limit regenerative braking and allow the vehicle to coast, thereby maintaining inertia. Regenerative braking is not 100% efficient. If you are coasting at 60 MPH, regen slows you down to 50, and then accelerates to 60 again, you will lose more energy than if the speed was kept at a steady 60 MPH. Regenerative braking is only useful if used for braking. The most efficient driving mode is the one that is smoothest. That means no hard acceleration or deceleration.

NOTE: When driving in one-pedal mode, the brake light will come on when the accelerator pedal is released and the vehicle starts to slow.

DECELERATION RATES

TERMINOLOGY Deceleration rates are measured in units of "feet per second, per second." What this means is that the vehicle will change in velocity during a certain time interval divided by the time interval.

Deceleration is abbreviated "ft/sec^2" (pronounced "feet per second, per second" or "feet per second squared") or meters per sec^2 (m/s^2) in the metric system.

EXAMPLES Typical deceleration rates include the following:

- Comfortable deceleration is about 8.5 ft/sec^2 (3 m/s^2).
- Loose items in the vehicle will "fly" above 11 ft/sec^2 (3.5 m/s^2).
- Maximum deceleration rates for most vehicles and light trucks range from 16 to 32 ft/sec^2 (5 to 10 m/s^2).

An average deceleration rate of 15 ft/sec^2 (FPSPS) (3 m/s^2) can stop a vehicle traveling at 55 mph (88 km/h) in about 200 ft (61 m) and in less than 4 seconds. Deceleration is also expressed in units called a g. One g is the acceleration of gravity, which is 32 feet per second, per second. With a conventional hydraulic braking system, the driver can brake extremely gently, thereby only imperceptibly slowing the vehicle. A typical hybrid using regenerative braking will normally indicate a 0.1 g (about 3 ft/sec^2) deceleration rate when the throttle is released and the brake pedal has not been applied. This rate is what a driver would normally expect to occur when the accelerator pedal is released. This slight deceleration feels comfortable to the driver, as well as the passengers, because this is what occurs in a non-hybrid vehicle that does not incorporate regenerative braking. When the brake pedal is pressed, the deceleration increases to a greater value than 0.1 g, which gives the driver the same feeling of deceleration that would occur in a conventional vehicle. Maximum deceleration rates are usually greater than 0.8 g and could exceed 1 g in most vehicles. ● **SEE FIGURE 91–10**.

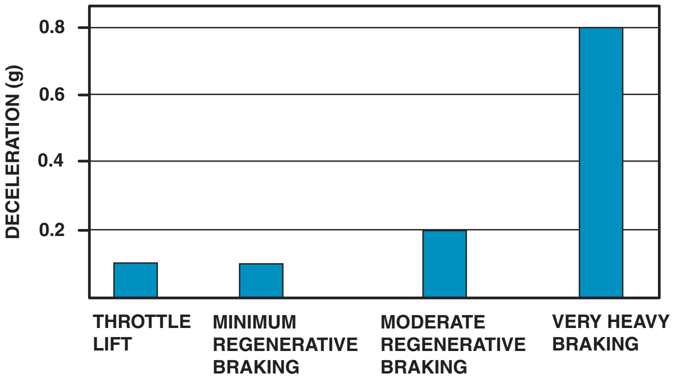


FIGURE 91–10 The graph compares the figures: at the far left, a throttle lift typically giving about 0.1 g deceleration; second from the left, a minimum regenerative braking of about 0.1 g; second from the right, a moderate regenerative braking is about 0.2 g; and on the far right, a hard emergency stop resulting in braking of (at least) 0.8 g, which uses both the regenerative braking system and the base hydraulic brake system.

SERVICING REGENERATIVE BRAKES

UNIQUE MASTER CYLINDERS Most hybrid electric vehicles use unique master cylinders that do not look like conventional master cylinders. Some use more than one brake fluid reservoir and others contain sensors and other components, which are often not serviced separately. ● **SEE FIGURE 91–11**.

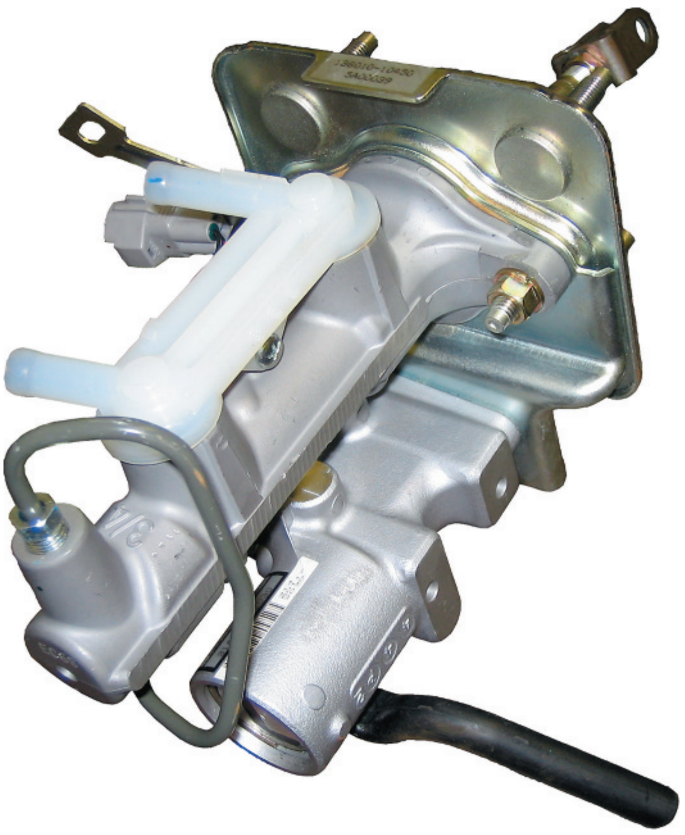


FIGURE 91–11 A master cylinder from a Toyota Highlander hybrid electric vehicle.

Late model GM EVs and PHEVs use an electromechanical brake booster combined with the ABS unit that allows the use of a more conventional master cylinder.

FORD ESCAPE PRECAUTIONS On the Ford Escape hybrid system, the regenerative braking system checks the integrity of the brake system as a self-test. After a certain amount of time, the brake controller will energize the hydraulic control unit and check that pressure can be developed in the system.

- This is performed when a door is opened as part of the wake-up feature of the system.
- The ignition key does not have to be in the ignition for this self-test to be performed.
- This is done by developing brake pressure for short periods of time.

To prevent physical harm or causing damage to the vehicle when servicing the braking system, the technician should do the following:

1. In order to change the brake pads, it is necessary to enter the “Pad Service Mode” on a scan tool and disable the self-test. This will prevent brake pressure from being applied.
2. Disconnect the wiring harness at the hydraulic control unit. ● **SEE FIGURE 91–12**.
3. Check service information regarding how to cycle the ignition switch to enter the Pad Service Mode.

CASE STUDY

Regenerative Brake Warning Message

The owner of an electric vehicle complained to the service department about a message on the dash that stated that the regenerative braking system is degraded. This can be considered normal in cold weather because lithium-ion batteries have no trouble discharging when cold, but do not accept a charge easily when cold. Regenerative braking relies on using the motors as generators, and the battery as the place to store that power. Cold batteries mean limited or no regenerative braking. Once the vehicle was driven and the high-voltage batteries increased in temperature, the regenerative braking system worked normally and the message was no longer displayed on the dash. ● **SEE FIGURE 91–13**.

Summary:

Complaint—Vehicle owner saw a message on the dash warning that the braking system was degraded.
Cause—The high-voltage batteries were cold and could not accept a charge from the regenerative brake system.
Correction—Once the high-voltage batteries increased in temperature, the message was not displayed and is considered to be normal operation at very cold temperatures.

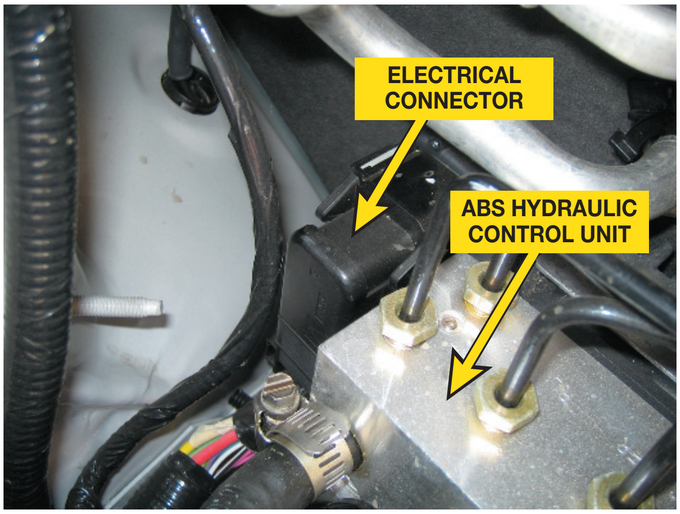


FIGURE 91–12 When working on the brakes on a Ford Escape or Mercury Mariner hybrid vehicle, disconnect the black electrical connector on the ABS hydraulic control unit located on the passenger side under the hood.

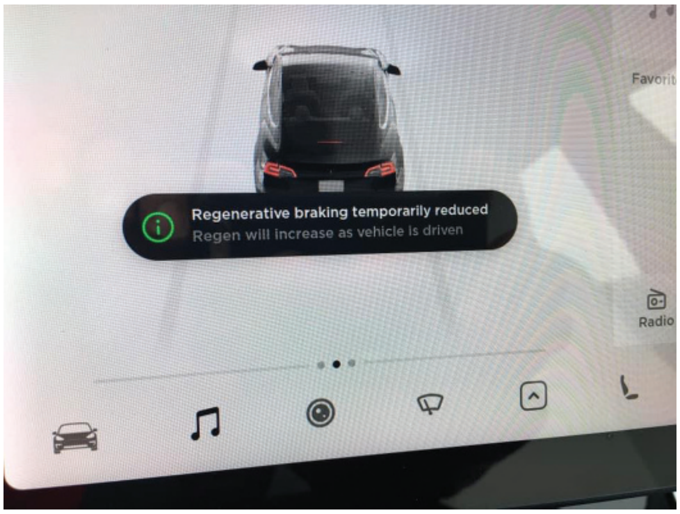

Regenerative braking temporarily reduced
Regen will increase as vehicle is driven

FIGURE 91–13 A notice displayed on the dash informing the driver that the regenerative brakes are degraded or temporarily reduced. When this occurs, the brake pedal feel will change because the system will use more of the base brakes, which may require a higher pedal effort.

REVIEW QUESTIONS

1. What is inertia?
2. What is the difference between series and parallel regenerative braking systems?
3. What happens in the regenerative braking system when the high-voltage batteries are fully charged?
4. What is meant by "one-pedal driving"?
5. What occurs when the driver first releases the accelerator pedal and starts to brake on a hybrid electric vehicle equipped with regenerative braking?

CHAPTER QUIZ

1. Which type of regenerative braking system uses an electro-hydraulic system?
   - **a.** Series
   - **b.** Parallel
   - **c.** Both series and parallel
   - **d.** Neither series nor parallel
2. Kinetic energy is _____________.
   - **a.** the energy that the driver exerts on the brake pedal
   - **b.** the energy needed from the batteries to propel a vehicle
   - **c.** the energy in any moving object
   - **d.** the energy that the motor produces to propel the vehicle
3. Inertia is _____________.
   - **a.** the energy of any moving object that has mass (weight)
   - **b.** the force that the driver exerts on the brake pedal during a stop
   - **c.** the electric motor force that is applied to the drive wheels
   - **d.** the force that the internal combustion engine and the electric motor together apply to the drive wheels during rapid acceleration
4. What are the benefits of regenerative brakes?
   - **a.** They reduce the drawdown of the battery charge.
   - **b.** They extend the overall life of the battery pack.
   - **c.** They reduce fuel consumption.
   - **d.** All of the above
5. During braking on a hybrid electric vehicle equipped with a regenerative braking system, what occurs when the driver depresses the brake pedal?
   - **a.** The friction brakes are only used as a backup and not used during normal braking.
   - **b.** The motors become generators.
   - **c.** The driver needs to apply a braking lever instead of depressing the brake pedal to energize the regenerative braking system.
   - **d.** The batteries are charged to 100% SOC.
6. Technician A says that a front-wheel-drive hybrid electric vehicle can only generate electricity during braking from the front wheel motor(s). Technician B says that antilock braking (ABS) is not possible on a vehicle equipped with a regenerative braking system. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. What precaution should be taken when servicing the brakes on a Ford Escape?
   - **a.** Leave a door open.
   - **b.** Put a cover over the master cylinder.
   - **c.** Energize the brake controller.
   - **d.** Put the vehicle in "Pad Service" mode.

8. Two technicians are discussing deceleration rates. Technician A says that a one “g” stop is a gentle slowing of the vehicle. Technician B says that a stopping rate of 8 ft/sec^2 is a severe stop. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. One-pedal system means ______________.
   - **a.** the vehicle is not equipped with a separate brake pedal
   - **b.** the accelerator pedal is used to accelerate and decelerate the vehicle
   - **c.** the vehicle uses regenerative braking only and not friction brakes
   - **d.** the vehicle does not use regenerative braking
10. Which of these two is the more efficient type of regenerative braking?
   - **a.** Series regeneration
   - **b.** Parallel regeneration
   - **c.** Both types are equally efficient
   - **d.** A third type, not mentioned, is the most efficient

Chapter 92

FUEL CELLS AND ADVANCED TECHNOLOGIES

LEARNING OBJECTIVES:

After studying this chapter the reader should be able to:

- Explain how a fuel cell generates electricity and the types of fuel cells.
- Discuss hydrogen refueling.
- Discuss fuel cell vehicle systems.
- Explain the purpose and function of fuel cell hybrid vehicles.
- Explain the purpose and function of hydrogen storage.
- Explain how ultracapacitors work in fuel-cell hybrid vehicles.
- Describe the HCCI combustion process.

KEY TERMS:

Electrolysis 1062 • Energy carrier 1062 • Fuel cell 1062 • Fuel-cell hybrid vehicle (FCHV) 1063 • Fuel-cell stack 1064 • Fuel-cell vehicle (FCV) 1063 • Homogeneous Charge Compression Ignition (HCCI) 1069 • Low-grade heat 1065 • Membrane electrode assembly (MEA) 1064 • Polymer electrolyte fuel cell (PEFC) 1064 • Proton exchange membrane (PEM) 1064 • Specific energy 1062 • Ultracapacitor 1069

FUEL-CELL TECHNOLOGY

BACKGROUND A **fuel cell** is an electrochemical device in which the chemical energy of hydrogen and oxygen is converted into electrical energy. The principle of the fuel cell was first discovered in 1639 by Sir William Grove, a Welsh physician. In the 1950s, National Aeronautics and Space Administration (NASA) put this principle to work in building devices for powering space exploration vehicles. Fuel cells are being developed to power homes and vehicles while producing low or zero emissions. ● **SEE FIGURE 92–1**.

PARTS AND OPERATION The chemical reaction in a fuel cell is the opposite of **electrolysis**. Electrolysis is the process in which electrical current is passed through water in order to break it into its components, hydrogen and oxygen. While energy is required to bring about electrolysis, this same energy can be retrieved by allowing hydrogen and oxygen to reunite in a fuel cell. While hydrogen can be used as a fuel, it is *not* an energy source. Instead, hydrogen is only an **energy carrier**, as energy must be expended to generate the hydrogen and store it so it can be used as a fuel.

HYDROGEN-POWERED BATTERY A fuel cell is a hydrogen-powered battery. Hydrogen is an excellent fuel because it has a very high **specific energy** when compared to an equivalent amount of fossil fuel. One kilogram (kg) of hydrogen has three times the energy content as one kilogram of gasoline. Hydrogen is the most common element on earth, but it does not exist by itself in nature. Hydrogen is 14 times lighter than air.

HYDROGEN SOURCES Hydrogen is a low-carbon, non-toxic fuel that is domestically produced from local resources. This is because its natural tendency is to react with oxygen in the atmosphere to form water (H_2O). Hydrogen is also found in many other compounds, such as natural gas or crude oil. In order to store hydrogen for use as a fuel, different processes must be undertaken to separate it from these materials. For example, hydrogen can be produced from water using an electric current to separate the hydrogen from the oxygen using a process called electrolysis. ● **SEE FIGURE 92–2**.

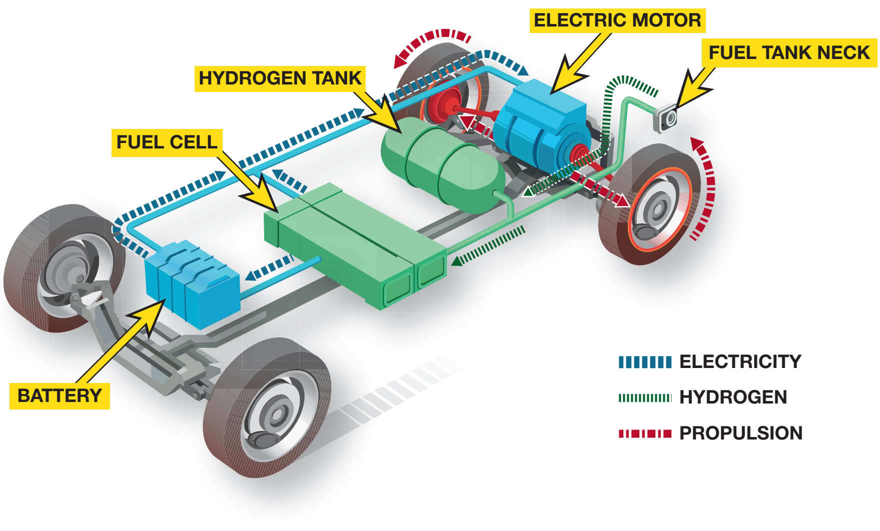


FIGURE 92–1 A fuel cell vehicle uses a fuel cell and a high-voltage battery to provide electrical power to the electric drive motor.

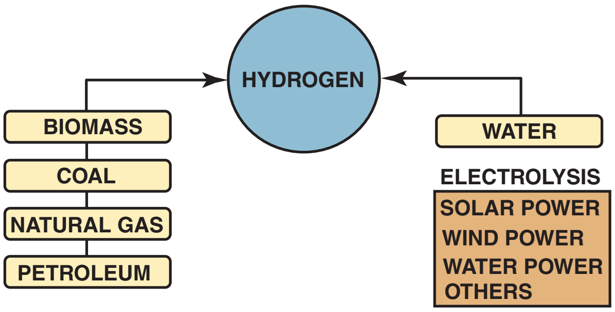


FIGURE 92–2 Hydrogen does not exist by itself in nature. Energy must be expended to separate it from other, more complex materials.

ADVANTAGES OF A FUEL CELL A fuel cell can be used to move a vehicle by generating electricity to power electric drive motors, as well as powering the remainder of the electrical system of the vehicle. Advantages include the following:

- Because they are powered by hydrogen and oxygen, fuel cells by themselves do not generate carbon emissions, such as CO_2. Instead, their only emissions are water vapor and heat, and this makes the fuel cell an ideal candidate for a ZEV (zero-emission vehicle).
- A fuel cell is also much more energy-efficient than a typical internal combustion engine (ICE). While a vehicle powered by an ICE is anywhere from 15% to 20% efficient, a fuel-cell vehicle can achieve efficiencies upward of 40%.
- Fuel cells have very few moving parts and have the potential to be very reliable. Vehicle manufacturers have spent many years and millions of dollars in order to develop a low-cost, durable, and compact fuel cell that operates satisfactorily under all driving conditions.

A **fuel-cell vehicle (FCV)** uses the fuel cell as its only source of power, whereas a **fuel-cell hybrid vehicle (FCHV)** also has an electrical storage device that can be used to power the vehicle. Most new designs of fuel-cell vehicles are now based on a hybrid configuration due to the significant increase in efficiency and drivability that can be achieved with this approach. ● **SEE FIGURE 92–3**.

TOYOTA
FCHV
FUEL CELL HYBRID VEHICLE

FIGURE 92–3 The Toyota FCHV is based on the Highlander platform and uses much of Toyota Hybrid Synergy Drive (HSD) technology in its design.

DISADVANTAGES OF FUEL CELLS While major automobile manufacturers continue to build demonstration vehicles and work on improving fuel-cell system design, no vehicle powered by a fuel cell has been placed into mass production. There are a number of disadvantages of fuel cells, including

- High cost
- Lack of refueling infrastructure
- Safety perception
- Insufficient vehicle range
- Lack of durability
- Cold weather starting problems
- Insufficient power density

All of these problems are being actively addressed by researchers, and significant improvements are being made. Once cost and performance levels meet that of current vehicles, fuel cells may be adopted as a mainstream technology.

FUEL-CELL TYPES There are a number of different types of fuel cells, and these are differentiated by the type of electrolyte

		FUEL-CELL TYPES		
	PEM (POLYMER ELECTROLYTE MEMBRANE)	**PAFC (PHOSPHORIC ACID FUEL CELL)**	**MCFC (MOLTEN CARBONATE FUEL CELL)**	**SOFC (SOLID OXIDE FUEL CELL)**
Electrolyte	Sulfonic acid in polymer	Orthophosphoric acid	Li and K carbonates	Yttrium-stabilized zirconia
Fuel	Natural gas, hydrogen, methanol	Natural gas, hydrogen	Natural gas, synthetic gas	Natural gas, synthetic gas
Operating Temp. (°F) (°C)	176–212°F 80–100°C	360–410°F 180–210°C	1100–1300°F 600–700°C	1200–3300°F 650–1800°C
Electric Efficiency	30% to 40%	40%	43% to 44%	50% to 60%
Manufacturers	Avista, Ballard, Energy Partners, H-Power, International, Plug Power	ONSI Corp.	Fuel Cell Energy, IHI, Hitachi, Siemens	Honeywell, Siemens-Westinghouse, Ceramic
Applications	Vehicles, portable power units, small stationary power units	Stationary power units	Industrial and institutional power units	Stationary power units, military vehicles

CHART 92-1

Types and details of fuel cells, including those most suitable to stationary power generation rather than for use in a vehicle.

that is used in their design. Some electrolytes operate best at room temperature, whereas others are made to operate at up to 1600°F (871°C).

The fuel-cell design that is best suited for automotive applications is the **Proton Exchange Membrane (PEM)**. A PEM fuel cell must have hydrogen for it to operate, and this may be stored on the vehicle or generated, as needed, from another type of fuel. There are several types of fuel cells, and except for the PEM type, however, most of the others are most suitable for use as power-generating units.

● **SEE CHART 92–1** for a comparison of the types of fuel cells and their most common uses.

PEM FUEL CELL OPERATION The Proton Exchange Membrane fuel cell is also known as a **Polymer Electrolyte Fuel Cell (PEFC)**. The PEM fuel cell is known for its lightweight and compact design, as well as its ability to operate at ambient temperatures.

This means that a PEM fuel cell can start quickly and produce full power without an extensive warm-up period. The PEM is a simple design based on a membrane that is coated on both sides with a catalyst, such as platinum or palladium.

- There are two electrodes, one located on each side of the membrane. These are responsible for distributing hydrogen and oxygen over the membrane surface, removing waste heat, and providing a path for electrical current flow.
- The part of the PEM fuel cell that contains the membrane, catalyst coatings, and electrodes is known as the **Membrane Electrode Assembly (MEA)**.
- The negative electrode (anode) has hydrogen gas directed to it, while oxygen is sent to the positive electrode (cathode). Hydrogen is sent to the negative electrode as H_2 molecules, which break apart into H ions (protons) in the presence of the catalyst. The electrons (e) from the H atoms are sent through the external circuit, generating electricity that can be used to perform work.

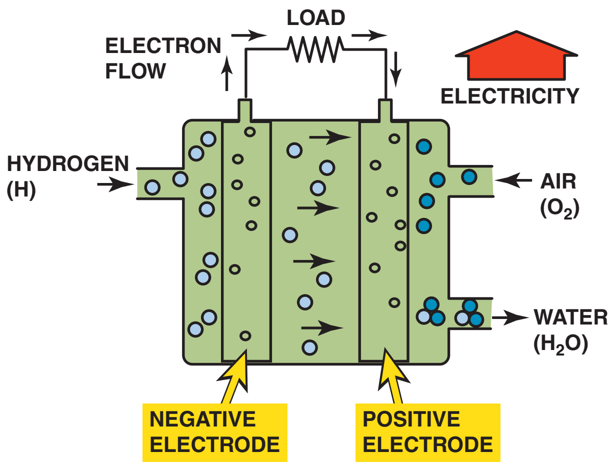


FIGURE 92–4 The polymer electrolyte membrane only allows H^+ ions (protons) to pass through it. This means that electrons must follow the external circuit and pass through the load to perform work.

- These same electrons are then sent to the positive electrode, where they rejoin the H ions that have passed through the membrane and have reacted with oxygen in the presence of the catalyst. This creates H_2O and waste heat, which are the only emissions from a PEM fuel cell. ● **SEE FIGURE 92–4**.

FUEL-CELL STACKS A single fuel cell by itself is not particularly useful as it generates less than 1 volt of electrical potential. It is more common for hundreds of fuel cells to be built together in a **fuel-cell stack**. In this arrangement, the fuel cells are connected in series so that total voltage of the stack is the sum of the individual cell voltages. The fuel cells are placed end-to-end in the stack, much like slices in a loaf of bread. Automotive fuel-cell stacks contain upward of 400 cells in their construction. ● **SEE FIGURE 92–5**.

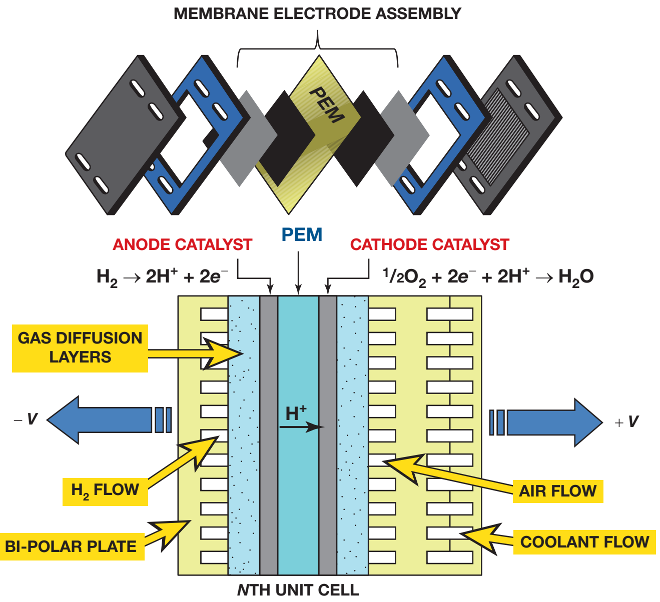


FIGURE 92–5 A fuel-cell stack is made up of hundreds of individual cells connected in series.

TECH TIP

CO Poisons the PEM Fuel-Cell Catalyst

Purity of the fuel gas is critical with PEM fuel cells. If more than 10 parts per million (PPM) of carbon monoxide is present in the hydrogen stream being fed to the PEM anode, the catalyst is gradually poisoned and the fuel cell is eventually disabled. This means that the purity must be "five nines" (99.999% pure). This is a major concern in vehicles where hydrogen is generated by reforming hydrocarbons, such as gasoline, because it is difficult to remove all CO from the hydrogen during the reforming process. In these applications, some means of hydrogen purification must be used to prevent CO poisoning of the catalyst.

The total voltage of the fuel-cell stack is determined by the number of individual cells incorporated into the assembly. The current-producing ability of the stack, however, is dependent on the surface area of the electrodes. Since output of the fuel-cell stack is related to both voltage and current (voltage × current = power), increasing the number of cells or increasing the surface area of the cells increases power output. Some fuel-cell vehicles use more than one stack, depending on power output requirements and space limitations.

REFUELING WITH HYDROGEN

FUELING PROCEDURE Hydrogen is a compressed gas that is stored aboveground at the station. Most hydrogen stations have fuel delivered by a tanker truck, although some stations make their fuel onsite. Like CNG, hydrogen is normally sold by the kilogram (2.2 lb). Filling a vehicle takes just minutes and, to obtain extended driving ranges in fuel-cell electric vehicles (FCEVs), the hydrogen needs to be filled at high pressures. Filling up with hydrogen is very similar to putting propane in a barbeque tank. Just clamp the nozzle onto the receptacle. When the seal is tight, the dispenser pushes high-pressure, gaseous hydrogen into the tank. When the tank is full, the dispenser stops and then the nozzle can be disconnected. To find a hydrogen station, visit the U.S. Department of Energy website: https://www.afdc.energy.gov/stations/#/find/nearest ● **SEE FIGURE 92–6.**

PRESSURES USED The two most commonly used pressures at hydrogen filling stations include

- H35 = 35 MPa (5,000 PSI)
- H70 = 70 MPa (10,000 PSI)

The higher the pressure, the more hydrogen can be added to the onboard storage tank(s). The speed of hydrogen fueling is directly related to the amount of cooling that the dispenser allows to offset the heat of compression. The three temperatures that are used to supply hydrogen include the following:

- T40 station H_2 @ −40°C (−40°F)
- T30 station H_2 @ −30°C (−22°F)
- T20 station H_2 @ −20°C (−4°F)

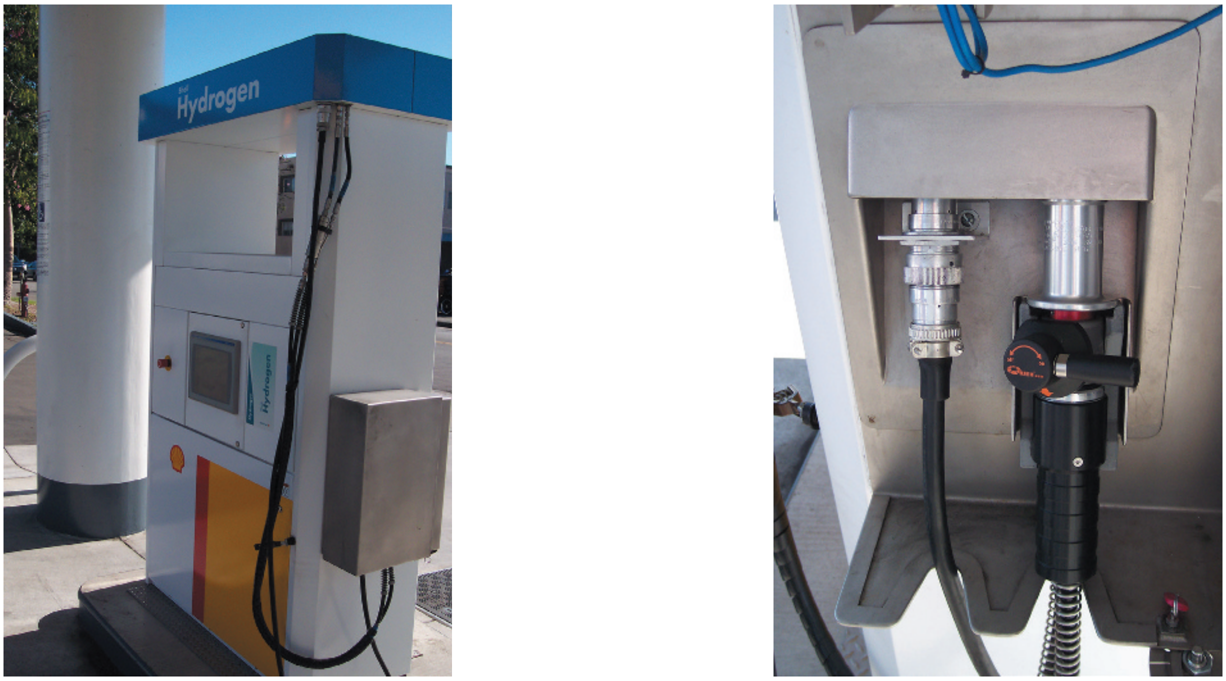
SAE J2601 SAE International-created standard J2601 is the standard for hydrogen-fueling protocol of hydrogen fuel-cell electric vehicles (FCEVs). This standard is used worldwide for hydrogen-fueling stations. The standard J2601 fueling protocol uses a simple control in which the dispenser fuels until the target pressure is reached, based on initial start conditions, giving a consistent hydrogen fueling. Therefore, a H70-T40 (10,000 PSI at −40°F) fueling dispenser enables this fast-fueling by providing hydrogen fuel to the fuel-cell vehicle in usually less than 3 minutes.

FUEL-CELL VEHICLE SYSTEMS

FUEL-CELL HUMIDIFIERS Water management inside a PEM fuel cell is critical. Too much water can prevent oxygen from making contact with the positive electrode; too little water can allow the electrolyte to dry out and lower its conductivity. The amount of water and where it resides in the fuel cell is also critical in determining at how low a temperature the fuel cell starts because water freezing in the fuel cell can prevent it from starting. The role of the humidifier is to achieve a balance where it is providing sufficient moisture to the fuel cell by recycling water that is evaporating at the cathode. The humidifier is located in the air line leading to the cathode of the fuel-cell stack. ● **SEE FIGURE 92–7.**

Some newer PEM designs manage the water in the cells in such a way that there is no need to pre-humidify the incoming reactant gases. This eliminates the need for the humidifier assembly and makes the system simpler overall.

FUEL-CELL COOLING SYSTEMS Heat is generated by the fuel cell during normal operation. Excess heat can lead to a breakdown of the polymer electrolyte membrane, so a liquid cooling system must be utilized to remove waste heat from the fuel-cell stack. One of the major challenges for engineers in this regard is the fact that the heat generated by the fuel cell is classified as **low-grade heat**. This means that there is only a small difference



(a)

(b)

FIGURE 92–6 (a) A hydrogen fueling station located at a Shell gasoline station in Los Angeles, CA. (b) The door on the side is opened to show the fill nozzle with shut-off valve. The hydrogen at this station is made on the roof of the dispenser using water and electricity. An electrical current separates the hydrogen from the oxygen in the water, then compresses the hydrogen, which is then sent to a storage tank, also on the roof.

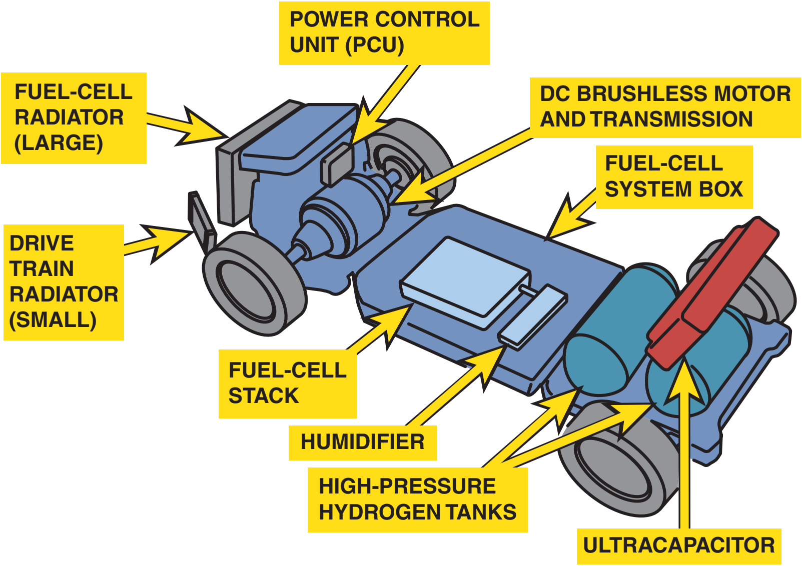

POWER CONTROL UNIT (PCU)
FUEL-CELL RADIATOR (LARGE)
DC BRUSHLESS MOTOR AND TRANSMISSION
FUEL-CELL SYSTEM BOX
DRIVE TRAIN RADIATOR (SMALL)
FUEL-CELL STACK
HUMIDIFIER
HIGH-PRESSURE HYDROGEN TANKS
ULTRACAPACITOR

FIGURE 92–7 Powertrain layout in a Honda FCX fuel-cell vehicle. Note the use of a humidifier behind the fuel-cell stack to maintain moisture levels in the membrane electrode assemblies.

between the temperature of the coolant and that of the ambient air. Heat transfers very slowly under these conditions, so heat exchangers with a much larger surface area must be used. ● **SEE FIGURE 92–8**.

In some cases, heat exchangers may be placed in other areas of the vehicle when available space at the front of the engine compartment is insufficient. In the case of Toyota FCHV, an auxiliary heat exchanger is located underneath the vehicle to increase the cooling system heat-rejection capacity. ● **SEE FIGURE 92–9**.

An electric water pump and a fan drive motor are used to enable operation of the fuel-cell cooling system. These and other support devices use electrical power that is generated by the fuel cell and, therefore, tend to decrease the overall efficiency of the vehicle.

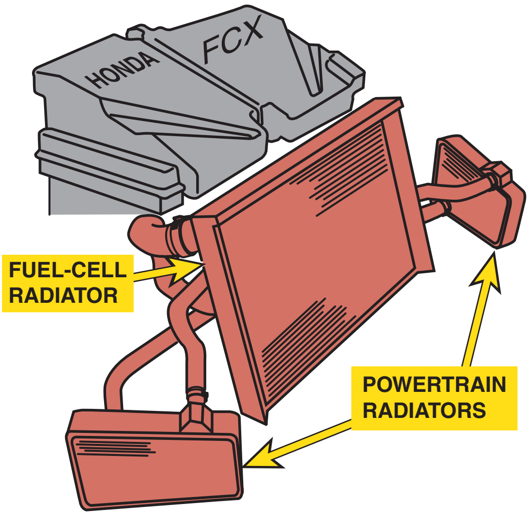

HONDA
FCX
FUEL-CELL RADIATOR
POWERTRAIN RADIATORS

FIGURE 92–8 The Honda FCX uses one large radiator for cooling the fuel cell, and two smaller ones on either side for cooling drivetrain components.

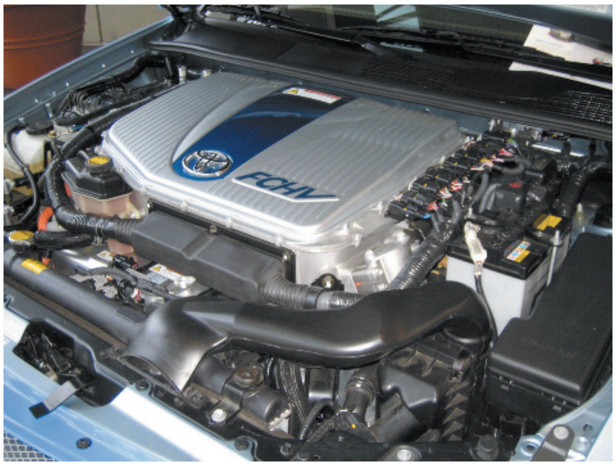


FIGURE 92–9 Space is limited at the front of the Toyota FCHV engine compartment, so an auxiliary heat exchanger is located under the vehicle to help cool the fuel-cell stack.

AIR SUPPLY PUMPS Air must be supplied to the fuel-cell stack at the proper pressure and flow rate to enable proper performance under all driving conditions. This function is performed by an onboard air supply pump that compresses atmospheric air and supplies it to the fuel-cell positive electrode (cathode). This pump is often driven by a high-voltage electric drive motor.

FUEL-CELL HYBRID VEHICLES

PURPOSE AND FUNCTION Hybridization tends to increase efficiency in vehicles with conventional drivetrains, as energy that was once lost during braking, and otherwise normal operation is instead stored for later use in a high-voltage battery. This same advantage can be gained by applying the hybrid design concept to fuel-cell vehicles. Whereas the fuel cell is the only power source in a fuel-cell vehicle, the fuel-cell hybrid vehicle relies on both the fuel cell and an electrical storage device for motive power. Drivability is also enhanced with this design, as the electrical storage device is able to supply energy immediately to the drive motors and overcome any “throttle lag” on the part of the fuel cell.

SECONDARY BATTERIES All hybrid vehicle designs require a means of storing electrical energy that is generated during regenerative braking and other applications. In most FCHV designs, a high-voltage nickel-metal hydride (NiMH) battery pack is used as a secondary battery. This is most often located near the back of the vehicle, either under or behind the rear passenger seat. ● **SEE FIGURE 92–10**.

The secondary battery is built similar to a fuel-cell stack because it is made up of many low-voltage cells connected in series to build a high-voltage battery.

HYDROGEN STORAGE

PURPOSE AND FUNCTION One of the issues with fuel-cell hybrid vehicles is how to store sufficient hydrogen onboard to allow for reasonable vehicle range. Modern drivers have grown accustomed to having a minimum of 300 miles between refueling stops, a goal that is extremely difficult to achieve when fueling the vehicle with hydrogen. Hydrogen has very high energy content on a pound-for-pound basis, but its energy density is less than that of conventional liquid fuels. This is because gaseous hydrogen, even at high pressure, has a very low physical density (mass per unit volume). ● **SEE FIGURE 92–11**.

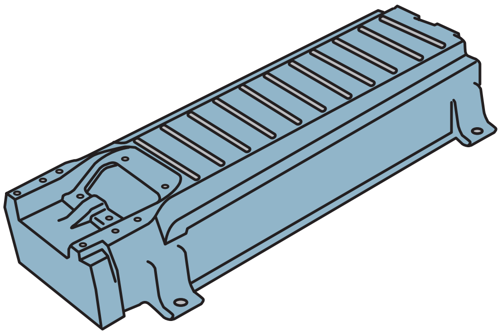


FIGURE 92–10 The secondary battery in a fuel-cell hybrid vehicle is made up of many individual cells connected in series, much like a fuel-cell stack.

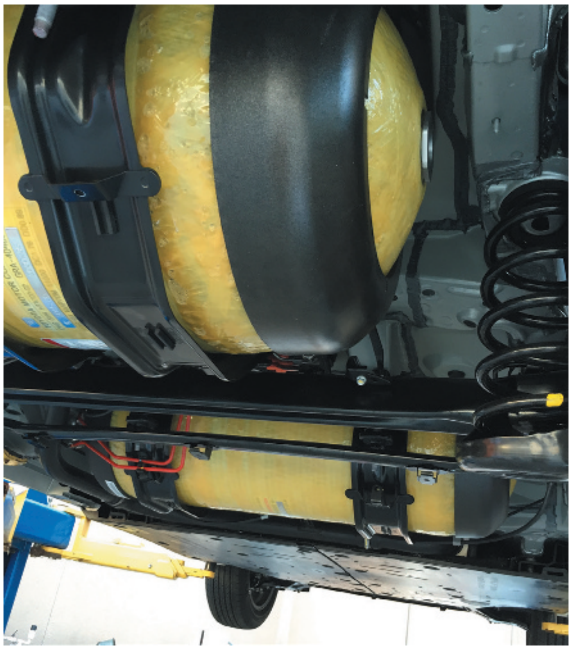


FIGURE 92–11 A photo showing the hydrogen storage tanks underneath a Toyota Mirai fuel-cell vehicle. This vehicle uses two carbon-fiber-reinforced fuel tanks.

A number of methods of hydrogen storage are being considered for use in fuel-cell hybrid vehicles. These include high-pressure compressed gas, liquefied hydrogen, and solid storage in metal hydrides. Efficient hydrogen storage is one of the technical issues that must be solved in order for fuel cells to be adopted for vehicle applications. Much research is being conducted to solve the issue of onboard hydrogen storage.

HIGH-PRESSURE COMPRESSED GAS Most current fuel-cell hybrid vehicles use compressed hydrogen that is stored in tanks as a high-pressure gas. This approach is the least complex of all the storage possibilities, but also has the least energy density. Multiple small storage tanks are often used rather than one large tank in order to fit them into unused areas of the vehicle. One drawback with this approach is that only cylinders can be used to

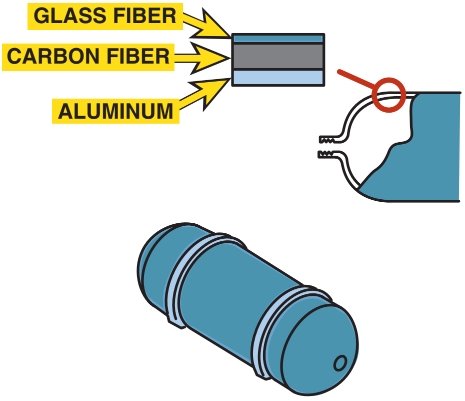


FIGURE 92–12 The Toyota FCHV uses high-pressure storage tanks that are rated at 350 bar. This is the equivalent of 5,000 pounds per square inch.

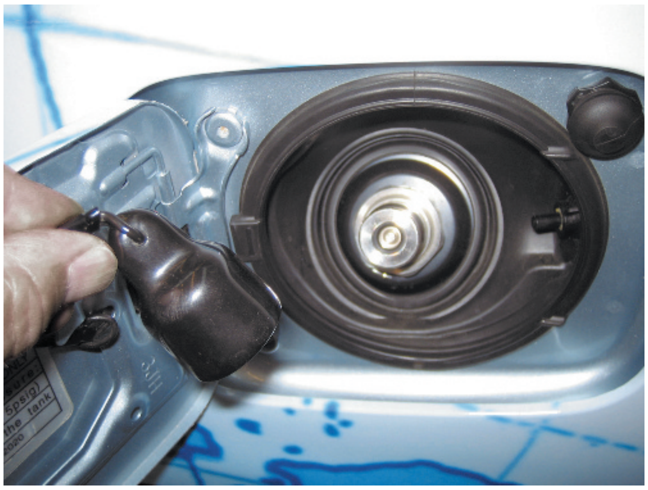


FIGURE 92–13 The high-pressure fitting used to refuel a fuel-cell hybrid vehicle.

store gases at the required pressures. This creates a good deal of unused space around the outside of the cylinders and leads to further reductions in hydrogen storage capacity. It is common for a pressure of 5,000 PSI (350 bar) to be used. ● **SEE FIGURE 92–12**.

Many newer systems use pressures as high as 10,000 PSI (700 bar) to increase the range of the fuel cell-powered vehicle. The tanks used for compressed hydrogen storage are typically made with an aluminum liner wrapped in several layers of carbon fiber and an external coating of fiberglass. In order to refuel the compressed hydrogen storage tanks, a special high-pressure fitting is installed in place of the filler neck used for conventional vehicles. ● **SEE FIGURE 92–13**.

There is also a special electrical connector that is used to enable communication between the vehicle and the filling station during the refueling process. ● **SEE FIGURE 92–14**.

The filling station utilizes a special coupler to connect to the vehicle high-pressure refueling fitting. The coupler is placed on the vehicle fitting, and a lever on the coupler is rotated to seal and lock it into place.

LIQUID HYDROGEN Hydrogen can be liquefied in an effort to increase its energy density, but this requires that it be stored in cryogenic tanks at −423°F (−253°C). This increases vehicle range, but impacts overall efficiency, as a great deal of energy is required to liquefy the hydrogen, and a certain amount of the liquid hydrogen "boils off" while in storage.

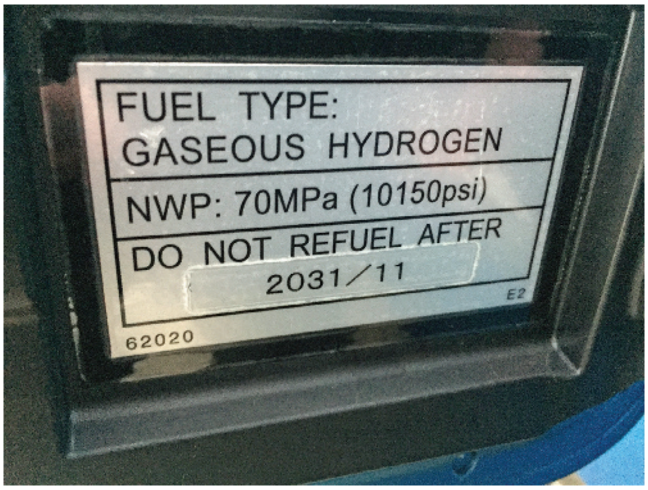


FIGURE 92–14 Note that high-pressure hydrogen storage tanks must be replaced in 2031.

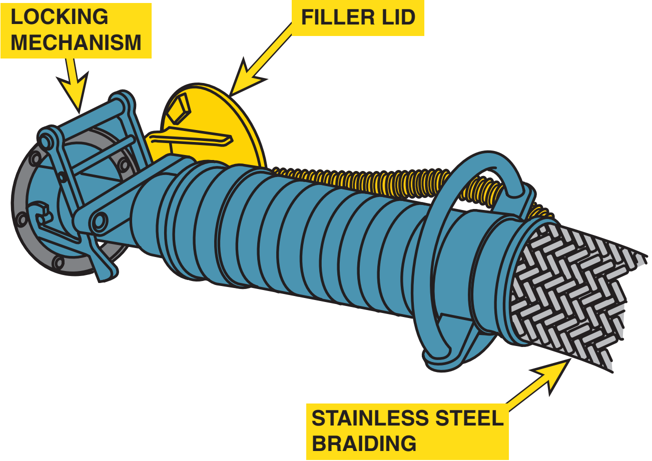


FIGURE 92–15 Refueling a vehicle with liquid hydrogen.

One liter of liquid hydrogen has only one-fourth the energy content of 1 liter of gasoline. ● **SEE FIGURE 92–15**.

SOLID STORAGE OF HYDROGEN One method discovered to store hydrogen in solid form is as a metal hydride, similar to how an NiMH battery works.

A demonstration vehicle features a lightweight fiber-wrapped storage tank under the body that stores about 6.6 pounds (3.3 kg) of hydrogen as a metal hydride at low pressure. The vehicle can travel almost 200 miles with this amount of fuel.

- One kilogram of hydrogen is equal to 1 gallon of gasoline.
- Three gallons of water generates 1 kilogram of hydrogen.

A metal hydride is formed when gaseous hydrogen molecules disassociate into individual hydrogen atoms and bond with the metal atoms in the storage tank. This process uses powdered metallic alloys capable of rapidly absorbing hydrogen to make this occur.

ULTRACAPACITORS

PURPOSE AND FUNCTION An alternative to storing electrical energy in batteries is to use ultracapacitors. A capacitor is best known as an electrical device that blocks DC, but allows AC to pass. However, a capacitor can also be used to store electrical energy, and it is able to do this without a chemical reaction. Instead, a capacitor stores electrical energy using the principle of electrostatic attraction between positive and negative charges.

PARTS AND OPERATION Ultracapacitors are built very different from conventional capacitors. **Ultracapacitor** cells are based on double-layer technology, in which two activated carbon electrodes are immersed in an organic electrolyte. The electrodes have a very large surface area and are separated by a membrane that allows ions to migrate, but prevents the electrodes from touching. ● **SEE FIGURE 92–16**.

Charging and discharging occurs as ions move within the electrolyte, but no chemical reaction takes place. Ultracapacitors can charge and discharge quickly and efficiently, making them especially suited for electric-assist applications in fuel-cell hybrid vehicles.

Ultracapacitors that are used in fuel-cell hybrid vehicles are made up of multiple cylindrical cells connected in parallel. ● **SEE FIGURE 92–17**.

This results in the total capacitance being the sum of the values of each individual cell. For example, ten 1.0-farad capacitors connected in parallel have a total capacitance of 10.0 farads. Greater capacitance means greater electrical storage ability, and this contributes to greater assist for the electric motors in a fuel-cell hybrid vehicle.

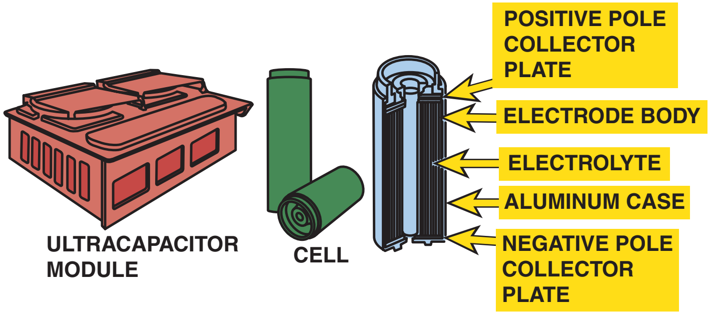

POSITIVE POLE COLLECTOR PLATE
ELECTRODE BODY
ELECTROLYTE
ALUMINUM CASE
NEGATIVE POLE COLLECTOR PLATE
ULTRACAPACITOR MODULE
CELL

FIGURE 92–16 The Honda ultracapacitor module and construction of the individual cells.

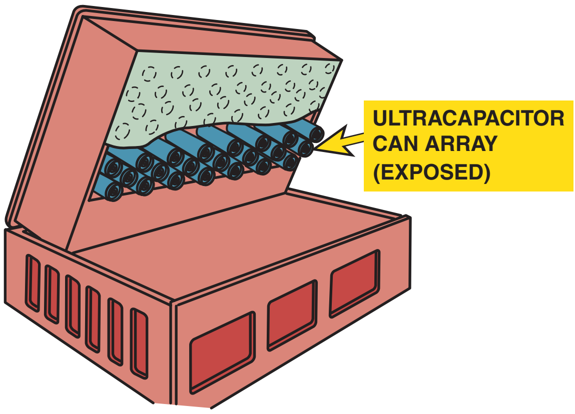

ULTRACAPACITOR CAN ARRAY (EXPOSED)

FIGURE 92–17 An ultracapacitor can be used in place of a high-voltage battery in a hybrid electric vehicle. This example is from the Honda FCX fuel-cell hybrid vehicle.

ADVANTAGES Ultracapacitors have excellent cycle life, meaning that they can be fully charged and discharged many times without degrading their performance. They are also able to operate over a wide temperature range and are not affected by low temperatures to the same degree as many battery technologies.

DISADVANTAGES The one major downside of ultracapacitors is a lack of specific energy, which means that they are best suited for sudden bursts of energy, as opposed to prolonged discharge cycles. Research is being conducted to improve this and other aspects of ultracapacitor performance.

HCCI

TERMINOLOGY **Homogeneous Charge Compression Ignition (HCCI)** is a combustion process. HCCI is the combustion of a very lean gasoline air–fuel mixture without the use of a spark ignition. It is a low-temperature, chemically controlled (flameless) combustion process. ● **SEE FIGURE 92–18**.

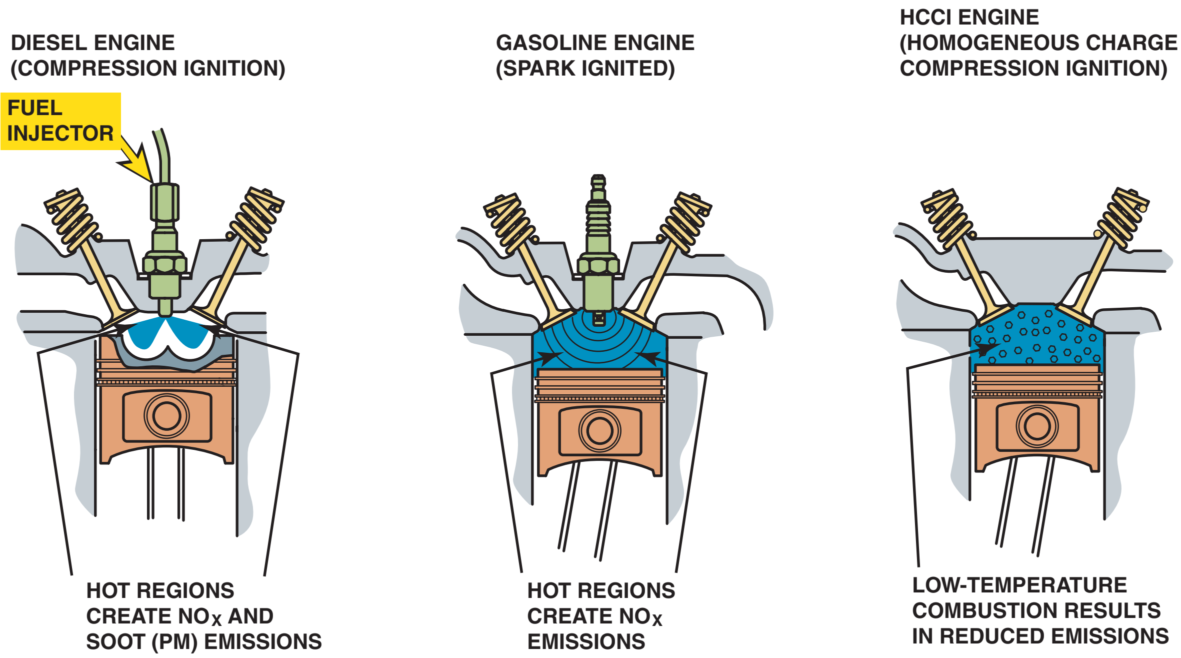

DIESEL ENGINE (COMPRESSION IGNITION)
FUEL INJECTOR
GASOLINE ENGINE (SPARK IGNITED)
HCCI ENGINE (HOMOGENEOUS CHARGE COMPRESSION IGNITION)
HOT REGIONS CREATE NO_X AND SOOT (PM) EMISSIONS
HOT REGIONS CREATE NO_X EMISSIONS
LOW-TEMPERATURE COMBUSTION RESULTS IN REDUCED EMISSIONS

FIGURE 92–18 Both diesel and conventional gasoline engines create exhaust emissions due to high peak temperatures created in the combustion chamber. The lower combustion temperatures during HCCI operation result in high efficiency with reduced emissions.

HCCI combustion is difficult to control and extremely sensitive to changes in temperature, pressure, and fuel type. While the challenges of HCCI are difficult, the advantages include having a gasoline engine being able to deliver 80% of diesel efficiency (a 20% increase in fuel economy) for 50% of the cost. A diesel engine using HCCI can deliver gasoline-like emissions. Spark and injection timing are no longer a factor as they are in a conventional port-fuel injection system.

FUTURE OF HCCI While much research and development needs to be performed using this combustion process, it has been shown to give excellent performance from idle to mid-load, and from ambient to warm operating temperatures, as well as cold start and run capability. Because the engine operates only in HCCI mode at light throttle settings, such as during cruise conditions at highway speeds, engineers need to improve the transition in and out of the HCCI mode. Work is also being done on piston and combustion chamber shape to reduce combustion noise and vibration that is created during operation in the HCCI operating mode.

Ongoing research is focusing on improving fuel economy under real-world operating conditions, as well as controlling costs.

REVIEW QUESTIONS

1. How does a fuel cell work?
2. What are the advantages and disadvantages of fuel cells?
3. How is hydrogen produced?
4. How does an ultracapacitor work?
5. What are the advantages and disadvantages of using hydrogen?

CHAPTER QUIZ

1. A fuel cell produces electricity from __________.
   a. gasoline/oxygen
   b. nitrogen/hydrogen
   c. hydrogen/oxygen
   d. water/oxygen
2. What are the by-products (emissions) from a fuel cell?
   a. Water vapor
   b. CO
   c. CO_2
   d. Nonmethane hydrocarbon
3. Which type of fuel cell is the most likely to be used to power vehicles?
   a. PAFC
   b. MCFC
   c. PEM
   d. SOFC
4. A disadvantage of a fuel cell vehicle is __________.
   a. limited refueling locations
   b. excessive hydrocarbon exhaust emissions
   c. the fuel is easily obtained
   d. All of the above
5. Which is *not* a function of an ultracapacitor?
   a. Can pass AC
   b. Can be charged with DC
   c. Discharges DC
   d. Can pass DC
6. The commonly used pressures at hydrogen filling stations include __________.
   a. H35
   b. H70
   c. H93
   d. Either a or b
7. Hydrogen storage tanks are usually constructed from __________.
   a. steel
   b. aluminum
   c. carbon fiber
   d. Both b and c
8. HCCI is a process that eliminates what parts or components in a gasoline engine?
   a. Fuel tank
   b. Battery
   c. Fuel injectors
   d. Ignition system
9. Hydrogen can be produced from __________.
   a. water
   b. natural gas
   c. crude oil
   d. Any of the above
10. What does H70-T40 mean when describing a hydrogen filling station?
    a. The type of hydrogen
    b. The temperature and pressure rating
    c. The size of the storage tank
    d. The estimated time needed to fill the tank

SECTION XI

BRAKES (A5)

CHAPTERS

93 Braking System Components and Performance Standards
94 Braking Principles and Friction Materials
95 Brake Hydraulic Systems
96 Brake Fluid, Lines, and Bleeding
97 Wheel Bearings and Service
98 Drum Brakes
99 Drum Brake Diagnosis and Service
100 Disc Brakes
101 Disc Brake Diagnosis and Service
102 Parking Brake Operation, Diagnosis, and Service
103 Machining Brake Drums and Rotors
104 Power Brake Unit Operation, Diagnosis, and Service
105 ABS Components and Operation
106 ABS Diagnosis and Service
107 Electronic Stability Control Systems

Chapter 93

BRAKING SYSTEM COMPONENTS AND PERFORMANCE STANDARDS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the fundamentals of brake systems.
- List the six brake system categories.
- State the purpose of an antilock brake system.
- Discuss federal brake standards.
- Discuss legal aspects of brake repair.

KEY TERMS:

Adjustable pedals 1074 • Antilock brake system (ABS) 1074 • Base brakes 1071 • Disc brakes 1072 • Department of Transportation (DOT) 1075 • Drum brakes 1072 • Electric adjustable pedals (EAP) 1074 • Federal Motor Vehicle Safety Standards (FMVSS) 1075 • Foundation brakes 1071 • Gross vehicle weight rating (GVWR) 1075 • Lightly loaded vehicle weight (LLVW) 1075 • Red brake warning lamp (RBWL) 1074 • Service brakes 1071

FUNDAMENTALS OF BRAKE SYSTEMS

TERMINOLOGY Brakes are by far the most important mechanism on any vehicle because the safety and lives of those riding in the vehicle depend on proper operation of the braking system. It has been estimated that the brakes on the average vehicle are applied 50,000 times a year!

Brakes are an energy-absorbing mechanism that converts vehicle movement into heat while stopping the rotation of the wheels. All braking systems are designed to reduce the speed and stop a moving vehicle and to keep it from moving if the vehicle is stationary. **Service brakes** are the main driver-operated brakes of the vehicle. Service brakes are also called **base brakes** or **foundation brakes**. ● **SEE FIGURE 93–1**.

BRAKE SYSTEM PARTS Most vehicles built since the late 1920s use a brake on each wheel. To stop a wheel, the driver exerts a force on a brake pedal. The force on the brake pedal pressurizes brake fluid in a master cylinder. This hydraulic force (liquid under pressure) is transferred through steel lines and flexible brake lines to a wheel cylinder or caliper at each wheel. Hydraulic pressure to each wheel cylinder or caliper is used to

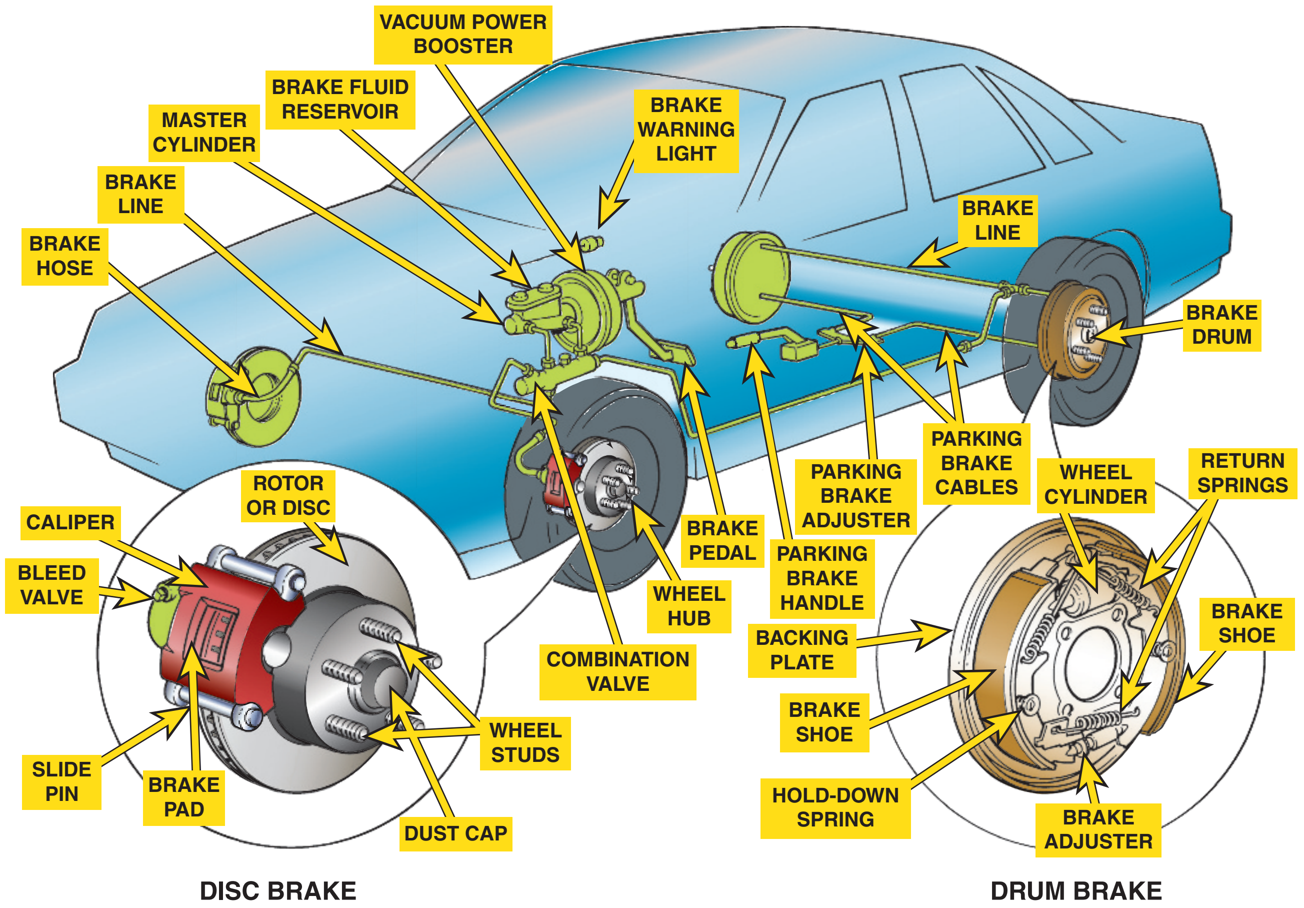

VACUUM POWER BOOSTER
BRAKE FLUID RESERVOIR
MASTER CYLINDER
BRAKE WARNING LIGHT
BRAKE LINE
BRAKE HOSE
BRAKE LINE
BRAKE DRUM
PARKING BRAKE CABLES
RETURN SPRINGS
WHEEL CYLINDER
PARKING BRAKE ADJUSTER
ROTOR OR DISC
CALIPER
BRAKE PEDAL
PARKING BRAKE HANDLE
BLEED VALVE
WHEEL HUB
BRAKE SHOE
BACKING PLATE
COMBINATION VALVE
BRAKE SHOE
WHEEL STUDS
SLIDE PIN
BRAKE PAD
HOLD-DOWN SPRING
BRAKE ADJUSTER
DUST CAP
DISC BRAKE
DRUM BRAKE

FIGURE 93–1 A vehicle brake system showing all typical components.

force friction materials against the brake drum or rotor. The friction between the stationary friction material and the rotating drum or rotor (disc) causes the rotating part to slow and eventually stop. Since the wheels are attached to the drums or rotors, the wheels of the vehicles also stop.

The heavier the vehicle and the higher the speed, the more heat the brakes have to be able to absorb. Long, steep hills can cause the brakes to overheat, reducing the friction necessary to slow and stop a vehicle.

DRUM BRAKES Drum brakes are used on the rear of many rear-wheel-drive, front-wheel-drive, and four-wheel-drive vehicles. When drum brakes are applied, brake shoes are moved outward against a rotating brake drum. The wheel studs for the wheels are attached to the drum. When the drum slows and stops, the wheels also slow and stop.

Drum brakes are economical to manufacture, service, and repair. Parts for drum brakes are generally readily available and reasonably priced. An additional drum brake is used as a parking brake on vehicles equipped with rear disc brakes. ● **SEE FIGURE 93–2**.

DISC BRAKES **Disc brakes** are used on the front of most vehicles built since the early 1970s, and on the rear wheels of many vehicles. A disc brake operates by squeezing brake pads on both sides of a rotor or disc that is attached to the wheel. ● **SEE FIGURE 93–3**.

To summarize, the sequence of events necessary to stop a vehicle includes the following:

1. The driver presses on the brake pedal.
2. The brake pedal force is transferred hydraulically to a wheel cylinder or caliper at each wheel.

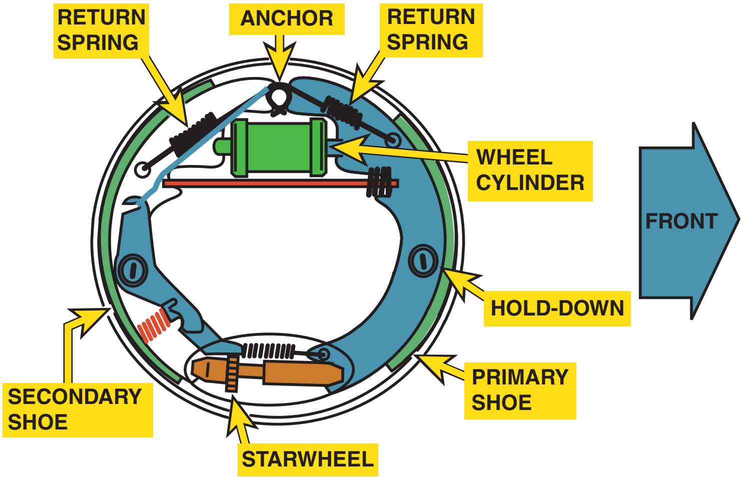

RETURN SPRING
ANCHOR
RETURN SPRING
WHEEL CYLINDER
FRONT
HOLD-DOWN
SECONDARY SHOE
PRIMARY SHOE
STARWHEEL

FIGURE 93–2 Typical drum brake assembly.

3. Hydraulic pressure inside the wheel cylinder or caliper presses friction materials (brake shoes or pads) against rotating brake drums or rotors.
4. The friction slows and stops the drum or rotor. Since the drum or rotor is bolted to the wheel of the vehicle, the wheel also stops.
5. When the wheels of the vehicle slow and stop, the tires must have friction (traction) with the road surface to stop the vehicle.

Type of Brake	Rotating Part	Friction Part
Drum brakes	Brake drum	Brake shoes
Disc brakes	Rotor or disc	Brake pads

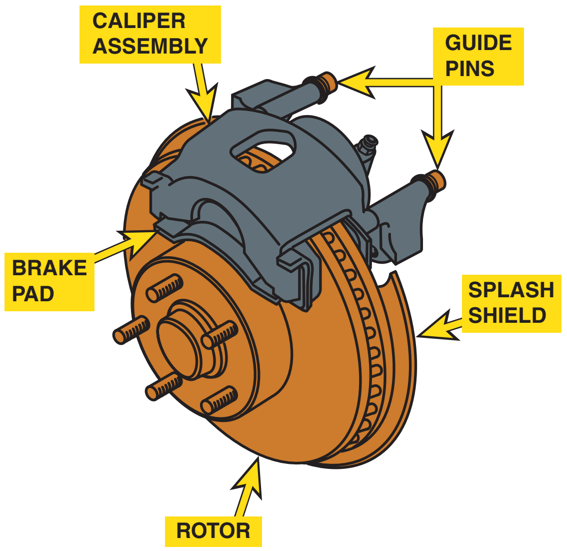

CALIPER ASSEMBLY
GUIDE PINS
BRAKE PAD
SPLASH SHIELD
ROTOR

FIGURE 93–3 Typical disc brake assembly.

BRAKE SYSTEM CATEGORIES

Brake system components can be classified and placed into six subsystem categories, depending on their function. ● **SEE FIGURE 93–4** for an overall view of the entire braking system.

1. **Apply system.** The driver starts the operation of the braking system by pressing on the brake pedal or applying the parking brake. The apply system includes all the levers, pedals, or linkage needed to activate a braking force.
2. **Boost system.** The boost (power brake) system is used on most vehicles to reduce the force that the driver must exert on the brake pedal.
3. **Hydraulic system.** The brake pedal force is transferred to the hydraulic system, where the force is directed through pipes and hoses to the wheel brakes.

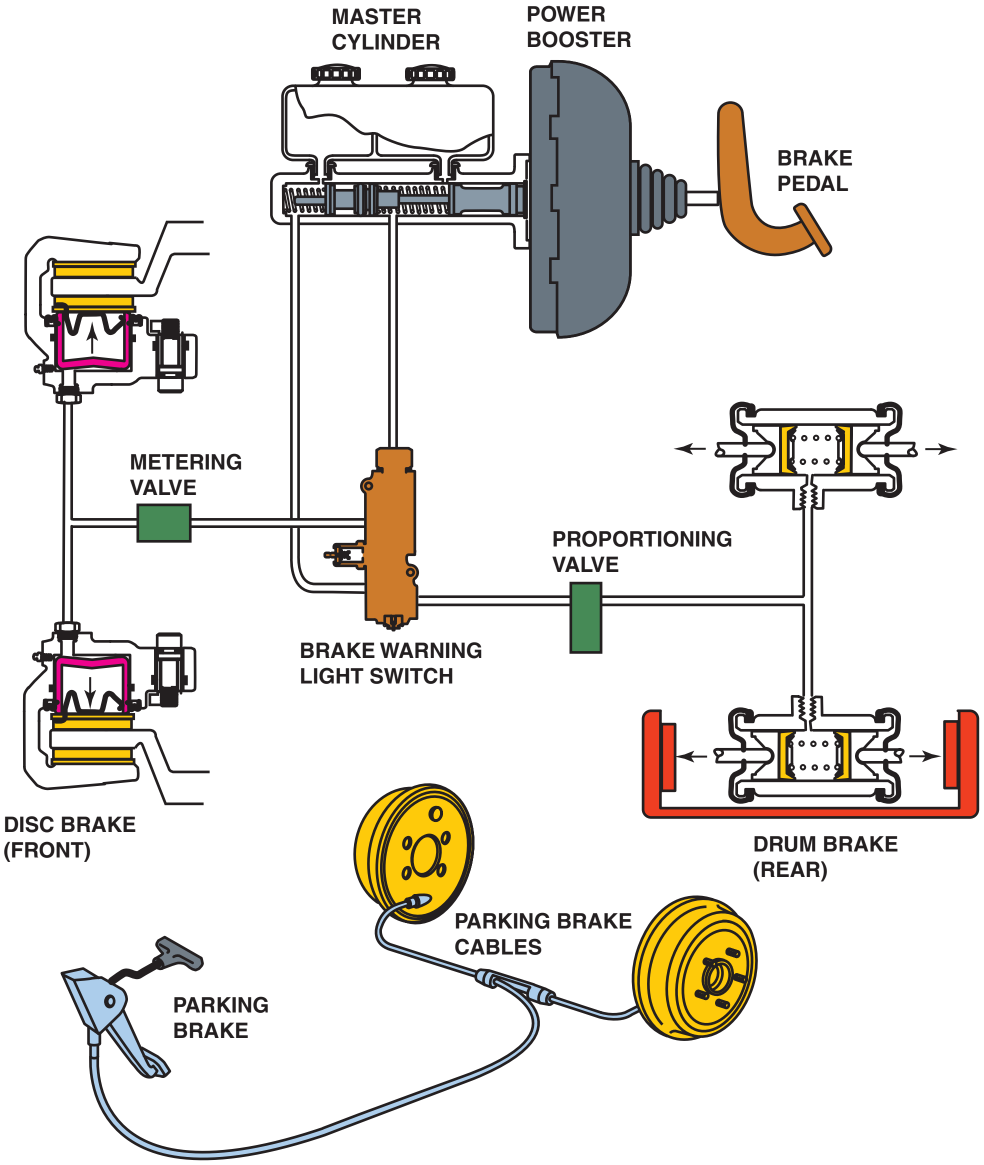

MASTER CYLINDER
POWER BOOSTER
BRAKE PEDAL
METERING VALVE
PROPORTIONING VALVE
BRAKE WARNING LIGHT SWITCH
DISC BRAKE (FRONT)
DRUM BRAKE (REAR)
PARKING BRAKE CABLES
PARKING BRAKE

FIGURE 93–4 Typical brake system components.

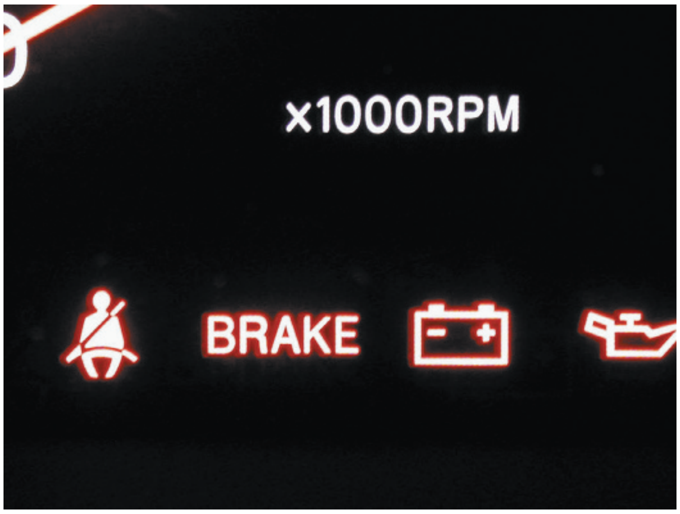


FIGURE 93–5 The red brake warning light remains on after a bulb test if there is a fault with the hydraulic part of the brake system or low brake fluid level has been detected.

4. **Wheel brakes.** Hydraulic pressure from the hydraulic system moves a piston, in either a disc or drum brake system, which uses friction to press material against a rotating drum or rotor. The resulting friction slows the rotation of the wheels.
5. **Brake balance control system.** Mechanical, electrical, and hydraulic components are used to ensure that brakes are applied quickly and with balanced pressure for safe operation. Components in this category include metering valves, proportioning valves, and antilock brake system components.
6. **Brake warning lights.** There are two brake system–related warning lights:
   - The **red brake warning lamp (RBWL)** lights whenever a hydraulic system failure occurs or low brake fluid level has been detected. The red brake warning lamp lights when the ignition is turned on as a bulb check, then goes out, unless a hydraulic fault has been detected. ● **SEE FIGURE 93–5**.

CAUTION: Do not test-drive a vehicle if the red brake warning light is on.

   - The amber ABS warning lamp or dim red brake light indicates an ABS self-test and/or a possible problem in the ABS. This warning light usually flashes several times during a self-test when the engine is first started and then goes out, unless a fault with the antilock brake system is detected. ● **SEE FIGURE 93–6**.

FIGURE 93–6 The ABS warning light is amber.

FREQUENTLY ASKED QUESTION

How Do Adjustable Pedals Work?

Adjustable pedals, also called **electric adjustable pedals (EAP)**, place the brake pedal and the accelerator pedal on movable brackets that are motor operated. A typical adjustable pedal system includes the following components:

- **Adjustable pedal position switch**, which allows the driver to position the pedals.
- **Adjustable pedal assembly**, which includes the motor, threaded adjustment rods, and a pedal position sensor. ● **SEE FIGURE 93–7**.

The position of the pedals, as well as the position of the seat system, is usually included as part of the memory seat function and can be set for two or more drivers.

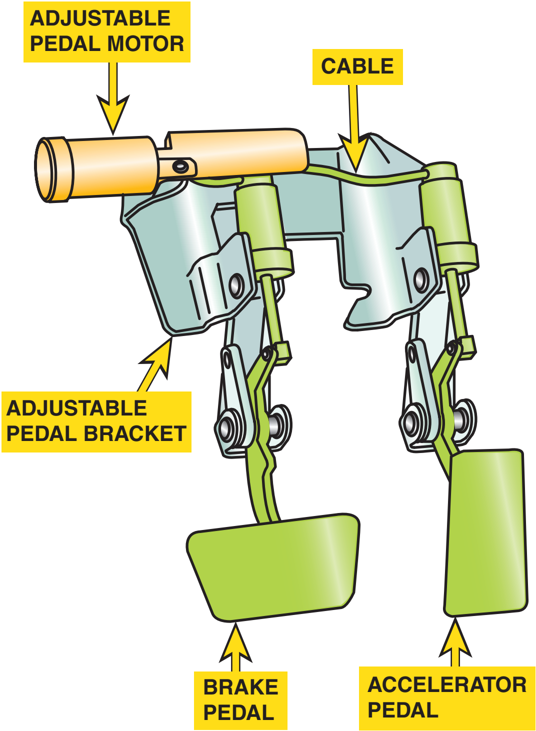


FIGURE 93–7 A typical adjustable pedal assembly. Both the accelerator and the brake pedal can be moved forward and rearward by using the adjustable pedal position switch.

ANTILOCK BRAKE SYSTEM OVERVIEW

The purpose of an **antilock brake system (ABS)** is to prevent the wheels from locking during braking, especially on low-friction surfaces, such as wet, icy, or snowy roads. It is the friction between the tire tread and the road that does the actual stopping of the vehicle. Therefore, ABS does not mean that a vehicle can stop quickly on all road surfaces. ABS uses sensors at the wheels to measure the wheel speed. If a wheel is rotating slower than the others, indicating possible lockup (e.g., on an icy spot), the ABS computer controls the brake fluid pressure to that wheel for a

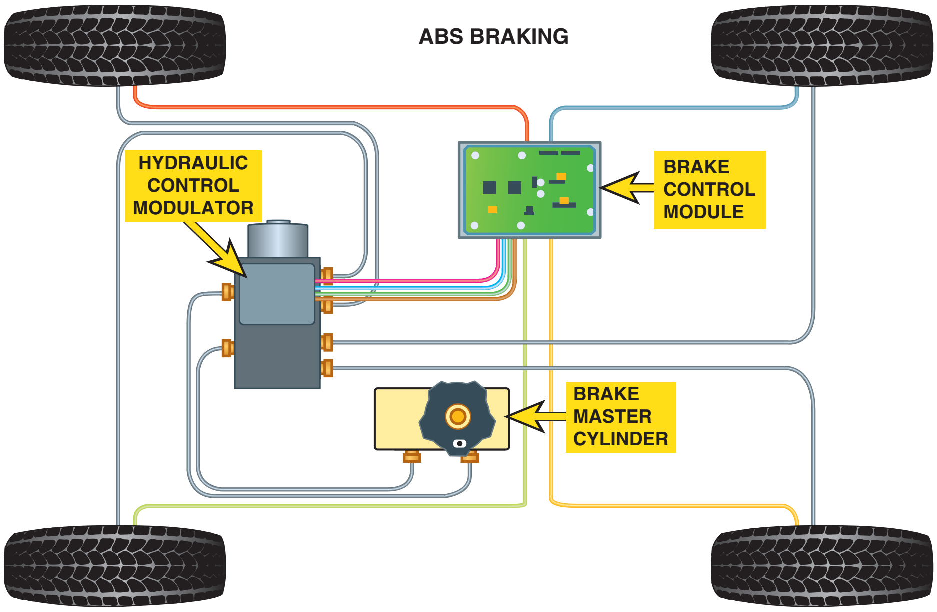


FIGURE 93–8 Typical components of an antilock brake system (ABS) used on a rear-wheel-drive vehicle.

fraction of a second. *A locked wheel has less traction to the road surface than a rotating wheel.*

The ABS computer can reapply the pressure from the master cylinder to the wheel a fraction of a second later. Therefore, if a wheel starts to lock up, the purpose of the ABS is to pulse the brakes on and off to maintain directional stability with maximum braking force. Many ABS units cause the brake pedal to pulse if the unit is working in the ABS mode. When ABS is pulsing the brakes, the driver can steer the vehicle so the driver has more control during braking than a vehicle without ABS. Some ABS units use an isolator valve to prevent brake pedal pulsations during ABS operation. With these types of systems, it is often difficult for the driver to know if and when the ABS unit is working to control a locking wheel. ● **SEE FIGURE 93–8** for an overview of a typical ABS on a rear-wheel-drive vehicle.

Another symptom of normal ABS unit operation is the activation of the hydraulic pressure pump used by many ABS units. In some ABS units, the hydraulic pump is run every time the vehicle is started and moved. Other types of units operate randomly or whenever the pressure in the system calls for the pump to operate.

FEDERAL BRAKE STANDARDS

The statutes pertaining to automotive brake systems are part of the **Federal Motor Vehicle Safety Standards (FMVSS)** established by the U.S. **Department of Transportation (DOT)**. Several standards apply to specific components within the brake system. The overall service and parking brake systems are dealt with in standard 135.

FMVSS 135 was first mandated on September 1, 2000, for passenger vehicles, and September 1, 2002, for multipurpose vehicles, trucks, and buses with a gross vehicle weight rating (GVWR) of 7,716 pounds (3,500 kg) or less. Its purpose is to “ensure safe braking performance under normal and emergency conditions.” FMVSS 135 applies to “passenger vehicles, multipurpose passenger vehicles, trucks, and buses.”

FMVSS 135 deals with brake system safety by establishing specific brake performance requirements. It does not dictate the *design* of the system, although some requirements may make older technologies impractical or obsolete. Only four parts of the brake system are specifically regulated:

- Fluid reservoir and labeling
- Dashboard warning lights
- A method of automatic adjustment
- A mechanically engaging, friction-type parking brake system

The FMVSS 135 tests are used by manufacturers to certify the braking performance of all new vehicles available for public purchase.

FMVSS 135 BRAKE TEST

The overall FMVSS 135 brake test procedure consists of up to 24 steps, depending on the vehicle’s configuration and braking system. The actual performance tests are made with the vehicle loaded to both the manufacturer’s specified **gross vehicle weight rating (GVWR)** and the **lightly loaded vehicle weight (LLVW)**, with certain applied brake forces. There are precise instructions for every step of the test, including the number of times the tests must be repeated, the sequence of the testing, and the allowable stopping distance for the particular type of vehicle. Some highlights of the testing procedure include the following:

- **Burnish Procedure.** The brakes are burnished by making 200 stops from 50 mph (80 km/h) at a fixed rate of deceleration with a controlled cool-down period after each stop. This procedure conditions the friction material.
- **Adhesion Utilization (torque wheel method).** For vehicles not equipped with ABS, this test is to determine if the brake system makes adequate use of the road surface in stopping the vehicle.
- **Cold Effectiveness.** This test is performed to determine if the vehicle has sufficient stopping power when the brake lining materials are not preheated by previous stops.
- **High-Speed Effectiveness.** This test is performed to determine if the brake system provides adequate stopping power for all loading conditions. The allowable stopping distance is calculated from the maximum speed the vehicle can attain.

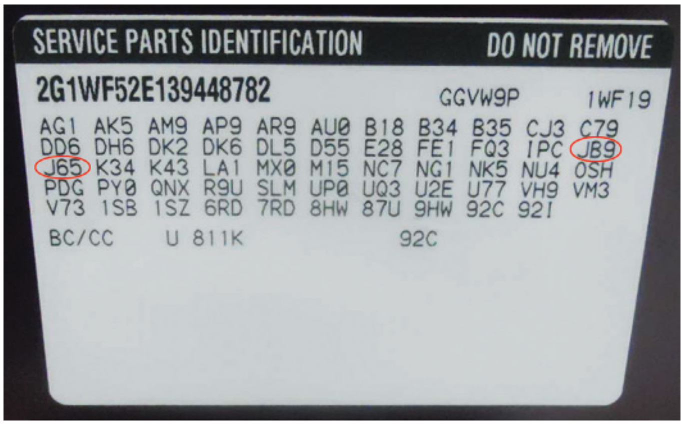
FREQUENTLY ASKED QUESTION

What Is a GM RPO Code?

The GM regular production code (RPO) is the code used when the vehicle was built, including all optional equipment listed, which includes letters and/or numbers. Most General Motors vehicles have the RPO sticker, also called the Service Parts Identification label, in the trunk, most often on the spare tire cover. Trucks usually have the RPO sticker in the glove box. ● **SEE FIGURE 93–9**.

Before ordering parts, take a photo of the vehicle identification number (VIN) and the RPO sticker. Having these available to answer any questions at the parts counter saves a lot of time and makes sure that the correct part is being ordered for the vehicle. The brake-related RPO codes start with the letter "J" and include the type or rating of the brake system. Some sample brake system–related RPO codes include

J41 BRAKE SYSTEM, PWR, FRT DISC, RR DRUM, CAST IRON
J42 BRAKE SYSTEM, PWR, FRT DISC, RR DRUM, ALUMINUM
J65 BRAKE SYSTEM, PWR, FRT & RR DISC
J85 BRAKE SYSTEM, PWR, FRT & RR DISC
JA1 BRAKE, LIGHT WEIGHT DISC DRUM
JA2 BRAKE, HEAVY WEIGHT DISC DRUM
JA8 BRAKE, MEDIUM WEIGHT DISC DRUM
JB3 BRAKE, POWER, DISC/DRUM, 4,600 LBS
JB5 BRAKE, POWER, DISC/DRUM, 6,400 LBS
JB6 BRAKE, POWER, DISC, DRUM 7,200 LBS
JB7 BRAKE, POWER, DISC, DRUM 8,400 L85
JB8 BRAKE, POWER, DISC, DRUM 10,000 LBS
JB9 BRAKE, LIGHT WEIGHT, DISC/DISC
JC4 BRAKE, POWER, DISC, DRUM 5,600 LBS
JC5 BRAKE, VAC POWER, 4-WHEEL DISC, 7,200 LBS
JD3 BRAKE, HYD POWER, DISC/DRUM
JE5 BRAKE, SYSTEM, PWR, ANTILOCK, FRT & RR WHL
JF9 BRAKE, HYD POWER, 4 WHEEL DISC
JH5 BRAKE, HYD POWER, 4-WHEEL DISC, 7,200 LBS
JH6 BRAKE, HYD POWER, 4-WHEEL DISC, 9,900 LBS
JL8 FRONT & REAR DISC BRAKES
JM5 BOOSTER, BRAKE, 200MM TANDEM, HIGH FLOW
JM8 BRAKE SYSTEM PWR, FRT DISC RR DRUM, ALUMINUM.



SERVICE PARTS IDENTIFICATION DO NOT REMOVE
2G1WF52E139448782 GGVW9P 1WF19
AG1 AK5 AM9 AP9 AR9 AU0 B18 B34 B35 CJ3 C79
DD6 DH6 DK2 DK6 DL5 D55 E28 FE1 FQ3 IPC JB9
J65 K34 K43 LA1 MX0 M15 NC7 NG1 NK5 NU4 OSH
PDG PY0 QNX R9U SLM UP0 UQ3 U2E U77 VH9 VM3
V73 1SB 1SZ 6RD 7RD 8HW 87U 9HW 92C 92I
BC/CC U 811K 92C

FIGURE 93–9 A typical Service Parts Identification (RPO) sticker is located on the inside of the trunk lid of a GM vehicle.

FREQUENTLY ASKED QUESTION

Do the FMVSS 135 Standards Apply to Replacement Brake Performance?

No. The Federal Motor Vehicle Safety Standard 135 applies to new vehicles. Replacement parts used during a brake repair or replacement may or may not permit the vehicle to achieve the same standards as when new.

To help ensure like-new braking performance, the service technician should always use quality brake parts from a known manufacturer.

- **Stops with the Engine Off.** This test is for vehicles equipped with brake power assist units. The vehicle, loaded to GVWR, must stop within 230 ft (70 m), from a speed of 62 mph (100 km/h). This test must be repeated six times.
- **Antilock Functional Failure.** This test ensures that service brakes function correctly in the event of an antilock functional failure, and the brake system warning indicator is activated when an ABS electrical function failure occurs.
- **Variable Brake Proportioning System.** This test is performed on vehicles equipped with either a mechanical or an electrical variable proportioning system. It ensures that, in the event of a failure, the vehicle can still come to a stop in an acceptable distance.
- **Hydraulic Circuit Failure.** This test is performed to ensure that the driver is alerted via the brake warning system indicator that a failure has occurred, and that the vehicle can still be stopped in an acceptable distance.
- **Brake Power Assist Unit Inoperative.** This test makes sure the service brake can stop the vehicle in an acceptable distance with the brake power assist unit in an inoperative state. It is performed on vehicles with brake power assist units turned off or inoperative.
- **Parking Brake.** The parking brake alone holds the vehicle stationary in either the forward or reverse direction on a 20% grade for a period of at least five minutes.
- **Brake Heat Test.** This procedure heats the brake system by making a series of 15 stops from a high speed. The vehicle is loaded to GVWR, with rapid acceleration between each stop to minimize cooling the brakes.
- **Hot Performance.** After the brake system has been heated by a series of heating snubs, the hot performance test is immediately performed. The vehicle is loaded to GVWR and two stops are made. The stopping distance must be within acceptable limits as specified in the test. This test ensures that the brake system on the vehicle does not fade following a series of high-speed stops at GVWR.

Although these tests may seem extreme, they are only a minimum standard of performance. Any brake repair work should also leave the brake system capable of meeting FMVSS 135.

BRAKE REPAIR AND THE LAW

Once a vehicle leaves the factory, the responsibility for maintaining the designed-in level of braking performance falls on the owner of the vehicle. Owners look to trained automotive technicians to service their brake systems. Many states have laws that regulate brake work to help ensure safe repairs. These laws vary from one area to another, but they may require special licensing for brake technicians, or special business practices when selling brake work. In some cases, the laws provide the consumer with specific warranties and the right to outside arbitration in cases of defective or substandard repairs.

Regardless of whether there are specific laws governing brake repair, a technician is always liable for damage or injuries resulting from repairs performed in an unprofessional or unworkman-like manner. Considering the lives and property that depend on good brakes, there is only one acceptable goal when making brake system repairs: to restore the system and its component parts so they perform to original specifications. In other words, *the purpose of any repair is to restore like-new performance.*

REVIEW QUESTIONS

1. List the differences between drum brakes and disc brakes.
2. List the six brake subsystem categories.
3. Explain how ABS units prevent wheel lockup.
4. List 10 of the brake tests performed under the Federal Motor Vehicle Safety Standard (FMVSS) 135.
5. What is the purpose of any brake repair?

CHAPTER QUIZ

1. Disc brakes use replaceable friction material called ________.
   a. linings
   b. pads
   c. core
   d. web
2. Drum brakes use replaceable friction material called ________.
   a. shoes
   b. pads
   c. core
   d. web
3. Technician A says that a power-assisted brake reduces stopping distances compared with a nonpower-assisted brake system. Technician B says that the power-assisted brake system reduces the force that the driver must exert on the brake pedal. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. What is the color of the antilock brake system (ABS) warning lamp?
   a. Red
   b. Amber
   c. Yellow
   d. Green
5. If a vehicle is equipped with antilock brakes, this means that ________.
   a. the vehicle is able to be steered during hard braking
   b. the brake pedal pulsates during normal braking
   c. the vehicle is able to stop in a shorter distance, regardless of road conditions
   d. All of the above
6. The FMVSS 135 standards determine ________.
   a. the design of the braking system
   b. the performance of the braking system
   c. the materials used in the braking system
   d. All of the above
7. An owner of a vehicle equipped with ABS brakes complained that whenever they tried to stop on icy or slippery roads, the brake pedal would pulse up and down rapidly. Technician A says that this is normal for many ABS units. Technician B says that the ABS unit is malfunctioning. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Which of the following will turn on the red brake warning lamp (RBWL)?
   a. Hydraulic system failure
   b. Low brake fluid level
   c. During a bulb check
   d. All of the above
9. All of the following are specified by the FMVSS 135 *except* ________.
   a. brake burnish procedure
   b. variable brake proportioning system
   c. brake noise levels
   d. cold effectiveness
10. What is the purpose of any brake repair?
    a. Reduce noise during braking
    b. Replace pads and linings
    c. Restore proper brake pedal height
    d. Restore like-new performance

Chapter 94

BRAKING PRINCIPLES AND FRICTION MATERIALS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the energy principles that apply to brakes.
- Discuss inertia as it applies to brakes.
- Discuss the friction principles that apply to brakes.
- Describe how brakes can fade due to excessive heat.
- Describe how deceleration rates are measured.
- Describe brake friction materials.
- Discuss asbestos as it applies to brakes.
- Describe semimetallic friction materials.
- Discuss non-asbestos/ceramic friction materials.
- Explain brake pad environmental concerns.
- Discuss the use of edge codes on friction materials.

KEY TERMS:

Asbestos 1083 • Brake fade 1080 • Ceramic 1084 • Coefficient of friction 1080 • Copper 1084 • Edge codes 1085 • Energy 1078 • Kinetic energy 1078 • Leaf mark 1085 • Lining fade 1081 • Mechanical fade 1081 • Mu (μ) 1080 • Non-asbestos 1083 • Non-asbestos organic (NAO) 1083 • Non-asbestos synthetic (NAS) 1083 • Semimetallic 1083 • Weight bias 1080 • Work 1078

ENERGY AND WORK

ENERGY **Energy** is the ability to do work. There are many forms of energy, but chemical, mechanical, and electrical energy are the most familiar kinds involved in the operation of an automobile. ● **SEE FIGURE 94–1**.

WORK **Work** is the transfer of energy from one physical system to another—especially the transfer of energy to an object through the application of force. This is precisely what occurs when a vehicle's brakes are applied: The force of the actuating system transfers the energy of the vehicle's motion to the brake drums or rotors where friction converts it into heat energy and stops the vehicle.

KINETIC ENERGY **Kinetic energy** is a fundamental form of mechanical energy. It is the energy of mass in motion. Every moving object possesses kinetic energy, and the amount of that energy is determined by the object's mass and speed. The greater the mass of an object and the faster it moves, the more kinetic energy it possesses. Even at low speeds, a moving vehicle has enough kinetic energy to cause serious injury and damage. The purpose and function of the brake system is to dispose of that

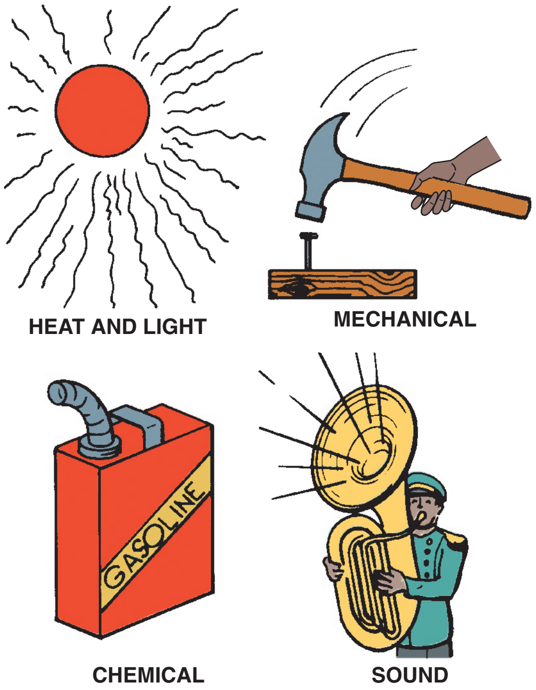


FIGURE 94–1 Energy, which is the ability to perform work, exists in many forms.

energy in a safe and controlled manner. Engineers calculate kinetic energy using the following formula:

$$\frac{mv^2}{29.9} = E_k$$

where

m = **mass or weight of the vehicle in pounds (lb)**

v = **velocity of the vehicle in miles per hour**

E_k = **kinetic energy in foot-pounds (ft-lb)**

NOTE: Mass is how much material something contains, whereas weight is the effect of gravity on an object.

Another way to express this equation is as follows:

$$\frac{\text{weight} \times \text{speed}^2}{29.9} = \text{kinetic energy}$$

KINETIC ENERGY EXAMPLE #1 A 3,000 lb vehicle traveling at 30 MPH is compared with a 6,000 lb vehicle, also traveling at 30 MPH. ● **SEE FIGURE 94–2**.

The equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ MPH}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{6{,}000 \text{ lb} \times 30^2 \text{ MPH}}{29.9} = 180{,}602 \text{ ft-lb}$$

The results show that

- When the weight of a vehicle is doubled from 3,000 to 6,000 lb, its kinetic energy is also doubled from 90,301 to 180,602 ft-lb.
- In mathematical terms, kinetic energy increases *proportionally* as weight increases. In other words, if the weight of a moving object doubles, its kinetic energy also doubles.
- If the weight quadruples, the kinetic energy becomes four times as great.

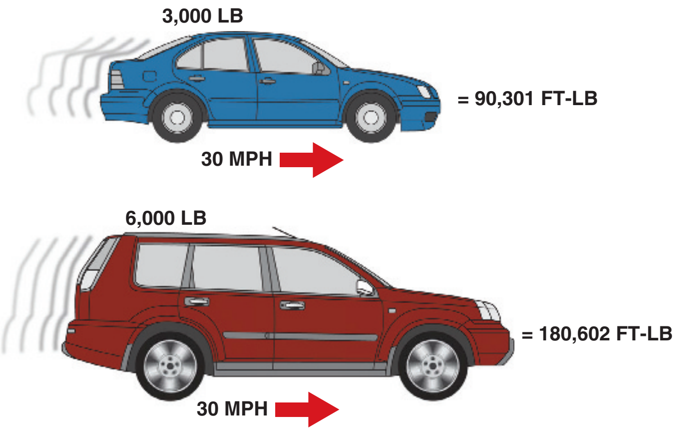


FIGURE 94–2 Kinetic energy increases in direct proportion to the weight of the vehicle.

TECH TIP

Brakes Stop Wheels, Not the Vehicle

Brakes are used to slow and stop the rotation of the wheels. The tires are attached to the wheels, and the friction between the tire tread and the pavement is what actually stops the vehicle. If the vehicle is on a slippery surface, such as gravel or snow, the wheels may be stopped by the brakes, but the vehicle can continue without slowing if there is a lack of traction between the tires and the ground.

KINETIC ENERGY EXAMPLE #2 A 3,000 lb vehicle traveling at 30 MPH is compared with the same vehicle, traveling at 60 MPH. ● **SEE FIGURE 94–3**.

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ MPH}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{3{,}000 \text{ lb} \times 60^2 \text{ MPH}}{29.9} = 361{,}204 \text{ ft-lb}$$

The results show that the vehicle traveling at 30 MPH has over 90,000 ft-lb of kinetic energy, but at 60 MPH the figure increases to over 350,000 ft-lb.

- At twice the speed, the vehicle has exactly four times as much kinetic energy.
- If the speed were doubled again to 120 MPH, the amount of kinetic energy grows to almost 1,500,000 ft-lb! In mathematical terms, kinetic energy increases as the *square of its speed*.
- In other words, if the speed of a moving object doubles (2), the kinetic energy becomes four times as great ($2^2 = 4$). And if the speed quadruples (4), say from 15 to 60 MPH, the kinetic energy becomes 16 times as great ($4^2 = 16$). This is the reason speed has such an impact on kinetic energy.

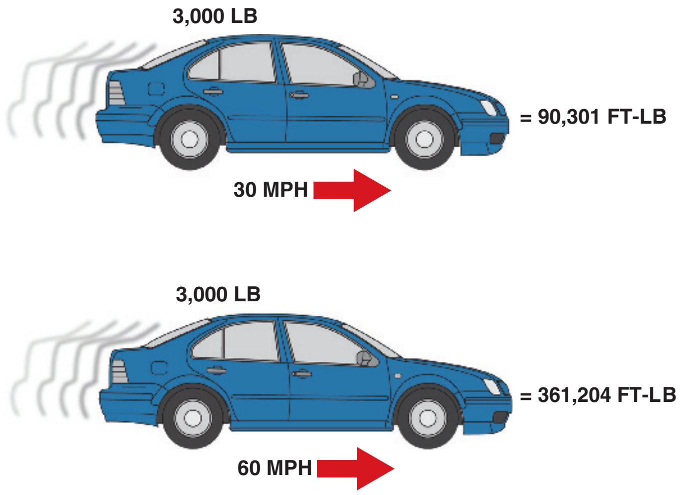


FIGURE 94–3 Kinetic energy increases as the square of any increase in vehicle speed.

INERTIA

DEFINITION Inertia is defined by Isaac Newton's first law of motion, which states that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line unless acted upon by an outside force.

WEIGHT TRANSFER Inertia, in the form of weight transfer, plays a major part in braking performance. Newton's first law of motion states, if applied to a vehicle:

> A moving vehicle remains in motion unless acted upon by an outside force.

The sequence that occurs when the brakes are applied includes

- The vehicle brakes provide that outside force, but when the brakes are applied at the wheel friction assemblies, only the wheels and tires begin to slow immediately.
- The rest of the vehicle, all of the weight carried by the suspension, attempts to remain in forward motion.
- The result is that the front suspension compresses, the rear suspension extends, and the weight is transferred toward the front of the vehicle. ● **SEE FIGURE 94–4**.

WEIGHT BIAS The total weight of the vehicle does not change during a brake application, only the amount supported by each axle. To compound the problem of weight transfer, most vehicles also have a forward **weight bias**, which means that even when stopped, more than 50% of their weight is supported by the front wheels. This occurs because the engine, transmission, and most other heavy parts are located toward the front of the vehicle. ● **SEE FIGURE 94–5**.

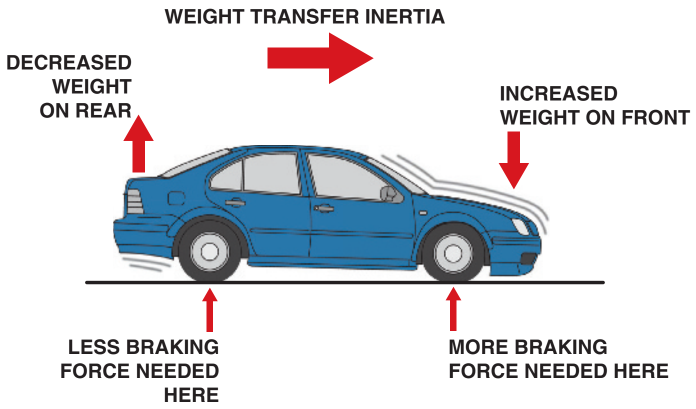

WEIGHT TRANSFER INERTIA
DECREASED WEIGHT ON REAR
INCREASED WEIGHT ON FRONT
LESS BRAKING FORCE NEEDED HERE
MORE BRAKING FORCE NEEDED HERE

FIGURE 94–4 Inertia creates weight transfer that requires the front brakes to provide most of the braking force.

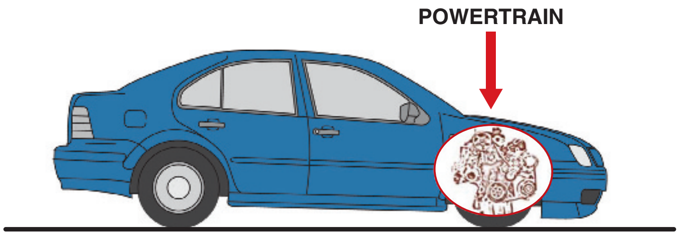


FIGURE 94–5 Front-wheel-drive vehicles have most of their weight over the front wheels.

Front-wheel-drive (FWD) vehicles, in particular, have a forward weight bias. Whenever the brakes are applied, weight transfer and weight bias greatly increase the load on the front wheels, while the load on the rear wheels is reduced. This requires the front brakes to provide 60% to 80% of the total braking force. To deal with the extra load, the front brakes are much more powerful than the rear brakes.

COEFFICIENT OF FRICTION

DEFINITION The amount of friction between two objects or surfaces is commonly expressed as a value called the **coefficient of friction** and is represented by the Greek letter **mu (μ)**, pronounced "mYOO." The coefficient of friction, also referred to as the *friction coefficient*, is determined by dividing tensile force by weight force. The tensile force is the pulling force required to slide one of the surfaces across the other. The weight force is the force pushing down on the object being pulled. The complete friction assembly (including lining and backing) is often called a *brake pad* or *brake shoe*. The friction coefficient (μ) for most standard brake pads is usually in the range of 0.25 to 0.55.

STATIC AND KINETIC FRICTION There are actually two measurements of the coefficient of friction: the static friction coefficient and the kinetic friction coefficient. The static value is the coefficient of friction with the two friction surfaces at rest. The kinetic value is the coefficient of friction while the two surfaces are sliding against one another. The coefficient of static friction is always higher than that of kinetic friction, which explains why it is harder to *start* an object moving than to *keep* it moving. ● **SEE FIGURE 94–6**.

It takes 100 pounds of tensile force to start the wooden block sliding, but once in motion, it takes only 50 pounds to keep it sliding. The relatively high static friction is harder to overcome than the somewhat lower kinetic friction. The static and kinetic friction coefficients for several combinations of materials are shown in ● **CHART 94–1**.

The difference between static and kinetic friction explains why parking brakes, although much less powerful than service brakes, are still able to hold a vehicle in position on a hill. The job of the parking brakes is relatively easy because

- The stationary vehicle has no kinetic energy.
- The brake lining and drum or discs are not moving when they are applied.
- To start the vehicle moving, enough force has to be applied to overcome the relatively high static friction of the parking brakes.

The service brakes, however, have a much more difficult job. The moving vehicle has a great deal of kinetic energy, and the fact that the brake friction surfaces are in relative motion means that kinetic friction makes them less efficient.

BRAKE FADE

DEFINITION If repeated hard stops are performed, the brake system components can overheat and lose effectiveness, or possibly fail altogether. This loss of braking power is called **brake fade**.

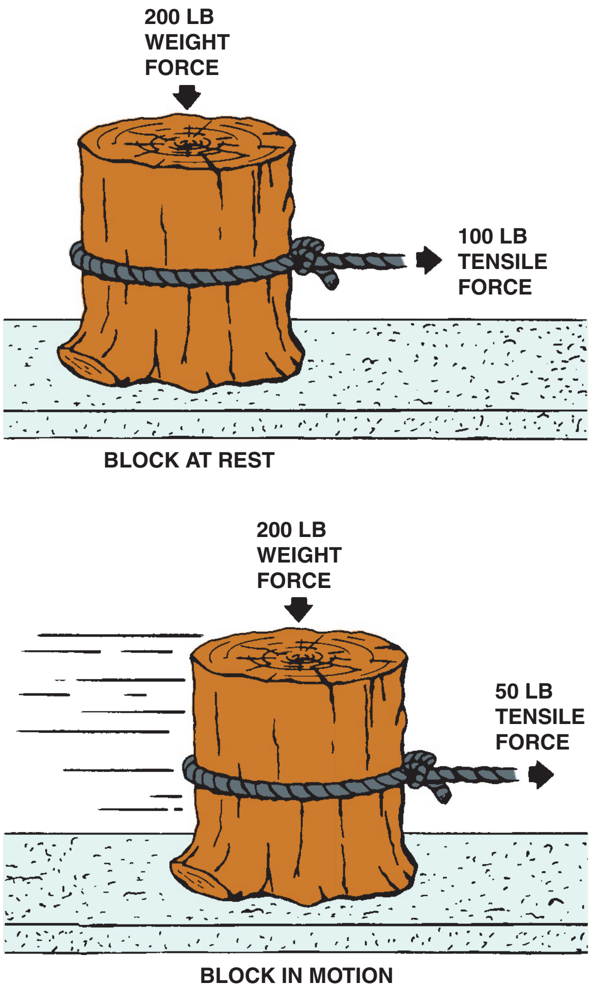


FIGURE 94–6 The static coefficient of friction of an object at rest is higher than the kinetic (dynamic) friction coefficient once in motion.

CONTACTING SURFACES	STATIC COEFFICIENT OF FRICTION	KINETIC COEFFICIENT OF FRICTION
Steel on steel (dry)	0.6	0.4
Steel on steel (greasy)	0.1	0.05
Teflon on steel	0.04	0.04
Brass on steel (dry)	0.5	0.4
Brake lining on cast iron	0.4	0.3
Rubber tires on smooth pavement (dry)	0.9	0.8

CHART 94–1

Every combination of materials has different static and kinetic friction coefficients.

MECHANICAL FADE **Mechanical fade** occurs when a brake drum overheats and expands away from the brake lining. To maintain braking power, the brake shoes must move farther outward, which requires additional brake pedal travel. When the drum expands to a point where there is not enough pedal travel to keep the lining in contact with the drum, brake fade occurs. Mechanical fade is not a problem with disc brakes because as a brake rotor heats up, it expands toward the brake pads, rather than away from them.

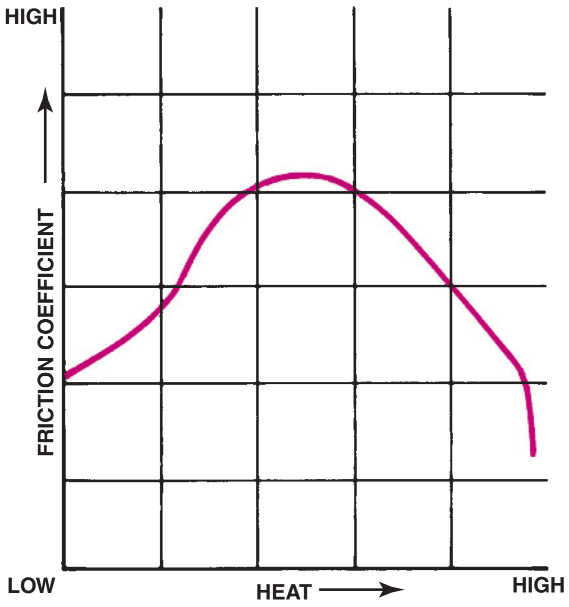


FIGURE 94–7 Some heat increases the coefficient of friction, but too much heat can cause it to drop off sharply.

LINING FADE **Lining fade** affects both drum and disc brakes and occurs when the friction material overheats to the point where its coefficient of friction drops off. ● **SEE FIGURE 94–7**.

When lining fade occurs on drum brakes, partial braking power can sometimes be restored by increasing pressure on the brake pedal, although this may only make matters worse, since the extra pressure increases the amount of heat and fade. With disc brakes, lining fade is possible, but is less of a problem because of disc brakes' superior ability to dissipate heat. The rotor friction surfaces are exposed to the passing air, and most rotors have internal ventilation passages that further aid in cooling.

GAS FADE Gas fade is a relatively rare type of brake fade that occurs under very hard braking when a thin layer of hot gases and dust particles builds up between the brake drum or rotor and linings. The gas layer acts as a lubricant and reduces friction. ● **SEE FIGURE 94–8**.

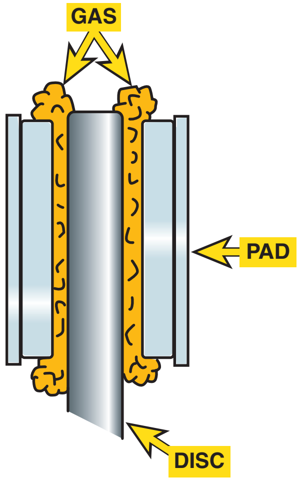


FIGURE 94–8 One cause of brake fade occurs when the phenolic resin, a part of the friction material, gets so hot that it vaporizes. The vaporized gas from the disc brake pads gets between the rotor (disc) and the friction pad. Because the friction pad is no longer in contact with the rotor, no additional braking force is possible.

- As with lining fade, greater application force at the brake pedal is required to maintain a constant level of stopping power.
- Gas fade becomes more of a problem as the size of the brake lining increases because gases and particles have a harder time escaping from under a drum brake shoe than a disc brake pad.
- Some high-performance brake shoes and pads have slotted linings to provide paths for gas and particles to escape.

In most cases, brake fade is a temporary condition and the brakes return to normal once they have all been allowed to cool.

WATER FADE If a vehicle is driven through deep water or during a severe rainstorm, water can get between the brake drum and the linings. When this occurs, no stopping power is possible until the water is pushed out and normal friction is restored. While water fade is most likely to occur with drum brakes, it can also occur on disc brakes. After driving through deep water, the wise driver should lightly apply the brakes to check the operation and to help remove any water trapped between the friction material and the rotor or drum.

DECELERATION RATES

TERMINOLOGY Deceleration rates are measured in units of "feet per second per second" (No, this is not a misprint). What it means is that the vehicle changes in velocity during a certain time interval divided by the time interval. Deceleration is abbreviated "ft/sec^2" (pronounced "feet per second per second" or "feet per second squared") or meters per sec^2 (m/sec^2) in the metric system.

TECH TIP

How to Reduce Possible Brake Fade?

To help prevent possible brake fade while descending long hills, place the gear selector into a lower drive range, such as "2," or even "1," if going slowly enough. This action allows for additional engine braking and takes the load off of the wheel brakes. ● **SEE FIGURE 94–9**.

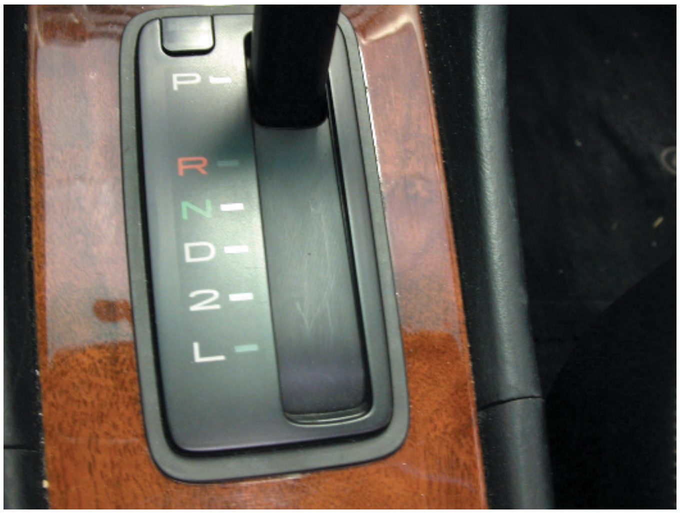


FIGURE 94–9 The gear selector is often called the "PRNDL," pronounced "prindle," regardless of the actual letters or numbers used. Move the gear selector to a low range when descending long steep grades to avoid overheating the brakes.

FIGURE 94–10 Rapid braking causes the brake friction material to wear more compared to gentle, less aggressive, braking.

TYPICAL DECELERATION RATES Typical deceleration rates include the following:

- Comfortable deceleration is about 8.5 ft/sec^2 (3 m/sec^2).
- Loose items in the vehicle "fly" above 11 ft/sec^2 (3.5 m/sec^2).
- Maximum deceleration rates for most vehicles and light trucks range from 16 to 32 ft/sec^2 (5 to 10 m/sec^2).

An average deceleration rate of 15 ft/sec^2 (3 m/sec^2) can stop a vehicle traveling at 55 MPH (88 km/h) in about 200 ft (61 m) in less than four seconds. ● **SEE FIGURE 94–10**.

BRAKE TEMPERATURE Temperatures at the front brake pads can reach

- 1,300°F (700°C) or higher during normal driving
- as high as 1,800°F (980°C) during braking from a high speed or during long descents

Brake fluid and rubber components may reach 300°F (150°C) or higher.

BRAKE FRICTION MATERIALS

PURPOSE AND FUNCTION Brake friction materials are composed of relatively soft, but tough, and heat-resistant material to provide the friction between the moveable part of the braking system (drum or rotor) and the stationary part of the braking system. The brake friction material has to provide the friction needed to slow and stop the vehicle quietly, and still provide a long service life.

BRAKE LINING COMPOSITION Brake shoes and pads operate under the most extreme conditions in the entire brake system and are subject to wear. Friction materials, such as disc brake pads or drum brake shoes, contain a mixture of ingredients. These materials include a binder, such as

- thermosetting resin
- fibers (for reinforcement)
- friction modifiers (to obtain a desired coefficient of friction)

BRAKE BLOCKS The various ingredients in brake lining are mixed and molded into the shape of the finished product. The fibers in the material are the only thing holding this mixture together. A large press is used to force the ingredients together to form a brake block, which eventually becomes the brake lining/pads.

ASBESTOS

DEFINITION **Asbestos** is the term used to describe naturally occurring silicate minerals that consist of long fibers. Asbestos mining began more than 4,000 years ago, but did not start large scale until the end of the nineteenth century when manufacturers and builders began using asbestos for

- sound absorption
- its resistance to fire, heat, electrical, and chemical damage
- affordability

It was used in such applications as electrical insulation for hotplate wiring and in building insulation. When asbestos is used for its resistance to fire or heat, the fibers are often mixed with cement or woven into fabric or mats. These desirable properties made asbestos a very widely used material, and its use continued to grow throughout most of the twentieth century until the carcinogenic (cancer-causing) effects of asbestos were discovered, which caused its effective demise as a mainstream construction and fireproofing material in most countries.

ASBESTOS HAZARDS Asbestos exposure can cause scar tissue to form in the lungs. This condition is called asbestosis. It gradually causes increasing shortness of breath, and the scarring to the lungs is permanent. Even low exposures to asbestos can cause mesothelioma, a type of fatal cancer of the lining of the chest or abdominal cavity. Asbestos exposure can also increase the risk of lung cancer, as well as cancer of the voice box, stomach, and large intestine. It usually takes 15 to 30 years or more for cancer or asbestos lung scarring to show up after exposure.

ASBESTOS BRAKE LININGS Asbestos was a popular component for vehicle brakes because of its heat resistance and strength. Brake friction materials that used asbestos were called *organic* linings/pads. The U.S. Environmental Protection Agency (EPA) has not banned the use of asbestos in drum brake linings or disc brake pads, even though it has banned its use in corrugated paper, roll board, commercial paper, specialty paper, and flooring felt.

The concentration of asbestos in brake lining was estimated at 30% to 50%. The routine tasks of "blowing out" brake surfaces (using an air hose to clean the surfaces) were considered to be the most common way workers were exposed. The use of asbestos for brake linings was never abandoned completely. ● **SEE CHART 94–2**.

INGREDIENT	TYPICAL FORMULA RANGE
Phenolic resin (binder)	9% to 15%
Asbestos fiber	30% to 50%
Organic friction modifiers (rubber scrap)	8% to 19%
Inorganic friction modifiers (barites, talc, whiting)	12% to 26%
Abrasive particles (alumina)	4% to 20%
Carbon	4% to 20%

CHART 94–2

Typical brake compositions for asbestos (organic) lining.

TECH TIP

Competitively Priced Brakes

The term "competitively priced" means lower cost. Most brake manufacturers offer "premium" as well as lower-price linings to remain competitive with other manufacturers, or with importers of brake lining material produced overseas by U.S. or foreign companies. Organic asbestos brake lining is inexpensive to manufacture. In fact, according to warehouse distributors and importers, the box often costs more than the brake lining inside. Professional brake service technicians should only install brake linings and pads that give braking performance equal to that of the original factory brakes. For best results, always purchase high-quality brake parts from a known brand-name manufacturer.

SEMIMETALLIC FRICTION MATERIALS

DEFINITION The term **semimetallic** refers to brake lining material that uses metal, rather than asbestos, in its formulation. It still uses resins and binders and is, therefore, not 100% metal, but rather semimetallic. Semimetallic pads are commonly called "semi-mets."

CONSTRUCTION The metal in most metallic linings is made from metal particles that have been fused together without melting. This process is called *sintering* and the result is called *sintered metal linings*. Most semimetallic linings do not contain asbestos. Semimetallic linings require a very smooth finish on the rotor because the metal in the lining does not conform to the surface of the rotor, as does asbestos lining. A major disadvantage of semimetallic disc brake pads is that it causes a lot of brake dust, which discolors the vehicle wheels. ● **SEE CHART 94–3**.

NON-ASBESTOS/CERAMIC FRICTION MATERIALS

TERMINOLOGY Brake pads and linings that use synthetic material, such as aramid fibers, instead of steel are usually referred to as

- **non-asbestos**
- **non-asbestos organic (NAO)**
- **non-asbestos synthetic (NAS)**

INGREDIENT	FORMULA RANGE
Phenolic resin	15% to 40%
Graphite or carbon particles	15% to 40%
Steel fibers	0% to 25%
Ceramic powders	2% to 10%
Steel, copper, brass metal powders	15% to 40%
Other modifiers (rubber scrap)	0% to 20%

CHART 94–3

Typical brake compositions for semimetallic disc brake pads.

INGREDIENT	FORMULA RANGE
Phenolic resin	15% to 40%
Graphite or carbon	20% to 30%
Copper	0% to 22% (Being phased out)
Ceramic powders	5% to 30%
Aluminum, barium, calcium, iron, potassium, magnesium, sodium	Each <2%
Fillers (barium sulfate, aramid fibers, ceramic fibers, other mined mineral powders)	5% to 10%

CHART 94–4

Typical compositions for NAO/ceramic friction materials.

These friction materials are often called **ceramic** in the American aftermarket because they include ceramic fibers, which are usually potassium titanite.

CONSTRUCTION Linings are called synthetic because synthetic fibers are used. These linings use aramid fiber instead of metal as the base material. Aramid is the generic name for aromatic polyamide fibers. Kevlar is the Dupont brand name of aramid and a registered trademark of E.I. Dupont de Nemours and Company.

- Non-asbestos linings are often quieter than semimetallic pads and cause less wear to brake rotors, as do semimetallic pads.
- Brake dust from NAO disc brake pads is less than from semimetallic pads. ● **SEE CHART 94–4**.

CARBON FIBER FRICTION MATERIALS Carbon fiber brake lining is the newest and most expensive of the lining materials.

Carbon fiber material is often called CFRC (carbon fiber-reinforced carbon). It is composed of a carbon mix into which reinforcing carbon fibers are embedded. CFRC is commonly used in the brakes of jet aircraft and racing cars. CFRC brakes provide constant friction coefficient whether cold or hot, low wear rates, and low noise development.

BRAKE PADS AND ENVIRONMENTAL CONCERNS

USE OF COPPER IN BRAKE PADS **Copper** is a soft metal with very high thermal and electrical conductivity and is used in most brake lining/pads because it

- Helps transfer heat efficiently and increases brake effectiveness in cold weather
- Helps prevent brakes from squeaking and shuddering
- Adds strength to the brake pad material
- Helps reduce fade so that brakes remain effective through extended braking events.

FREQUENTLY ASKED QUESTION

What Are Ceramic Pads Exactly?

NAO/Ceramic friction materials contain some ceramic powders or fibers. They are not "ceramic matrix composites," but rather they are an organic matrix composite molded using a phenolic resin. NAO materials typically exhibit low friction and/or high wear rates at high temperatures. To counteract this behavior, they sometimes contain many other raw materials (such as abrasives and metal sulfides) to maintain thermal stability. Metal sulfides generally provide lubrication and reduce noise created by these friction materials. Ceramic compounds provide much quieter braking because the ceramic compound helps dampen noise by generating a frequency beyond the human hearing range.

Another characteristic that makes ceramic materials attractive is the absence of noticeable dust. All brake pads produce dust as they wear. The ingredients in ceramic compounds produce a light-colored dust that is much less noticeable and less likely to stick to the wheels. Ceramic pads meet or exceed all original equipment standards for durability, stopping distance, and noise.

This is quite an improvement over organic and semimetallic brake materials that typically sacrifice pad life to reduce noise, or vice versa.

FREQUENTLY ASKED QUESTION

What Do D^{3}EA and BEEP Mean?

Original equipment brake pads and shoes are required to comply with the Federal Motor Vehicle Safety Standard (FMVSS) 135, which specifies maximum stopping distances. There is also a requirement for fade resistance, but no standard for noise or wear. Aftermarket (replacement) brake pads and shoes are not required to meet the FMVSS standard. However, several manufacturers of replacement brake pads and shoes are using a standardized test that closely matches the FMVSS standard and is called the "Dual Dynamometer Differential Effectiveness Analysis" or D^{3}EA. This test is currently voluntary and linings that pass the test can have a "D^{3}EA certified" seal placed on the product package. BEEP stands for "Brake Effectiveness Evaluation Procedure" and is a series of tests on aftermarket brake components that is similar to the FMVSS tests and SAE J2430 standards.

Not all brake pads contain copper. Copper content varies from manufacturer to manufacturer, and even among pads made by the same manufacturer for different applications.

ENVIRONMENTAL CONCERN Tiny amounts of copper from brakes fall onto the streets and parking lots every time the brakes are used. Copper is a pollutant because

- It is toxic to certain sensitive species of algae (phytoplankton) that form the base of the aquatic food chain.
- Copper also directly damages the sensory capabilities of salmon, making it difficult for them to avoid predators or find their way back to their spawning grounds.

Copper is not necessarily harmful to the environment because it is vital to the health of both plants and animals. Copper from brakes account for anywhere from 35% to 60% of copper in California's urban watershed runoff. In some urban watersheds, this added copper may be enough to cause water concentrations to exceed the water quality standard for copper. This led to determining a course of action that addresses the issue.

LEGAL REQUIREMENTS TO REDUCE COPPER The issue of copper in the environment has been under consideration since the 1990s when cities south of San Francisco were having trouble meeting Clean Water Act (CAA) requirements to reduce copper in urban runoff flowing into San Francisco Bay. Studies indicated that brake pads were a major source of copper in that runoff. California and Washington in 2010 passed laws mandating a reduction in the amount of copper used in automotive brake pads. Both bills mandate that brake pads sold in each state contain no more than 0.5% of copper by weight and must meet all applicable safety standards. The laws differ in timing. In California, the law takes effect no later than January 1, 2025.

LEAF MARK Washington State legislation mandates that all brake pads and shoes manufactured after January 1, 2015, are required to have a **leaf mark** icon indicating the level of compliance with state friction material content legislation. To demonstrate brake manufacturers' compliance with new state regulations, the Brake Manufacturers Council (BMC) of the Automotive Aftermarket Suppliers Association and the Motor and Equipment Manufacturers Association (MEMA) have selected NSF International to serve as its official registrar. NSF International is an independent organization that writes standards, tests, and certifies products for the food, water, and consumer goods industries to minimize adverse health effects and protect the environment (www.nsf.org). In addition to copper, all of the new standards restrict the following from brake friction materials:

- Asbestos fibers, less than 0.1% by weight
- Cadmium and its compounds, less than 0.01% by weight
- Chromium (VI)-salts, less than 0.1% by weight
- Lead and its compounds, less than 0.1% by weight
- Mercury and its compounds, less than 0.1% by weight

The leaf marks refer to the following ratings:

- **Level "A" standard (one leaf)**: Contains more than 5% of copper by weight (2015 Standard)
- **Level "B" standard (two leafs)**: Contains between 0.5% and 5% of copper by weight (2021 Standard)
- **Level "N" standard (three leafs)**: Contains less than 0.5% of copper by weight (2025 Standard)

● **SEE FIGURE 94–11**.

EDGE CODES

PURPOSE Starting in 1964, brake linings have been using a standardized way to identify the brake lining materials. The edge codes follow the Society of Automotive Engineers (SAE) Standard J866a.

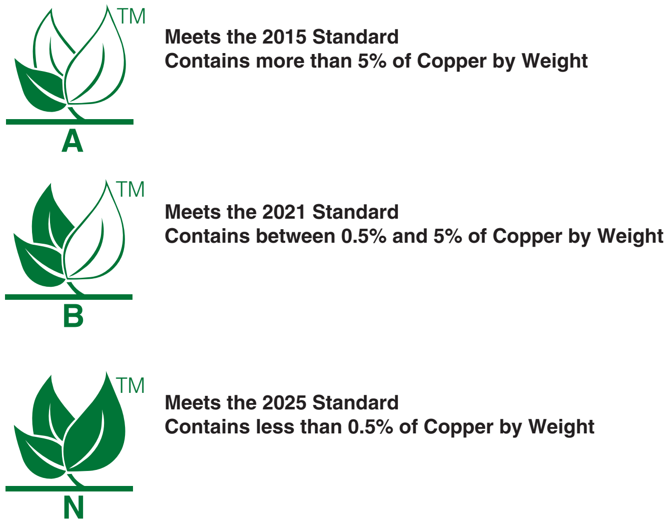

TM
A
Meets the 2015 Standard
Contains more than 5% of Copper by Weight
TM
B
Meets the 2021 Standard
Contains between 0.5% and 5% of Copper by Weight
TM
N
Meets the 2025 Standard
Contains less than 0.5% of Copper by Weight

FIGURE 94–11 All boxes of brake linings and pads should be labeled with the leaf mark, which gives a visual clue as to the standard under which the brake friction materials meet certain state laws regarding the amount of copper.

EDGE CODE INFORMATION After January 1, 2014, all brake shoes and pads were required to have manufacturer's **edge codes**, which indicate all of the following:

- Company code
- Pad number
- Formulation code
- Vendor number
- Friction code
- Week number that the brakes were made
- Environmental code (A, B, or N)
- Year of manufacture

Because these edge codes now contain so much information, many manufacturers of brake friction material print this information on the backing of the friction material instead of on the edge of the lining to make it easier to see and read. ● **SEE FIGURES 94–12 AND 94–13**.

COEFFICIENT OF FRICTION EDGE CODE The edge codes for the coefficient of friction include letters that represent a range of coefficient of friction. ● **SEE CHART 94–5**.

COLD AND HOT COEFFICIENT OF FRICTION There are always two letters used side by side; the first letter indicates the coefficient of friction when brakes are cold (250°F/121°C), and the

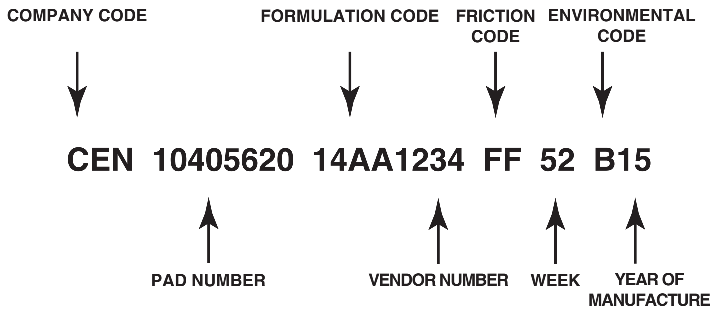


FIGURE 94–12 The edge codes include a lot of information about the brake friction material.

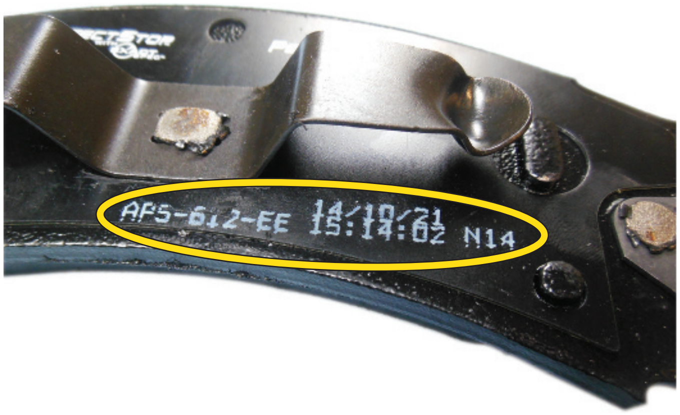


FIGURE 94–13 The “edge codes” are now printed on the backing of the brake pad because there is so much required information that it often does not fit on the edge of the brake pad or shoe.

TECH TIP

Edge Codes Do Not Represent Quality

The coefficient of friction letters do not mean the relative quality of the lining material. Lining wear, fade resistance, tensile strength, heat recovery rate, wet friction, noise, and coefficient of friction must be considered when purchasing high-quality linings. For best brake performance, always purchase the best-quality brake pads and lining from a well-known brand name.

second letter indicates the coefficient of friction of the brake lining when the brakes are hot (600°F/316°C). For example, FF indicates that the brake lining material has a coefficient of friction between 0.35 and 0.45 when both cold and hot. ● **SEE FIGURE 94–14**.

CODE LETTER	COEFFICIENT OF FRICTION RANGE
Code C	0.00–0.15
Code D	0.15–0.25
Code E	0.25–0.35
Code F	0.35–0.45
Code G	0.45–0.55
Code H	0.55 and above
Code Z	Ungraded

CHART 94–5

Edge code letters represent a range of coefficient of friction of the linings.

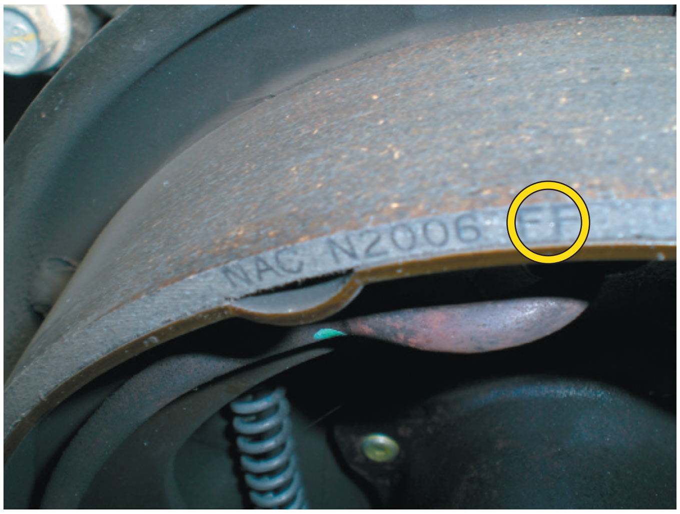


FIGURE 94–14 Typical drum brake lining edge codes, showing the coefficient of friction codes for cold and hot circled.

REVIEW QUESTIONS

1. What is kinetic energy?
2. What is inertia?
3. What is the coefficient of friction?
4. Why is copper being removed from brake friction material?
5. What is the meaning of the friction code letter printed on the edge of brake linings and pads?

CHAPTER QUIZ

1. Which Greek letter is used to represent the coefficient of friction?
   - **a.** Mu (μ)
   - **b.** Omega (Ω)
   - **c.** Delta (Δ)
   - **d.** Pi (Π)
2. The amount of asbestos in brake friction material is being restricted because ___________.
   - **a.** it does not transfer heat to the drum/rotor
   - **b.** it is a health hazard
   - **c.** asbestos worn from brakes contaminates rivers and streams
   - **d.** it causes excessive brake drum/rotor wear
3. What type of binder is used in all brake friction materials?
   - **a.** Rubber scrap
   - **b.** Carbon
   - **c.** Phenolic resin
   - **d.** Ceramic powders
4. An edge code reading for coefficient of friction is EF. This means ___________.
   - **a.** the coefficient of friction is 0.50
   - **b.** the coefficient of friction is higher when the brakes are cold
   - **c.** the coefficient of friction is higher when the brakes are hot
   - **d.** a higher quality brake has a code of FF
5. Brake pads and linings that use synthetic material, such as aramid fibers, instead of steel are usually referred to as ___________.
   - **a.** NAO
   - **b.** NAS
   - **c.** Ceramic
   - **d.** Any of the above

6. What can the driver do to reduce the possibility of brake fade caused by heat?

- **a.** Ride the brakes to keep the shoes and pads against the drum or rotor
- **b.** Pump the brake pedal while descending a steep hill
- **c.** Select a lower transmission gear
- **d.** Shift the transmission into neutral and allow the vehicle to coast down long or steep hills

7. Brake fade can occur due to ____________.

- **a.** mechanical fade
- **b.** gas fade
- **c.** water fade
- **d.** Any of the above

8. Why is copper being reduced in brake friction materials?

- **a.** Because it is a health concern when it becomes airborne
- **b.** Because it can affect life in rivers and streams
- **c.** To help reduce the weight of the vehicle
- **d.** To help reduce the cost of the brake linings/pads

9. The kinetic energy of a vehicle traveling at 60 MPH is ____________ when compared to the same vehicle traveling at 30 MPH.

- **a.** twice as much
- **b.** three times higher
- **c.** four times as much
- **d.** ten times higher

10. Disc brake pads can reach temperatures as high as ____________.

- **a.** 300°F (150°C)
- **b.** 1,000°F (540°C)
- **c.** 1,300°F (700°C)
- **d.** 1,800°F (980°C)

Chapter

95

BRAKE HYDRAULIC SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain how the noncompressibility of liquids is used in brake systems.
- State Pascal's law.
- Describe the function, purpose, operation, and types of master cylinders.
- Describe the process of diagnosing and troubleshooting master cylinders.
- Discuss the different valves and switches used in the brake hydraulic system, including the fluid level switch, proportioning valve, and metering valve.
- Explain electronic brake proportioning (EBP).
- List the components included in a combination valve.
- Describe how a brake light switch works.

KEY TERMS:

Brake pedal position sensor (BPP) 1105 • Breather port 1091 • Combination valve 1104 • Compensating port 1091 • Dynamic rear proportioning (DRP) 1103 • Electronic brake proportioning (EBP) 1103 • Filler port 1091 • Height-sensing proportioning valve 1102 • Master cylinder 1090 • Metering valve 1104 • Pascal’s law 1088 • Pedal free play 1097 • Pedal height 1097 • Proportioning valve 1100 • Replenishing port 1091 • Slope 1102 • Split point 1102 • Vent port 1091

HYDRAULIC PRINCIPLES

NEED FOR HYDRAULICS In addition to the mechanical advantage provided by leverage at the brake pedal assembly, all vehicles use hydraulic pressure to help increase brake application force. All braking systems require that a driver’s force is transmitted to the drum or rotor attached to each wheel. ● **SEE FIGURE 95–1**.

The force that can be exerted on the brake pedal varies due to the strength and size of the driver. Engineers design braking systems to require less than 150 pounds of force (68 kg) from the driver, yet provide the force necessary to stop a heavy vehicle from high speed.

NONCOMPRESSIBILITY OF LIQUIDS Hydraulic systems use liquids to transmit motion. For all practical purposes, a liquid cannot be compressed. No matter how much pressure or force is placed on a quantity of liquid, its volume remains the same. This fact enables liquids in a closed system to transmit motion. ● **SEE FIGURE 95–2**.

If piston A is moved a distance of 1 inch, the liquid is displaced ahead of it and piston B moves 1 inch as well. Liquids cannot be compressed, but any air trapped in the system can be compressed.

In ● **FIGURE 95–3**, the simple hydraulic system has been contaminated with air. Even though piston A is moved a distance of 1 inch, piston B does not move if the load on it is greater than the pressure of the air in the system. For example, if the load on piston B is 50 pounds per square inch (PSI), the movement of piston A must compress the air in the system to that same pressure before piston B begins to move. A brake hydraulic system must be air free or the brakes do not operate correctly and the driver feels a spongy brake pedal that is also often lower than normal.

PASCAL’S LAW

DEFINITION The hydraulic principles that permit a brake system to function were discovered by a French physicist, Blaise Pascal (1632–1662). **Pascal’s law** states:

> When force is applied to a liquid confined in a container or an enclosure, the pressure is transmitted equally and undiminished in every direction.

EXAMPLE OF PASCAL’S LAW To help understand this principle, assume that a force of 10 pounds is exerted on a piston

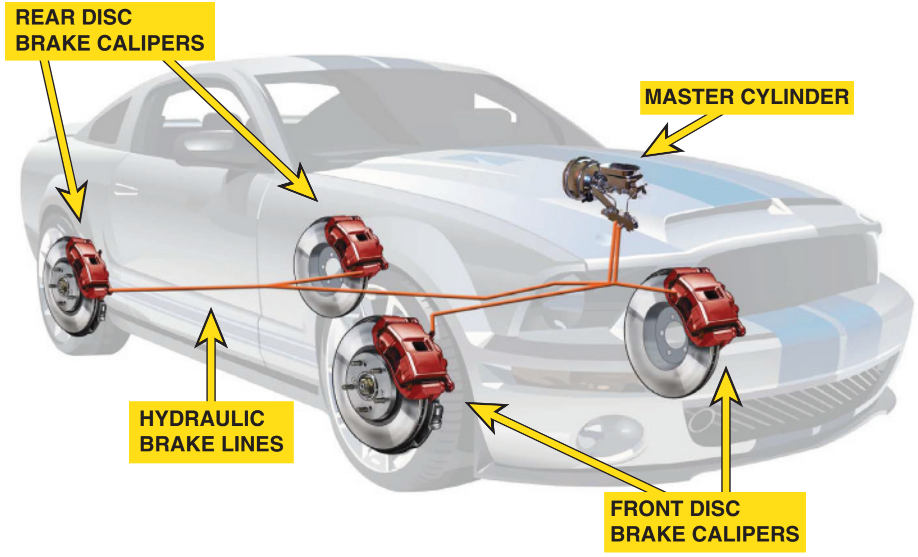


FIGURE 95–1 Hydraulic brake lines transfer the brake effort to each brake assembly attached to all four wheels.

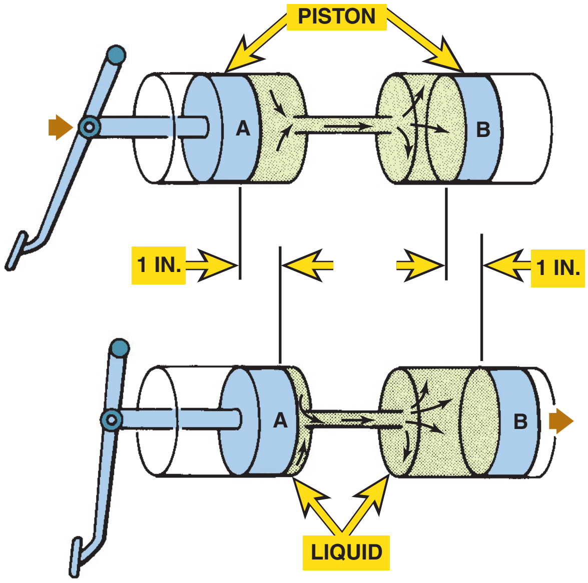


FIGURE 95–2 Because liquids cannot be compressed, they are able to transmit motion in a closed system.

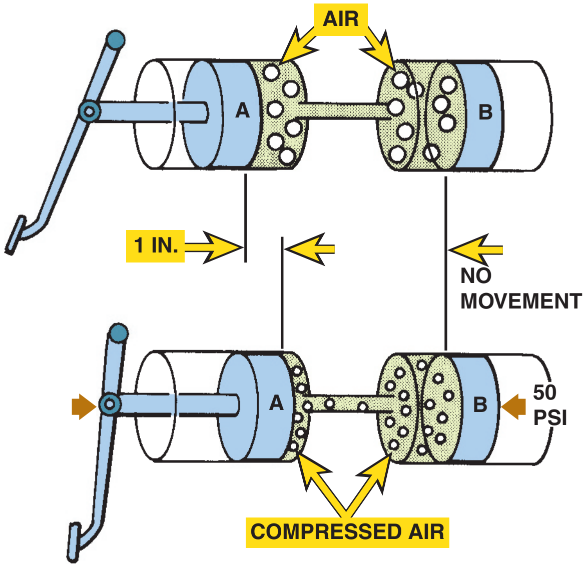


FIGURE 95–3 Hydraulic system must be free of air to operate properly. If air is in the system, the air is compressed when the brake pedal is depressed and the brake fluid does not transmit the force to the wheel brakes.

with a surface area of 1 square inch. Since this *force* measured in lb or Newtons (N) is applied to a piston with an area measured in square inches (sq. in.), the *pressure* is the force divided by the area or "10 PSI." It is this "pressure" that is transmitted, without loss, throughout the entire hydraulic system. ● **SEE FIGURE 95–4**.

F = P × A (force is equal to the pressure multiplied by the area)

P = F ÷ A (pressure is equal to the force divided by the area)

A = F ÷ P (area is equal to the force divided by the pressure)

where the capital letters mean:

F **= force (lb) (Newtons)**

P **= pressure in lb per sq. in. (kilo Pascals [kPa])**

A **= area in sq. in. (cm^2)**

If two out of the three factors are known, then the other one can be calculated by using this formula. A practical example involves a master cylinder with a piston area of 1 sq. in., one wheel cylinder with an area of 1 sq. in., and one wheel cylinder with a piston area of 2 sq. in. ● **SEE FIGURE 95–5**.

BRAKE HYDRAULIC FORCES The real "magic" of a hydraulic brake system is the fact that different forces can be created at different wheel cylinders. More force is necessary for front brakes than for rear brakes because, as the brakes are applied, the weight of the vehicle moves forward.

Larger (area) pistons are used in brake calipers on the front wheels to increase the force used to apply the front brakes. Not only can hydraulics act as a "force machine" (by varying piston size), but the hydraulic system also can be varied to change piston stroke distances. On a typical vehicle, a driver-input force of 150 lb (660 Newtons) is boosted both mechanically (through the brake pedal linkage) and by the power booster to a fluid pressure of about 1,700 PSI (11,700 kPa).

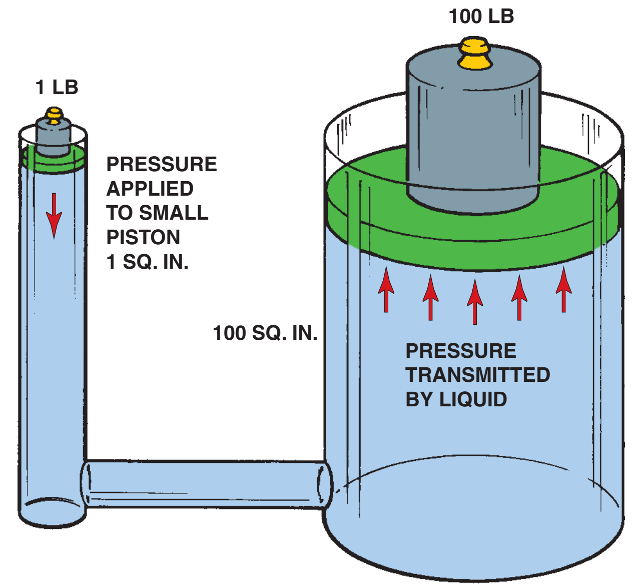

100 LB
1 LB
PRESSURE
APPLIED
TO SMALL
PISTON
1 SQ. IN.
100 SQ. IN.
PRESSURE
TRANSMITTED
BY LIQUID

FIGURE 95–4 A 1 pound force exerted on a small piston in a sealed system transfers the pressure to each square inch throughout the system. In this example, the 1 pound force is able to lift a 100-lb weight because it is supported by a piston that is 100 times larger in area than the small piston.

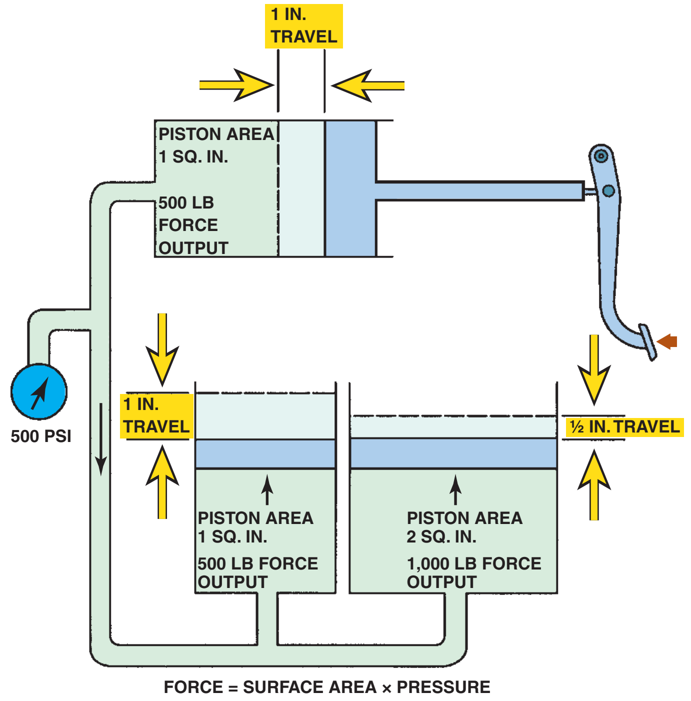

1 IN.
TRAVEL
PISTON AREA
1 SQ. IN.
500 LB
FORCE
OUTPUT
500 PSI
1 IN.
TRAVEL
PISTON AREA
1 SQ. IN.
500 LB FORCE
OUTPUT
PISTON AREA
2 SQ. IN.
1,000 LB FORCE
OUTPUT
½ IN. TRAVEL
FORCE = SURFACE AREA × PRESSURE

FIGURE 95–5 The amount of force (*F*) on the piston is the result of pressure (*P*) multiplied by the surface area (*A*).

FREQUENTLY ASKED QUESTION

How Much Brake Fluid Is Moved When the Brake Pedal Is Depressed?

During a typical brake application, only about 1 teaspoon (5 ml or cc) of brake fluid actually is moved from the master cylinder and into the hydraulic system to cause the pressure buildup to occur.

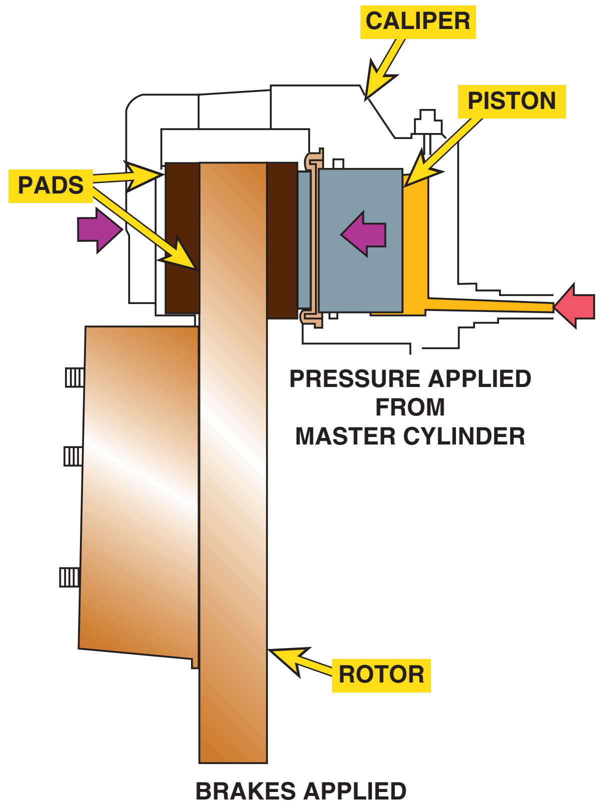

CALIPER
PISTON
PADS
PRESSURE APPLIED
FROM
MASTER CYLINDER
ROTOR
BRAKES APPLIED

FIGURE 95–6 The brake pad (friction material) is pressed on both sides of the rotating rotor by the hydraulic pressure of the caliper.

- With a drum brake, the wheel cylinder expands and pushes the brake shoes against a brake drum. The distance the shoes move is only about 0.005 to 0.012 inch (5 to 12 thousandths of an inch) (0.015 to 0.30 mm).
- With a disc brake, brake fluid pressure pushes on the piston in the caliper a small amount and causes a clamping of the disc brake pads against both sides of a rotor (disc). The typical distance the pads move is only about 0.001 to 0.003 inch (1 to 3 thousandths of an inch) (0.025 to 0.076 mm). ● **SEE FIGURE 95–6**.

MASTER CYLINDERS

PURPOSE AND FUNCTION The **master cylinder** is the heart of the entire braking system. No braking occurs until the driver depresses the brake pedal. The brake pedal linkage is used to apply the force of the driver's foot into a closed hydraulic system.

MASTER CYLINDER RESERVOIRS Most vehicles built since the early 1980s are equipped with see-through master cylinder reservoirs, which permit owners and service technicians to check the brake fluid level without having to remove the top of the reservoir. Some countries have laws that require this type of reservoir. ● **SEE FIGURE 95–7**.

- The reservoir capacity is great enough to allow for the brakes to become completely worn out and still have enough reserve for safe operation.
- The typical capacity of the entire braking system is usually 2 to 3 pints (1 to 1.5 L). Vehicles equipped with four-wheel disc brakes usually hold 4 pints (2 L) or more.

CASE STUDY

Bigger Is Not Better

A vehicle owner wanted better braking performance from his off-road race vehicle. Thinking that a larger master cylinder would help, a technician replaced the original 1 inch bore-diameter master cylinder with a larger 1 1/8 inch bore-diameter master cylinder.

After bleeding the system, the technician was anxious to test-drive the “new” brake system. During the test-drive, the technician noticed that the brake pedal “grabbed” much higher than with the original master cylinder. This delighted the technician. The owner of the vehicle was also delighted until they tried to stop from highway speed. The driver had to use both feet to stop!

The technician realized, after the complaint, that the larger master cylinder was able to move more brake fluid, but with less pressure to the wheel cylinders. The new master cylinder gave the impression of better brakes because the fluid was moved into the wheel cylinders (and calipers) quickly, and the pads and shoes contacted the rotor and drums sooner because of the greater volume of brake fluid moved by the larger pistons in the master cylinder. To calculate the difference in pressure between the original (stock) master cylinder and the larger replacement, the technician used Pascal’s law with the following results:

Original Master Cylinder (1 Inch Bore)	**Replacement Master Cylinder (1 1/8 Inch Bore)**
$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$	$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$
$\text{PSI} = \frac{450 \text{ lb}}{\text{Area}}$ (typical)	$\text{PSI} = \frac{450 \text{ lb}}{\text{Area}}$ (typical)
$\text{Area} = \pi r^2 = 3.14 \times 0.5^2$ (1/2 of 1 inch)	$\text{Area} = \pi r^2 = 3.14 \times 0.5625^2$ (1/2 of 1 1/8 inch)
$\text{Area} = 3.14 \times 0.25$	$\text{Area} = 3.14 \times 0.316$
$\text{Area} = 0.785$ sq. in.	$\text{Area} = 0.992$ sq. in.
$\text{Pressure} = \frac{450}{0.785} = 573 \text{ PSI}$	$\text{Pressure} = \frac{450}{0.992} = 454 \text{ PSI}$

The difference in pressure is 119 PSI less with the larger master cylinder ($573 - 454 = 119$).

The stopping power of the brakes was reduced because the larger-diameter master cylinder piston produced lower pressure (the same force was spread over a larger area and this means that the pressure [PSI] is less). All master cylinders are sized correctly from the factory for the correct braking effort, pressure, pedal travel, and stopping ability. A technician should never change the sizing of any hydraulic brake component on any vehicle.

Summary:

Complaint—Customer wanted better brakes for racing.
Cause—A larger-diameter master cylinder was tried, but it required more driver effort to stop.
Correction—The original master cylinder was reinstalled which restored proper vehicle braking.

TECH TIP

Don’t Fill the Master Cylinder without Seeing Me!

The boss explained to the beginning technician that there are two reasons why the customer should be told not to fill the master cylinder reservoir when the brake fluid is down to the “minimum” mark, as shown in ● **FIGURE 95–8**.

1. If the master cylinder reservoir is low, there may be a leak that should be repaired.
2. As the brakes wear, the disc brake piston moves outward to maintain the same distance between friction materials and the rotor. Therefore, as the disc brake pads wear, the brake fluid level goes down to compensate.

Therefore, if the brake fluid is low, the vehicle should be serviced—either for new brakes or to repair a leak.

MASTER CYLINDER OPERATION The master cylinder is the heart of any hydraulic braking system. Brake pedal movement and force are transferred to the brake fluid and directed to wheel cylinders or calipers. ● **SEE FIGURE 95–9**.

The master cylinder is also separated into two pressure-building chambers (or circuits) to provide braking force to one-half of the brake in the event of a leak or damage to one circuit. ● **SEE FIGURE 95–10**.

Both pressure-building sections of the master cylinder contain two holes from the reservoir. According to the Society of Automotive Engineers (SAE), the terms used include

- The forward (tapered) high-pressure hole is the **vent port**, also called the **compensating port**.
- The rearward straight drilled low-pressure hole is called the **replenishing port**, also called the inlet port, bypass port, **filler port**, or the **breather port**.
  ● **SEE FIGURE 95–11**.

AT-REST POSITION The primary sealing cups are between the compensating port hole and the inlet port hole. In this position, the brake fluid is free to expand and move from the calipers, wheel cylinders, and brake lines up into the reservoir through the vent port (compensation port) if the temperature rises and the fluid expands. If the fluid was trapped, the pressure of the brake fluid would increase with temperature, causing the brakes to self-apply. The pistons (primary and secondary) are retained by a clip at the pushrod end and held in position by return springs. ● **SEE FIGURE 95–12**.

APPLIED POSITION When the brake pedal is depressed, the pedal linkage forces the pushrod and primary piston down the bore of the master cylinder. ● **SEE FIGURE 95–13**.

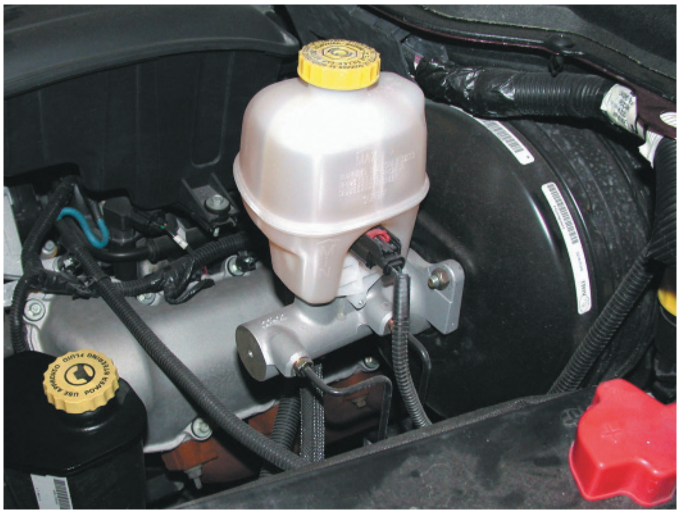


FIGURE 95–8 Master cylinder with brake fluid level at the "max" (maximum) line.

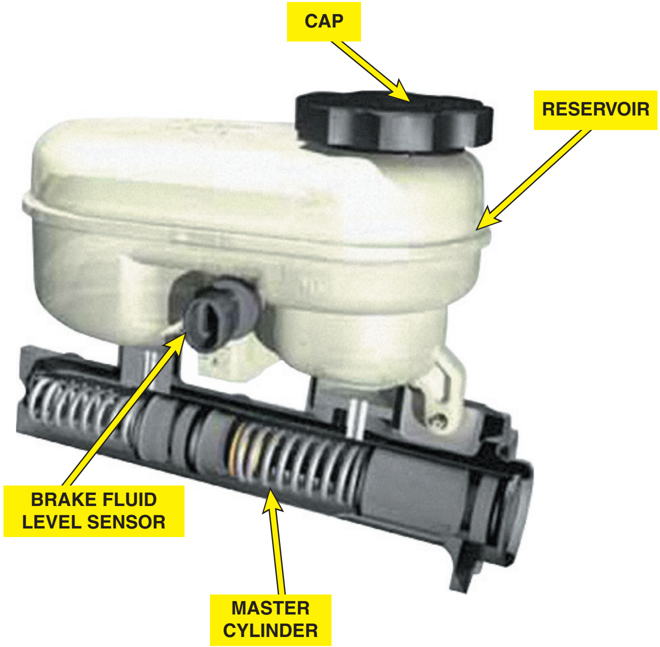

CAP
RESERVOIR
BRAKE FLUID LEVEL SENSOR
MASTER CYLINDER

FIGURE 95–7 A master cylinder showing the see-through reservoir and the location of the brake fluid level sensor with a cutaway showing the internal pistons.

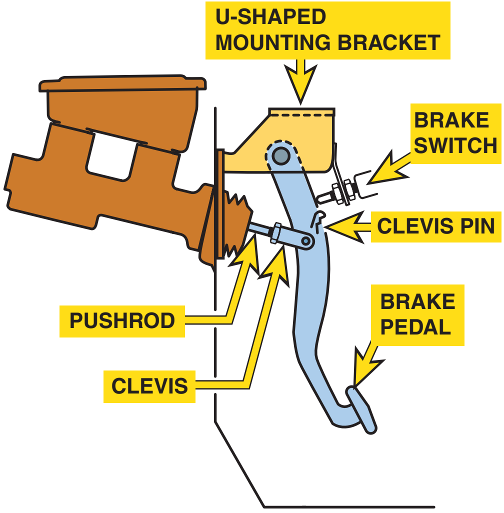

U-SHAPED MOUNTING BRACKET
BRAKE SWITCH
CLEVIS PIN
PUSHROD
BRAKE PEDAL
CLEVIS

FIGURE 95–9 The typical brake pedal is supported by a mount and attached to the pushrod by a U-shaped bracket. The pin used to retain the clevis to the brake pedal is usually called a clevis pin.

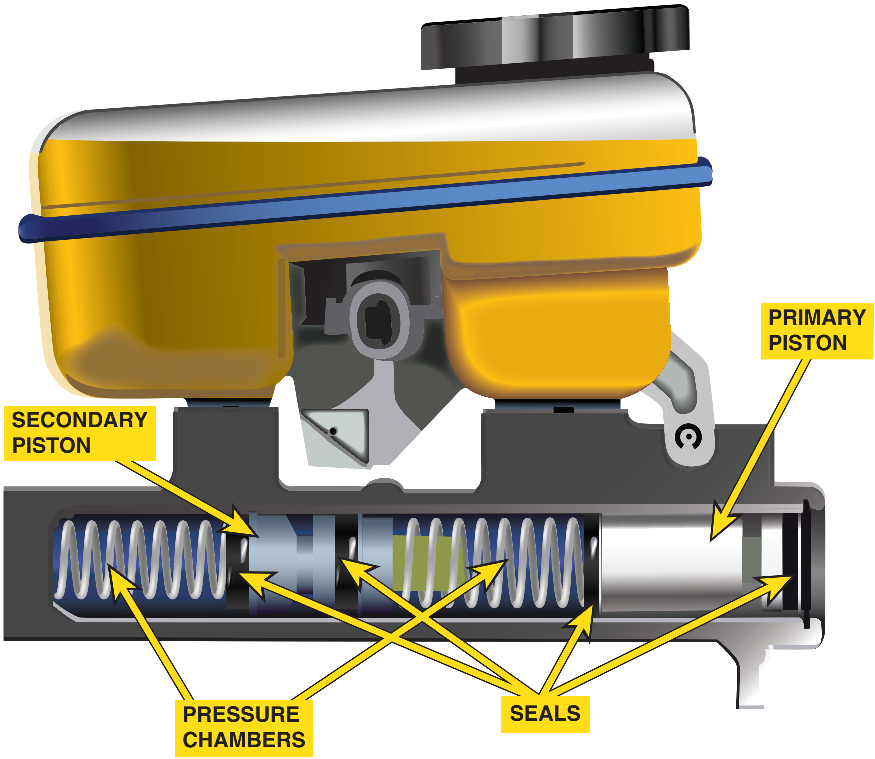
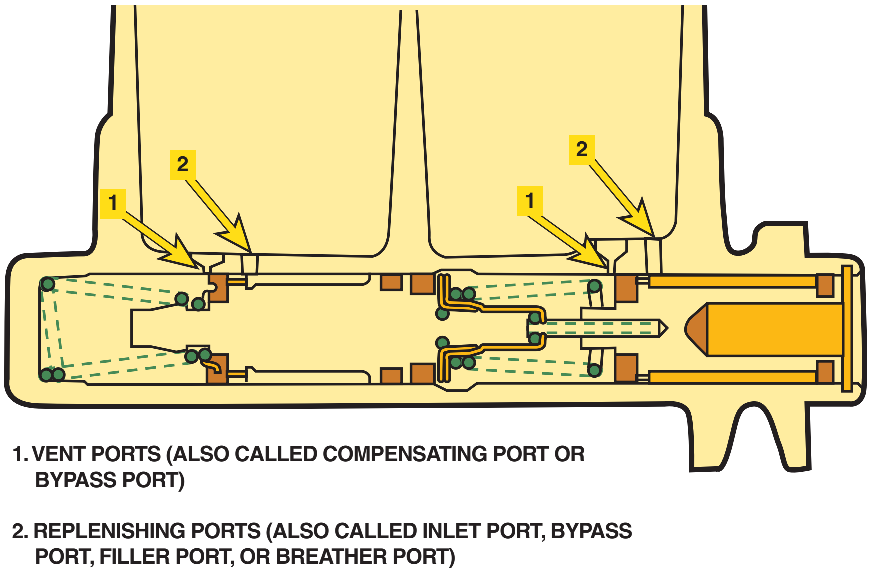

PRIMARY PISTON
SECONDARY PISTON
PRESSURE CHAMBERS
SEALS

FIGURE 95–10 A cutaway of a master cylinder. The reservoir feeds both chambers and uses a fluid level switch that activates the red brake warning lamp if the brake fluid level drops too low.

FIGURE 95–11 Note the various names for the vent port (front port) and the replenishing port (rear port). Names vary by vehicle and brake component manufacturer. *Vent port* and *replenishing port* are the terms recommended by the Society of Automotive Engineers (SAE).


2
1
2
1
1. VENT PORTS (ALSO CALLED COMPENSATING PORT OR BYPASS PORT)
2. REPLENISHING PORTS (ALSO CALLED INLET PORT, BYPASS PORT, FILLER PORT, OR BREATHER PORT)

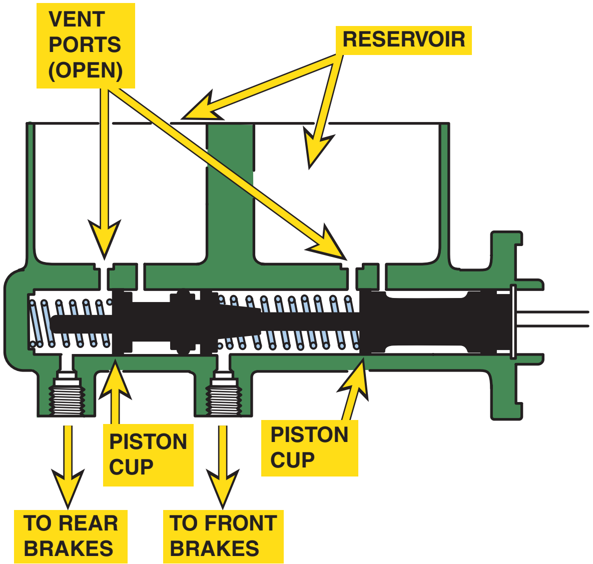

VENT PORTS (OPEN)
RESERVOIR
PISTON CUP
PISTON CUP
TO REAR BRAKES
TO FRONT BRAKES

FIGURE 95–12 The vent ports must remain open to allow brake fluid to expand when heated by the friction material and transferred to the caliper and/or wheel cylinder. As the brake fluid increases in temperature, it expands. The heated brake fluid can expand and flow back into the reservoir through the vent ports.

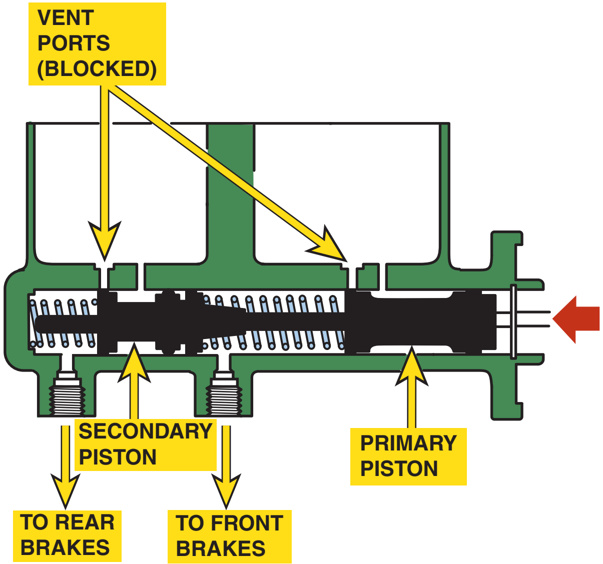

VENT PORTS (BLOCKED)
SECONDARY PISTON
PRIMARY PISTON
TO REAR BRAKES
TO FRONT BRAKES

FIGURE 95–13 As the brake pedal is depressed, the pushrod moves the primary piston forward, closing off the vent port. As soon as the port is blocked, pressure builds in front of the primary sealing cup, which pushes on the secondary piston. The secondary piston also moves forward, blocking the secondary vent port and building pressure in front of the sealing cup.

- As the piston moves forward, the primary sealing cup covers and blocks off the vent port (compensating port).
- Hydraulic pressure builds in front of the primary seal as the pushrod moves forward. The back of the piston is kept filled through the replenishing port. This stops any suction (vacuum) from forming behind the piston. ● **SEE FIGURE 95–14**.
- The secondary piston is moved forward as pressure is exerted by the primary piston. If, for any reason, such as a leak, the primary piston cannot build pressure, a mechanical link on the front of the primary piston touches the secondary piston and moves it forward, as the primary piston is pushed forward by the pushrod and brake pedal.

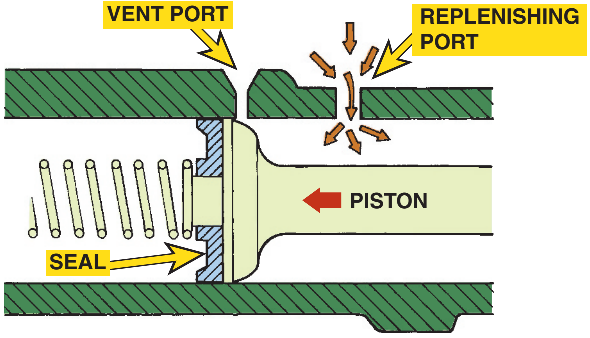

VENT PORT
REPLENISHING PORT
PISTON
SEAL

FIGURE 95–14 The purpose of the replenishing port is to keep the volume behind the primary piston filled with brake fluid from the reservoir as the piston moves forward during a brake application.

RELEASED POSITION Releasing the brake pedal removes the pressure on the pushrod and master cylinder pistons.

- A spring on the brake pedal linkage returns the brake pedal to its normal at-rest (up) position. The spring in front of the master cylinder piston expands, pushing the pistons rearward.
- At the same time, pressure is released from the entire braking system and the released brake fluid pressure is exerted on the master cylinder pistons, forcing them rearward.
- As the piston is pushed back, the lips of the seal fold forward, allowing fluid to quickly move past the piston. Some pistons have small holes that allow the fluid to move more quickly. Once the primary seal passes the vent port, the remaining hydraulic pressure forces any excess fluid into the reservoir. ● **SEE FIGURE 95–15**.

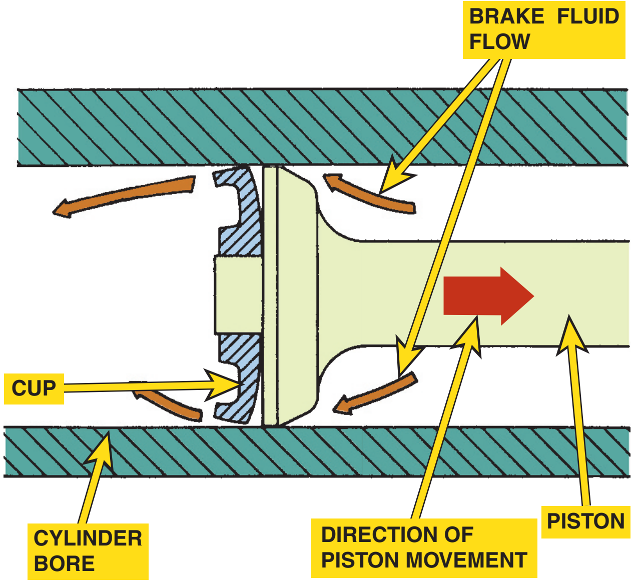

BRAKE FLUID FLOW
CUP
CYLINDER BORE
DIRECTION OF PISTON MOVEMENT
PISTON

FIGURE 95–15 When the brake pedal is released, the master cylinder piston moves rearward. Some of the brake fluid is pushed back up through the replenishing port, but most of the fluid flows past the sealing cup. Therefore, when the driver pumps the brake pedal, the additional fluid in front of the pressure-building sealing cup is available quickly.

FRONT/REAR SPLIT MASTER CYLINDERS Used on rear wheel drive vehicles, front/rear split master cylinders use two separate pressure-building sections. One section operates the front brakes and the other section operates the rear brakes. ● **SEE FIGURE 95–16**.

The nose end of the master cylinder is the closed end toward the front of the vehicle. The open end is often called the pushrod end of the master cylinder. ● **SEE FIGURE 95–17**.

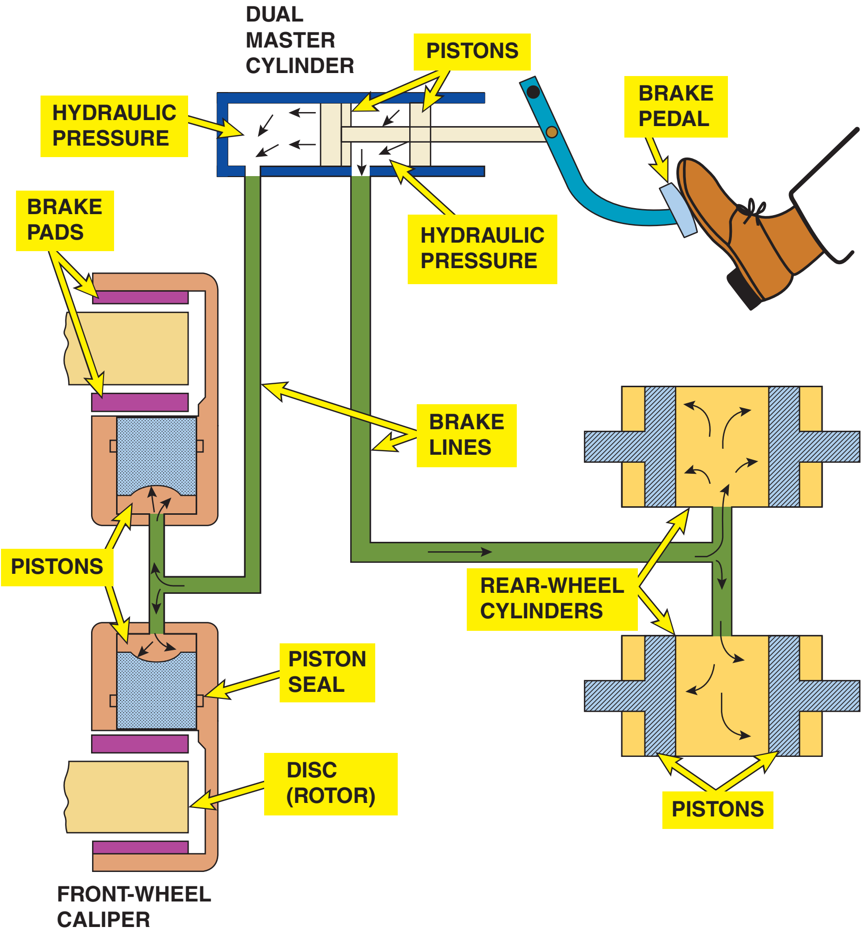

DUAL MASTER CYLINDER
PISTONS
HYDRAULIC PRESSURE
BRAKE PEDAL
HYDRAULIC PRESSURE
BRAKE PADS
BRAKE LINES
PISTONS
REAR-WHEEL CYLINDERS
PISTON SEAL
DISC (ROTOR)
PISTONS
FRONT-WHEEL CALIPER

FIGURE 95–16 Rear-wheel-drive vehicles use a front/rear split master cylinder.

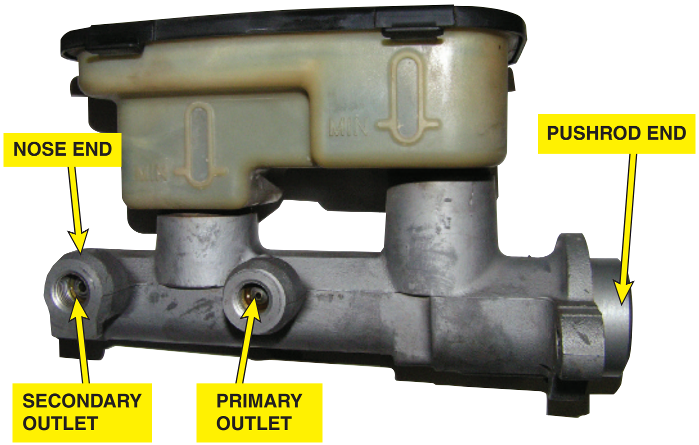


FIGURE 95–17 The primary outlet is closest to the pushrod end of the master cylinder and the secondary outlet is closest to the nose end of the master cylinder.

TECH TIP

Too Much Is Bad

Some vehicle owners or inexperienced service people may fill the master cylinder to the top. Master cylinders should only be filled to the "maximum" level line or about 1/4 inch (6 mm) from the top to allow room for expansion when the brake fluid gets hot during normal operation. If the master cylinder is filled to the top, the expanding brake fluid has no place to expand and can leak out of the top of the reservoir. The spilled brake fluid removes paint and can cause corrosion of any electrical wiring or components located under the master cylinder.

HYDRAULIC FAILURE If the rear section of the hydraulic system fails, the primary piston does not build pressure to operate the secondary piston. To permit the operation of the secondary piston (nose end piston) in the event of a hydraulic failure of the rear section, the primary piston extension mechanically contacts and pushes on the secondary piston. ● **SEE FIGURE 95–18**.

If there is a failure of the front-section hydraulic system, the primary piston (pushrod end) operates normally and exerts pressure on the secondary piston. The secondary piston, however, is not able to build pressure because of the leak in the system.

DIAGONAL SPLIT MASTER CYLINDERS With front-wheel-drive vehicles, the weight of the entire power train is on the front wheels and 80% to 90% of the braking force is achieved by the front brakes. This means that only 10% to 20% of the braking force is being handled by the rear brakes. If the front brakes fail, the rear brakes alone cannot provide adequate braking force. The solution is the use of a diagonal split master cylinder. ● **SEE FIGURE 95–19**.

- In a diagonal split braking system, the left front brake and the right rear brake are on one circuit, and the right front with the left rear is another circuit of the master cylinder.
- If one circuit fails, the remaining circuit can still stop the vehicle in a reasonable fashion because each circuit has one front brake.
- To prevent this one front brake from causing the vehicle to pull toward one side during braking, the front suspension is designed with negative scrub radius geometry. This effectively eliminates any handling problem in the event of a brake circuit failure.

TECH TIP

Always Check for Venting (Compensation)

Whenever diagnosing any braking problem, start the diagnosis at the master cylinder—the heart of any braking system. Remove the reservoir cover and observe the brake fluid for spurting while an assistant depresses the brake pedal.

- **Normal operation (movement of fluid observed in the reservoir)** There should be a squirt or movement of brake fluid out of the vent port of both the primary and secondary chambers. This indicates that the vent port is open and that the sealing cup is capable of moving fluid upward through the port before the cup seals off the port as it moves forward to pressurize the fluid.
- **No movement of fluid observed in the reservoir in the primary piston** This indicates that brake fluid is not being moved as the brake pedal is depressed. This can be caused by the following:
  a. Incorrect brake pedal height—brake pedal or pushrod adjustment could be allowing the primary piston to be too far forward, causing the seal cup to be forward of the vent port. Adjust the brake pedal height to a higher level and check for a too-long pushrod length.
  b. A defective or swollen rubber sealing cup on the primary piston could cause the cup itself to block the vent port.

NOTE: If the vent port is blocked for any reason, the brakes of the vehicle may self-apply when the brake fluid heats up during normal braking. Since the vent port is blocked, the expanded hotter brake fluid has no place to expand and instead increases the pressure in the brake lines. The increase in pressure causes the brakes to apply. Loosening the bleeder valves and releasing the built-up pressure is a check that the brakes are self-applying. Then check the master cylinder to see if it is "venting."

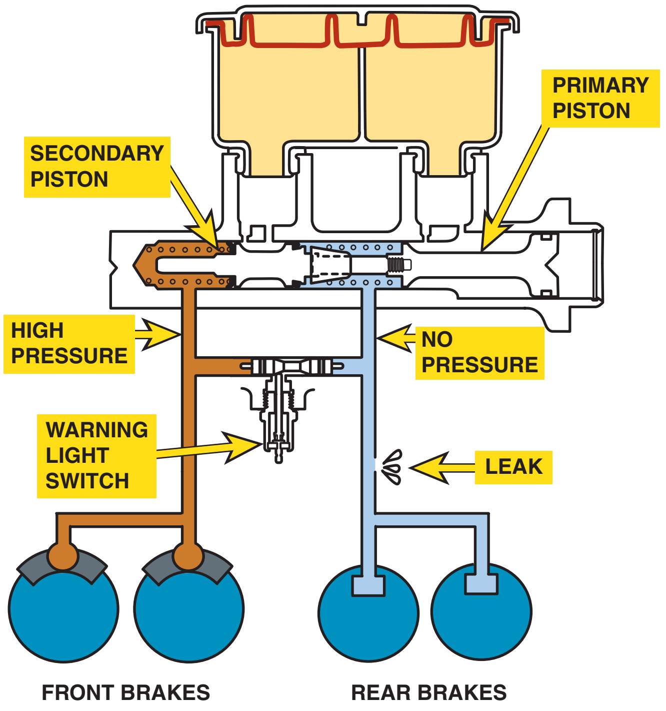

PRIMARY PISTON
SECONDARY PISTON
HIGH PRESSURE
NO PRESSURE
WARNING LIGHT SWITCH
LEAK
FRONT BRAKES
REAR BRAKES

FIGURE 95–18 In the event of a primary system failure, no hydraulic pressure is available to push the second piston forward. As a result, the primary piston extension contacts the secondary piston and pushes on the secondary piston mechanically, rather than hydraulically. The loss of pressure in the primary system is usually noticed by the driver by a lower-than-normal brake pedal and the lighting of the red brake warning lamp.

DIAGNOSING MASTER CYLINDERS

VISUAL INSPECTION A thorough visual inspection is important when inspecting any master cylinder. The visual inspection should include checking the following items:

1. Check the brake fluid for proper level and condition. Brake fluid should not be rusty, thick, or contaminated.

TECH TIP

The Brake Pedal Depressor Trick

The master cylinder can be used to block the flow of brake fluid. Whenever any hydraulic brake component is removed, brake fluid tends to leak out because the master cylinder is usually higher than most other hydraulic components, such as wheel cylinders and calipers.

To prevent brake fluid loss that can easily empty the master cylinder reservoir, simply depress the brake pedal slightly or prop a stick or other pedal depressor to keep the brake pedal down. When the brake pedal is depressed, the piston sealing cups move forward, blocking off the reservoir from the rest of the braking system. The master cylinder stays full and the brake fluid stops dripping out of brake lines that have been disconnected. ● **SEE FIGURE 95–20**.

NOTE: Try this—put a straw into a glass of water. Use a finger to seal the top of the straw and then remove the straw from the glass of water. The water remains in the straw because air cannot get into the top of the straw. This is why the brake pedal depressor trick works to prevent the loss of brake fluid from the system, even if the brake line is totally disconnected.

2. Check that the vent holes in the reservoir cover are open and clean.
3. Check for any external leaks at the lines or at the pushrod area. ● **SEE FIGURE 95–21**.

TECH TIP

Quick and Easy Brake Reserve Test

Brake pedal reserve distance can be easily checked by depressing the brake pedal with the right foot and attempting to slide your left foot under the brake pedal. ● **SEE FIGURE 95–22**.

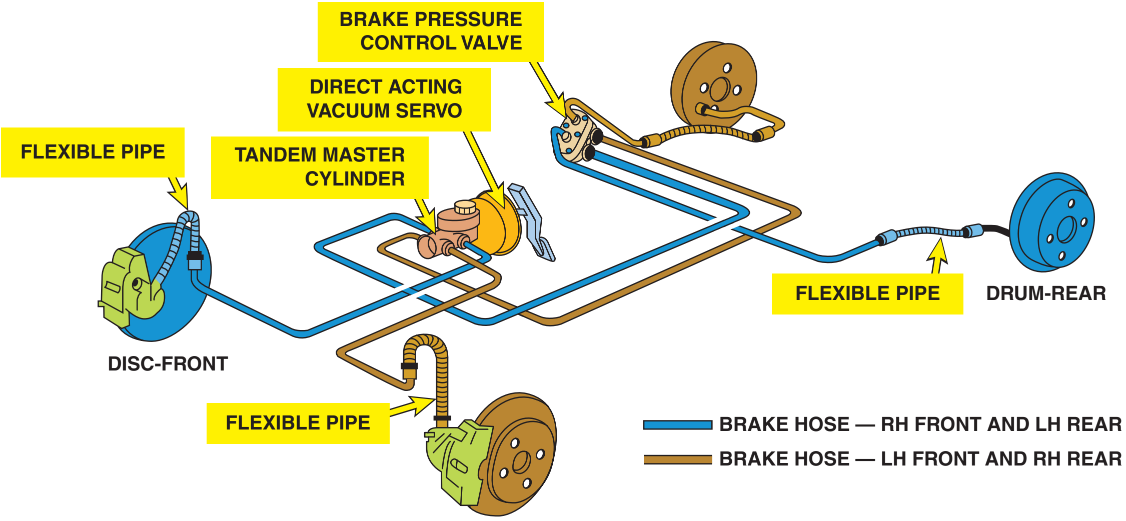

BRAKE PRESSURE CONTROL VALVE
DIRECT ACTING VACUUM SERVO
FLEXIBLE PIPE
TANDEM MASTER CYLINDER
FLEXIBLE PIPE
DRUM-REAR
DISC-FRONT
FLEXIBLE PIPE
BRAKE HOSE — RH FRONT AND LH REAR
BRAKE HOSE — LH FRONT AND RH REAR

FIGURE 95–19 Front-wheel-drive vehicles use a diagonal split master cylinder. In this design, one section of the master cylinder operates the right front and the left rear brake and the other section operates the left front and right rear. In the event of a failure in one section, at least one front brake still functions.

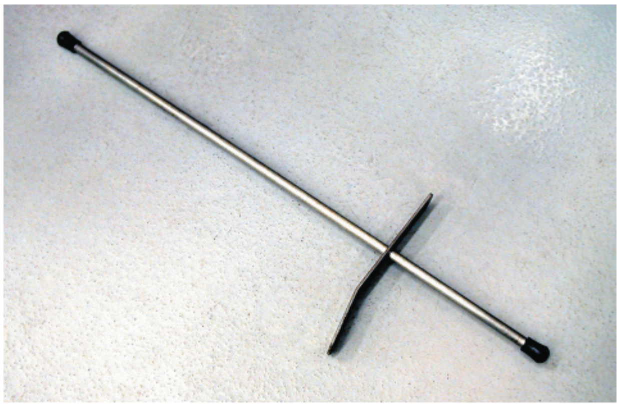


FIGURE 95–20 A brake pedal depressor like this can be used during brake service to block the flow of brake fluid from the master cylinder during service work on the hydraulic system.

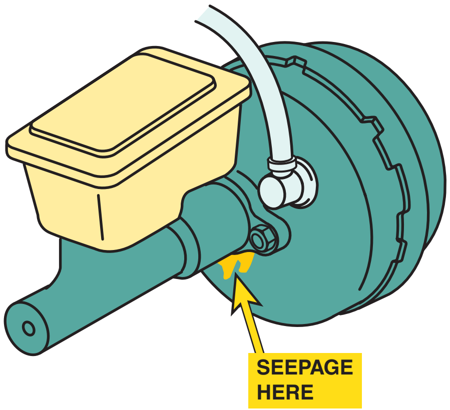


FIGURE 95–21 Seepage at the booster indicates a leaking secondary (end) seal.

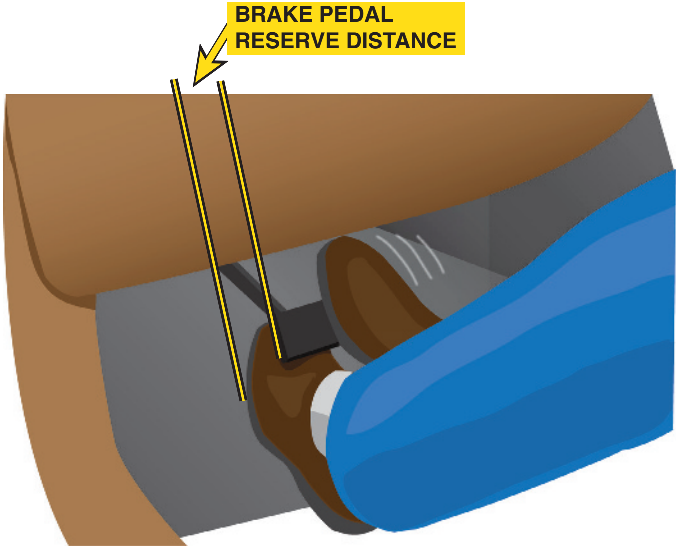


FIGURE 95–22 Pedal height is usually measured from the floor to the top of the brake pedal. Always follow the manufacturer's recommended procedures and measurements.

BRAKE PEDAL HEIGHT Proper brake **pedal height** is important for the proper operation of the stop (brake) light switch. If the pedal is not correct, the pushrod may be in too far forward, preventing the master cylinder cups from uncovering the compensation port. If the pedal is too high, the free play is excessive. ● **SEE FIGURE 95–23**.

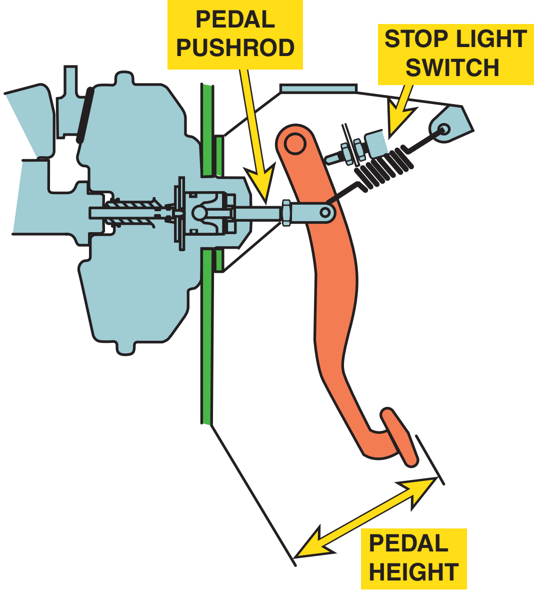


FIGURE 95–23 Pedal height is usually measured from the floor to the top of the brake pedal. Always follow the manufacturer's recommended procedures and measurements.

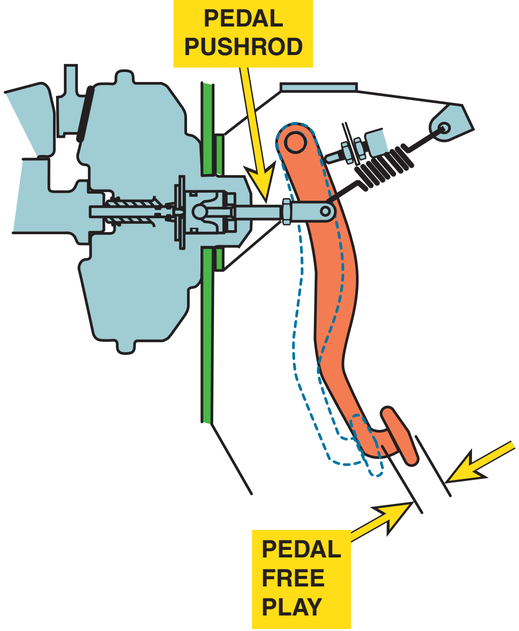


FIGURE 95–24 Brake pedal free play is the distance between the brake pedal fully released and the position of the brake pedal when braking resistance is felt.

BRAKE PEDAL FREE PLAY **Pedal free play** is the distance the brake pedal travels before the primary piston in the master cylinder moves. Most vehicles require brake pedal free play between 1/8 and 1 1/2 inch (3 to 38 mm). Too little or too much free play can cause braking problems that can be mistakenly attributed to a defective master cylinder. Check service information for the exact specifications and testing procedures for the vehicles being tested. ● **SEE FIGURE 95–24**.

BRAKE PEDAL TRAVEL A more accurate measurement is obtained using a pedal pressure gauge and ruler, following these steps:

STEP 1 With the ignition off, pump the brake pedal until it becomes firm (depletes power booster reserve).

STEP 2 Measure and record the distance from the brake pedal to the lower rim of the steering wheel. ● **SEE FIGURE 95–25**.

STEP 3 Apply the brakes with 100 pounds of pressure. Use a brake pedal pressure gauge, if available, to help ensure accurate test results.

STEP 4 While holding the pedal with 100 pounds of force, measure and record the distance from the pedal to the lower rim of the steering wheel. ● **SEE FIGURE 95–26**.

STEP 5 Subtract the applied measurement from the unapplied measurement to get the total travel.

Compare the pedal travel with the specification found in service information. As an example, a typical specification is 2.0 inches (5 cm).

NOTE: The brake pedal travel checks on many hybrid electric vehicles are different from this procedure. Refer to service information before checking these vehicles.

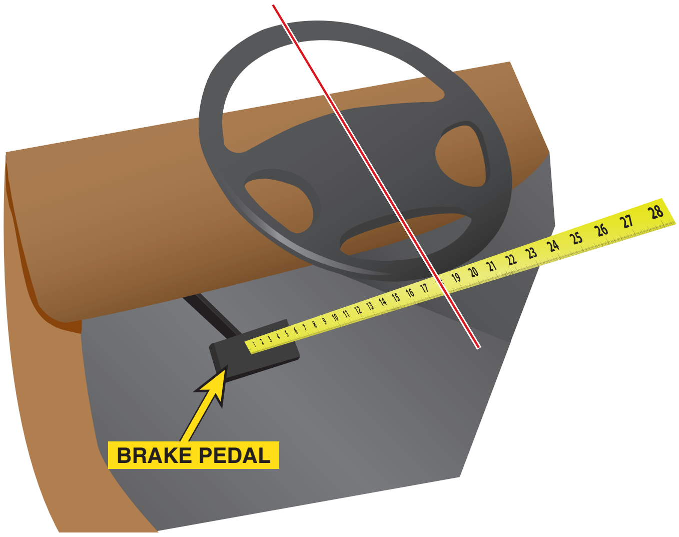


FIGURE 95–25 Measure the unapplied distance between the brake pedal and the steering wheel.

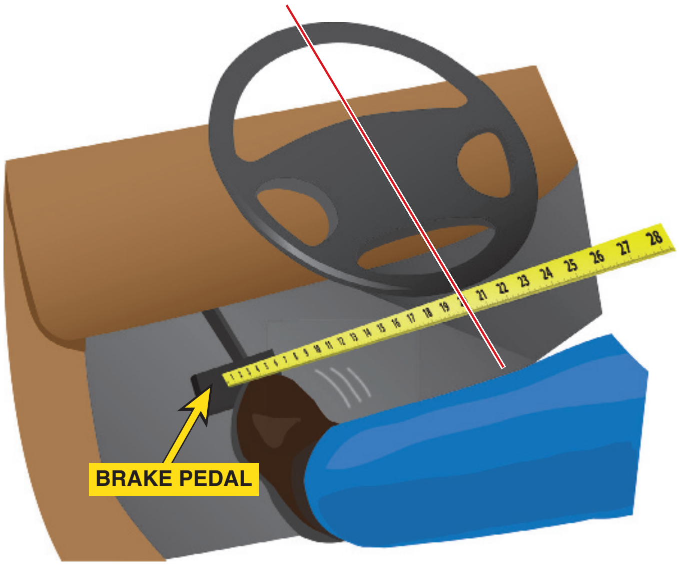


FIGURE 95–26 Apply the brakes and measure the distance again.

MASTER CYLINDER SYMPTOMS

Some common master cylinder fault symptoms include

- **Spongy brake pedal.** A spongy pedal with a larger-than-normal travel indicates air in the lines. Check for leaks and bleed the air from the system, as discussed later in this chapter.
- **Lower-than-normal brake pedal.** A brake pedal that travels downward more than normal and then gets firm is an indication that one circuit of the dual-circuit hydraulic system is probably not working. Check for leaks in the system and repair as necessary. Another possible reason is an out-of-adjustment drum brake allowing too much pedal travel before the shoes touch the brake drum.

NOTE: A lower-than-normal brake pedal may also be an indication of air in the hydraulic system.

- **Sinking brake pedal.** If the brake pedal sinks all the way to the floor especially when the vehicle is not moving, suspect a defective master cylinder that is leaking internally. This internal leakage is often called bypassing because the brake fluid is leaking past the sealing cups, allowing pressure from one chamber to leak into the other chamber.

INSTALLING THE MASTER CYLINDER

After the master cylinder has been bench bled, it can be installed in the vehicle. Tighten the fasteners to factory specifications. Bleed the system as needed. Bench bleed the master cylinder before installing. ● **SEE FIGURE 95–27**.

NOTE: Brake fluid can drip from the outlet of the master cylinder and could drip onto the vehicle. Brake fluid is very corrosive and can remove paint. Use fender covers and avoid letting brake fluid touch any component of the vehicle. ● **SEE FIGURE 95–28**.

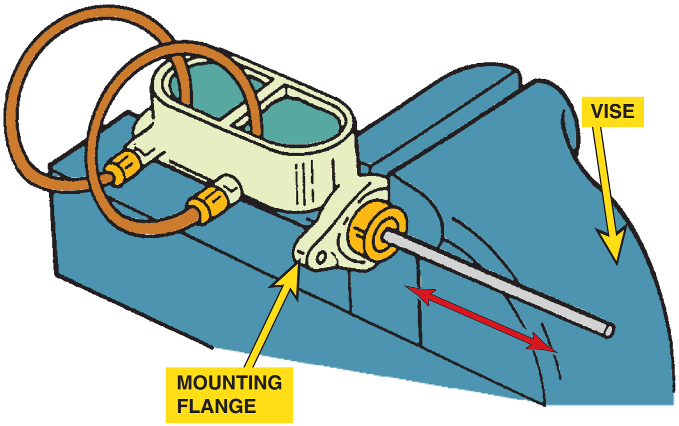


FIGURE 95–27 Bleeding a master cylinder before installing it on the vehicle. The master cylinder is clamped into a bench vise while using a rounded end of a dowel rod to push on the pushrod end with bleeder tubes down into the brake fluid. Master cylinders should be clamped on the mounting flange, as shown, to prevent distorting the master cylinder bore.

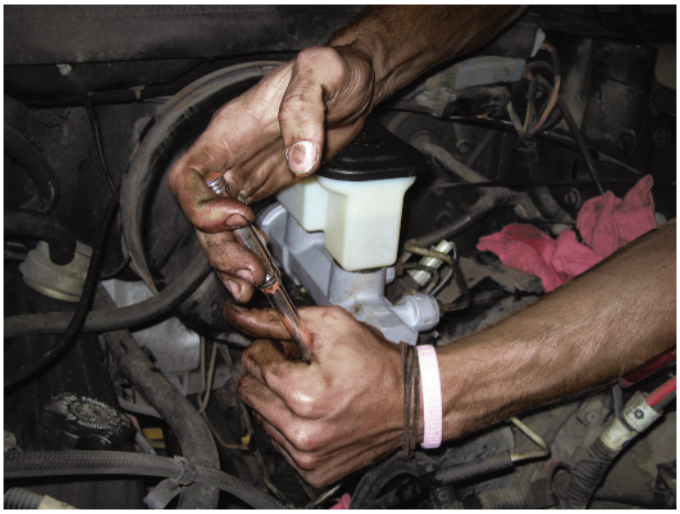


FIGURE 95–28 Installing a master cylinder. Always tighten the retaining fasteners and brake lines to factory specifications.

HYDRAULIC VALVES AND SWITCHES

PRESSURE-DIFFERENTIAL SWITCH (BRAKE WARNING SWITCH) A pressure-differential switch is used on vehicles built after 1967 with front/rear master cylinders to warn the driver of a loss of pressure in one of the two separate systems by lighting the dashboard red brake warning indicator lamp. This system was used until it was replaced with the brake fluid level sensors used on newer vehicles. ● **SEE FIGURE 95–29**.

The brake lines from both the front and the rear sections of the master cylinder are sent to this switch, which lights the brake warning indicator lamp in the event of a "difference in pressure" between the two sections. A failure in one part of the brake system does not result in a failure of the entire hydraulic system. ● **SEE FIGURE 95–30**.

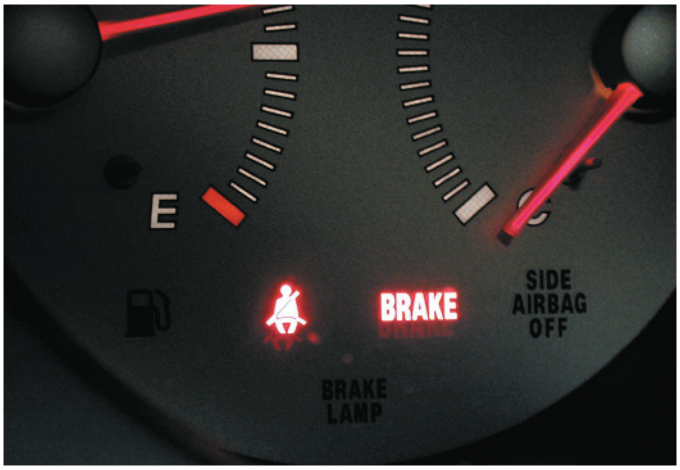

E
BRAKE
SIDE AIRBAG OFF
BRAKE LAMP

FIGURE 95–29 A red brake warning lamp.

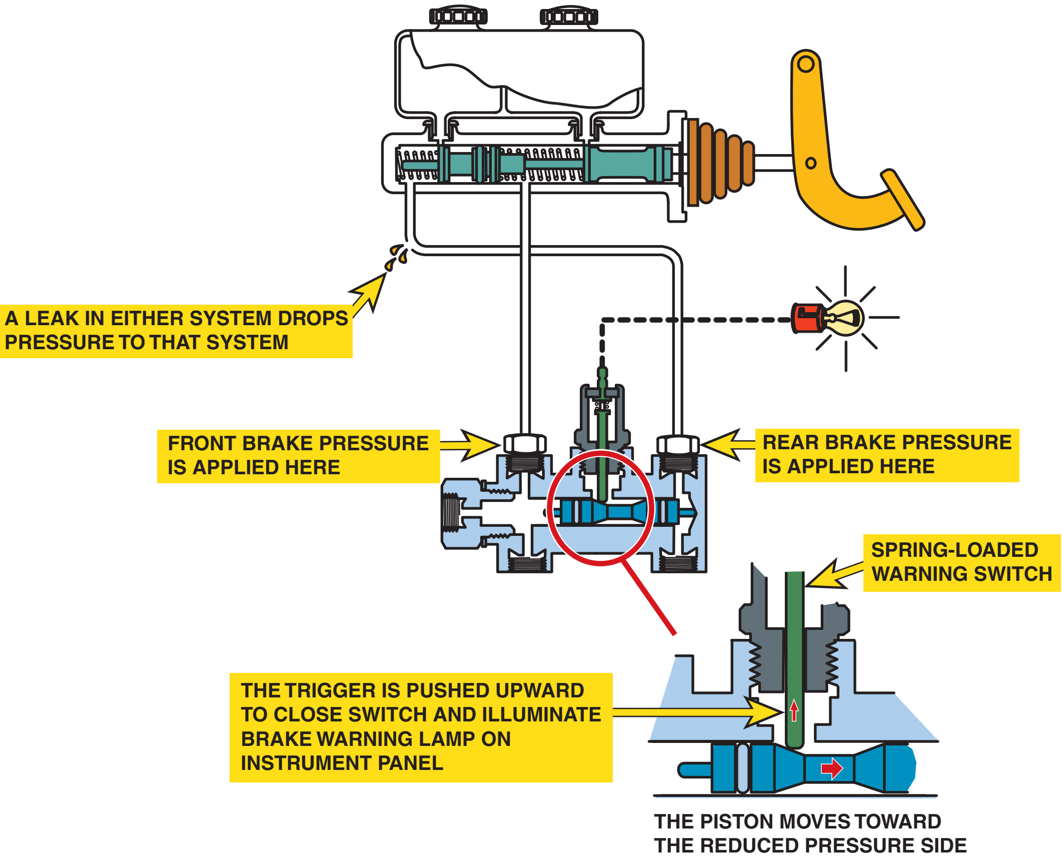
PRESSURE-DIFFERENTIAL SWITCH RESET After the hydraulic system has been repaired and bled, moderate pressure on the brake pedal centers the piston in the switch and turns off the warning lamp.

If the lamp remains on, it may be necessary to do the following:

1. Apply light pressure to the brake pedal.
2. Momentarily open the bleeder valve on the side that did not have the failure.

This procedure should center the pressure-differential switch valve in those vehicles that are not equipped with self-centering springs. If the lamp still remains on, it means that the plunger inside the differential valve is stuck in place. The whole assembly should be replaced, if this is the case.

FIGURE 95–30 A leak in the hydraulic system causes unequal pressures between the two different brake circuits. This difference in pressures causes the plunger inside the pressure-differential switch to move, which completes the electrical circuit for the red brake warning lamp.


A LEAK IN EITHER SYSTEM DROPS PRESSURE TO THAT SYSTEM
FRONT BRAKE PRESSURE IS APPLIED HERE
REAR BRAKE PRESSURE IS APPLIED HERE
SPRING-LOADED WARNING SWITCH
THE TRIGGER IS PUSHED UPWARD TO CLOSE SWITCH AND ILLUMINATE BRAKE WARNING LAMP ON INSTRUMENT PANEL
THE PISTON MOVES TOWARD THE REDUCED PRESSURE SIDE

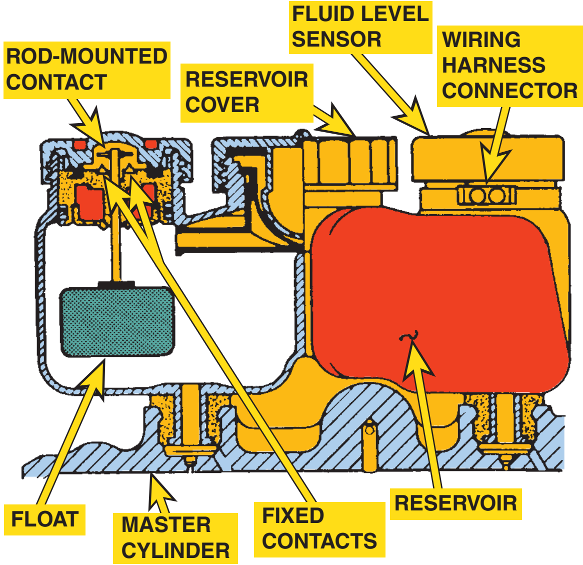


FIGURE 95–31 A movable contact brake fluid level switch.

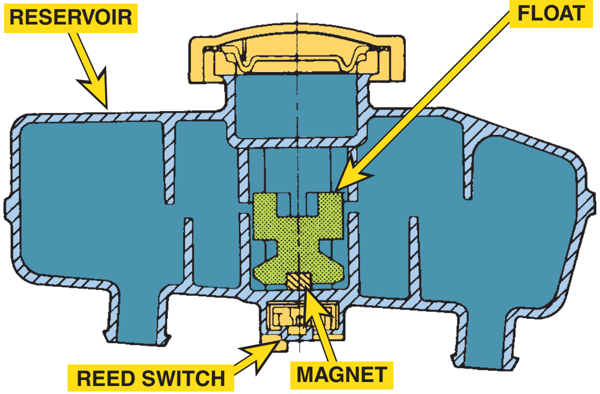


FIGURE 95–32 A magnetic brake fluid level switch.

BRAKE FLUID LEVEL SENSOR Since the late 1990s, master cylinders use a brake fluid level sensor or switch in the master cylinder reservoir. This sensor lights the red brake warning lamp (RBWL) on the dash if low brake fluid level is detected. A float-type sensor or a magnetic reed switch is commonly used and provides a complete electrical circuit when the brake fluid level is low. After refilling the master cylinder reservoir to the correct level, the RBWL should go out. ● **SEE FIGURES 95–31 AND 95–32**.

DIAGNOSING A RED "BRAKE" WARNING LAMP The RBWL can be on for several reasons, including

- **Parking brake on**. The same dash warning lamp is used to warn the driver that the parking brake is on.
- **Low brake fluid**. This condition causes the red dash warning lamp to come on if the vehicle is equipped with a master cylinder reservoir brake fluid level switch.
- **Unequal brake pressure**. The pressure-differential switch is used on older vehicles with a front/rear brake split system to warn the driver whenever there is low brake pressure to either the front or rear brakes.
- **Worn brake pads**. Vehicles equipped with electronic pad wear sensors can turn on the light when the pads wear out.

NOTE: Brake systems use either a pressure-differential switch or a low brake fluid switch to light the dash red "brake" lamp, but not both.

TECH TIP

Check Service Information for the Red Brake Light Input

Older vehicles control the red brake warning lamp using straight wiring and switches. It is becoming more common for this function to be controlled by onboard computers and data systems instead. The brake fluid level switch is often an input to a body control module (BCM) and the dash lamp is the output. ● **SEE FIGURE 95–33**.

The most likely cause of the RBWL being on is low brake fluid caused by worn-out brake pads or a leaking brake line, wheel cylinder, or caliper. Therefore, the first step is to determine the cause of the lamp being on, then to repair the problem.

STEP 1 **Check the Level of the Brake Fluid**. If low, carefully inspect the entire hydraulic brake system for leaks and repair, as necessary. Don't forget that the fluid level normally goes down as the brake pads wear. Badly worn pads can drop the fluid level low enough to turn on the warning light.

STEP 2 **Disconnect the Wire from the Pressure-Differential Switch**. If the lamp is still "on," the problem is due to the parking brake lever switch being "on" or grounded, or the wire going to the switch is shorted to ground. If the red brake warning lamp is "off" after being disconnected from the pressure-differential switch, then the problem is due to a hydraulic failure (a low pressure in either the front or the rear system that creates a difference in pressure of at least 150 PSI).

PROPORTIONING VALVE A **proportioning valve** improves brake balance during hard stops by limiting hydraulic pressure to the rear brakes. ● **SEE FIGURE 95–34**.

A proportioning valve is necessary because inertia creates weight shift toward the front of the vehicle during braking. The weight shift unloads the rear axle, which reduces traction between the tires and the road, and limits the amount of stopping power that can be delivered. Unless application pressure to the rear wheels is limited, the brakes lock, making the vehicle unstable and likely to skid. The best overall braking performance is achieved when the front brakes lock just before the rear brakes. Vehicles with front disc and rear drum brakes require a proportioning valve for two reasons:

1. Disc brakes require higher hydraulic pressure for a given stop than do drum brakes. In a disc/drum system, the front brakes always need more pressure than the rear brakes.
2. Once braking has begun, drum brakes require less pressure to maintain a fixed level of stopping power than they did to establish that level. In a disc/drum system, the rear brakes always need less pressure than the front brakes.

A proportioning valve can be either one part used to control both rear brakes or two parts, one part of each rear brake.

PROPORTIONING VALVE OPERATION The proportioning valve does not work at all times. During light or moderate braking, there is insufficient weight transfer to make rear wheel locking a problem.

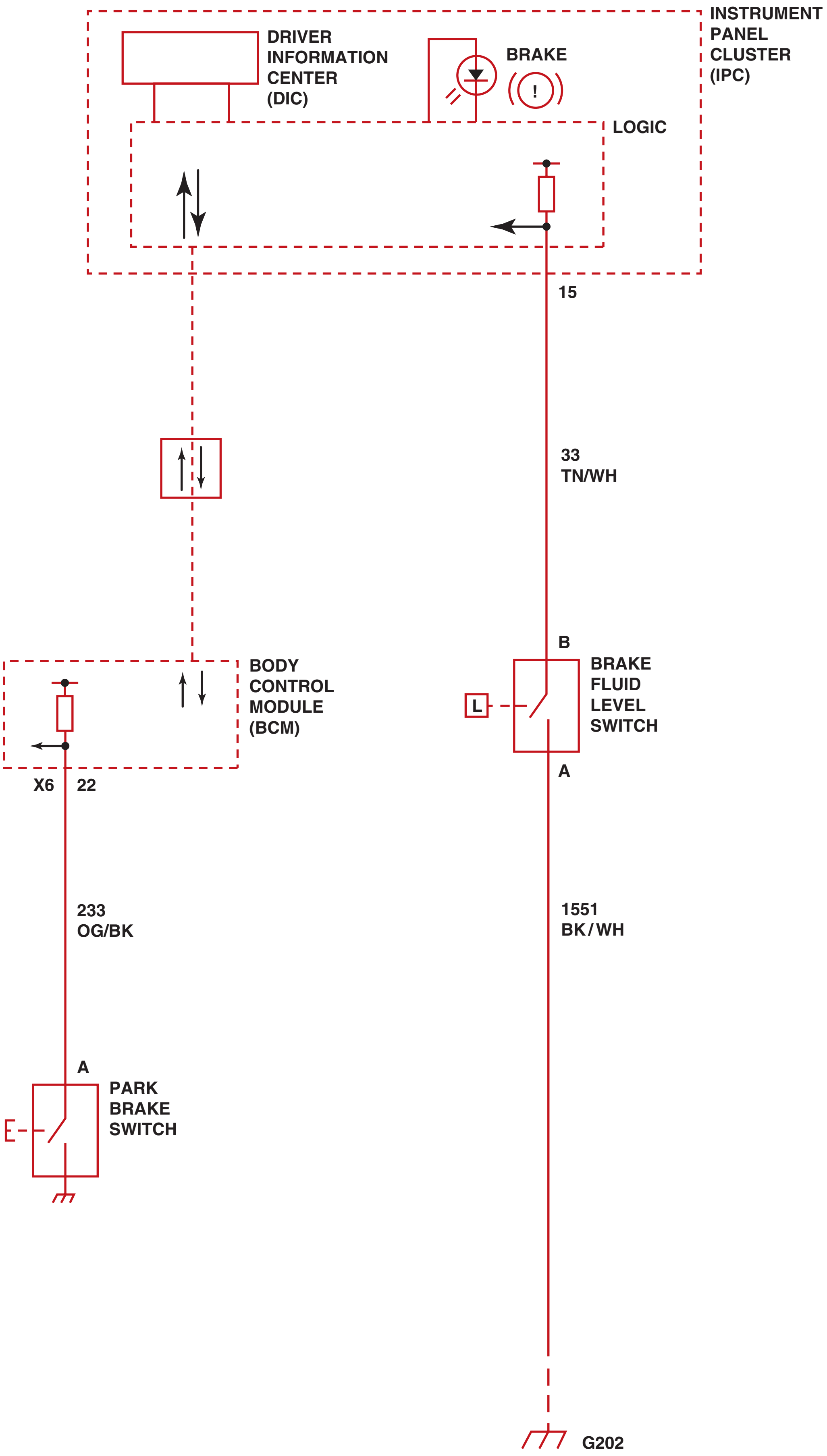

INSTRUMENT PANEL CLUSTER (IPC)
DRIVER INFORMATION CENTER (DIC)
BRAKE
!
LOGIC
15
33
TN/WH
BODY CONTROL MODULE (BCM)
B
BRAKE FLUID LEVEL SWITCH
L
A
X6
22
233
OG/BK
1551
BK/WH
A
PARK BRAKE SWITCH
G202

FIGURE 95–33 A wiring diagram of a typical red brake warning light circuit showing that the park brake switch is an input to the body control module (BCM) and the brake fluid level switch is an input directly to the instrument panel cluster (IPC). The command to turn on the red brake warning light is sent from the BCM to the IPC through the data lines, shown by the two parallel arrows.

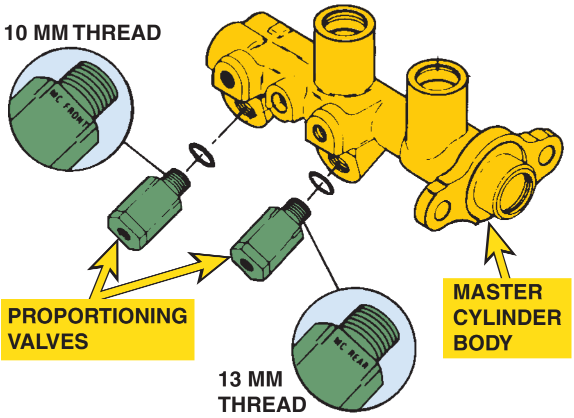


FIGURE 95–34 Some proportioning valves are mounted directly to the master cylinder in the outlet to the rear brakes.

- Before proportioning action begins, brake system hydraulic pressure must reach a minimum level, called the **split point**. Below the split point, full system pressure is supplied to the rear brakes. ● **SEE FIGURE 95–35**.
- Above the split point, the proportioning valve allows only a portion of the pressure through to the rear brakes. The proportioning valve gets its name from the fact that it regulates pressure to the rear brakes in proportion to the pressure applied to the front brakes.
- Once system hydraulic pressure exceeds the split point, the rear brakes receive a fixed percentage of any further increase in pressure.
- Brake engineers refer to the ratio of front-to-rear brake pressure proportioning as the **slope**. Full system pressure to the rear brakes equals a slope of 1, but if only half the pressure is allowed to reach the rear brakes, the proportioning valve is said to have a slope of 0.50. The proportioning valves on most vehicles have a slope between 0.25 and 0.50. ● **SEE FIGURES 95–36 AND 95–37**.

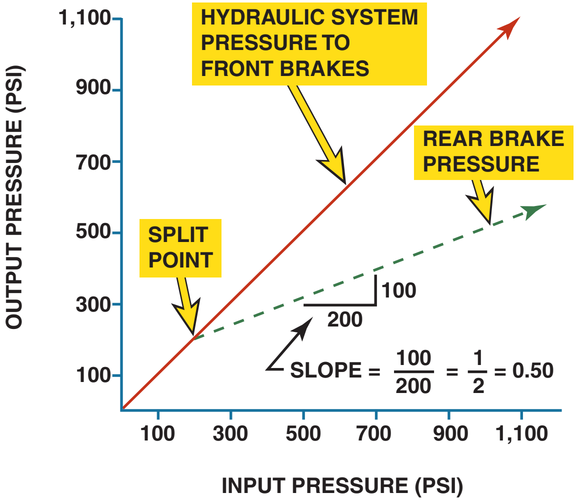


FIGURE 95–35 Typical proportioning valve pressure relationship. Note that, at low pressures, the pressure is the same to the rear brakes as is applied to the front brakes. After the split point, only a percentage (called the slope) of the master cylinder pressure is applied to the rear brakes.

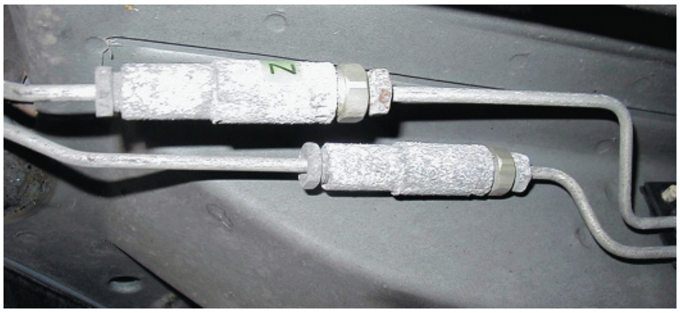


FIGURE 95–36 These two proportioning valves are found under the vehicle on this Dodge minivan.

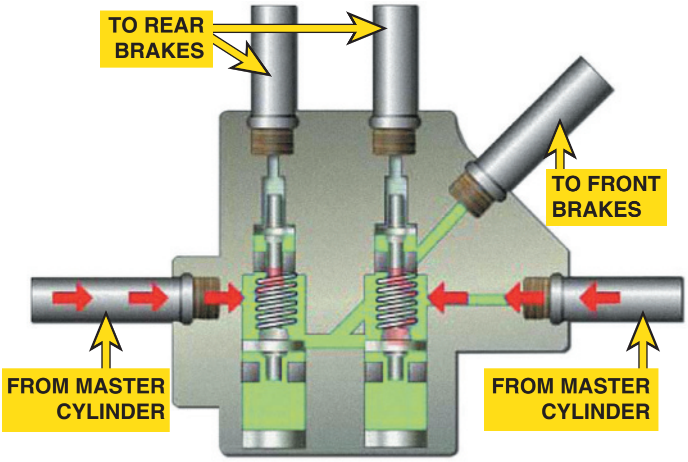


FIGURE 95–37 A vehicle with a diagonal split braking system often uses a one-piece proportioning valve with two pistons, one for each rear wheel.

HEIGHT-SENSING PROPORTIONING VALVES

Many vehicles use a proportioning valve that varies the amount of pressure that can be sent to the rear brakes, depending on the height of the rear suspension. This type of valve is called a **height-sensing proportioning valve**.

- If the vehicle is lightly loaded, the rear suspension is high, especially during braking. In this case, the amount of pressure allowed to the rear brakes is reduced. This *helps* prevent rear-wheel lockup and possible skidding. Besides, a lightly loaded vehicle requires less braking force to stop than a heavily loaded vehicle.
- When the vehicle is loaded, the rear suspension is forced downward. The lever on the proportioning valve moves and allows a greater pressure to be sent to the rear brakes. This greater pressure allows the rear brakes to achieve more braking force, helping to slow a heavier vehicle. When a vehicle is heavily loaded in the rear, the chances of rear-wheel lockup are reduced. ● **SEE FIGURES 95–38 AND 95–39**.

CAUTION: Some vehicle manufacturers warn that service technicians should never install replacement air lift shock absorbers or springs that may result in a vehicle height different than specified by the vehicle manufacturer. If the ride height is increased, the front-to-rear brake proportional relationship is changed and could reduce stopping distances.

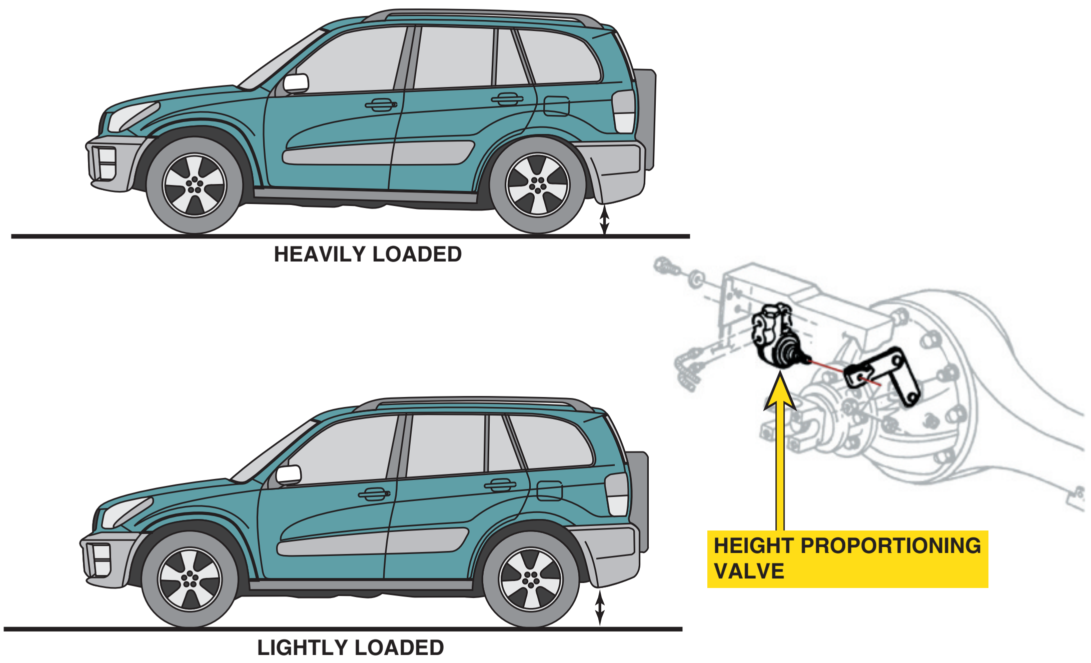

HEAVILY LOADED
HEIGHT PROPORTIONING VALVE
LIGHTLY LOADED

FIGURE 95–38 A height-sensing proportioning valve provides the vehicle with variable brake balance. The valve allows higher pressure to be applied to the rear brakes when the vehicle is heavily loaded and less pressure when the vehicle is lightly loaded.

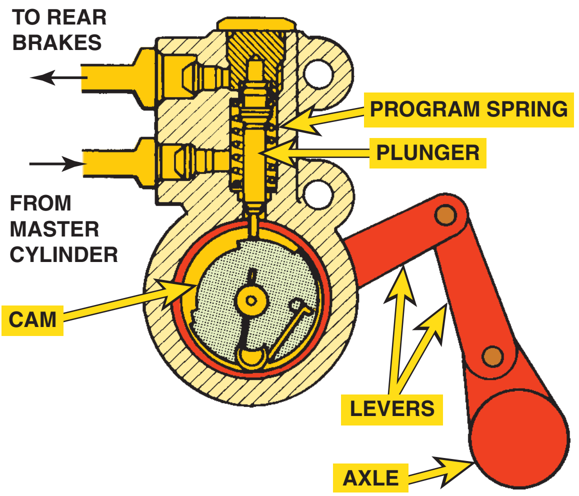

TO REAR BRAKES
PROGRAM SPRING
PLUNGER
FROM MASTER CYLINDER
CAM
LEVERS
AXLE

FIGURE 95–39 A stepped cam is used to alter the split point of this height-sensing proportioning valve.

ELECTRONIC BRAKE PROPORTIONING

PURPOSE AND FUNCTION Most new vehicles with antilock brake systems have eliminated the need for a conventional brake proportioning valve. Instead, this becomes a function of the antilock brake system controller. Often referred to as **dynamic rear proportioning (DRP)** or **electronic brake proportioning (EBP)**, this system removes the need for a mechanical proportioning valve.

PARTS AND OPERATION Most proportioning valves are calibrated to reduce pressure to the rear brakes by a fixed amount, which may increase the risk of rear-wheel lockup if the vehicle is loaded differently or is braking on a wet or slick surface. Dynamic rear proportioning uses the ABS controller software and the rear wheel hydraulic control circuits to maintain optimum front-to-rear balance under all conditions.

Electronic brake proportioning (EBP) in the ABS is accomplished by monitoring brake switch input and front- and rear-wheel speeds, and reducing pressure to the rear brakes as needed using the ABS solenoids when there is a difference in wheel deceleration rates. The controller energizes the inlet valve solenoids for both rear brakes to hold pressure in the lines and then energizes both rear outlet valve solenoids to release pressure, as needed. ● **SEE FIGURE 95–40**.

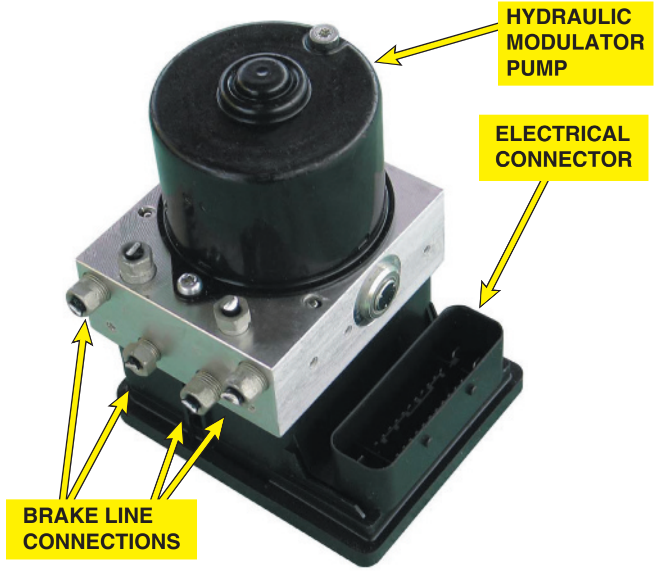

HYDRAULIC MODULATOR PUMP
ELECTRICAL CONNECTOR
BRAKE LINE CONNECTIONS

FIGURE 95–40 The ABS control module performs the functions of the metering and proportioning valves on most ABS-equipped vehicles.

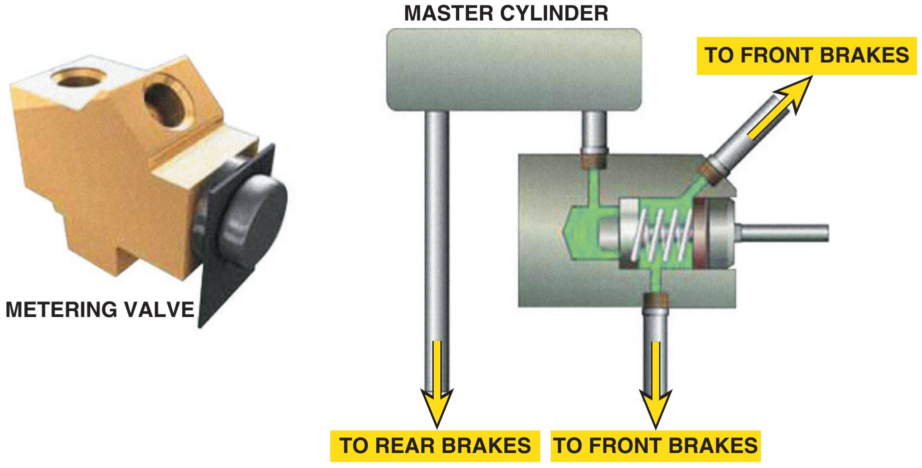


FIGURE 95–41 The metering valve may be a separate component or part of the combination valve.

METERING VALVE (HOLD-OFF) OPERATION A **metering valve** is used on many front-disc, rear-drum-brake-equipped vehicles. The metering valve prevents the full operation of (holds off) the disc brakes until between 75 to 125 PSI is sent to the rear drum brakes to overcome rear-brake return spring pressure. This allows the front and rear brakes to apply at the same time for even stopping. Most metering valves also allow for the pressure to the front brakes to be gradually blended up to the metering valve pressure to prevent front brake locking under light pedal pressures on icy surfaces. ● **SEE FIGURE 95–41**.

SYSTEMS WITHOUT METERING VALVES Braking systems that are diagonal split, such as those found on most front-wheel-drive vehicles, do *not* use a metering valve. A metering valve is only used on front/rear split braking systems, such as those found on most rear-wheel-drive vehicles.

TECH TIP

Push-In or Pull-Out Metering Valve?

Whenever bleeding the air out of the hydraulic brake system using pressure bleeding equipment, the metering valve should be bypassed. The metering valve stops the passage of brake fluid to the front wheels until pressure exceeds about 125 PSI (860 kPa). To bypass the metering valve, the service technician has to push or pull a small button located on the metering valve. An easy way to remember whether to push in or to pull out is to inspect the button itself.

- *If the button is rubber coated, then push in.*
- *If the button is steel, then pull out.*

Special tools allow the metering valve to be held in the bypass position. Failure to remove the tool after bleeding the brakes can result in premature application of the front brakes before the rear drum brakes have enough pressure to operate.

Most rear-wheel-drive vehicles without metering valves are equipped with four-wheel disc brakes. Because the clearance between the pads and rotors is approximately the same at all four wheels, there is no need to delay front brake actuation.

COMBINATION VALVES

Most vehicle manufacturers combine the function of a proportioning valve with one or more other valves into one unit, called a **combination valve**. On a rear-wheel-drive vehicle, a combination valve consists of the following components all in one replaceable unit:

- Metering valve
- Proportioning valve
  Pressure-differential switch
  ● **SEE FIGURES 95–42 AND 95–43**.

Some combination valves have only two functions and contain just

- the pressure differential and
- metering valve.

Other units combine the pressure differential with the proportioning valve. ● **SEE FIGURE 95–44**.

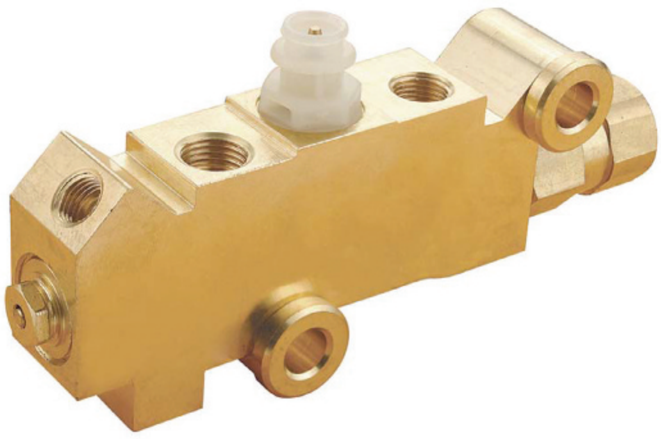
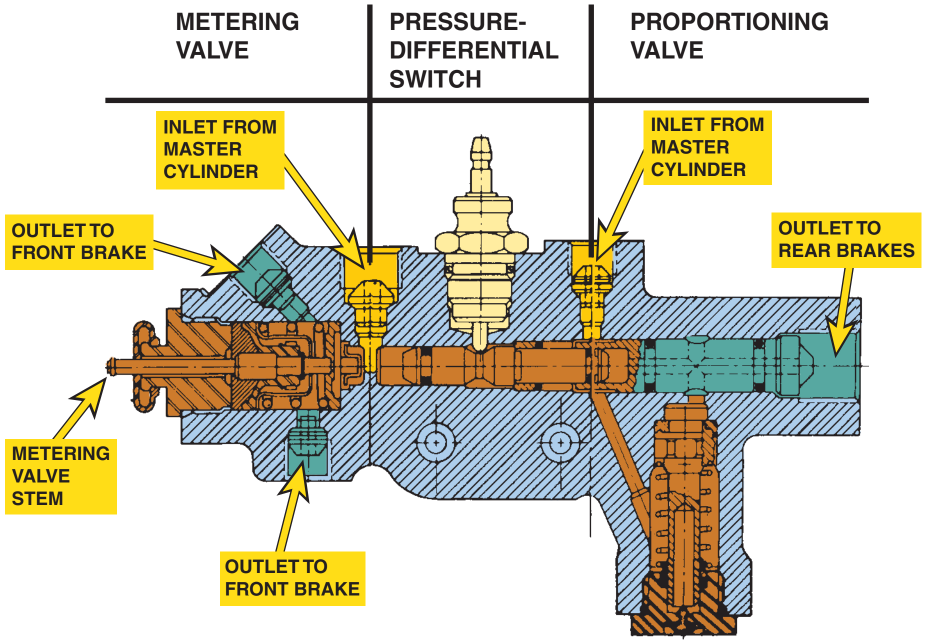


FIGURE 95–42 This combination valve contains the pressure-differential valve, the metering valve, and the proportioning valve.

FIGURE 95–43 Combination valve containing metering, pressure-differential (warning switch), and proportioning valves all in one unit. This style is often called a "pistol grip" design because the proportioning valve section resembles the grip section of a handgun.


METERING VALVE
PRESSURE-DIFFERENTIAL SWITCH
PROPORTIONING VALVE
INLET FROM MASTER CYLINDER
INLET FROM MASTER CYLINDER
OUTLET TO FRONT BRAKE
OUTLET TO REAR BRAKES
METERING VALVE STEM
OUTLET TO FRONT BRAKE

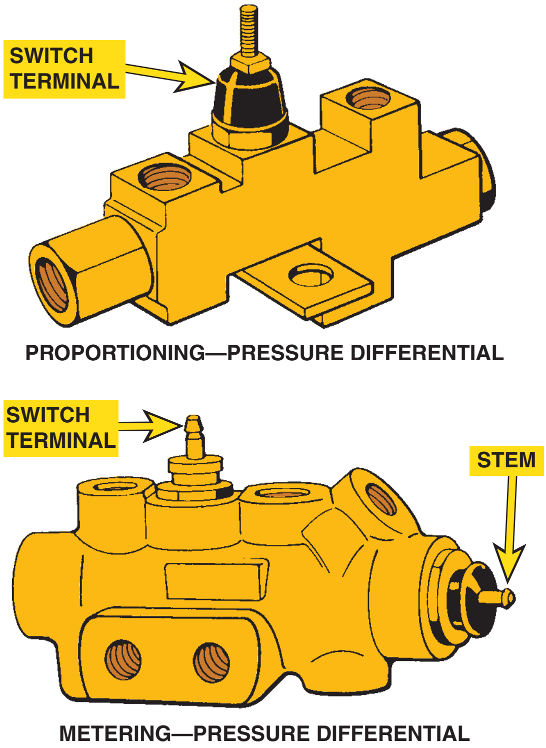

SWITCH TERMINAL
PROPORTIONING—PRESSURE DIFFERENTIAL
SWITCH TERMINAL
STEM
METERING—PRESSURE DIFFERENTIAL

FIGURE 95–44 Typical two-function combination valves.

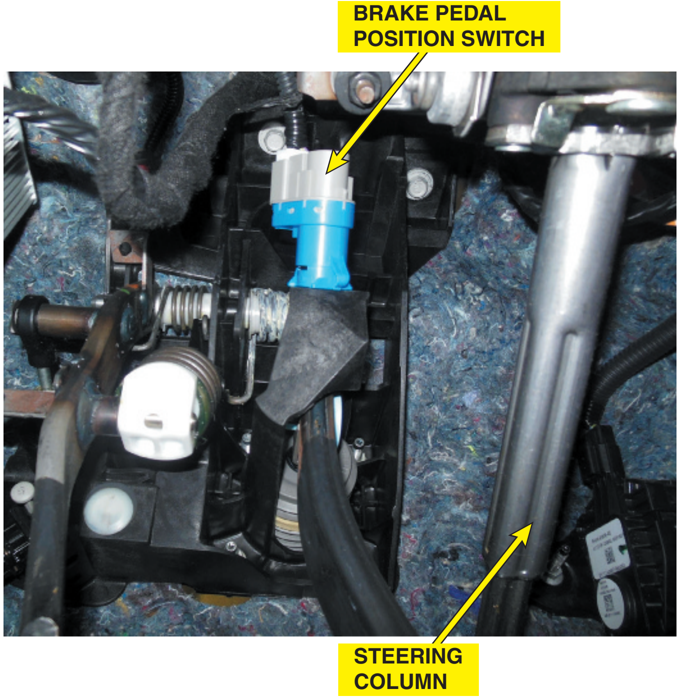

BRAKE PEDAL POSITION SWITCH
STEERING COLUMN

FIGURE 95–45 The brake pedal position (BPP) sensor (switch) and arm mounts to the brake pedal, under the dash.

BRAKE PEDAL POSITION SENSOR/SWITCH

PURPOSE AND FUNCTION On older vehicles, the brake switch was used to turn on the brake lights. Most new vehicles use the **brake pedal position (BPP) sensor** or switch as an input to the body computer for many functions, including the following:

- Brake lights
- ABS input signal
- Traction control is disabled when the brake pedal is depressed
- Electronic stability control (ESC) system input signal

Vehicles with ABS and ESC may also use a brake pedal position sensor in addition to the brake pedal switch. This sensor is a three-wire potentiometer that returns a variable voltage signal to the ABS controller to indicate the position of the brake pedal. ● **SEE FIGURE 95–45**.

BRAKE LIGHT SWITCH TESTING The brake light switch or sensor is most easily checked with the use of a scan tool. Both the powertrain data list and the ABS data list show the brake switch as an "ON/OFF" status when the pedal is pressed. A DMM (digital multimeter) set to ohms can be used to check a brake switch on or off the vehicle. Access the two wires from the switch and back probe the connectors with the meter test leads. ● **SEE FIGURES 95–46 AND 95–47**.

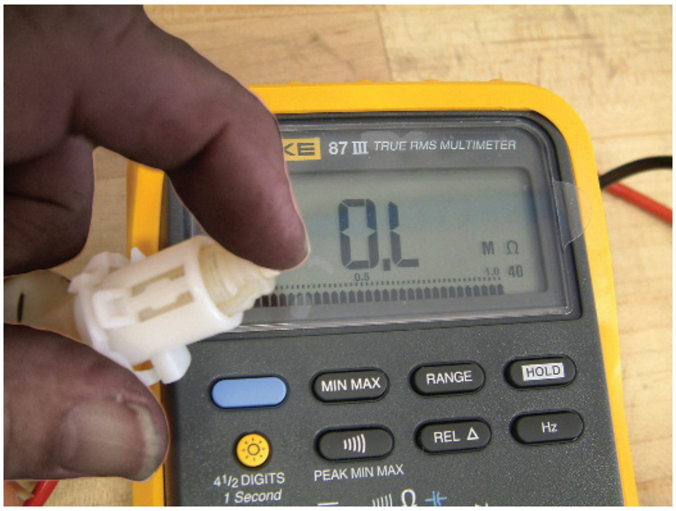


FIGURE 95–46 With the plunger pressed in (pedal up), the meter should show an open circuit (switch open).

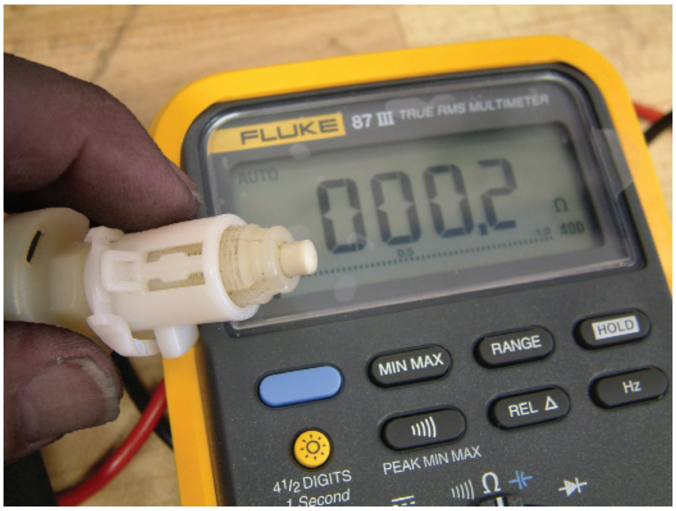


FIGURE 95–47 With the plunger released (pedal down), the switch should show very low resistance (switch closed).

TECH TIP

No Valves Can Cause a Pull to One Side

When diagnosing a pull to one side during braking, some technicians tend to blame the metering valve, the proportioning valve, the pressure-differential switch, or the master cylinder itself.

Just remember that if a vehicle pulls during braking, the problem *has* to be due to an individual wheel brake or brake line. The master cylinder and all the valves control front or rear brakes together or diagonal brakes and cannot cause a pull if not functioning correctly.

REVIEW QUESTIONS

1. What does Pascal's law state?
2. What are the symptoms of a faulty master cylinder?
3. What could cause the red brake warning lamp to come on during driving?
4. How do the metering and proportioning valves work?
5. What is the difference between a brake pedal switch and a brake pedal sensor?

CHAPTER QUIZ

1. What law of hydraulics does the brake system use?
   - **a.** Ohm's Law
   - **b.** Pascal's Law
   - **c.** Watt's Law
   - **d.** All of the above
2. The primary brake circuit fails due to a leak in the lines, leaving the secondary section of a front/rear split master cylinder. Technician A says that the driver will notice a lower-than-normal brake pedal and some reduced braking power. Technician B says that the brake pedal will "grab" higher than normal. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Two technicians are discussing a problem where the brake pedal travels too far before the vehicle starts to slow. Technician A says that the brakes may be out of adjustment. Technician B says that one circuit from the master cylinder may be leaking or defective. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Air in the lines causes what type of problem?
   - **a.** Vibration in the brake pedal during stops
   - **b.** Low spongy brake pedal
   - **c.** Brake noise
   - **d.** Hard brake pedal

5. Technician A says the metering valve controls the flow of brake fluid to the front brakes. Technician B says that proportioning valve is used to control the brake fluid pressure to the rear brakes. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. A typical brake pedal switch is ___________.
   - **a.** electrically normally open
   - **b.** electrically normally closed
   - **c.** checked using an ammeter
   - **d.** checked using a special tester
7. A combination valve could include ___________.
   - **a.** metering and proportioning valves
   - **b.** proportioning valve and pressure-differential switch
   - **c.** proportioning and metering valves and pressure-differential switch
   - **d.** Any of the above, depending on the make and model of the vehicle
8. Technician A says a pull to the right during braking could be caused by a defective metering valve. Technician B says a pull to the left could be caused by a defective proportioning valve. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. Brake fluid pressure is measured in what unit?
   - **a.** Square inches
   - **b.** Pounds
   - **c.** Inches
   - **d.** PSI
10. A vehicle with dynamic rear proportioning (DRP) uses ___________ to control rear-wheel lockup.
   - **a.** the ABS controller
   - **b.** ABS solenoids
   - **c.** wheel speed sensors
   - **d.** All of the above

Chapter

96

BRAKE FLUID, LINES, AND BLEEDING

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the purpose, function, and properties of brake fluids.
- Discuss brake fluid specifications.
- Describe brake service procedures and precautions.
- Discuss the use of brake lines.
- Discuss the need for brake bleeding.
- Discuss the various methods of loosening the brake bleeder valve.
- Describe the bleeding sequence for most vehicles.
- Describe the manual bleeding procedure.
- Discuss how to vacuum bleed the hydraulic brake system.
- Discuss how to gravity bleed the hydraulic brake system.
- Discuss how to pressure bleed the hydraulic brake system.
- Describe how to bleed the ABS hydraulic unit.
- Describe brake fluid replacement or flushing.

KEY TERMS:

Armored brake line 1115 • Bleeder valve 1119 • Brake bleeding 1118 • Brake fluid 1108 • Brake pipes 1113 • Brake tubing 1113 • DOT 3 1109 • DOT 4 1109 • DOT 5 1110 • DOT 5.1 1110 • Double flare 1114 • Flexible brake hoses 1117 • Gravity bleeding 1122 • Hygroscopic 1109 • ISO 1114 • Non-hygroscopic 1110 • Polyglycol 1108 • Power bleeding 1123 • Pressure bleeding 1123 • Silicone brake fluid 1110 • Single stroke bleeding method 1120 • Vacuum bleeding 1121

BRAKE FLUID

PURPOSE AND FUNCTION **Brake fluid** is designed to function in the hydraulic brake system under all operating conditions. Brake fluid boiling point is one of the most critical aspects and ratings for brake fluid. As brake fluid ages, it absorbs moisture, which lowers its boiling point and causes increased corrosion of the brake system components. All automotive experts agree that brake fluid should be changed regularly as part of normal routine service. Even though the driver may not notice an immediate improvement, the reduced corrosion will eventually result in less money being spent for brake system component replacement in the future. Getting the old low-boiling-point brake fluid out of the system could prevent a total loss of brakes due to brake fluid boiling. All brake fluids must be able to pass tests for the following:

1. Fluidity at low temperatures
2. Controlled percentage loss due to evaporation at high temperatures (tested at 212°F [100°C])
3. Compatibility with other brake fluids
4. Resistance to oxidation
5. Specific effects on rubber, including the following:
    a. No disintegration
    b. No increase in hardness of the rubber tested
    c. Limited amount of decrease in hardness of the rubber

PHYSICAL PROPERTIES Brake fluid is made from a combination of various types of glycol, a non-petroleum-based fluid. Brake fluid is a polyalkylene-glycol-ether mixture called **polyglycol** for short. All *polyglycol brake fluid is clear to amber in color*. Brake fluid has to have the following characteristics:

- A high boiling point
- A low freezing point
- No ability to damage rubber parts in the brake system

BRAKE FLUID SPECIFICATIONS

FMVSS 116 All automotive brake fluid must meet Federal Motor Vehicle Safety Standard (FMVSS) 116. The Society of Automotive Engineers (SAE) and the Department of Transportation (DOT) have established brake fluid specification standards. ● **SEE CHART 96–1**.

The wet boiling point is often referred to as "equilibrium reflux boiling point" (ERBP). ERBP refers to the method in the specification (SAE J1703) by which the fluid is exposed to moisture and tested.

DOT 3		DOT 4	DOT 5.1	DOT 5
Dry Boiling Point				
°F	401	446	500	500
°C	205	230	260	260
Wet Boiling Point				
°F	284	311	356	356
°C	140	155	160	180

CHART 96–1

Chart showing the type of brake fluid and the wet and dry boiling temperatures for each rating.

FREQUENTLY ASKED QUESTION

What Is "Synthetic" Brake Fluid?

All glycol brake fluids are synthetic and are not petroleum-based. Brake fluid manufacturers get calls every week from people who have questions about brake fluid. For example, some are concerned because the old familiar brands have changed from "premium" to "synthetic" on the bottle. The DOT class system sets standards and testing procedures only; the ingredients used are up to the manufacturer. If it meets the standards, it will qualify as "brake fluid." Based on a combination of the properties determined by testing, glycol-based brake fluids are labeled DOT 3, 4, or 5.1 and all are synthetic.

DOT 3 **DOT 3** brake fluid is the type most often used. There are, however, certain important characteristics.

1. DOT 3 absorbs moisture. According to the SAE, DOT 3 can absorb 2% of its volume in water per year. Moisture is absorbed by the brake fluid through microscopic seams in the brake system and around seals. Over time, the water will corrode the system and thicken the brake fluid. The moisture can also cause a spongy brake pedal, due to reduced vapor-lock temperature. ● **SEE FIGURES 96–1 AND 96–2.**

DOT 3
Brake Fluid
For ABS, Disc And Drum Brakes
Conforms to DOT 3, 49CFR 571.116
and FMVSS 116, SAE-J1703
WARNING
IRRITANT

FIGURE 96–1 Brake fluid can absorb moisture from the air even through plastic, so many experts recommend that brake fluid be purchased in metal containers, if possible.

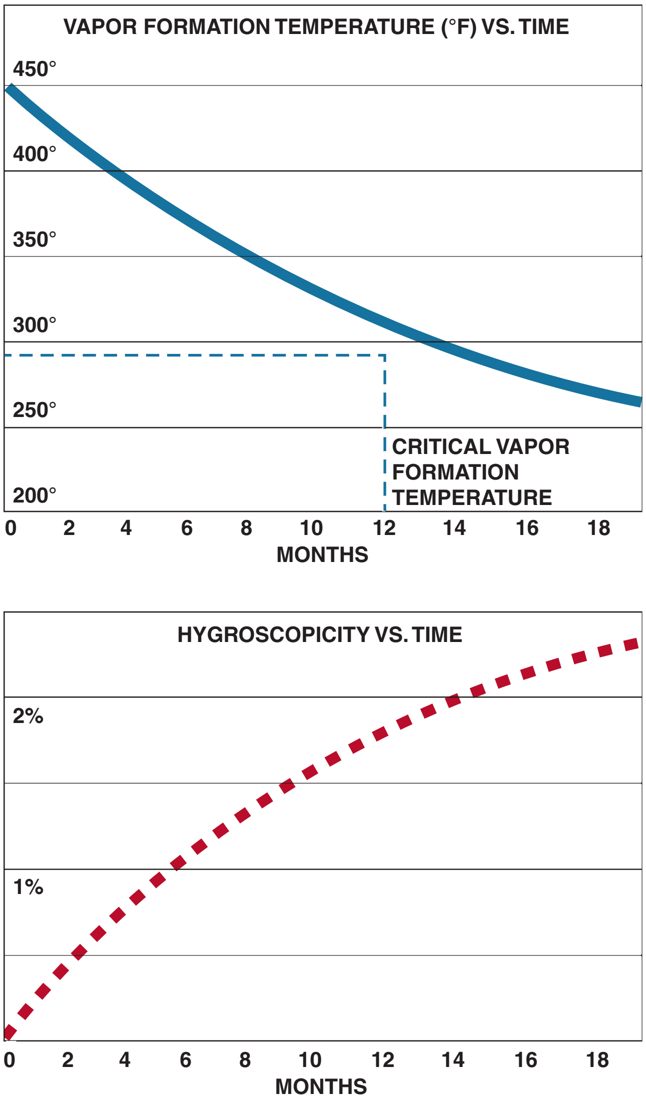


FIGURE 96–2 Brake fluid absorbs moisture from the air at the rate of about 2% per year. As the brake fluid absorbs water, its boiling temperature decreases.

2. DOT 3 must be used from a sealed (capped) container. If allowed to remain open for any length of time, DOT 3 will absorb moisture from the surrounding air, which is called **hygroscopic**.
3. Always check the brake fluid recommendations on the top of the master cylinders of imported vehicles before adding DOT 3.

CAUTION: DOT 3 brake fluid is a very strong solvent and can remove paint! Care is required when working with DOT 3 brake fluid to avoid contact with the vehicle's painted surfaces. It also takes the color out of leather shoes.

DOT 4 **DOT 4** brake fluid is the specified brake fluid for use in many European vehicles. DOT 4 is polyglycol based but has borate esters added to provide an extra buffer for the fluid against acids that can form in the moisture that has been absorbed in the fluid when it is heated. DOT 4 is approximately double the cost of DOT 3. DOT 4 can often be used where DOT 3 is used and even though the two types of brake fluid are compatible and miscible (able to be mixed), some vehicle manufacturers recommend that DOT 3 and DOT 4 not be mixed. If DOT 4 is to be used, the system should be purged of all of the old DOT 3 and replaced with DOT 4.

FREQUENTLY ASKED QUESTION

What Are the Types of DOT 4 Brake Fluid?

There are several types or specifications under the DOT 4 designation including the following:

- **DOT 4**—Specified for use in many European vehicles and some domestic vehicles. ● **SEE FIGURE 96–3**.
- **DOT 4 (long life)**
- **DOT 4+**—Specified for use in many Mercedes and Volvo vehicles.
- **DOT 4 LV (low viscosity)**—Specified for use in some newer vehicles.
- **DOT 4 racing brake fluid**—Usually blue in color to make it easy to see when all of the old fluid has been purged from the system during a brake fluid replacement procedure.

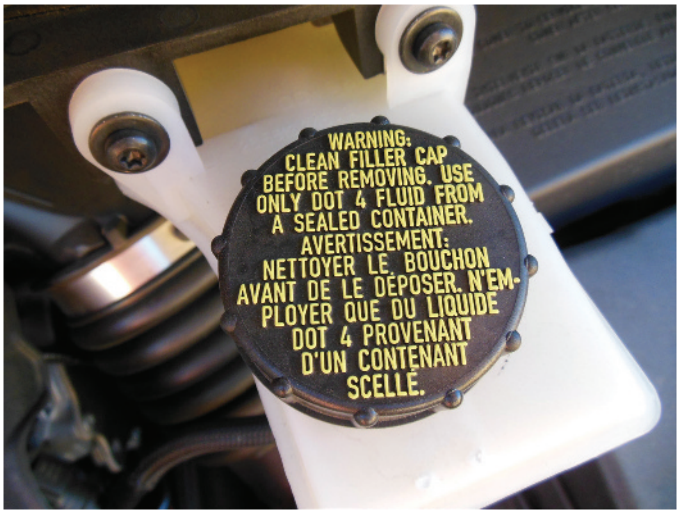


FIGURE 96–3 This Ford Escape requires DOT 4 as stated on the cap of the master cylinder.

NOTE: Because brake fluid absorbs moisture over time, many vehicle manufacturers recommend changing the brake fluid as part of the standard services to be performed routinely. The typical recommended brake fluid change interval is every two years or every 30,000 miles (48,000 km), whichever comes first. This is particularly important for vehicles equipped with an antilock brake system (ABS) because of the problem of expensive brake component wear or corrosion caused by contaminated brake fluid.

DOT 5.1 **DOT 5.1** brake fluid is a non-silicone-based polyglycol fluid and is clear to amber in color. This severe duty fluid has a boiling point of over 500°F equal to the boiling point of silicone-based DOT 5 fluid. Unlike DOT 5, DOT 5.1 can be mixed with either DOT 3 or DOT 4 according to brake fluid manufacturer's recommendations.

CAUTION: Some vehicle manufacturers such as Chrysler do not recommend the use of or the mixing of other types of polyglycol brake fluid and specify the use of DOT 3 brake fluid only. Always follow the vehicle manufacturer's recommendation.

DOT 5 **DOT 5** brake fluid is commonly called **silicone brake fluid** and is made from polydimethylsiloxanes. DOT 5 brake fluid is purple (violet) in color to distinguish it from DOT 3 or DOT 4 brake fluid. It does not absorb any water and is therefore called **non-hygroscopic**. Even though DOT 5 does not normally absorb water, it is still tested using standardized SAE procedures in a humidity chamber. After a fixed amount of time, the brake fluid is measured for boiling point. Since it has had a chance to absorb moisture, the boiling point after this sequence is called the minimum wet boiling point. Silicones have about three times the amount of dissolved air as glycol fluids (about 15% of dissolved air versus only about 5% for standard glycol brake fluid). It is this characteristic of silicone brake fluid that causes the most concern about its use.

1. Silicone brake fluid has an affinity for air; therefore, it is more difficult to bleed the hydraulic system of trapped air.
2. The trapped air expands with increasing temperature. This causes the brake pedal to feel "mushy" because the pressure exerted on the hydraulic system simply compresses the air in the system and does not transfer the force to the wheel cylinders and calipers as it should.

NOTE: The characteristic of DOT 5 silicone brake fluid to absorb air is one of the major reasons why it is not recommended for use with an antilock brake system (ABS). In an ABS, valves and pumps are used that can aerate the brake fluid. Brake fluid filled with air bubbles cannot properly lubricate the ABS components and will cause a low, soft brake pedal.

3. The air trapped in the silicone brake fluid can also "off-gas" at high altitudes, causing a mushy brake pedal and reduced braking performance. DOT 5 brake fluid has been known to create a braking problem during high-altitude (over 5,000 ft [1,500 m]) and high-temperature driving. The high altitude tends to vaporize (off-gassing) some parts of the liquid, creating bubbles in the brake system, similar to having air in the brake system.
4. DOT 5 brake fluid should not be mixed with any other type of brake fluid. Therefore, the entire braking system must be completely flushed and refilled with DOT 5.
5. DOT 5 does not affect rubber parts and will not cause corrosion.
6. DOT 5 is expensive. It is approximately four times the cost of DOT 3 brake fluid. ● **SEE FIGURE 96–4**.

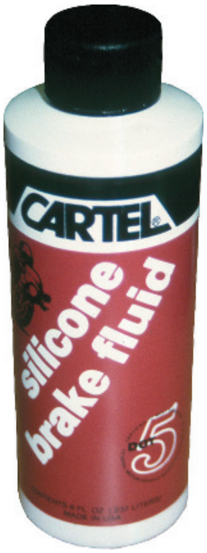


FIGURE 96–4 DOT 5 brake fluid is used mostly in motorcycles because if spilled, it will not hurt painted surfaces.

FREQUENTLY ASKED QUESTION

What Is Hydraulic Brake System Mineral Oil?

Some older French-built Citroen and British-designed Rolls-Royce vehicles used hydraulic system mineral oil (HSMO) as part of their hydraulic control systems. The systems in these vehicles use a hydraulic pump to pressurize hydraulic oil for use in the suspension leveling and braking systems.

CAUTION: Mineral hydraulic oil should never be used in a braking system that requires DOT 3 or DOT 4 polyglycol-based brake fluid.

If any mineral oil, such as engine oil, transmission oil, or automatic transmission fluid (ATF), gets into a braking system that requires glycol brake fluid, every rubber part in the entire braking system must be replaced. Mineral oil causes the rubber compounds that are used in glycol brake fluid systems to swell. ● **SEE FIGURE 96–5**.

To help prevent hydraulic system mineral oil from being mixed with glycol brake fluid, hydraulic mineral oils are *green.*

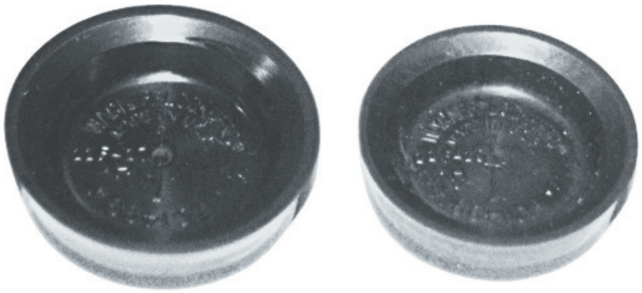


FIGURE 96–5 Both rubber sealing cups were exactly the same size. The cup on the left was exposed to mineral oil. Notice how the seal greatly expanded.

BRAKE FLUID INSPECTION AND TESTING The brake fluid should be inspected regularly by performing the following tests:

1. **Proper level.** The brake fluid level should be above the minimum level (labeled MIN) and below the maximum (labeled MAX) on the side of the master cylinder reservoir. Do not add brake fluid unless the entire brake system is carefully inspected for worn brake pads and shoes and for signs of any external leakage.
2. **Color/condition.** New brake fluid is clear or amber in color. If the brake fluid is black or discolored like black coffee or coffee with cream, the fluid should be changed. ● **SEE FIGURE 96–6**.
3. **Tested using a tester or test strips.** Often, brake fluid does not look as if it is bad but has absorbed moisture enough to reduce its effectiveness. Test strips can be used to measure copper ions that increase as the brake fluid becomes deteriorated. The copper comes from sealing washers and other brass or copper brake system components. ● **SEE FIGURE 96–7**.
4. **Boiling point tester.** An electronic tester can be used to measure the actual boiling temperature of the brake fluid. The tester probe is inserted into the brake fluid and then a

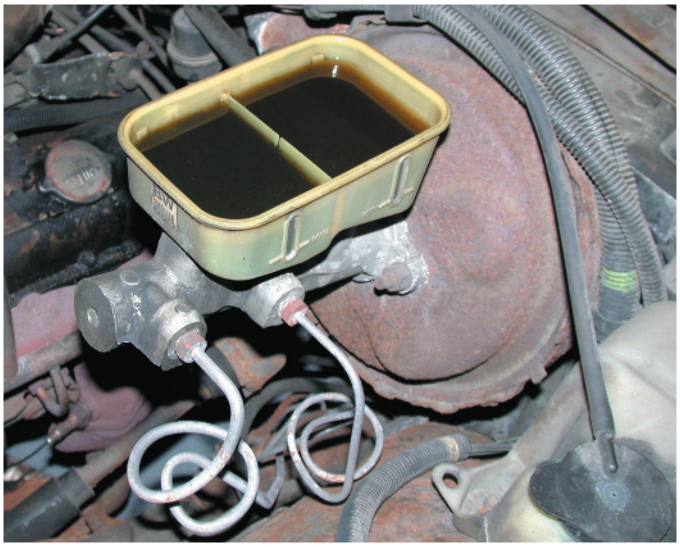
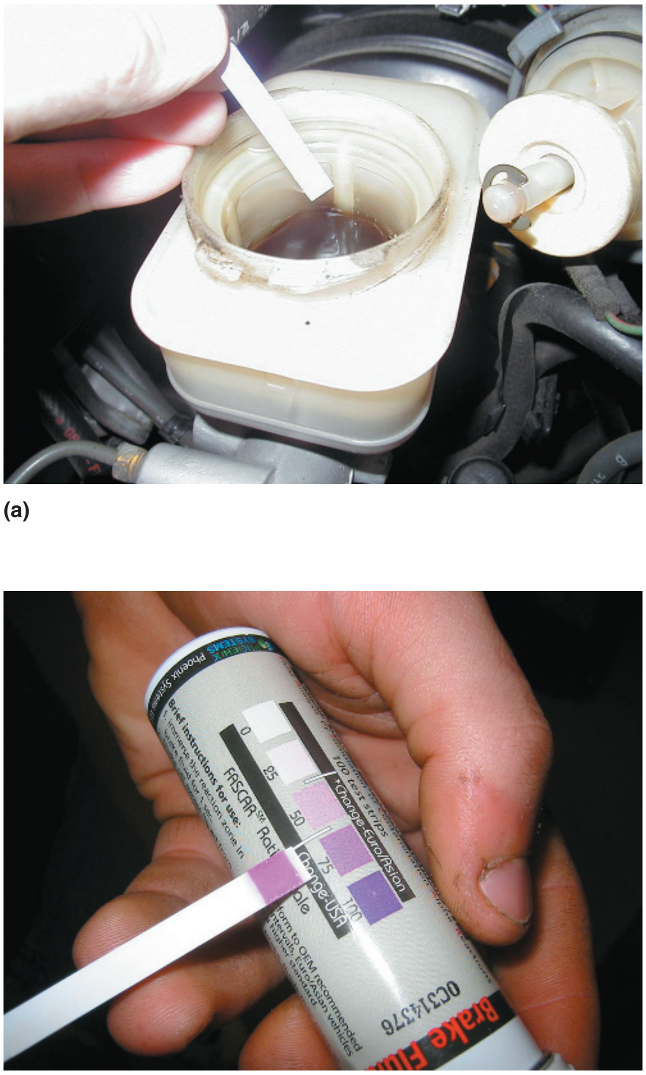


FIGURE 96–6 If the brake fluid is black in color, it should be replaced.



(a)

(b)

FIGURE 96–7 (a) A brake fluid test strip is being used to test the condition of the brake fluid. (b) The color of the test strip is then compared with a chart on the package, which indicates the condition and if the fluid should be replaced.

CASE STUDY

The Sinking Brake Pedal

This author has experienced what happens when brake fluid is not changed regularly. Just as many technicians will tell you, we do not always do what we know should be done to our own vehicles. While driving a four-year-old vehicle on vacation in very hot weather in a mountainous country, the brake pedal sank to the floor. When the vehicle was cold, the brakes were fine. But after several brake applications, the pedal became soft and spongy and sank slowly to the floor if pressure was maintained on the brake pedal. Because the brakes were okay when cold, I knew it had to be boiling brake fluid. Old brake fluid (four years old) often has a boiling point under 300°F (150°C). With the air temperature near 100°F (38°C), it does not take much more heat to start boiling the brake fluid. After bleeding over a quart (1 L) of new brake fluid through the system, the brakes worked normally. I'll never again forget to replace the brake fluid as recommended by the vehicle manufacturer.

Summary:

Complaint—Brake pedal would sink to the floor when driving in mountainous country.
Cause—The brake fluid was boiling causing the loss of brakes.
Correction—The brake fluid was replaced and the system bled.

button is pushed and the boiling temperature is displayed. ● **SEE FIGURE 96–8**.

5. **Brake fluid contamination test.** If brake fluid is mixed with any mineral oil, such as engine oil, power steering fluid, or automatic transmission fluid, rubber components will swell and cause brake system failure. To check for possible contamination, remove the reservoir cover from the master cylinder. If the rubber diaphragm is swelled or distorted, brake fluid contamination is likely. To check the brake fluid, use a Styrofoam cup filled with water.
   - Place a teaspoon (1 ml) of brake fluid from the master cylinder into the water.
   - Pure brake fluid will completely dissolve in the water. Petroleum or mineral oil fluids will float on the surface of the water and retain their color. Petroleum fluids will also dissolve the Styrofoam cup at the waterline.
   - If the brake fluid is contaminated, the entire braking system must be drained and flushed and all rubber components replaced.

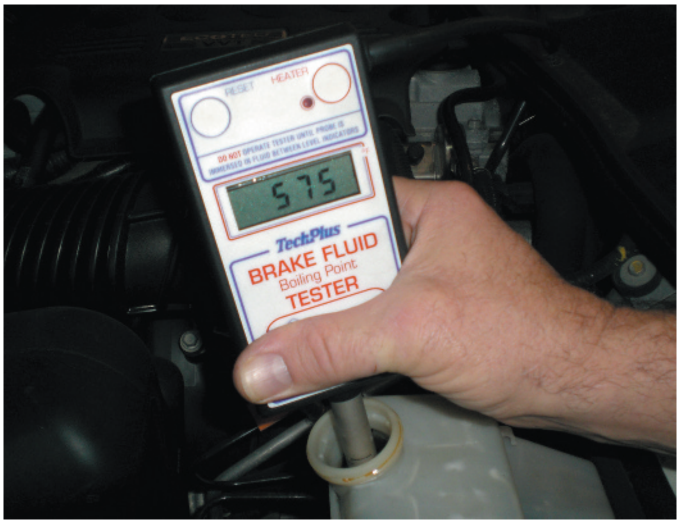

RESET
HEATER
DO NOT OPERATE TESTER UNTIL PROBE IS IMMERSED IN FLUID BETWEEN LEVEL INDICATORS
575
TechPlus
BRAKE FLUID
Boiling Point
TESTER

FIGURE 96–8 An electronic tester that measures the boiling temperature of the brake fluid is useful to help determine if the brake fluid needs to be replaced. The boiling temperature of brake fluid decreases as the fluid ages.

BRAKE FLUID SERVICE PROCEDURES

STORAGE OF BRAKE FLUID

1. Store brake fluid only in its original container.
   - To help prevent possible contamination with moisture, air, or other products, purchase brake fluid in small containers.
   - Keep all brake fluid containers tightly closed to prevent air (containing moisture) from being absorbed.
2. Before opening a brake fluid container, remove any dirt, moisture, or other contamination from the top and outside of the container.
3. When a brake fluid container is empty, it should be discarded—the container should never be used for anything except brake fluid.
4. Do not transfer brake fluid to any other container that may have contained oil, kerosene, gasoline, antifreeze, water, cleaners, or any other liquids or chemicals.
5. Do not reuse brake fluid that has been siphoned from another vehicle or drawn out during a brake bleeding operation. (Brake bleeding means to open special bleeder valves in the hydraulic system to rid the system of any trapped air.)
6. Use only fresh, new brake fluid for flushing the hydraulic brake system.

CAUTION: Alcohol or flushing fluids should not be used because they cannot be totally removed and will contaminate the system. Disassembled parts, however, can and should be cleaned with denatured alcohol or spray brake cleaner where the parts can be visually inspected to be free of cleaning solutions.

BRAKE FLUID HANDLING AND DISPOSAL Polyglycol brake fluid presents little toxicity hazard, but for some individuals, brake fluid may produce moderate eye and skin irritation. For good safety practice, protective clothing and safety glasses or goggles should be worn. Brake fluid becomes a hazardous waste if spilled onto open ground, where it can seep into groundwater. The disposal requirements for brake fluid spilled onto open ground vary with the exact amount spilled and other factors. Refer to local EPA guidelines and requirements for the exact rules and regulations in your area.

CASE STUDY

The Pike's Peak Brake Inspection

All vehicles must stop about halfway down Pike's Peak Mountain in Colorado (14,110 ft [4,300 m]) for a "brake inspection." When this author stopped at the inspection station, a uniformed inspector simply looked at the right front wheel and waved us on. I pulled over and asked the inspector what he was checking. He said that when linings and drums/rotors get hot, the vehicle loses brake effectiveness. But if the brake fluid boils, the vehicle loses its brakes entirely. The inspector was listening for boiling brake fluid at the front wheel and feeling for heat about 1 ft (30 cm) from the wheel. The inspector used an infrared pyrometer to measure the front wheel brakes and if the brakes were too hot to continue, you would be instructed to pull over and wait for the brakes to cool. The inspector recommended placing the transmission into a lower gear, which uses the engine to slow the vehicle during the descent without having to rely entirely on the brakes.

Summary:

Complaint—Vehicle was stopped for an inspection.
Cause—If the brakes are too hot, the brake fluid can boil and as a result a total loss of brakes is likely.
Correction—Informed driver that this is normal procedure and a safety precaution.

BRAKE LINES

CONSTRUCTION High-pressure double-walled steel brake lines or high-strength flexible lines are used to connect the master cylinder to each wheel. The steel brake lines are also called **brake pipes** or **brake tubing**. Brake lines carry brake fluid from the master cylinder to the wheel cylinder and brake calipers. The brake lines contain and direct the pressure of the brake hydraulic system. Most of the total length of the brake line consists of rigid tubing. For maximum strength and durability, all brake systems use double-walled brake tubing made from plated steel sheet. There are two types of double-walled tubing:

- Seamless
- Multiple ply ● **SEE FIGURE 96–9**.

All double-walled brake tubing is plated with tin, zinc, or other similar substances for protection against rust and corrosion. The Society of Automotive Engineers has guidelines for brake tubing.

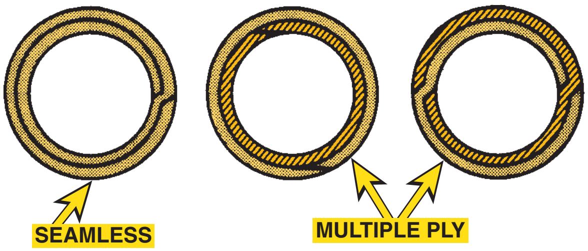


FIGURE 96–9 Steel brake tubing is double walled for strength and plated for corrosion resistance.

WARNING

Copper tubing should never be used for brake lines. Copper tends to burst at a lower pressure than steel.

SAE Standard J1047 specifies that a sample section of brake line must be able to withstand 8,000 PSI (55,000 kPa), plus other standards for resistance to fatigue, heat, rust, and corrosion.

STEEL BRAKE LINE COATINGS Because steel tube alone does not have adequate corrosion resistance, it requires a coating. The coatings in wide use include

- Aluminum-rich paint (called AlGal)
- Nylon-coated (called NyGal)
- Zinc
- Terne plate (lead and tin alloy)
- Epoxy
- PVF (Polyvinylfluoride)—olive green color

While these coatings have been effective, the liquid sodium chloride and rock salt used to de-ice winter roads break down and will eventually destroy steel tubing lines.

COPPER-NICKEL BRAKE LINES Copper-nickel brake line is commonly referred to as "90-10 copper" because it contains about 90% copper and 10% nickel. Copper-nickel brake lines have been used on several European vehicle brake systems since the 1970s, including

- Volvo
- Audi
- Porsche
- Aston Martin

Copper-nickel alloy brake tubing meets SAE Standard J1047 and ISO 4038, meeting all international and U.S. requirements for brake tubing and has the strength of steel lines, but is much more corrosion-resistant. This type is also pliable, making flaring and bending easier than when using steel brake lines.

FREQUENTLY ASKED QUESTION

Why Is the Government Asking Me to Wash My Vehicle?

If you live where salt is used to clear the roads of snow and ice, U.S. safety regulators have a message for you: "Wash the underside of your vehicle." The message came from the National Highway Traffic Safety Administration (NTHSA), which closed a five-year investigation into rusting brake fluid lines which the agency said was caused by road salt and a lack of washing. The agency urged people in 20 cold-weather states and Washington, D.C., to get their car and truck undercarriages washed several times during and after the winter, and to get their brake lines inspected for rust and replace them if necessary. ● **SEE FIGURE 96–10**.

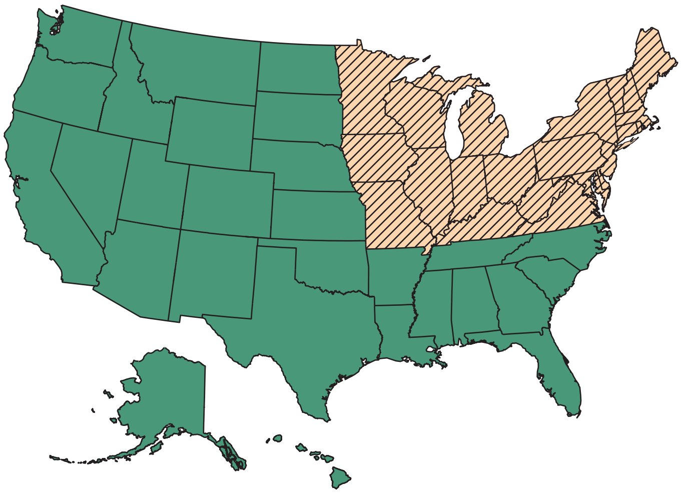


FIGURE 96–10 The rust prone states are areas where snow and the use of salt contribute to the brake line rust. Vehicles that operate outside this area also rust, but not to the extent that they do in the states known for rust problems.

TYPES OF FLARES All steel brake lines have one of two basic types of ends:

- **Double flare.** ● **SEE FIGURE 96–11**.
- **ISO**, which means International Standards Organization (also called a *ball flare* or *bubble flare*). ● **SEE FIGURE 96–12**.

BRAKE HOSE INSPECTION All brake lines, flexible hoses, and fittings should be visually inspected at least every year for the following faults:

- leaks
- dents
- kinks
- rust
- cracks

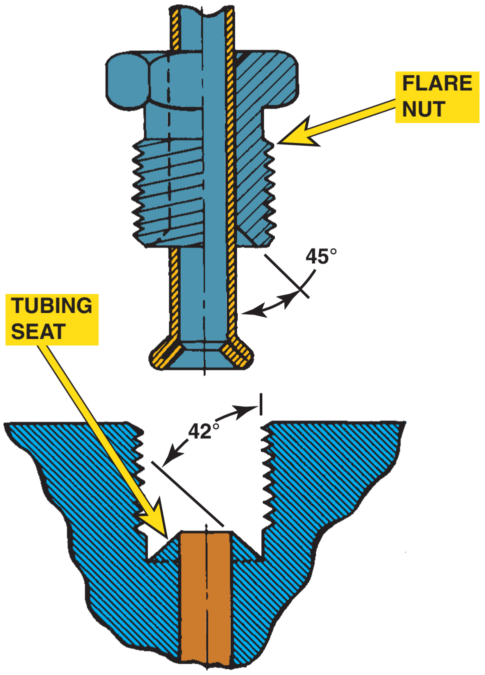


FIGURE 96–11 Because of the slight difference in flare angle, double-flare fitting seals cause a wedging action.

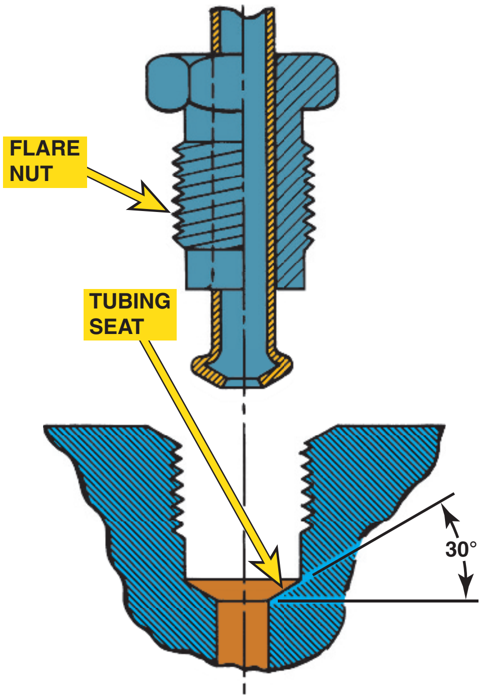


FIGURE 96–12 An ISO fitting, also called a ball or bubble flare.

- bulging
- wear
- loose fittings/supports

If any of these issues are found then the brake line/hoses should be replaced. Most experts recommend that if one flexible brake hose is replaced, then all should be replaced because they all were operating under the same conditions and if one fails, then the others may also fail soon.

BRAKE LINE REPLACEMENT If replacing a brake line, there are two options:

OPTION 1 Purchase pre-made lines in the diameter and length needed. Brake line can also be purchased in selected lengths already correctly flared. They are available in different diameters, the most commonly used with an outside diameter (OD) of

- 3/16 inch (4.8 mm)
- 1/4 inch (6.4 mm)
- 5/16 inch (7.9 mm)

OPTION 2 Cut and flare lines to match what is needed. When replacing steel brake lines, new steel tubing should be used and a double lap flare or an ISO flare needs to be completed at each end using a special flaring tool. Always follow the instructions that came with the flaring tool for best results. ● **SEE FIGURES 96–13 AND 96–14**.

⚠ WARNING

According to vehicle manufacturer's recommended procedures, compression fittings should never be used to join two pieces of steel brake line. Only use double-flare ends and connections, if necessary, when replacing damaged steel brake lines.

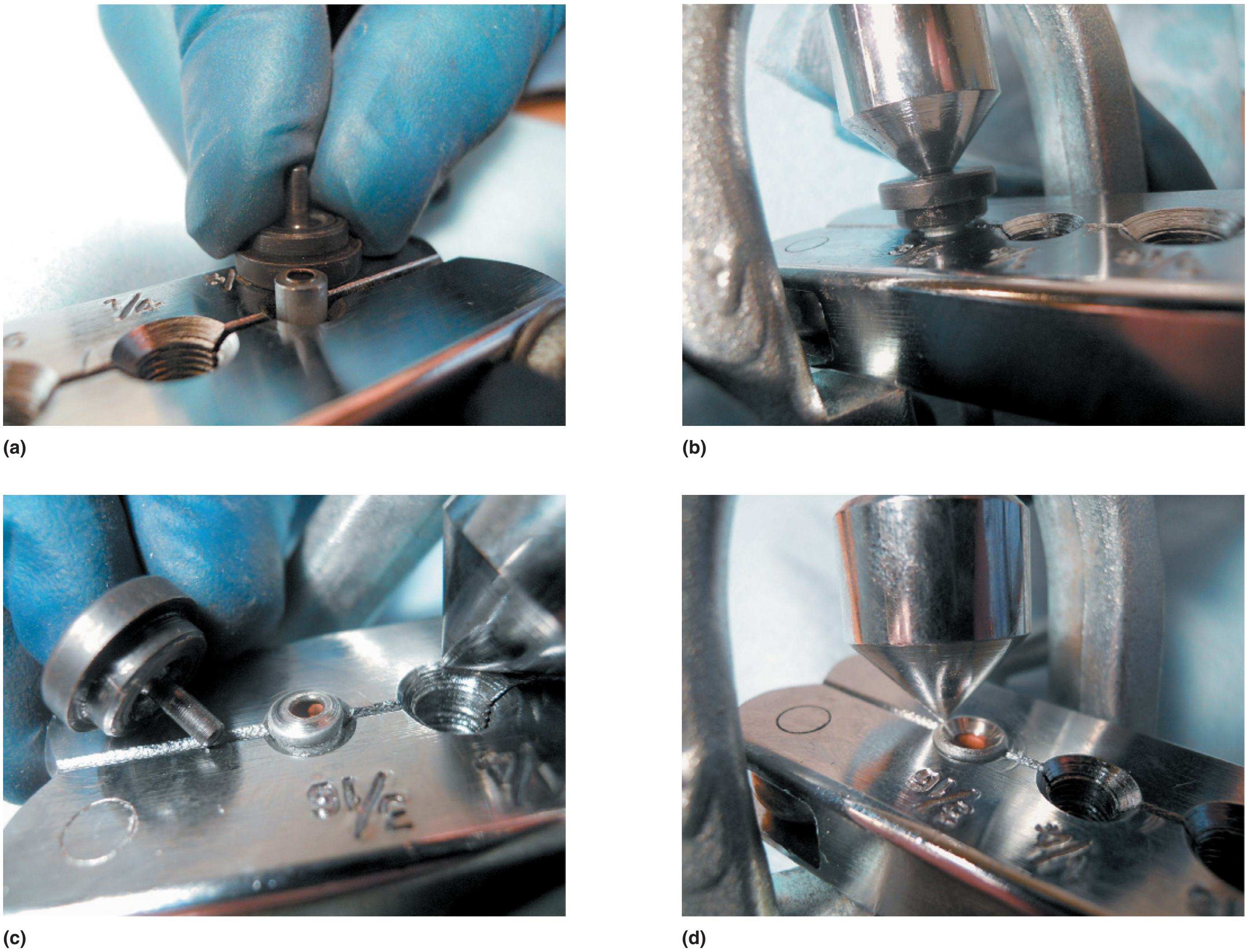

(a) (b) (c) (d)

FIGURE 96–13 Double flaring the end of a brake line. (a) Clamp the line at the correct height above the surface of the clamping tool using the shoulder of the insert as a gauge. (b) The insert is pressed into the end of the tubing. This creates the first bend. (c) Remove the insert and use the pointed tool to complete the overlap double flare. (d) The completed operation as it appears while still in the clamp.

COILED BRAKE LINE Steel brake line is often coiled to allow movement between the brake components without stress that could lead to metal fatigue and brake line breakage. The typical master cylinder attaches to the bulkhead of the vehicle and the combination valve is often attached to the frame. Because the body and frame are usually insulated from each other using rubber isolators, some movement occurs while driving. ● **SEE FIGURE 96–15**.

ARMORED BRAKE LINE In many areas of the brake system, the steel brake line is covered with a wire coil wrap. This type of brake line is called **armored brake line**. This armor is designed to prevent damage from stones and other debris that could dent or damage the brake line. If a section of armored brake line is to be replaced, armored replacement line should be installed. ● **SEE FIGURE 96–16**.

TECH TIP

Bend It Right the First Time

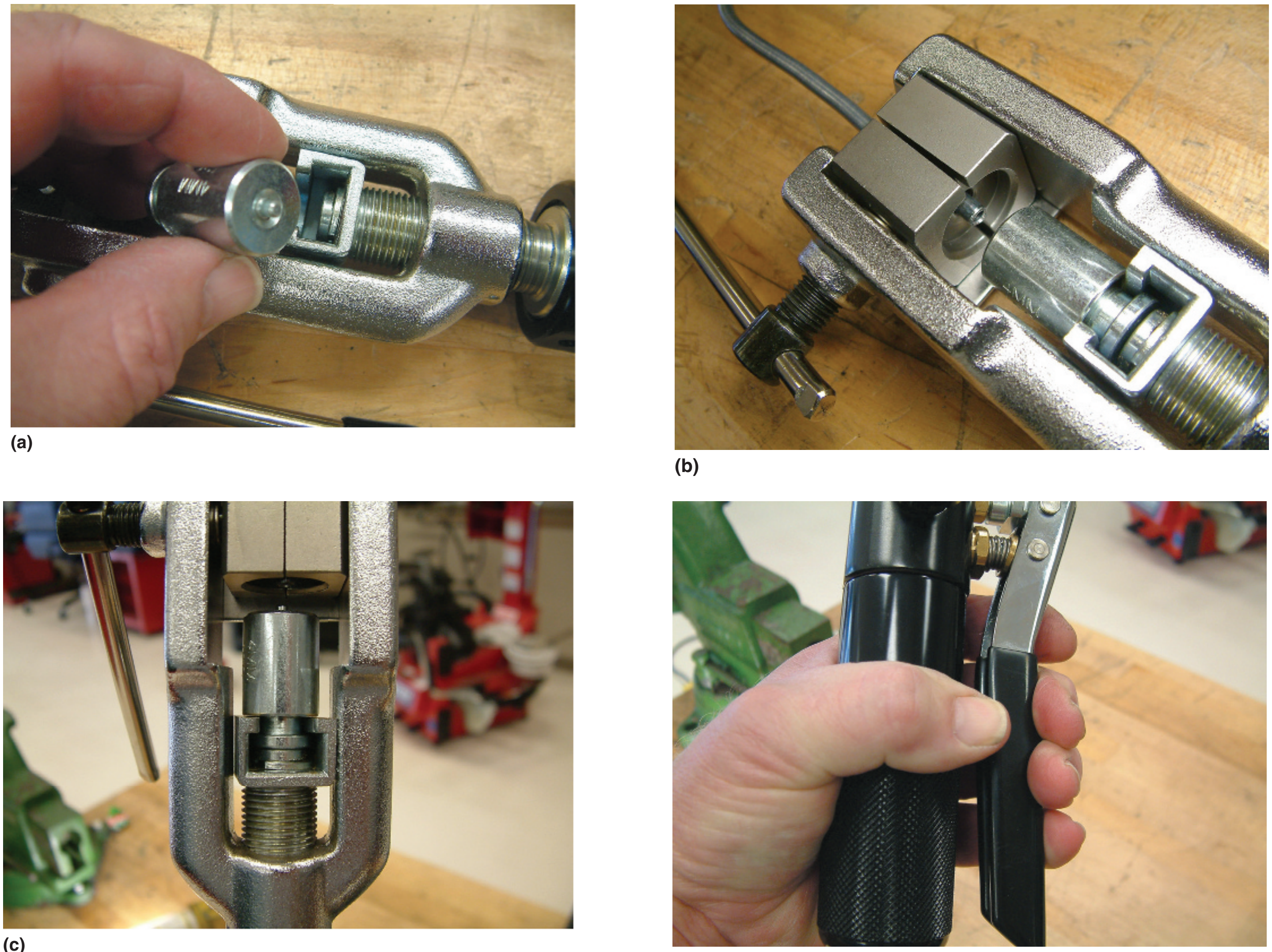
Replacing rusted or damaged brake line can be a difficult job. It is important that the replacement brake line be located in the same location as the original to prevent possible damage from road debris or heat from the exhaust. Often this means bending the brake line with many angles and turns. To make the job a lot easier, perform the following steps:

STEP 1 Use a stiff length of wire and bend the wire into the exact shape necessary.

STEP 2 Then use the wire as a pattern to bend the brake line.

STEP 3 Always use a tubing bender to avoid kinking the brake line. A kink not only restricts the flow of brake fluid, but also weakens the line. ● **SEE FIGURE 96–17**.

NOTE: Always use a tubing cutter instead of a hacksaw when cutting brake line. A hacksaw will leave a rough and uneven end that will not flare properly except when forming an ISO flare. A hacksaw is used to provide a rough surface to allow the flaring tool to grip the line during the procedure. Always check the instructions that came with the flaring tool for the exact procedure to follow. ● **SEE FIGURE 96–18.**

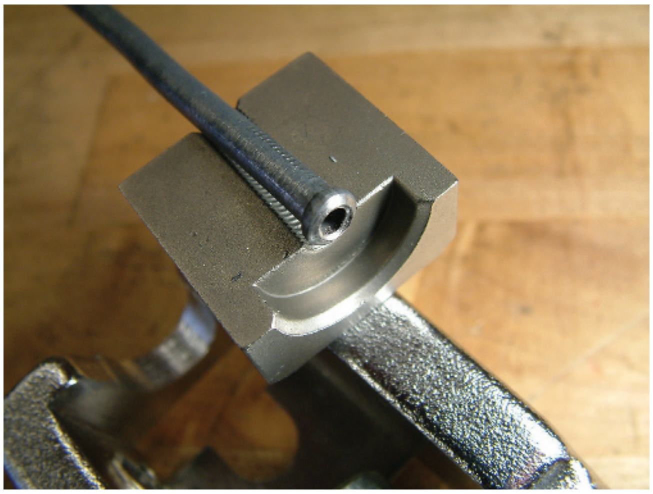


(a)

(b)

(c)

(d)



(e)

FIGURE 96–14 Making an ISO flare requires a special tool. (a) Select the proper size forming mandrel. (b) Clamp the tubing flush with the split die and place the mandrel into the tool. (c)Thread the tool handle in until the mandrel pilot seats into the tubing. (d) Close the tool valve and pump the handle until the mandrel seats in the die. (e) The strong hydraulic pressure forms the ISO flare.

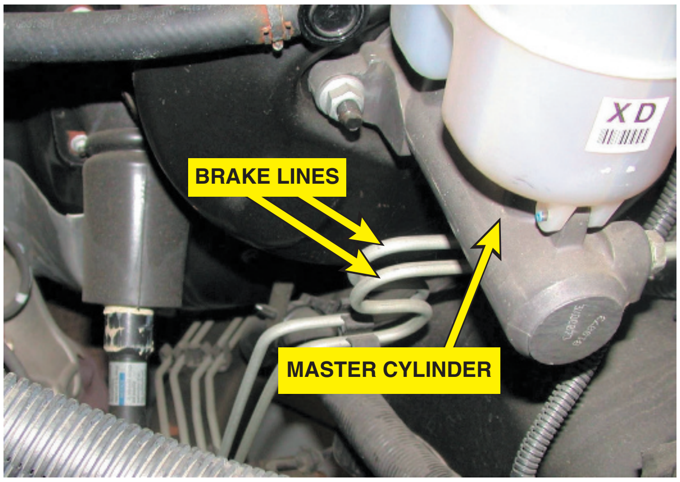


FIGURE 96–15 The coils in the brake line help prevent cracks caused by vibration.

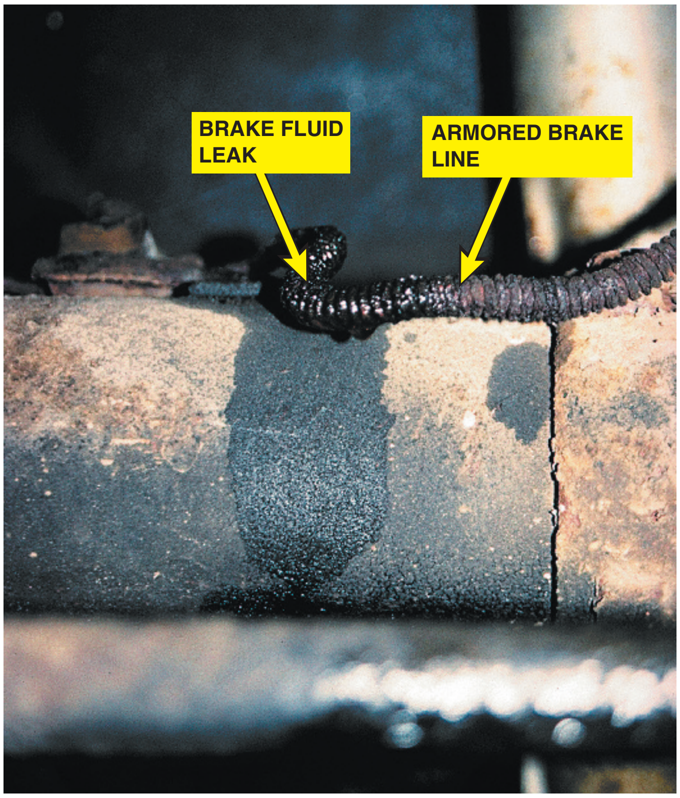


FIGURE 96–16 Armored brake line is usually used in the location where the line may be exposed to rock or road debris damage. Even armored brake line can leak and a visual inspection is an important part of any brake service.

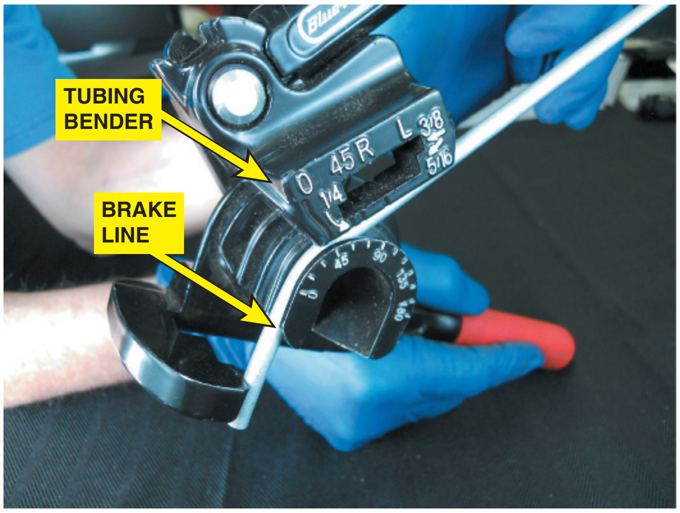


FIGURE 96–17 A tube bender being used to bend a brake line.

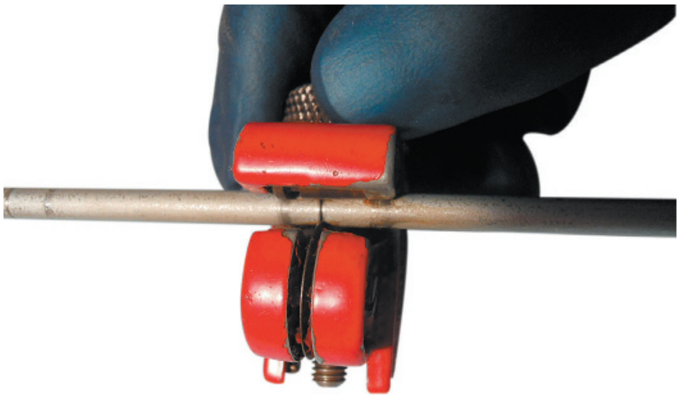


FIGURE 96–18 A tubing cutter is the preferred tool to use to cut brake line because it leaves a clean edge.

FLEXIBLE BRAKE HOSE **Flexible brake hoses** are used on each front wheel to allow for steering and suspension movement and at the rear to allow for rear suspension travel. ● **SEE FIGURE 96–19**.

Flexible brake hose is made from synthetic yarn (poly vinyl alcohol, abbreviated PVA) that is braided into position from multi-end yarn spindles. By braiding the yarn, all of the strands operate in tension and, therefore, have great strength to withstand braking system pressure over 1,000 PSI (6,900 kPa).

- A typical brake hose has an inner tube for moving the brake fluid and a cushion liner that is between the braided layers to prevent the braids from chafing. All three layers use ethylene-propylene-diene-monomer (EPDM)-type thermosetting polymers, which help prevent the hose from absorbing moisture from the outside air.
- An outside jacket is made from rubber and protects the reinforcement fabric from moisture and abrasion.
- The outside covering is also ribbed as part of the manufacturing process to hide surface blemishes. These ribs also make it easy for the technician to see if the hose is twisted. It is not unusual for flexible brake lines to become turned around and twisted when the disc brake caliper is removed and then replaced during a brake pad change. ● **SEE FIGURE 96–20**.

These rubber high-strength hoses can crack, blister, or leak and should be inspected at least every six months. ● **SEE FIGURE 96–21**.

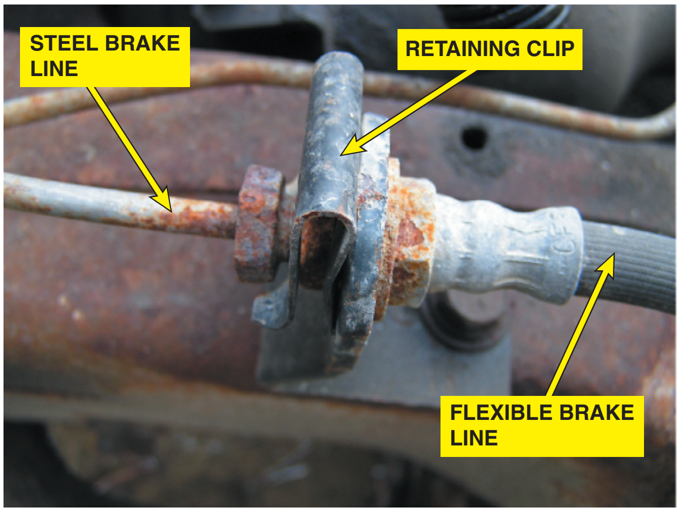


FIGURE 96–19 Flexible brake hoses are used between the frame or body of the vehicle and the wheel brakes. Because of suspension and/or steering movement, these flexible brake lines must be strong enough to handle high brake fluid pressures, yet remain flexible.

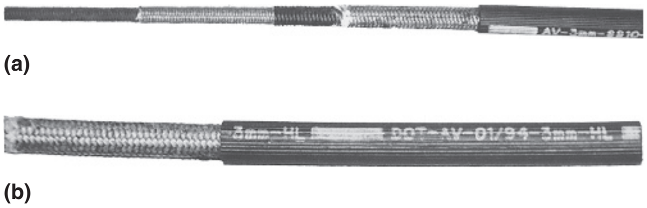


FIGURE 96–20 (a) Typical flexible brake hose showing the multiple layers of rubber and fabric. (b) The inside diameter (ID) is printed on the hose (3 mm).

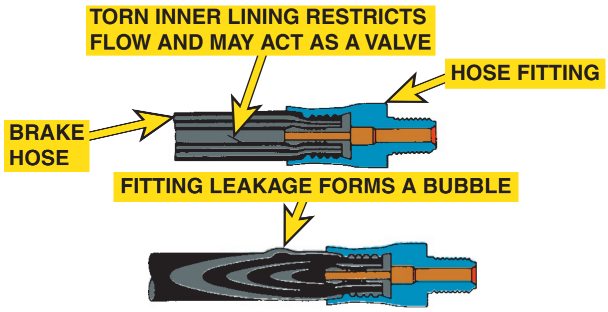

TORN INNER LINING RESTRICTS FLOW AND MAY ACT AS A VALVE
HOSE FITTING
BRAKE HOSE
FITTING LEAKAGE FORMS A BUBBLE

FIGURE 96–21 Typical flexible brake hose faults. Many faults cannot be seen, yet can cause the brakes to remain applied after the brake pedal is released.

A constricted brake hose can cause the brakes to remain applied, thereby causing excessive brake pad wear and unequal braking. A constricted flexible brake line can also cause the vehicle to pull to one side. ● **SEE FIGURE 96–22**.

CAUTION: Never allow a disc brake caliper to hang by the flexible brake line. Damage to the line can result. Always use a wire to support the weight of the caliper and always use two line wrenches when disconnecting or reattaching brake lines. ● SEE FIGURE 96–23.

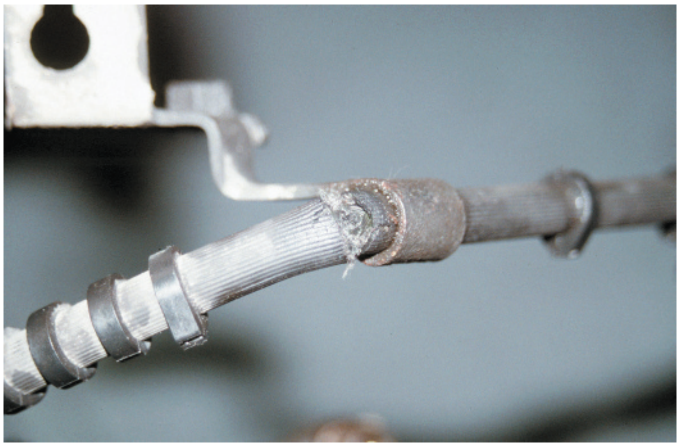


FIGURE 96–22 Flexible brake hose should be carefully inspected for cuts or other damage, especially near sections where the brake hose is attached to the vehicle. Notice the crack and cut hose next to the mounting bracket.

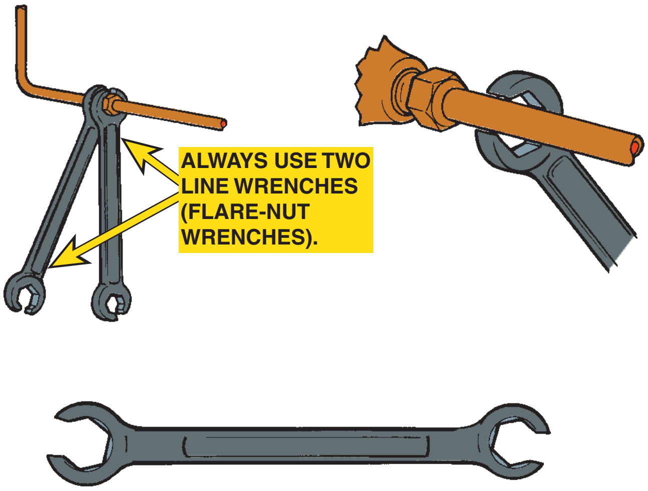

ALWAYS USE TWO LINE WRENCHES (FLARE-NUT WRENCHES).

FIGURE 96–23 Whenever disconnecting or tightening a brake line, always use the correct size flare-nut wrench. A flare-nut wrench is also called a tube-nut wrench or a line wrench.

BRAKE BLEEDING

THE NEED FOR BRAKE BLEEDING **Brake bleeding** is removing any trapped air from the hydraulic system. If air is in the brake hydraulic system, the brake pedal will often feel "spongy." The brake pedal will also travel farther (lower-than-normal brake pedal) before the brakes start to apply. Air can get into the hydraulic system whenever any hydraulic brake line or unit is opened. Air can also be drawn into the hydraulic system through small holes or loose brake line connections during the release of the brake pedal. A common source of air in the brake system of this type can occur through very small holes in rubber flexible brake lines. Another source of air in the braking system is through the absorption of moisture by the brake fluid. When moisture is absorbed, the boiling point of the brake fluid is reduced. During severe braking, the heat generated can cause the brake fluid to boil and create air bubbles in the hydraulic brake system. Air eventually travels to the highest part of the brake system, if not restricted by pressure control valves.

BLEEDING THE MASTER CYLINDER Whenever the master cylinder is replaced or the hydraulic system has been left opened for several hours, the air may have to be bled from the master cylinder. The master cylinder is located in the highest section of the hydraulic braking system. Some master cylinders are equipped with bleeder valves. If the master cylinder is not equipped with bleeder valves, it can be bled by loosening the brake line fittings at the master cylinder. Bleed the master cylinder "on the bench" before installing it on the vehicle. ● **SEE FIGURE 96–24**.

If bleeding the master cylinder after working on the hydraulic system, follow these steps:

STEP 1 Fill the master cylinder with clean brake fluid from a sealed container up to the recommended "full" level.

STEP 2 Have an assistant slowly depress the brake pedal as you "crack open" the master cylinder bleed screw starting with the section closest to the brake pedal. It is very important that the primary section of the master cylinder be bled before attempting to bleed the air out of the secondary section of the master cylinder. Before the brake pedal reaches the floor, close the bleeder valve.

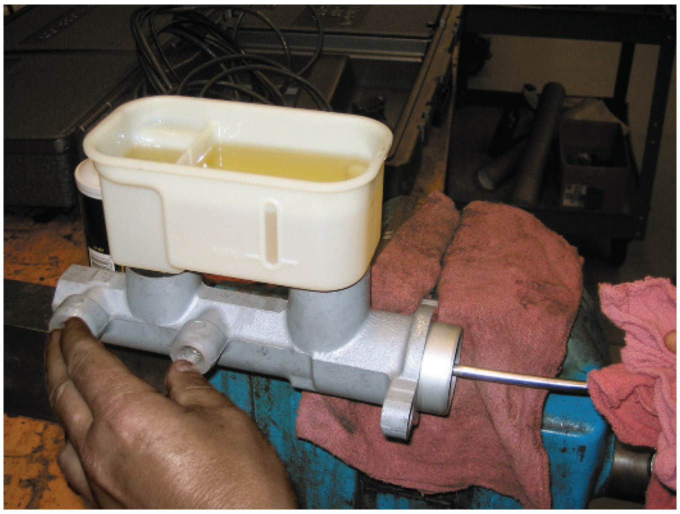


FIGURE 96–24 Bench bleeding a master cylinder. Always clamp a master cylinder in a vise by the mounting flange to prevent distortion of the cylinder bore. Bench bleeding tubes can also be used that route the fluid back into the reservoir.

TECH TIP

Check That All Bleeder Valves Are Pointing Up

Make certain all the brake components such as calipers and wheel cylinders are correctly installed with the bleeder valve located on the highest section of the part. Some wheel cylinders and calipers (such as many Ford calipers) can be installed upside down!

This usually occurs whenever both front calipers are off the vehicle and they accidentally get reversed left to right. If this occurs, the air will never be completely bled from the caliper.

NOTE: A proper manual bleeding of the hydraulic system requires that accurate communications occur between the person depressing the brake pedal and the person opening and closing the bleeder valve(s). The bleeder valve (also called a *bleed valve*) should be open only when the brake pedal is being depressed. The valve *must* be closed when the brake pedal is released to prevent air from being drawn into the system.

STEP 3 Repeat the procedure several times until a solid flow of brake fluid is observed leaving the bleeder valve. If the master cylinder is not equipped with bleeder valves, the outlet tube nuts can be loosened instead.

BRAKE BLEEDER VALVE LOOSENING METHODS

Attempting to loosen a bleeder valve often results in breaking (shearing off) the bleeder valve. Several of these service procedures can be tried that help prevent the *possibility* of breaking a bleeder valve. Bleeder valves are tapered and become wedged in the caliper on the wheel cylinder housing. ● **SEE FIGURES 96–25 AND 96–26**. All of these methods use shock to "break the taper" and to loosen the stuck valve.

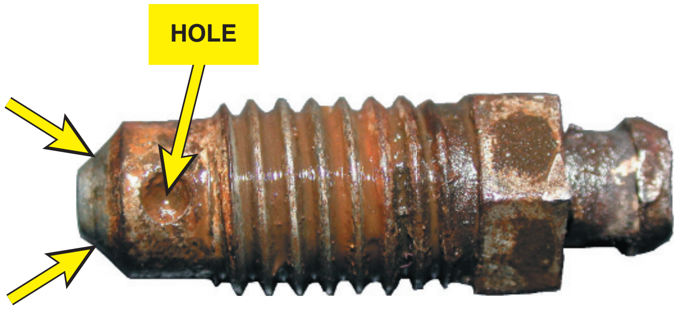


FIGURE 96–25 Typical bleeder valve from a disc brake caliper. The arrows point to the taper section that does the actual sealing. It is this taper that requires a shock to loosen. If the bleeder is simply turned with a wrench, the bleeder usually breaks off because the tapered part at the bottom remains adhered to the caliper or wheel cylinder. Once loosened, brake fluid flows around the taper and out through the hole in the side of the bleeder valve. The hole is clogged in this example and needs to be cleaned out.

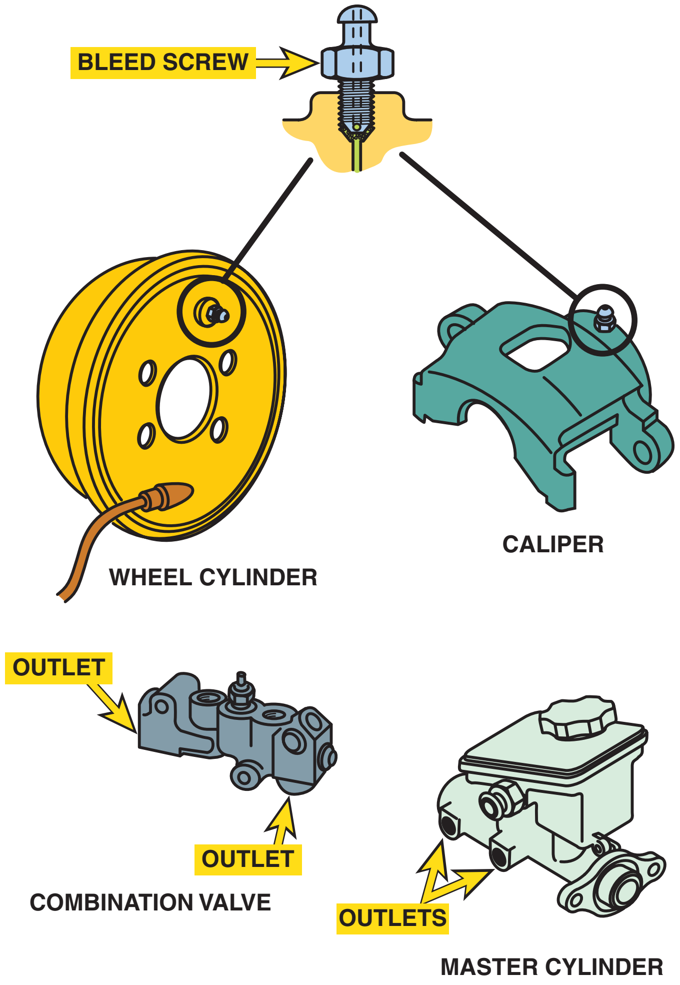


FIGURE 96–26 Typical bleeder locations. Note that the combination valve and master cylinder shown do not have bleeder valves; therefore, bleeding is accomplished by loosening the brake line at the outlet ports.

HIT AND TAP METHOD

STEP 1 Tap on the end of the bleeder valve with a steel hammer. This shock often "breaks the taper" at the base of the bleeder valve. The shock also breaks loose any rust or corrosion on the threads.

STEP 2 Using a 6-point wrench or socket, *tap* the bleeder valve in the clockwise direction (tighten).

STEP 3 Using the same 6-point socket or wrench, *tap* the bleeder valve counterclockwise to loosen and remove the bleeder valve.

NOTE: It is the *shock* of the tap on the wrench that breaks loose the bleeder valve. Simply pulling on the wrench often results in breaking off the bleeder.

STEP 4 If the valve is still stuck (frozen), repeat steps 1 through 3.

AIR PUNCH METHOD Use an air punch near the bleeder valve while attempting to loosen the bleeder valve at the same time. ● **SEE FIGURE 96–27.**

The air punch creates a shock motion that often loosens the taper and threads of the bleeder valve from the caliper or wheel cylinder. It is also helpful to first attempt to turn the bleeder valve in the clockwise (tightening) direction, then turn the bleeder in the counterclockwise direction to loosen and remove the bleeder valve.

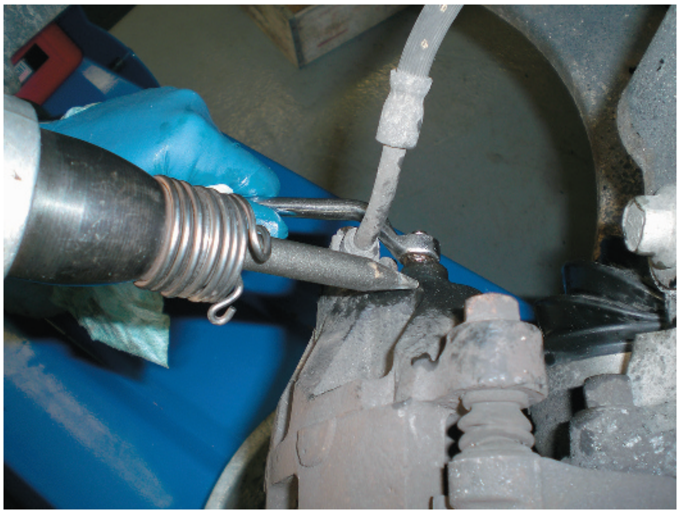


FIGURE 96–27 Using an air punch next to the bleeder valve to help "break the taper" on the bleeder valve.

HEAT AND TAP METHOD

Heat the area around the bleeder valve with a torch. The heat expands the size of the hole and usually allows the bleeder to be loosened and removed.

CAUTION: The heat from a torch will damage the rubber seals inside the caliper or wheel cylinder. Using heat to free a stuck bleeder valve will *require* that all internal rubber parts be replaced.

WAX METHOD

STEP 1 Heat the bleeder valve itself with a torch. The heat causes the valve itself to expand.

STEP 2 Remove the heat from the bleeder valve. As the valve is cooling, touch paraffin wax or candle wax to the hot valve. The wax will melt and run down around the threads of the bleeder valve.

STEP 3 Allow the bleeder valve to cool until it can be safely touched with your hand. This assures that the temperature is low enough for the wax to return to a solid and provide the lubricating properties necessary for the easy removal of the bleeder valve. Again, turn the bleeder valve clockwise before turning the valve counterclockwise to remove.

BLEEDING SEQUENCE

After bleeding the master cylinder, the combination valve should be bled if equipped. Check the level in the master cylinder frequently being careful not to allow the master cylinder to run dry and keep it filled with clean brake fluid throughout the brake bleeding procedure.

For most rear-wheel-drive vehicles equipped with a front/rear split system, start the bleeding with the wheel farthest from the master cylinder and work toward the closest. ● **SEE FIGURE 96–28**.

For most vehicles, this sequence is as follows:

1. Right rear
2. Left rear
3. Right front
4. Left front

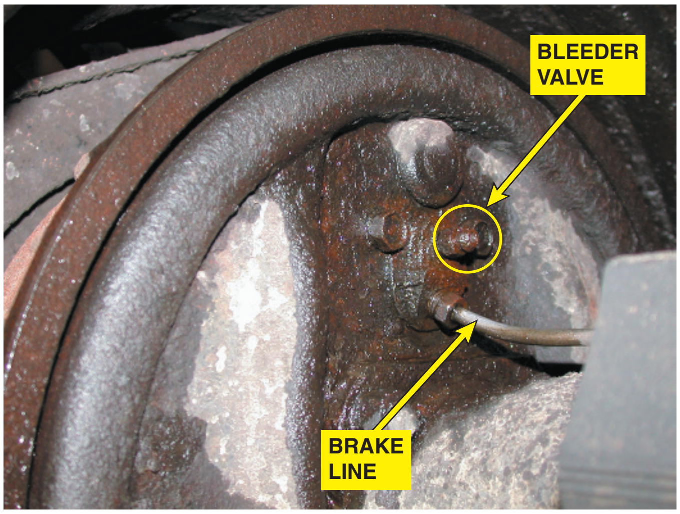


FIGURE 96–28 Most vehicle manufacturers recommend starting the brake bleeding process at the rear wheel farthest from the master cylinder.

NOTE: If the vehicle has two wheel cylinders on one brake, bleed the upper wheel cylinder first.

For vehicles equipped with a diagonal split section or equipped with ABS, follow the brake bleeding procedure recommended in the service information for the vehicle.

MANUAL BLEEDING

Manual bleeding is the most commonly used method and uses hydraulic pressure created by the master cylinder to pump fresh fluid through the brake system. This method is also called the **single stroke bleeding method**.

ADVANTAGES OF MANUAL BLEEDING

The manual method of brake bleeding is the most common. Manual bleeding requires the following:

- An assistant to apply and release the brake pedal
- A bleeder screw wrench
- Approximately 2 feet of clear, plastic hose with an inside diameter small enough to fit snugly over the bleeder screws
- A clear jar partially filled with clean brake fluid

MANUAL BLEEDING PROCEDURE

To manually bleed the brake system, follow these steps:

STEP 1 Discharge the vacuum or hydraulic power booster (if equipped) by pumping the brake pedal with the ignition OFF until the pedal feels hard.

STEP 2 Fill the master cylinder reservoir with new brake fluid and make sure it remains at least half full throughout the bleeding procedure.

STEP 3 Attach the plastic hose over the bleeder screw of the first wheel cylinder or caliper in the bleeding sequence, and submerge the end of the tube in the jar of brake fluid. ● **SEE FIGURE 96–29**.

STEP 4 Loosen the bleeder screw approximately one-half turn, and have an assistant slowly depress the brake pedal. It is extremely important when manually bleeding a brake system that the pedal be applied and released slowly

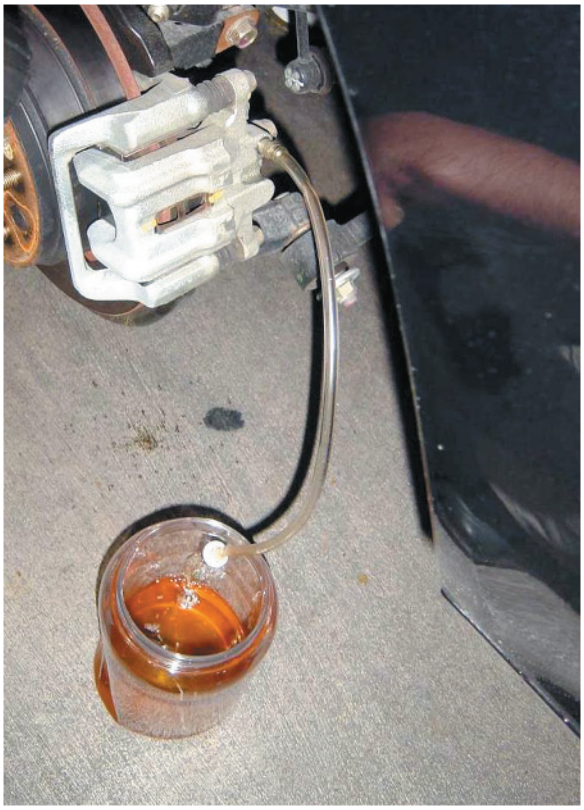


FIGURE 96–29 Bleeding brakes using clear plastic tubing makes it easy to see air bubbles. Submerging the hose in a container of clean brake fluid helps ensure that all of the air will be purged by the system.

and gently. Rapid pedal pumping can churn up the fluid and reduce the size of trapped air bubbles, making them more difficult to bleed from the system. Air bubbles leaving the bleeder screw will be visible in the hose to the jar.

STEP 5 Tighten the bleeder screw, then have your assistant slowly release the brake pedal.

STEP 6 Wait at least 15 seconds to allow time for any small bubbles to form into larger bubbles. See the Tech Tip called "Tiny Bubbles."

STEP 7 Repeat steps 4 and 5 until no more air bubbles emerge from the bleeder.

STEP 8 Transfer the plastic hose to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 4 through 7. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.

VACUUM BLEEDING

Vacuum bleeding uses a special suction pump that attaches to the bleeder screw. The pump creates a low-pressure area at the bleeder screw, which allows atmospheric pressure to force brake fluid through the system when the bleeder screw is opened.

ADVANTAGES OF VACUUM BLEEDING Vacuum bleeding requires only one technician. It is easy and the equipment needed can be low cost.

DISADVANTAGES OF VACUUM BLEEDING The disadvantage of using a vacuum bleeding method is that a vacuum tool must be used and often air can be drawn into the line between the bleeder valve and the hose creating some bubbles that can be interpreted by the technician as air in the system.

VACUUM BLEEDING PROCEDURE To vacuum bleed a brake system, use the following steps:

STEP 1 Fill the master cylinder reservoir with new brake fluid and make sure it remains at least half full throughout the bleeding procedure.

STEP 2 Attach the plastic tube from the vacuum bleeder to the bleeder screw of the first wheel cylinder or caliper in the bleeding sequence. ● **SEE FIGURES 96–30 AND 96–31**. If necessary, use one of the adapters provided with the vacuum in the catch bottle.

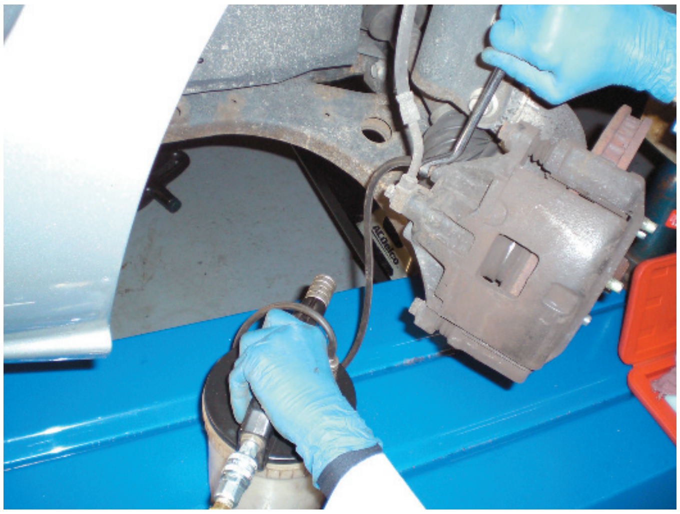


FIGURE 96–30 Using a compressed air-powered vacuum bleeder.

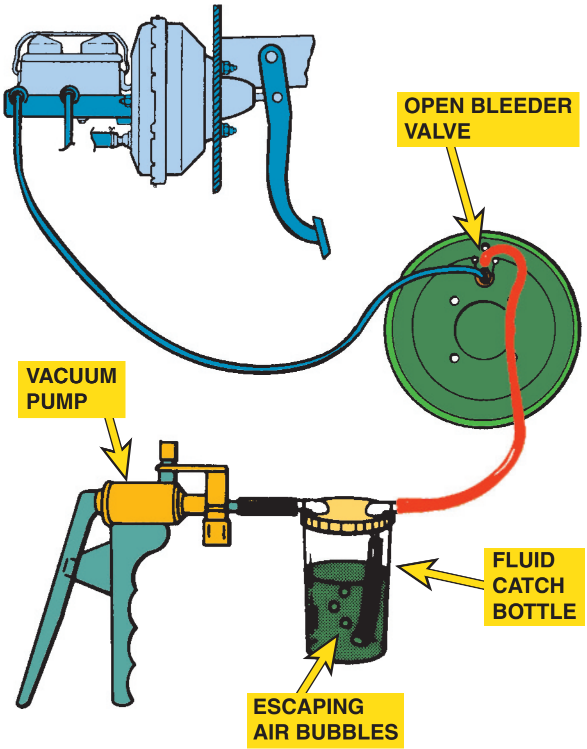


FIGURE 96–31 Vacuum bleeding uses atmospheric pressure to force brake fluid through the hydraulic system.

TECH TIP

Tiny Bubbles

Do not use excessive brake pedal force while bleeding and never bleed the brake with the engine running! The extra assist from the power brake unit greatly increases the force exerted on the brake fluid in the master cylinder. The trapped air bubbles may be dispersed into tiny bubbles that often cling to the inside surface of the brake lines. These tiny air bubbles may not be able to be bled from the hydraulic system until enough time has allowed the bubbles to re-form. To help prevent excessive force, do *not* start the engine. Without power assistance, the brake pedal force can be kept from becoming excessive. If the dispersal of the air into tiny bubbles is suspected, try tapping the calipers or wheel cylinders with a plastic hammer. After this tapping, simply waiting for a period of time will cause the bubbles to re-form into larger and easier-to-bleed air pockets. Most brake experts recommend waiting *15 seconds or longer* between attempts to bleed each wheel. This waiting period is critical and allows time for the air bubbles to form.

NOTE: To help prevent depressing the brake pedal down too far, some experts recommend placing a 2 × 4 inch board under the brake pedal. This helps prevent the seals inside the master cylinder from traveling over unused sections inside the bore that may be corroded or rusty.

STEP 3 Operate the pump handle to create a partial vacuum in the catch bottle.

STEP 4 Loosen the bleeder screw approximately one-half turn. Brake fluid and air bubbles will flow into the bottle. When the fluid flow stops, tighten the bleeder screw.

STEP 5 Repeat steps 3 and 4 until no more air bubbles emerge from the bleeder.

STEP 6 Transfer the vacuum bleeder to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 3 and 4. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.

GRAVITY BLEEDING

Gravity bleeding is a slow, but effective, method that will work on many vehicles to rid the hydraulic system of air. The procedure involves simply opening the bleeder valve and waiting until brake fluid flows from the open valve. Any air trapped in the part being bled will rise and escape from the vent port when the valve is opened. It may take several minutes before brake fluid escapes. Gravity bleeding works because any liquid tends to seek its own level. This means that the brake fluid in the master cylinder tends to flow downward toward the wheel cylinders or calipers. As long as the brake fluid level in the master cylinder is higher than the bleeder valve, the brake fluid will flow downward and out the open bleeder valve, as shown in ● **FIGURE 96–32**.

This flow of brake fluid can even get past the metering valve and proportioning valve. The proportioning valve is normally open to the rear brakes until the pressure reaches a predetermined level when it starts to limit increasing pressure to the rear brakes. The metering valve used to control or delay the operation of the front brakes is open to the front wheels until the pressure exceeds 10 to 15 PSI (70 to 100 kPa). Therefore, as long as no one is pushing on the brake pedal, the metering valve remains open to the front wheels and the brake fluid from the master cylinder can easily flow downward through the valve and out the open bleeder valve.

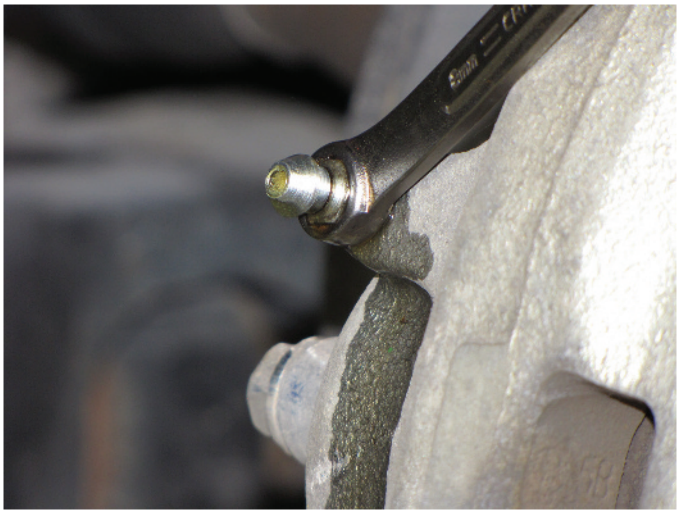


FIGURE 96–32 Gravity bleeding is simply opening the bleeder valve and allowing gravity to force the brake fluid out of the bleeder valve. Because air is lighter than brake fluid, all of the air escapes before the brake fluid runs out.

Since no pressure is exerted on the brake fluid, the large air bubbles remain large air bubbles and are not separated into smaller, harder-to-bleed air bubbles that can occur with manual bleeding.

ADVANTAGES OF GRAVITY BLEEDING All four-wheel brakes can be bled at one time using the gravity method. In this process, the bleeder screws at all four wheels are opened at the same time, and the system is allowed to drain naturally until the fluid coming out of the bleeders is free of air. Gravity bleeding can be done by a single technician, who is freed to attend to other jobs while the brakes bleed.

DISADVANTAGES OF GRAVITY BLEEDING Gravity bleeding is a slow process that can take an hour or more. When other bleeding procedures fail, gravity bleeding can sometimes be effective on brake systems that trap small pockets of air.

GRAVITY BLEEDING PROCEDURE Gravity bleeding requires the following:

- A bleeder wrench
- Four lengths of plastic hose that fit snugly over the bleeder screws
- Four jars to catch the dripping fluid—one for each wheel brake

Unless a plastic hose is used to "start a siphon" at each bleeder screw, it is possible that air may enter the system rather than be bled from it. This can occur because the total open area of the four bleeder screws is somewhat larger than that of the two compensating ports through which the fluid must enter the system. To gravity bleed the brake system, follow these steps:

STEP 1 Fill the master cylinder reservoir with new brake fluid and leave the cap off. During the bleeding process, check the fluid level periodically to ensure that the reservoir remains at least half full.

TECH TIP

The Master Cylinder One-Drip-Per-Second Test

Excessive brake wear is often caused by misadjusted brake linkage or brake light switches keeping the brake pedal from fully releasing. If the brake pedal is not fully released, the primary piston sealing cup blocks the compensating port from the brake fluid reservoir. To test if this is the problem, loosen both lines from the master cylinder. Brake fluid should drip out of both lines about one drip per second. This is why this test is also called the "Master Cylinder Drip Test." If the master cylinder does not drip, the brake pedal may not be allowing the master cylinder to fully release. Have an assistant pull up on the brake pedal. If the dripping starts, the problem is due to a misadjusted brake light or speed (cruise) control switch or pedal stop. If the master cylinder still does not drip, loosen the master cylinder from the power booster. If the master cylinder now starts to drip, the pushrod adjustment is too long.

If the master cylinder still does not drip, the problem is in the master cylinder itself. Check for brake fluid contamination. If mineral oil, such as engine oil, power steering fluid, or automatic transmission fluid (ATF), has been used in the system, the rubber sealing cups swell and can block off the compensating port. If contamination is discovered, *every* brake component that contains rubber *must* be replaced.

STEP 2 Attach a length of plastic tubing to each bleeder screw and place the ends of the tubes in jars to catch the drainage. Open each bleeder screw approximately one full turn and make sure that fluid begins to drain. Allow the system to drain until the fluid flowing from the bleeder screws is free of air bubbles. If no brake fluid comes out, remove the bleeder valve entirely—it may be clogged. Nothing but air and brake fluid will be *slowly* coming out of the wheel cylinder or caliper when the bleeder valve is removed. *Do not press on the brake pedal with the bleeder valve out while gravity bleeding.*

STEP 3 Close the bleeder screws and top up the fluid level in the master cylinder reservoir and replace the master cylinder reservoir cap.

PRESSURE BLEEDING

Pressure bleeding, sometimes called **power bleeding**, is a common method used to bleed the brake hydraulic system. In this process, a pressure bleeder attached to the master cylinder forces brake fluid through the system under pressure to purge any trapped air. Once the hydraulic system is pressurized, the technician simply opens the bleeder screws in the prescribed order and allows fluid to flow until it is free of air bubbles.

The tools required for pressure bleeding include a plastic hose and fluid catch jar as used in manual bleeding, as well as a pressure bleeder, a source of air pressure to charge the bleeder, and an adapter to attach the pressure bleeder to the master cylinder fluid reservoir. Cast-metal cylinders with integral reservoirs commonly use a flat, plate-type adapter that seals against the same surface as the reservoir cover. ● **SEE FIGURE 96–33**.

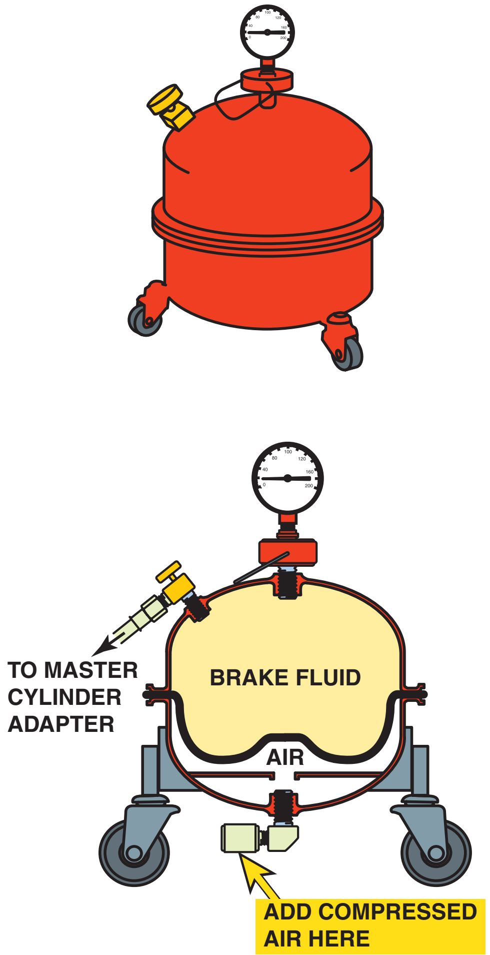


FIGURE 96–33 A typical pressure bleeder. The brake fluid inside is pressurized with air pressure in the air chamber. This air pressure is applied to the brake fluid in the upper section. A rubber diaphragm separates the air from the brake fluid.

Some plastic master cylinder reservoirs also use plate-type adapters, but others require adapters that seal against the bottom of the reservoir. ● **SEE FIGURE 96–34**. Pressure bleeder manufacturers offer many adapters to fit specific applications.

METERING VALVE OVERRIDE TOOLS In addition to the tools previously described, a metering valve override tool is required when pressure bleeding the front brakes of certain vehicles. The override tool is used to deactivate the metering valve because the operating pressure of power bleeders is within the range where the metering valve blocks fluid flow to the front brakes. Metering valves that require an override tool have a stem or button on one end that is either pushed in or pulled out to hold the valve open. The override tool performs this service.

To install the override tool used on General Motors vehicles, loosen the combination valve mounting bolt and slip the slot in the tool under the bolt head.

Push the end of the tool toward the valve body until it depresses the valve plunger, then tighten the mounting bolt to hold the tool in place.

Some full-size Ford vehicles have a metering valve with a stem that must be pushed in to bleed the front brakes, but Ford does not offer a special tool for this purpose. An assistant is needed to override the valve when the front brakes are being bled.

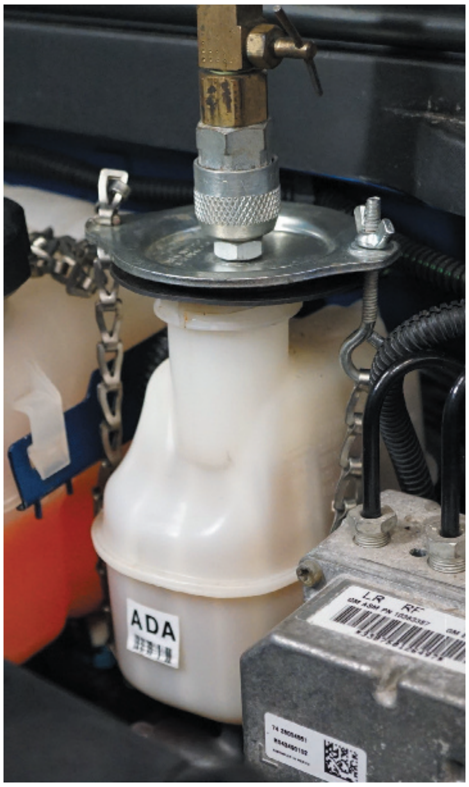


FIGURE 96–34 Brake fluid under pressure from the power bleeder is applied to the top of the master cylinder. It is very important that the proper adapter be used for the master cylinder. Failure to use the correct adapter or failure to release the pressure on the brake fluid before removing the adapter can cause fluid to escape under pressure.

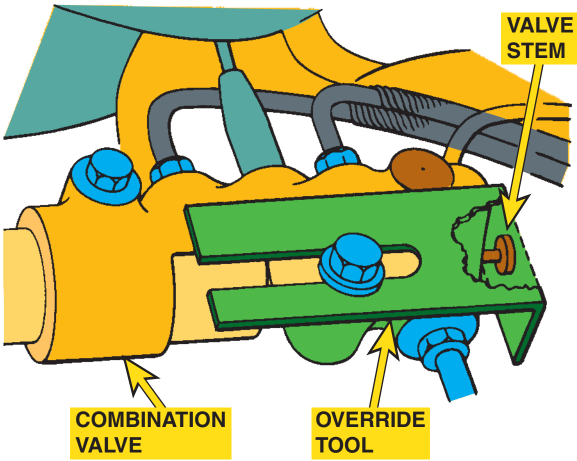


FIGURE 96–35 Metering valve override tool on a General Motors vehicle.

To install the override tool used on older Chrysler and Ford vehicles, slip one fork of the tool under the rubber boot and the other fork under the valve stem head. ● **SEE FIGURE 96–35**.

The spring tension of the tool holds the valve open, but allows the valve stem to move slightly when the system is pressurized. If the valve is held rigidly open, internal damage will result.

PRESSURE BLEEDING PROCEDURE Just as in manual bleeding, it is important to follow the proper sequence when pressure bleeding a brake system. Some manufacturers recommend one sequence for manual bleeding and another for pressure bleeding. To pressure bleed a brake system, follow these steps:

STEP 1 If it has not already been done, consult the equipment manufacturer's instructions and fill the pressure bleeder with the proper type of brake fluid.

STEP 2 Make sure the bleeder is properly sealed and the fluid supply valve is closed, then use compressed air to pressurize the bleeder until approximately 30 PSI (207 kPa) is indicated on the bleeder gauge.

STEP 3 If the vehicle is equipped with a metering valve, override it with the appropriate tool. ● **SEE FIGURE 96–36**.

STEP 4 Clean the top of the master cylinder, then remove the master cylinder cover and clean around the gasket surface. Be careful not to allow any dirt to fall into the reservoir.

STEP 5 Fill the reservoir about half full with new brake fluid, then install the proper pressure bleeder adapter on the master cylinder.

STEP 6 Connect the pressure bleeder fluid supply hose to the adapter, making sure the hose fitting is securely engaged.

STEP 7 Open the fluid supply valve on the pressure bleeder to allow pressurized brake fluid to enter the system. Check carefully for fluid leaks that can damage the vehicle finish.

STEP 8 Slip the plastic hose over the bleeder screw of the first wheel cylinder or caliper to be bled, and submerge the end of the tube in the jar of brake fluid.

STEP 9 Open the bleeder screw approximately one-half turn, and let the fluid run until air bubbles no longer emerge from the tube. Close the bleeder screw.

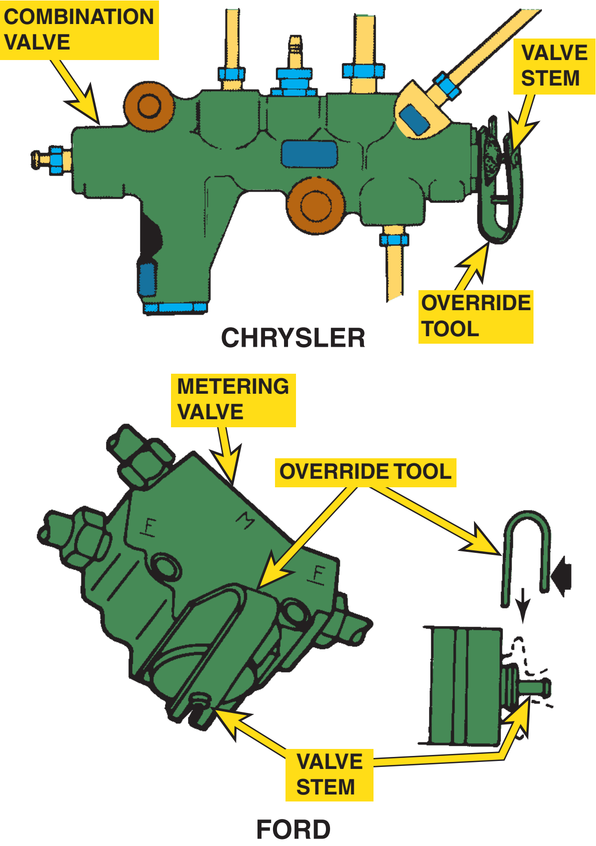


FIGURE 96–36 Pull-out-type metering valves being held out using a special override tool.

STEP 10 Transfer the plastic hose to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 8 and 9. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.

STEP 11 Remove the metering valve override tool.

STEP 12 Close the fluid supply valve on the pressure bleeder.

STEP 13 Wrap the end of the fluid supply hose in a shop towel, and disconnect it from the master cylinder adapter. Be careful to avoid spilling brake fluid.

STEP 14 Remove the master cylinder adapter, adjust the fluid level to the full point, and install the fluid reservoir cover.

HYDRAULIC ABS SERVICE

CHECK SERVICE INFORMATION Before doing any brake work on a vehicle equipped with antilock brakes, always consult the appropriate service information for the exact vehicle being serviced. For example, some manufacturers recommend discharging the hydraulic accumulator by depressing the brake pedal many times before opening bleeder valves. Many service checks require that a pressure gauge be installed in the system.

BLEEDING THE ELECTRONIC-HYDRAULIC ASSEMBLY Air can easily get trapped in the ABS electronic-hydraulic (E-H) assembly whenever the hydraulic system is opened. Even though the master cylinder and all four wheel cylinders/calipers have been bled, sometimes the brake pedal will still feel spongy. Some E-H units can be bled through the use of a scan tool where the valves are pulsed in sequence by the electronic brake controller (computer). Some units are equipped with bleeder valves while others must be bled by loosening the brake lines. Bleeding the E-H unit also purges out the older brake fluid, which can cause rust and corrosion damage. Only DOT 3 brake fluid is specified for use in an antilock brake system. Always check the label on the brake fluid reservoir and/or service manual or owner's manual.

CAUTION: Some ABS units require that the brake pedal be depressed as many as 40 times to discharge brake fluid fully from the accumulator. Failure to discharge the accumulator fully can show that the brake fluid level is too low. If additional brake fluid is added, the fluid could overflow the reservoir during an ABS stop when the accumulator discharges brake fluid back into the reservoir.

MANUALLY BLEEDING ABS WHEEL BRAKES During routine brake service, attempt to keep the air from entering the hydraulic system by doing the following:

1. Do not allow the brake system to run dry. Use a brake pedal depressor or plug any open brake line to keep brake fluid from flowing out of the brake master cylinder reservoir.
2. Do not allow the master cylinder to run dry during the bleeding operation. Check the master cylinder reservoir often and keep it filled with fresh brake fluid from a sealed container.
3. Always bench bleed a replacement master cylinder to help prevent against introducing air into the hydraulic system.

After depressing the unit as per manufacturer's recommended procedures, the brakes can be bled using the same procedure as for a vehicle without ABS. Air trapped in the ABS hydraulic unit may require that a scan tool be used to cycle the valves. ● **SEE FIGURES 96–37 AND 96–38.**

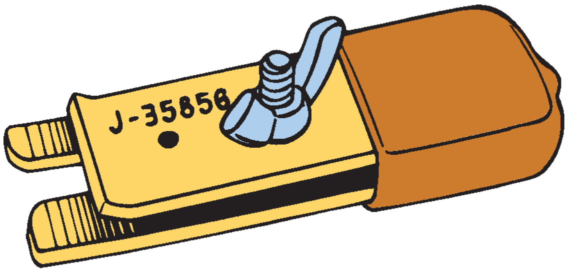


FIGURE 96–37 Special bleed valve tools are often required when bleeding some ABS units such as the Kelsey-Hayes. 4WAL system.

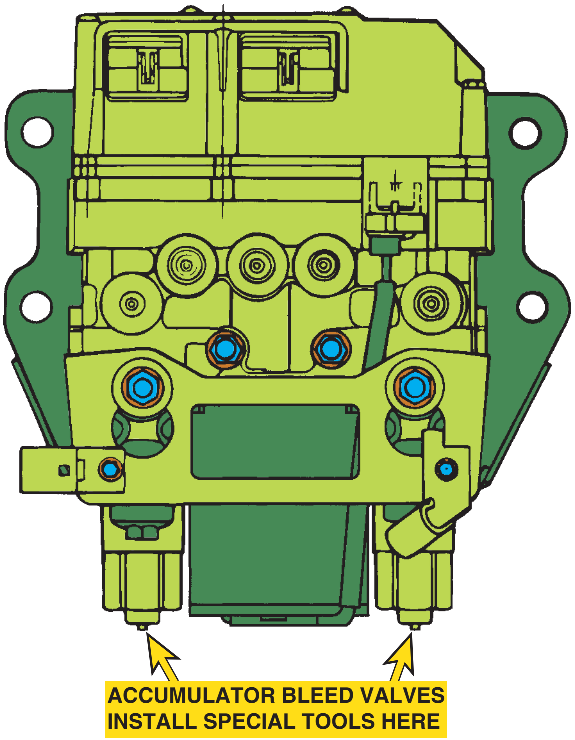


FIGURE 96–38 Two bleed valve tools are needed to bleed the Kelsey-Hayes 4WAL system, which attaches to the bleeder valves on the accumulator.

The bleeding procedure for vehicles equipped with antilock brakes is often different than vehicles without ABS. Consult the service information for the specified bleeding procedure and sequence.

SCAN TOOL BLEEDING To bleed the system using a scan tool, use the following steps:

STEP 1 Check service information and determine the specified procedure to follow. This usually involves manually bleeding the wheel brakes before using a scan tool.

STEP 2 Use a factory scan tool or one that is capable of performing an automated bleed procedure.

STEP 3 Connect the scan tool to the data link connector (DLC). This connector can be located under the dash or in the center console or even covered by a panel. Check service information for the exact location of the DLC for the vehicle being serviced. ● **SEE FIGURE 96–39.**

STEP 4 Enter vehicle information as shown on the display of the scan tool and locate the antilock brake system (ABS) function area. ● **SEE FIGURE 96–40.**

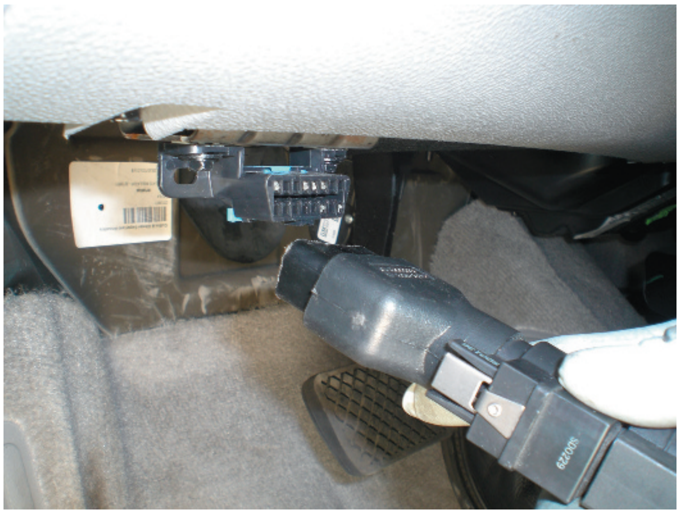


FIGURE 96–39 To perform an automated brake bleed procedure on an antilock brake system (ABS), first connect a factory or enhanced scan tool to the data link connector (DLC) located under the dash on this vehicle.

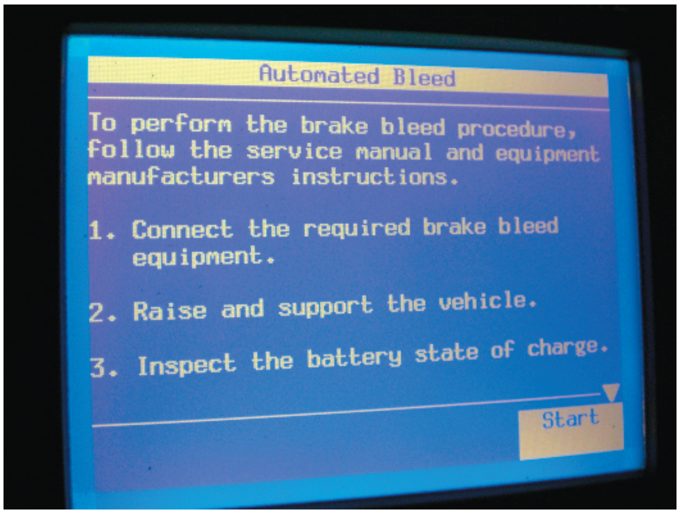
FIGURE 96–40 Access the menu that includes antilock brake system (ABS) functions.

STEP 5 Select ABS automated bleed from the ABS menu. The instructions on the scan tool could include several steps including manually bleeding the system, then allowing the scan tool to cycle the hydraulic ABS solenoid valves and then bleeding again. ● **SEE FIGURE 96–41**.

TECH TIP

ABS Bleeding Made Easy

To avoid having to bleed the hydraulic unit, use a brake pedal depressor during brake service to avoid losing brake fluid. This simple precaution keeps air from getting into the hard-to-bleed passages of the hydraulic unit.



Automated Bleed

To perform the brake bleed procedure, follow the service manual and equipment manufacturers instructions.

1. Connect the required brake bleed equipment.
2. Raise and support the vehicle.
3. Inspect the battery state of charge.

FIGURE 96–41 Scroll through the menus and select automated bleed procedure and follow the on-screen instructions.

BRAKE FLUID REPLACEMENT/FLUSHING

Brake fluid flushing is a procedure where the old brake fluid is removed and new brake fluid is added to the hydraulic system.

FLUSHING PROCEDURE The brake fluid flushing procedure usually requires the following:

- An assistant to pump the brake pedal
- A bleeder screw wrench
- Approximately 2 feet of clear, plastic hose with an inside diameter small enough to fit snugly over the bleeder screw
- A jar partially filled with clean brake fluid

To flush a brake system, use the following steps:

STEP 1 Using a turkey baster or similar tool, remove the old brake fluid from the master cylinder reservoir. ● **SEE FIGURE 96–42**.

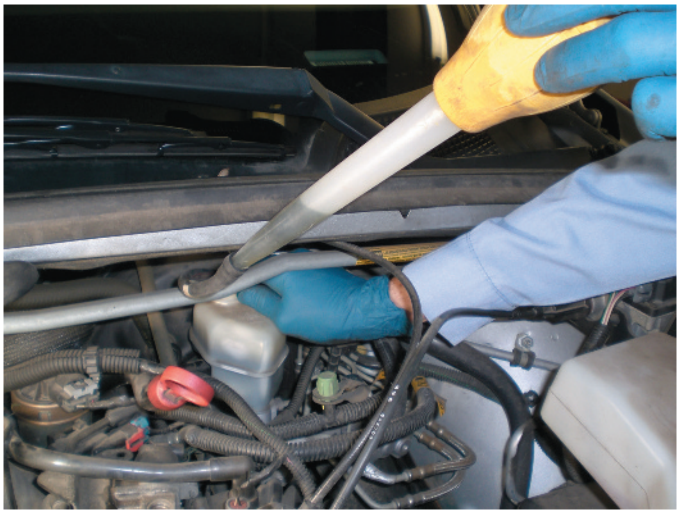


FIGURE 96–42 A turkey baster can be used to remove the old brake fluid from the master cylinder reservoir. A rubber hose was attached to the end of the turkey baster to get access to the brake fluid.

TECH TIP

Block Off the Master Cylinder

Technicians often get frustrated when trying to repair a low or spongy brake pedal. While many times, the cause is due to air trapped somewhere in the brake hydraulic system, the problem could also be due to a fault in some components such the ABS or master cylinder. One method that works is to isolate the system to see what part of the system is causing the problem. For example, if the brake line to the front brakes is blocked off using a plug and the brake pedal is now normal, then the source of the problem has been narrowed to the front brakes components.
● **SEE FIGURE 96–43**.

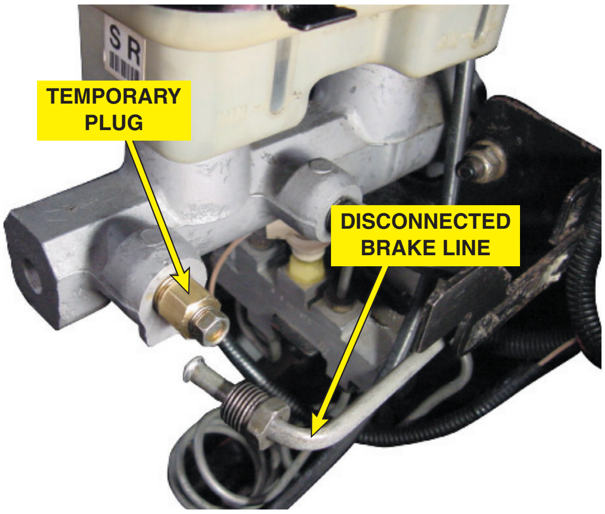


FIGURE 96–43 Using a plug at the outlet of the master cylinder is a common method when diagnosing a low brake pedal complaint.

STEP 2 Fill the master cylinder reservoir with new brake fluid from a sealed container.

STEP 3 Slip the plastic hose over the bleeder screw of the wheel cylinder or caliper to be bled and submerge the end of the tube in the jar of brake fluid.

STEP 4 Open the bleeder screw approximately one-half turn.

STEP 5 With the bleeder screw *open*, have your assistant slowly depress the brake pedal.

STEP 6 While your assistant holds the brake pedal to the floor, close the bleeder screw.

STEP 7 Continue to bleed at each wheel until the fluid that emerges from the bleeder screw is free of any discoloration and contamination.

STEP 8 Repeat steps 4 through 7 at each bleeder screw in the recommended order.

STEP 9 Check the brakes for proper operation and rebleed the system if needed.

REVIEW QUESTIONS

1. What is the difference between DOT 3, DOT 4, DOT 5.1, and DOT 5 brake fluid?
2. What four things should be done during a thorough inspection of the brake fluid?
3. Describe how to bleed the master cylinder.
4. What are the two types of flares used on brake lines?
5. Why are some brake lines coiled?

CHAPTER QUIZ

1. The type of brake fluid most often recommended by vehicle manufacturers is _____________.
   - **a.** DOT 3
   - **b.** DOT 4
   - **c.** DOT 5
   - **d.** DOT 5.1
2. Vacuum is applied where during vacuum bleeding?
   - **a.** At each wheel brake bleeder valve
   - **b.** At the master cylinder reservoir
   - **c.** At the vacuum booster check valve
   - **d.** At the metering valve end of the combination valve
3. The two types of flares used on brake lines are _____________.
   - **a.** SAE and DOT
   - **b.** double flare and ISO
   - **c.** ball flare and bubble flare
   - **d.** SAE and double flare
4. Flexible brake hose should be inspected for all of the following *except* _____________.
   - **a.** cracks
   - **b.** leakage
   - **c.** twisted
   - **d.** worn outer ribs
5. Two technicians are discussing how to loosen bleeder valves. Technician A says that a shock is usually necessary to break the taper at the base of the valve. Technician B says to apply steady, loosening torque to the bleeder valve using a 6-point wrench. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B

6. The brake bleeding procedure usually specified for a rear-wheel-drive vehicle with a front/rear split master cylinder is ______________.

a. RR, LR, RF, LF
b. LF, RF, LR, RR
c. RF, LR, LF, RR
d. LR, RR, LF, RF

7. When bleeding the brakes on a vehicle equipped with an antilock brake system, what is the function of the scan tool?

a. To open the bleeder valves
b. To maintain the fluid level in the reservoir
c. To cycle the solenoids in the ABS unit
d. To turn off the ABS light

8. Air in the brake hydraulic system can cause all of these *except* ______________.

a. a spongy brake pedal
b. a hard brake pedal
c. a lower-than-normal brake pedal
d. it may require the driver to "pump up" the brakes before they will stop the vehicle

9. The usual maximum pressure that should be used when pressure bleeding a brake system is ______________.

a. 20 PSI
b. 30 PSI
c. 50 PSI
d. 70 PSI

10. Technician A says that the brake pedal should be depressed with as much force as possible during the manual bleeding procedure. Technician B says that the brake pedal should be pumped rapidly during the manual bleeding procedure to force the air down toward the bleeder valve(s). Which technician is correct?

a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

Chapter

97

WHEEL BEARINGS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the types of antifriction bearings.
- Discuss bearing greases.
- Discuss types of seals.
- Explain the diagnosis of defective wheel bearings.
- Describe wheel bearing service.
- Describe sealed bearing service.
- Discuss rear drive axle classifications.
- Describe rear axle bearing and seal replacement.
- State the reasons for bearing failure.

KEY TERMS:

Antifriction bearings 1129 • Axial load 1130 • Ball bearings 1130 • Bearing race 1129 • Brinelling 1140 • Cage 1130 • Cone (inner ring) 1130 • Cup (outer ring) 1130 • Dynamic seals 1132 • Garter spring 1132 • GC-LB 1132 • Grease 1131 • Grease seal 1135 • Needle rollers 1130 • National Lubricating Grease Institute (NLGI) 1132 • Radial load 1130 • Retainer plate-type axle 1138 • Roller bearings 1130 • Spalling 1140 • Static seal 1132 • Tapered roller bearing 1136

ANTIFRICTION BEARINGS

PURPOSE AND FUNCTION Bearings allow the wheels of a vehicle to rotate and still support the weight of the entire vehicle. **Antifriction bearings** use rolling parts inside the bearing to reduce friction. Four styles of rolling contact bearings include ball, roller, needle, and tapered roller bearings, as shown in ● **FIGURE 97–1**. All four styles convert sliding friction into rolling motion. All of the weight of a vehicle or load on the bearing is transferred through the rolling part. In a ball bearing, the entire load is concentrated into small spots where the ball contacts the *inner and outer race (rings).* ● **SEE FIGURE 97–2**.

PARTS OF A WHEEL BEARING Wheel bearings are constructed using friction-reducing elements such as steel round balls or steel rollers inside of a housing. The parts involved and their names include

Inner race—The inner support that provides the rolling surface for the friction-reducing balls or rollers is called a **bearing race**, also called

- bearing cone
- bearing ring
- bearing cup

This inner race is located on the spindle or drive axle shaft.

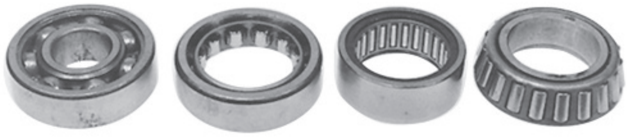


FIGURE 97–1 Rolling contact bearings include (left to right) ball, roller, needle, and tapered roller.

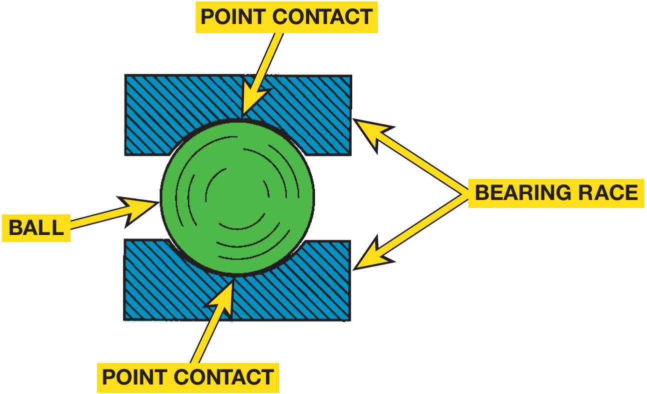


FIGURE 97–2 Ball bearing point contact.

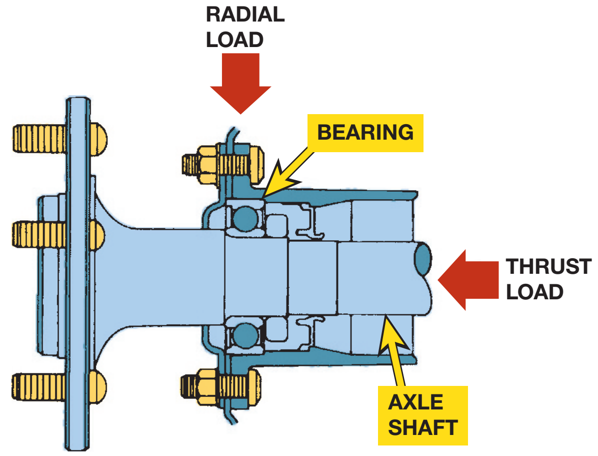


FIGURE 97–3 Radial load is the vehicle weight pressing on the wheels. The thrust load occurs as the chassis components exert a side force during cornering.

Ball bearings or roller bearings—The purpose and function of the steel balls or steel rollers is to reduce the friction of the rotating parts. Roller bearings can be either straight or tapered. These are the antifriction elements inside a bearing assembly.

Outer race—The outer race, also called the cup or cone, supports the steel balls or steel rollers. The outer race is pressed into the bearing hub or steering knuckle.

BALL BEARINGS

Ball bearings use hardened steel balls between the inner and outer race to reduce friction. While ball bearings cannot support the same weight as roller bearings, there is less friction in ball bearings and they generally operate at higher speeds. ● **SEE FIGURE 97–3**. Ball bearings can control thrust movement of an axle shaft because the balls ride in grooves on the inner and outer races. The groove walls resist lateral movement of the wheel on the spindle. Many front-wheel-drive vehicles use sealed double-row ball bearings as a complete sealed unit and are non-serviceable except as an assembly.

ROLLER BEARINGS

Roller bearings use rollers between the inner and outer race to reduce friction. A roller bearing having a greater (longer) contact area can support heavier loads than a ball bearing. ● **SEE FIGURE 97–4**.

A needle bearing is a type of roller bearing that uses smaller rollers called **needle rollers**. The clearance between the diameter of the straight roller is manufactured into the bearing to provide the proper *radial clearance* and is *not adjustable*.

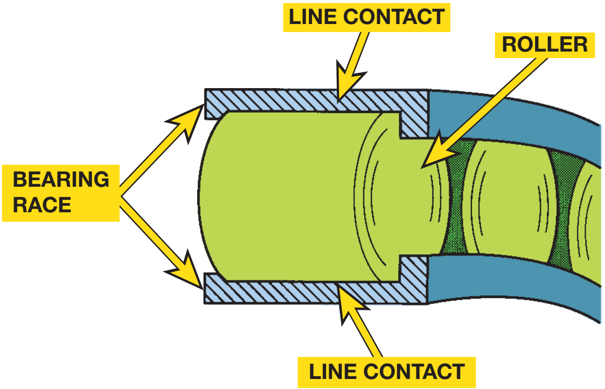


FIGURE 97–4 Roller bearing line contact.

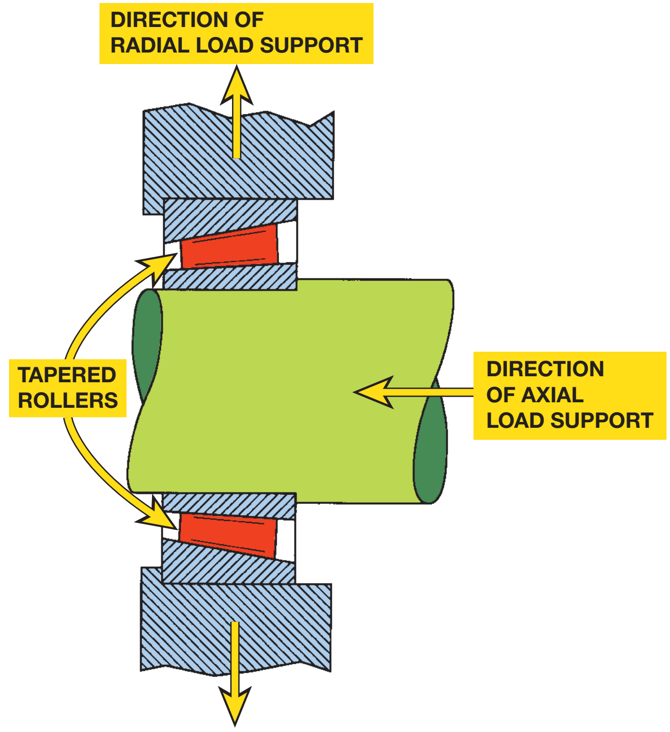

DIRECTION OF RADIAL LOAD SUPPORT
TAPERED ROLLERS
DIRECTION OF AXIAL LOAD SUPPORT

FIGURE 97–5 A tapered roller bearing will support a radial load and an axial load in only one direction.

TAPERED ROLLER BEARINGS

The most commonly used automotive wheel bearing is the **tapered roller bearing**. Not only is the bearing itself tapered, but the rollers are also tapered. By design, this type of bearing can withstand **radial loads** (up and down) as well as **axial loads** (thrust) in one direction. ● **SEE FIGURE 97–5**.

Many non-drive-wheel bearings use tapered roller bearings. The taper allows more weight to be handled by the friction-reducing bearings because the weight is directed over the entire length of each roller rather than concentrated on a small spot, as with ball bearings. The rollers are held in place by a **cage** between the inner race (also called the **inner ring or cone**) and the outer race (also called the **outer ring or cup**). Tapered roller bearings must be loose in the cage to allow for heat expansion. Tapered roller bearings should always be adjusted for a certain amount of free play to allow for heat expansion. ● **SEE FIGURE 97–6**.

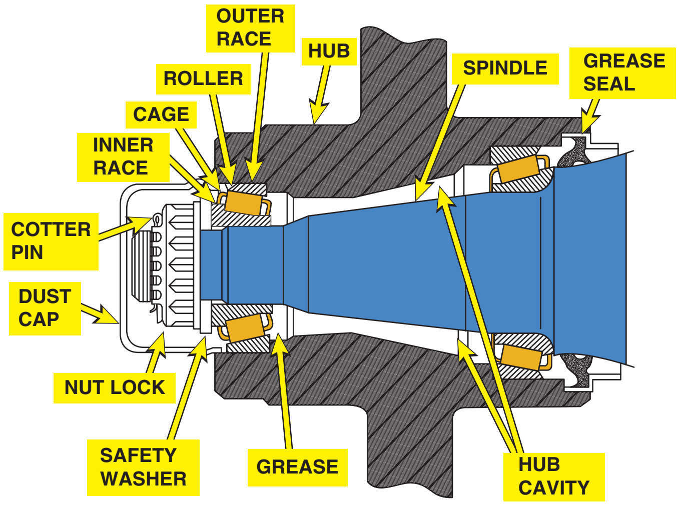


FIGURE 97–6 A cross-sectional view of a typical front wheel bearing showing the larger tapered roller bearing with grease seal on the right and the smaller outer tapered roller bearing on the left.

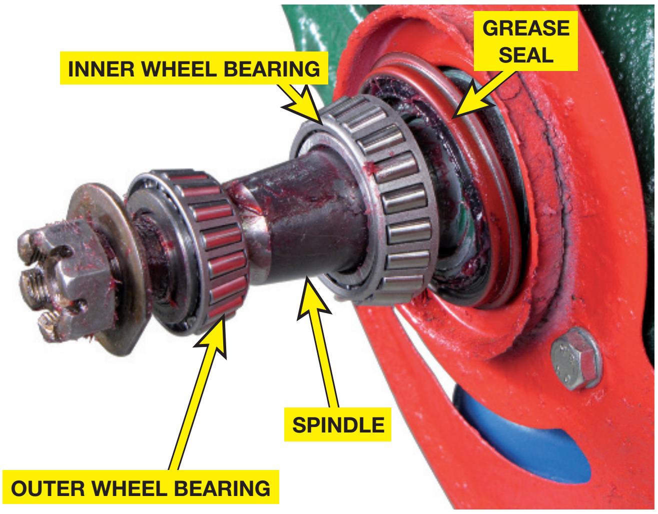


FIGURE 97–7 Non-drive-wheel hub with inner and outer tapered roller bearings. By angling the inner and outer in opposite directions, axial (thrust) loads are supported in both directions.

INNER AND OUTER WHEEL BEARINGS Many rear-wheel-drive vehicles use an inner and an outer wheel bearing on the front wheels. The inner wheel bearing is always the larger bearing because it is designed to carry most of the vehicle weight and transmit the weight to the suspension through to the spindle. Between the inner wheel bearing and the spindle, there is a grease seal, which prevents grease from getting onto the braking surface and prevents dirt and moisture from entering the bearing. ● **SEE FIGURE 97–7**.

SEALED FRONT-WHEEL-DRIVE BEARINGS Most front-wheel-drive vehicles use a sealed nonadjustable front wheel bearing. This type of bearing can include either two preloaded tapered roller bearings or a double-row ball bearing. This type of sealed bearing is also used on the rear of many front-wheel-drive vehicles.

Double-row ball bearings are often used because of their reduced friction and greater seize resistance. ● **SEE FIGURES 97–8 AND 97–9**.

BEARING GREASES

DEFINITION OF GREASE Vehicle manufacturers specify the type and consistency of grease for each application. The technician should know what these specifications mean. **Grease** is oil with a thickening agent to allow it to be installed in places where a liquid lubricant would not stay. Greases are named for their thickening agent, such as aluminum, barium, calcium, lithium, or sodium.

GREASE ADDITIVES Commonly used additives in grease include the following:

- Antioxidants
- Antiwear agents
- Rust inhibitors
- Extreme pressure (EP) additives such as sulfurized fatty oil or chlorine

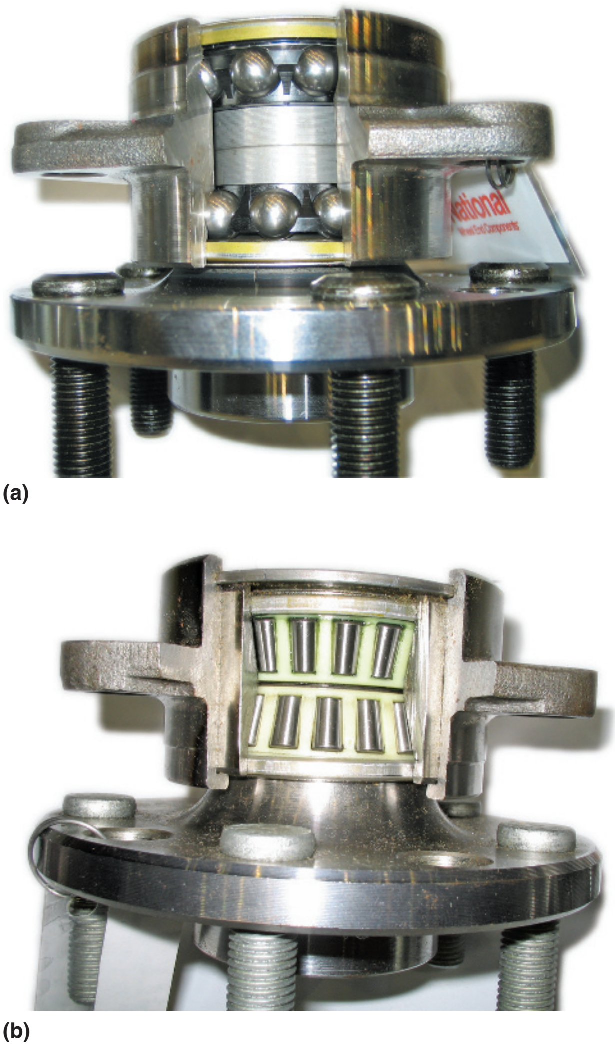


FIGURE 97–8 Sealed bearing and hub assemblies are used on the front and rear wheels of many vehicles. (a) A type using a double row of ball bearings. (b) A type using tapered roller bearings.

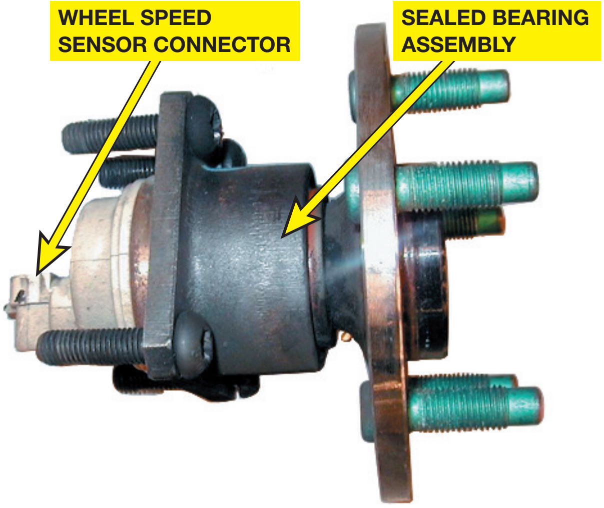


FIGURE 97–9 Sealed bearing and hub assemblies are serviced as a complete unit as shown. This hub assembly includes the wheel speed sensor.

Grease also contains a dye to not only provide product identification, but also give the grease a consistent color.

The grease contains a solid, such as graphite or molybdenum disulfide (moly), which acts as an antiseize additive.

FREQUENTLY ASKED QUESTION

What Do Different Grease Colors Mean?

Nothing. According to grease manufacturers, grease is colored for identification, marketing, and for consistency of color reasons.

- **Identification.** The color is often used to distinguish one type of grease from another within the same company. The blue grease from one company may be totally different from the blue grease produced or marketed by another company.
- **Marketing.** According to grease manufacturers, customers tend to be attracted to a particular color of grease and associate that color with quality.
- **Consistency of color.** All greases are produced in batches, and the color of the finished product often varies from one batch to another. By adding color to the grease, the color can be made consistent.

Always use the grease recommended for the service being performed.

NLGI CLASSIFICATION The **National Lubricating Grease Institute (NLGI)** uses the penetration test as a guide to assign the grease a number. Low numbers are very fluid and higher numbers are more firm or hard. Number 2 grease is the most commonly used. See the chart for other numbers.

Grease is also classified according to quality. Wheel bearing classifications include the following:

- GA—mild duty
- GB—moderate duty
- GC—severe duty, high temperature (frequent stop-and-go service)

GC indicates the highest quality. Chassis grease, such as that used to lubricate steering and suspension components, includes the following classifications:

- LA—mild duty (frequent relubrication)
- LB—high loads (infrequent relubrication)

LB indicates the highest quality. Most multipurpose greases are labeled with both wheel bearing and chassis grease classifications, such as **GC-LB**.

NATIONAL LUBRICATING GREASE INSTITUTE (NLGI) NUMBERS

NLGI NUMBER	RELATIVE CONSISTENCY
000	Very fluid
00	Fluid
0	Semi-fluid
1	Very soft
2	Soft (typically used for wheel bearings)
3	Semi-firm
4	Firm
5	Very firm
6	Hard

More rolling bearings are destroyed by overlubrication than by underlubrication because the heat generated in the bearings cannot be transferred easily to the air through the excessive grease. The cavity between the inner and out bearings should never be filled beyond one-third to one-half of their grease capacity by volume.

SEALS

PURPOSE AND FUNCTION Seals are used in all vehicles to keep lubricant, such as grease, from leaking out and to prevent dirt, dust, or water from getting into the bearing or lubricant.

TYPES OF SEALS Two general applications of seals are static and dynamic.

- **Static seals** are used between two surfaces that do not move.
- **Dynamic seals** are used to seal between two surfaces that move.

Wheel bearing seals are dynamic-type seals that must seal between rotating axle hubs and the stationary spindles or axle housing. Most dynamic seals use a synthetic rubber lip seal encased in metal. The lip is often held in contact with the moving part with the aid of a **garter spring**, as seen in ● **FIGURE 97–10**. The sealing lip should be installed toward the grease or fluid being contained. ● **SEE FIGURE 97–11**.

BEARING DIAGNOSIS

SYMPTOMS OF A DEFECTIVE BEARING Wheel bearings control the positioning and reduce the rolling resistance of vehicle wheels. Whenever a bearing fails, the wheel may not be kept in position and noise is usually heard. Symptoms of defective wheel bearings include the following:

1. A hum, rumbling, or growling noise that increases with vehicle speed
2. Roughness felt in the steering wheel that changes with the vehicle speed or cornering

SAFETY TIP

Smoking Can Kill You

Some greases contain polymers such as Teflon® that turn to a deadly gas when burned. Always wash your hands thoroughly after handling grease that contains these ingredients before smoking. If some of the grease is on the cigarette paper and is burned, these polymers turn into nitrofluoric acid—a deadly toxin.

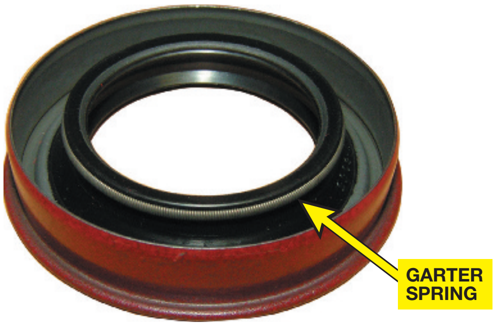


FIGURE 97–10 Typical lip seal with a garter spring.

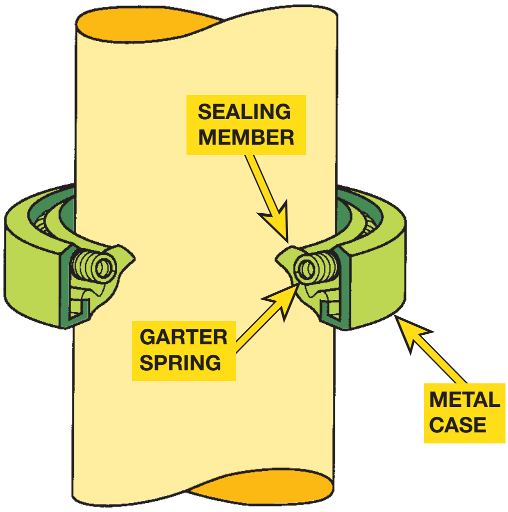


FIGURE 97–11 A garter spring helps hold the sharp lip edge of the seal tight against the shaft.

3. Looseness or excessive play in the steering wheel, especially while driving over rough road surfaces
4. A loud grinding noise in severe cases, indicating a defective front wheel bearing
5. Pulling during braking

DETERMINING BEARING NOISE FROM TIRE NOISE A defective wheel bearing is often difficult to diagnose because the noise is similar to a noisy winter tire or a severely cupped tire. Customers often request that tires be replaced as a result of the noise when the real problem is a bad wheel bearing. To help determine if the noise is caused by a wheel bearing or a tire, try the following tests:

TEST #1	Drive the vehicle over a variety of road surfaces. If the noise changes with a change in road surface, the noise is caused by a tire(s). If the noise remains the same, then the cause is a defective wheel bearing.
TEST #2	Try temporarily overinflating the tires. If the noise changes, then the tires are the cause. If the noise is the same, then defective wheel bearings are the cause.

TECH TIP

Easy Wheel Bearing Looseness Test

Looseness in a front wheel bearing can allow the rotor to move whenever the front wheel hits a bump, forcing the caliper piston in, which causes the brake pedal to kick back and creates the feeling that the brakes are locking up. Loose wheel bearings are easily diagnosed by removing the cover of the master cylinder reservoir and watching the brake fluid as the front wheels are turned left and right with the steering wheel. If the brake fluid moves while the front wheels are being turned, caliper piston(s) are moving in and out, caused by loose wheel bearing(s). If everything is OK, the brake fluid should not move. Loose wheel bearings can also cause the brake pedal to sink due to movement of the rotor, causing the caliper piston to move. This sinking brake pedal is usually caused by a defective master cylinder. Before replacing a master cylinder, check the wheel bearings.

TESTING A WHEEL BEARING With the vehicle off the ground, rotate the wheel by hand, listening and feeling carefully for bearing roughness. Grasp the wheel at the top and bottom and wiggle it back and forth, checking for bearing looseness.

WHEEL BEARING SERVICE

The steps in a non-drive-wheel bearing inspection include the following:

1. Hoist the vehicle safely.
2. Remove the wheel.
3. Remove the brake caliper assembly and support it with a coat hanger or other suitable hook to avoid allowing the caliper to hang by the brake hose.
4. Remove the grease cap (dust cap). ● **SEE FIGURE 97–12**.
5. Remove the old cotter key and discard.

NOTE: The term *cotter*, as in cotter key or cotter pin, is derived from the Old English verb meaning "to close or fasten."

6. Remove the spindle nut (castle nut).
7. Remove the washer and the outer wheel bearing.
8. Remove the bearing hub from the spindle. The inner bearing will remain in the hub and may be removed (simply lifted out) after the grease seal is pried out. ● **SEE FIGURE 97–13**.
9. Most vehicle and bearing manufacturers recommend cleaning the bearing thoroughly in solvent or acetone. ● **SEE FIGURE 97–14**. If there is no acetone, clean the solvent off the bearings with denatured alcohol or brake cleaner to make certain that the thin solvent layer is completely washed off and dry. *All solvent must be removed or allowed to dry from the bearing because the new grease will not stick to a layer of solvent.*

CAUTION: Never use compressed air to spin a bearing because the bearing can be damaged.

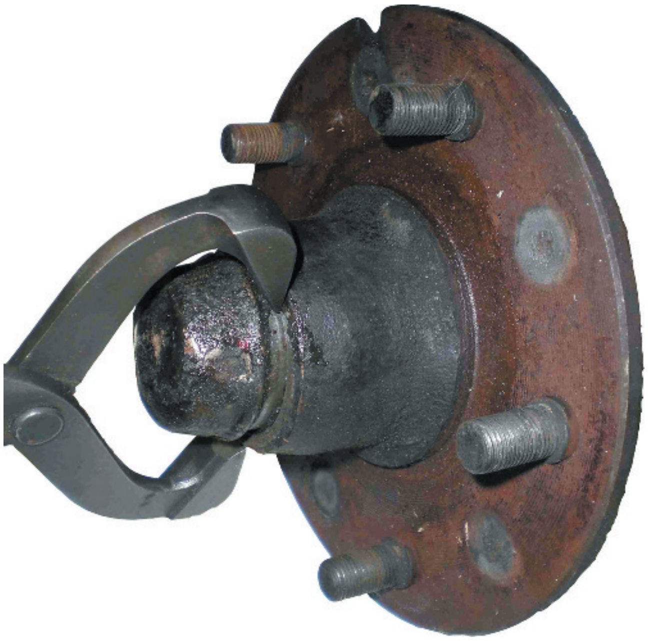


FIGURE 97–12 Removing the grease cap with grease cap pliers.

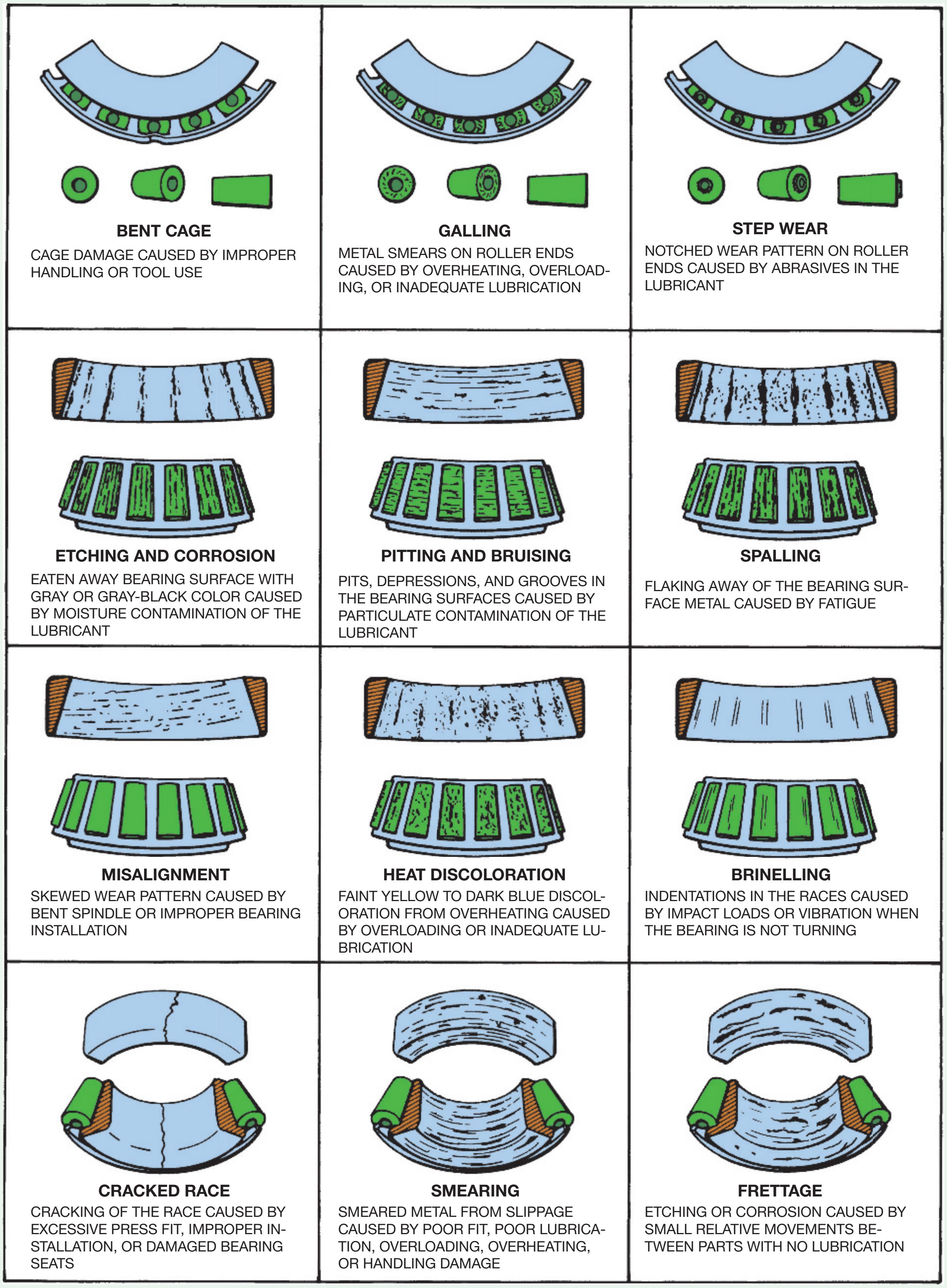

BENT CAGE
CAGE DAMAGE CAUSED BY IMPROPER HANDLING OR TOOL USE
GALLING
METAL SMEARS ON ROLLER ENDS CAUSED BY OVERHEATING, OVERLOADING, OR INADEQUATE LUBRICATION
STEP WEAR
NOTCHED WEAR PATTERN ON ROLLER ENDS CAUSED BY ABRASIVES IN THE LUBRICANT
ETCHING AND CORROSION
EATEN AWAY BEARING SURFACE WITH GRAY OR GRAY-BLACK COLOR CAUSED BY MOISTURE CONTAMINATION OF THE LUBRICANT
PITTING AND BRUISING
PITS, DEPRESSIONS, AND GROOVES IN THE BEARING SURFACES CAUSED BY PARTICULATE CONTAMINATION OF THE LUBRICANT
SPALLING
FLAKING AWAY OF THE BEARING SURFACE METAL CAUSED BY FATIGUE
MISALIGNMENT
SKEWED WEAR PATTERN CAUSED BY BENT SPINDLE OR IMPROPER BEARING INSTALLATION
HEAT DISCOLORATION
FAINT YELLOW TO DARK BLUE DISCOLORATION FROM OVERHEATING CAUSED BY OVERLOADING OR INADEQUATE LUBRICATION
BRINELLING
INDENTATIONS IN THE RACES CAUSED BY IMPACT LOADS OR VIBRATION WHEN THE BEARING IS NOT TURNING
CRACKED RACE
CRACKING OF THE RACE CAUSED BY EXCESSIVE PRESS FIT, IMPROPER INSTALLATION, OR DAMAGED BEARING SEATS
SMEARING
SMEARED METAL FROM SLIPPAGE CAUSED BY POOR FIT, POOR LUBRICATION, OVERLOADING, OVERHEATING, OR HANDLING DAMAGE
FRETTAGE
ETCHING OR CORROSION CAUSED BY SMALL RELATIVE MOVEMENTS BETWEEN PARTS WITH NO LUBRICATION

CHART 97–1

Wheel bearing inspection chart. Replace the bearing if it has any of the faults shown.

10. Carefully inspect the bearings and the races for the following:

a. The outer race for lines, scratches, or pits.

b. The cage should be round. If the round cage has straight sections, this is an indication of an overtightened adjustment or a dropped cage. ● **SEE CHART 97–1**.

If either of the above is observed, then the bearing, including the outer race, must be replaced. Failure to replace the outer race (which is included when purchasing a bearing) could lead to rapid failure of the new bearing. ● **SEE FIGURES 97–15 AND 97–16**.

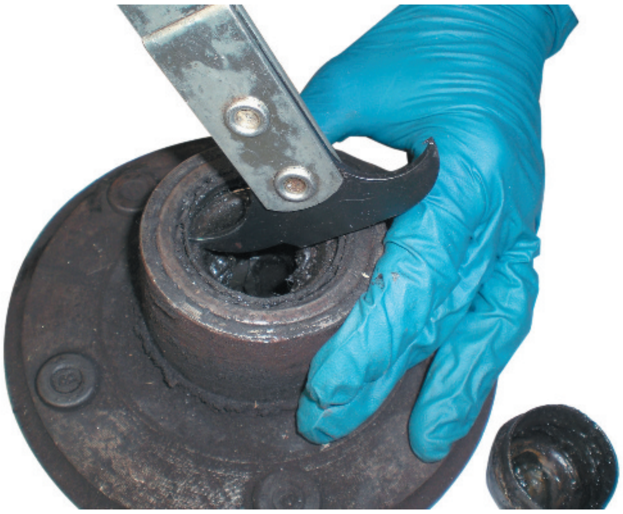


FIGURE 97–13 Using a seal puller to remove the grease seal.

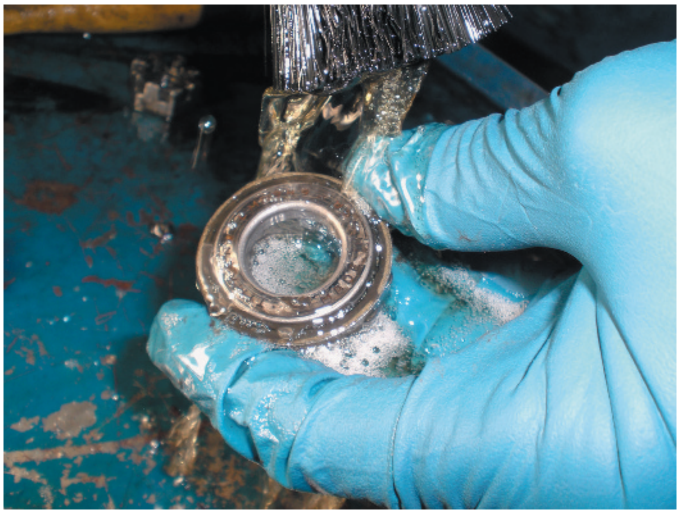


FIGURE 97–14 Cleaning a wheel bearing with a parts brush and solvent.

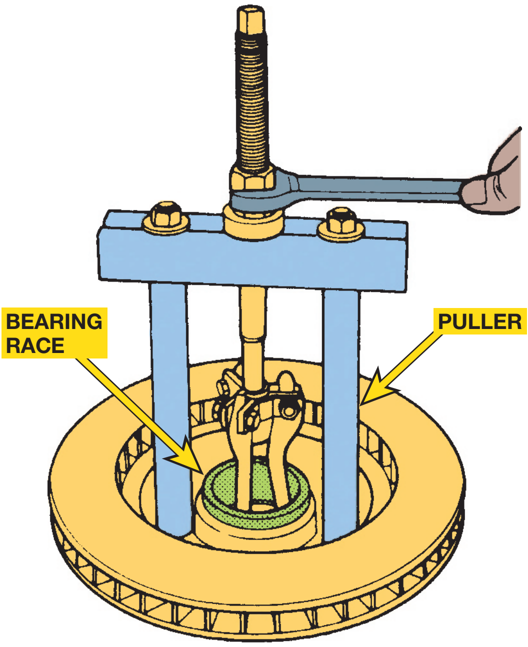


FIGURE 97–15 A wheel bearing race puller.

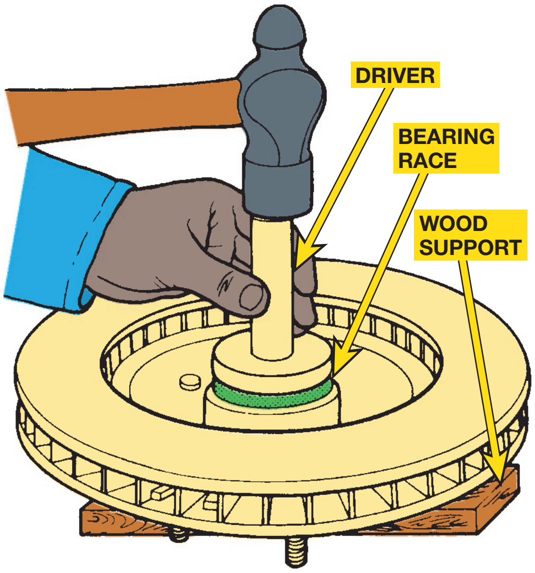


FIGURE 97–16 Installing a bearing race with a driver.

11. Pack the cleaned or new bearing thoroughly with clean, new, approved wheel bearing grease. Always clean out all of the old grease before applying the recommended type of new grease. *Because of compatibility problems, it is not recommended that greases be mixed*. There are several different ways to pack wheel bearings including
    - **By hand.** Place some grease in the palm of the hand and then force the grease through the bearing until grease can be seen out the other side. ● **SEE FIGURE 97–17**.
    - **Hand-operated bearing packer.** A hand-operated bearing packer is faster to use and produces excellent results. ● **SEE FIGURE 97–18**.
    - **Grease gun-type bearing packer.** This type of bearing packer uses a grease gun to fill the bearing with grease. The grease gun can be hand-operated or powered by electric or air. ● **SEE FIGURE 97–19**.
12. Place a thin layer of grease on the outer race.
13. Apply a thin layer of grease to the spindle, being sure to cover the outer bearing seat, inner bearing seat, and shoulder at the grease seal seat.
14. Install a new **grease seal** (also called a *grease retainer*) flush with the hub using a seal driver.

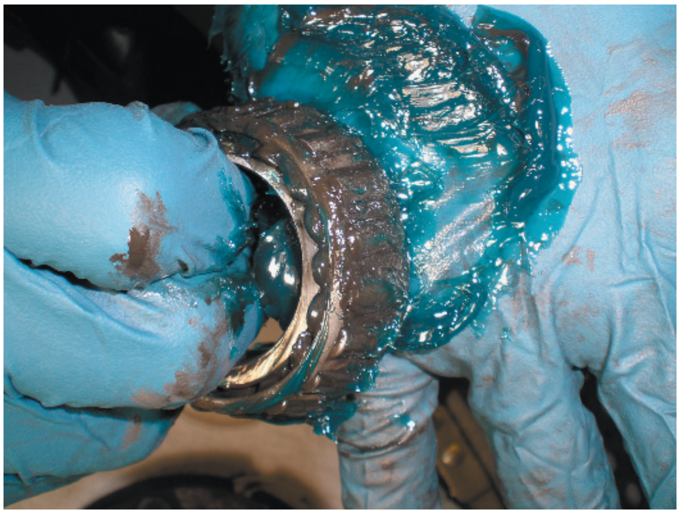


FIGURE 97–17 Notice the new blue grease has been forced through the bearing.

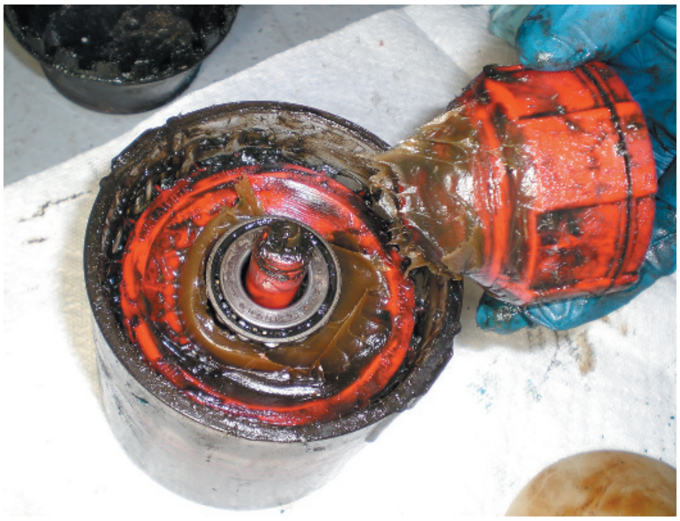


FIGURE 97–18 A commonly used hand-operated bearing packer.

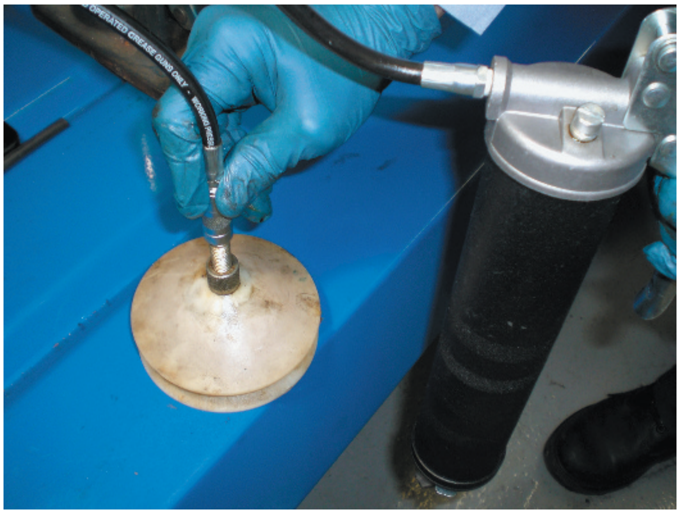


FIGURE 97–19 The wheel bearing is placed between two nylon cones and then a grease gun is used to inject grease into the center of the bearing.

15. Place approximately three tablespoons of grease into the grease cavity of the wheel hub. Excessive grease could cause the inner grease seal to fail, with the possibility of grease getting on the brakes. Place the rotor with the inner bearing and seal in place over the spindle until the grease seal rests on the grease seal shoulder.
16. Install the outer bearing and the bearing washer.
17. Install the spindle nut and, while rotating the tire assembly, tighten to about 12 to 30 lb-ft with a wrench to “seat” the bearing correctly in the race (cup) and on the spindle. ● **SEE FIGURE 97–20**.
18. While still rotating the tire assembly, loosen the nut approximately one-half turn and then *hand tighten only* (about 5 lb-in.).

NOTE: If the wheel bearing is properly adjusted, the wheel will still have about 0.001–0.005 inch (0.03 to 0.13 mm) end play. To check for proper clearance, grasp the wheel at the top and bottom and check for a slight looseness. This looseness is necessary to allow the tapered roller bearing to expand when hot and not bind or cause the wheel to lock up.

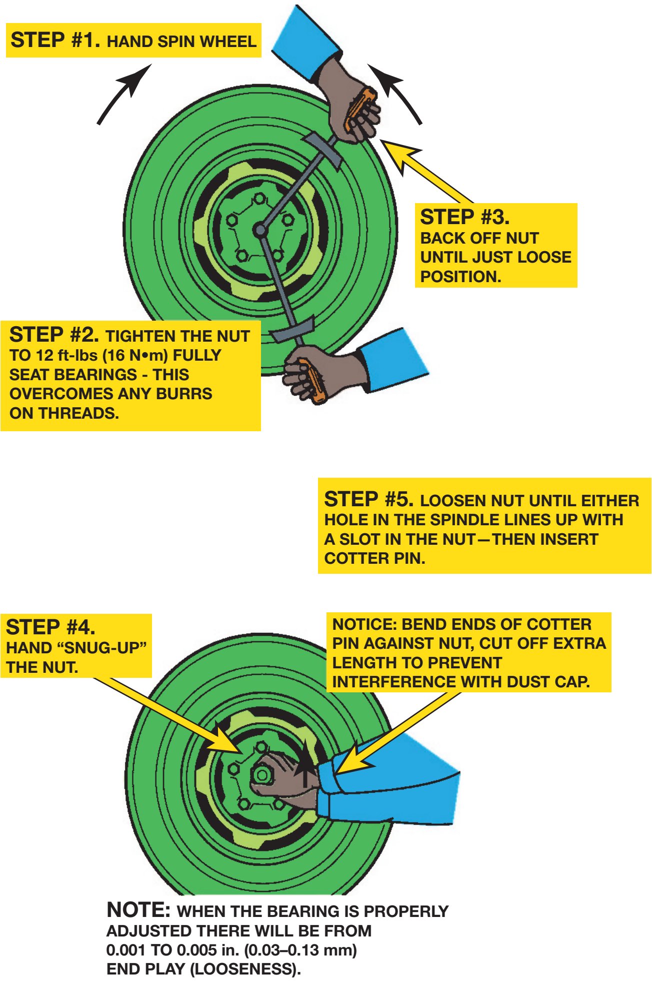

STEP #1. HAND SPIN WHEEL
STEP #3. BACK OFF NUT UNTIL JUST LOOSE POSITION.
STEP #2. TIGHTEN THE NUT TO 12 ft-lbs (16 N•m) FULLY SEAT BEARINGS - THIS OVERCOMES ANY BURRS ON THREADS.
STEP #5. LOOSEN NUT UNTIL EITHER HOLE IN THE SPINDLE LINES UP WITH A SLOT IN THE NUT—THEN INSERT COTTER PIN.
STEP #4. HAND “SNUG-UP” THE NUT.
NOTICE: BEND ENDS OF COTTER PIN AGAINST NUT, CUT OFF EXTRA LENGTH TO PREVENT INTERFERENCE WITH DUST CAP.
NOTE: WHEN THE BEARING IS PROPERLY ADJUSTED THERE WILL BE FROM 0.001 TO 0.005 in. (0.03–0.13 mm) END PLAY (LOOSENESS).

FIGURE 97–20 The front wheel bearing adjustment procedure as specified for rear-wheel-drive vehicles. Always check service information for the specified procedure to follow.

19. Install a new cotter key. (An old cotter key could break a part off where it was bent and lodge in the bearing, causing major damage.)

NOTE: Most vehicles use a cotter key that is 1/8 inch in diameter by 1 1/2 inch long.

20. If the cotter key does not line up with the hole in the spindle, loosen slightly (no more than 1/16 in. of a turn) until the hole lines up. Never tighten more than hand tight.
21. Bending the cotter key ends up and around the nut, not over the end of the spindle where the end of the cotter key could rub on the grease cap, causing noise. ● **SEE FIGURE 97–21**.
22. Install the grease cap (dust cap) using a seal driver that applies force to the outside edge of the seal to prevent denting the grease cap. Install the wheel cover or hub cap.
23. Clean grease off the disc brake rotors or drums after servicing the wheel bearings. Use a brake cleaner and a shop cloth. Even a slight amount of grease on the friction surfaces of the brakes can harm the friction lining and/or cause brake noise.

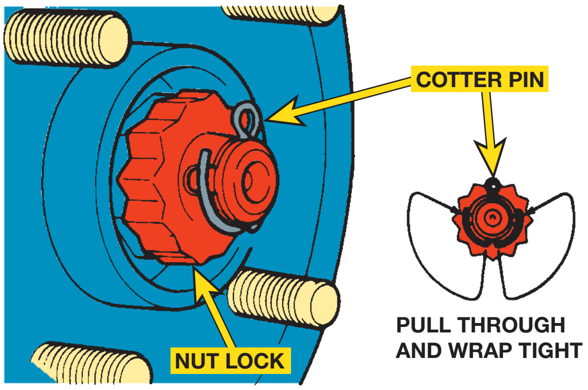

COTTER PIN
NUT LOCK
PULL THROUGH AND WRAP TIGHT

FIGURE 97–21 A properly secured wheel bearing adjust nut.

SEALED BEARING SERVICE

DIAGNOSIS Diagnosing a defective front bearing on a front-wheel-drive vehicle is sometimes confusing. A defective wheel bearing is usually noisy while driving straight, and the noise increases with vehicle speed (wheel speed). A drive axle shaft U-joint (CV joint) can also be the cause of noise on a front-wheel-drive vehicle, but usually makes *more noise* while turning and accelerating. Most front-wheel-drive vehicles use a sealed bearing assembly that is bolted to the steering knuckle and supports the drive axle or the rear, as shown in ● **FIGURE 97–22**.

REPLACEMENT Many front-wheel-drive vehicles use a bearing that must be pressed off the steering knuckle. Special aftermarket tools are also available to remove many of the bearings without removing the knuckle from the vehicle. Check the service information for the exact procedures to follow for the vehicle being serviced. ● **SEE FIGURES 97–23 AND 97–24**.

REAR DRIVE AXLE CLASSIFICATIONS

There are three rear drive axle classifications:

- Full-floating
- Three-quarter-floating
- Semi-floating

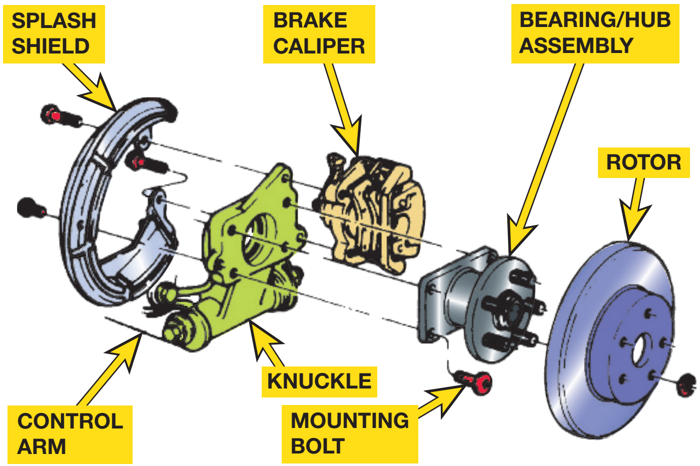

SPLASH SHIELD
BRAKE CALIPER
BEARING/HUB ASSEMBLY
ROTOR
CONTROL ARM
KNUCKLE
MOUNTING BOLT

FIGURE 97–22 A rear wheel sealed bearing hub assembly.

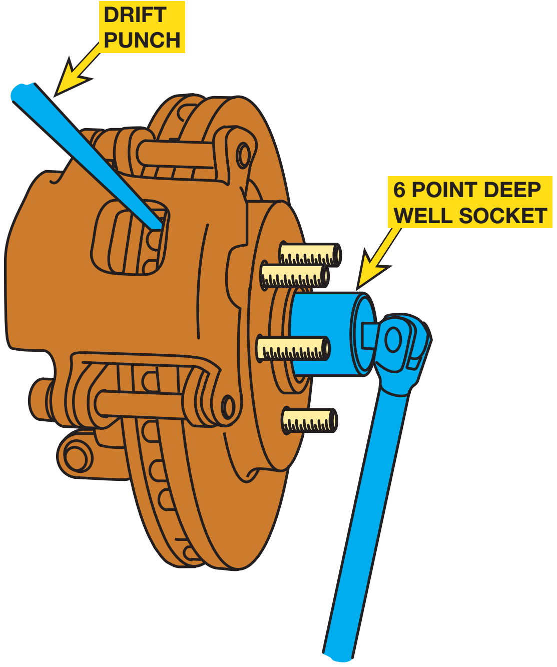

DRIFT PUNCH
6 POINT DEEP WELL SOCKET

FIGURE 97–23 Removing the drive axle shaft hub nut. This nut is usually very tight and the drift (tapered) punch wedged into the cooling fins of the brake rotor keeps the hub from revolving when the nut is loosened. Never use an air impact wrench to loosen or tighten the drive axle shaft nut because the hammering action will damage the bearings.

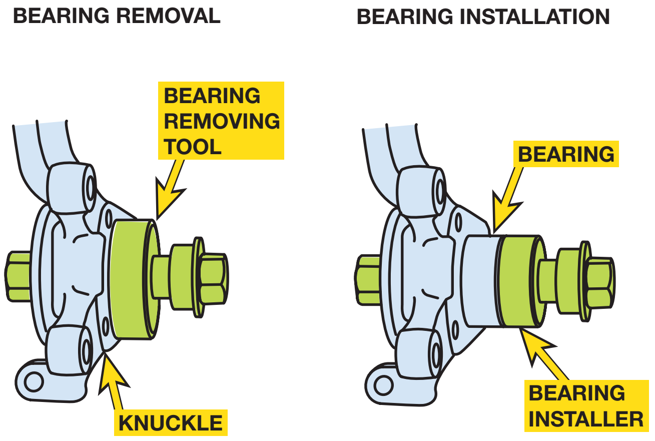

BEARING REMOVAL
BEARING INSTALLATION
BEARING REMOVING TOOL
KNUCKLE
BEARING
BEARING INSTALLER

FIGURE 97–24 A special puller makes the job of removing the hub bearing from the knuckle easy without damaging any component.

These classifications indicate whether the axle shafts or the axle housing supports the wheel. The category of a rear drive axle is determined by how the wheel and wheel bearing mount to the axle or housing.

FULL-FLOATING AXLE On a full-floating axle, the bearings are mounted and retained in the hub of the brake drum or rotor. The hub and bearing mount onto the axle housing, and are held in place by a bearing retainer or adjustment nuts and safety locks. The flanged end of the drive axle is attached to the hub by bolts or nuts. The inner end of the axle splines into the differential side gears. The wheel mounts onto the hub, and lug bolts or nuts retain it. In this design, the axle shafts "float"

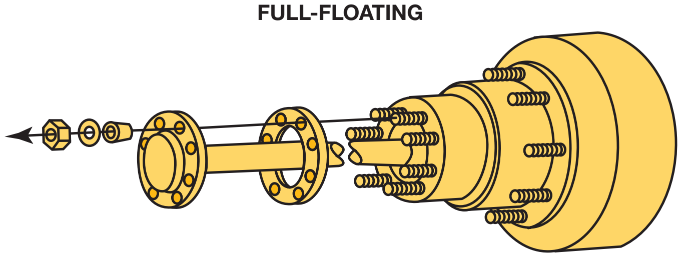


FIGURE 97–25 A typical full-floating rear axle assembly.

in the axle housing and drive the wheels without supporting their weight. Because the axle shafts do not retain the wheel, the axle shafts can usually be removed from the vehicle while it is standing on the wheels. Many three-quarter-ton pickups, all heavy-duty truck tractors, and trailers use full-floating axles. ● **SEE FIGURE 97–25**.

THREE-QUARTER-FLOATING AXLE The bearings in a three-quarter-floating axle are mounted and retained in the brake drum or rotor hub, which mounts onto the axle housing. The outer extension of the hub fits onto the end of the axle, which is usually splined and tapered, and a nut and cotter pin secure the hub to the axle. The axle shaft splines to the side gears inside the differential. The wheels are mounted on the hub and retained by lug bolts or nuts. As in the full-floating axle, the axle housing and bearings in the hub support the weight in a three-quarter-floating axle. Because of the construction of a three-quarter-floating axle, the wheel must be removed before removing the axle shaft from the vehicle. ● **SEE FIGURE 97–26**.

SEMI-FLOATING AXLE The wheel bearings in a semi-floating axle either press onto the axle shaft or are installed in the outer end of the axle housing. A retainer plate at the outer end of the axle shaft or a C-clip inside the differential at the other end keeps the axle shaft in the housing. The brake drum or rotor fits onto the end of the axle, and lug bolts or nuts fasten the wheel to the drum or rotor and to the axle. These axles are called "semi-floating" because only the inboard ends of the axle shaft "float" in the housing. The outboard end of the shaft retains the wheel and transmits the weight of the wheel to the housing. Most solid-axle rear-wheel-drive cars and light trucks use a semi-floating type of axle. ● **SEE FIGURE 97–27**.

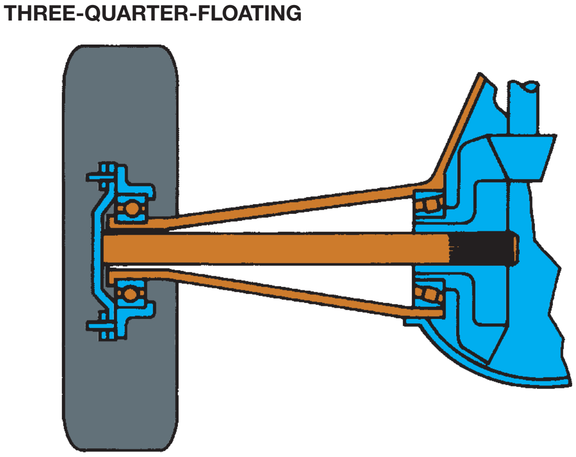


FIGURE 97–26 A three-quarter-floating rear axle.

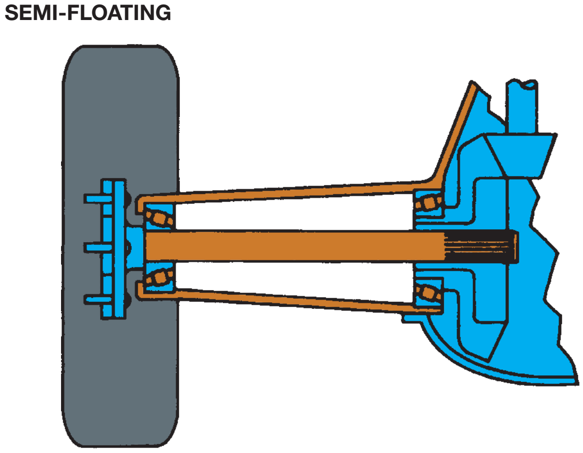


FIGURE 97–27 A semi-floating rear axle housing is the most commonly used in light rear-wheel-drive vehicles.

REAR AXLE BEARING AND SEAL REPLACEMENT

The rear bearings used on rear-wheel-drive vehicles are constructed and serviced differently from other types of wheel bearings. Rear axle bearings are either sealed or lubricated by the rear-end lubricant. The rear axle must be removed from the vehicle to replace the rear axle bearing. There are two basic types of axle retaining methods:

- **Retainer plate-type**
- **C-lock**

RETAINER PLATE-TYPE REAR AXLES The retainer plate-type rear axle uses four fasteners that retain the axle in the axle housing. To remove the axle shaft and the rear axle bearing and seal, the retainer bolts or nuts must be removed.

NOTE: If the axle flange has an access hole, then a retainer plate-type axle is used.

The hole or holes in the wheel flange permit a socket wrench access to the fasteners. After the fasteners have been removed, the axle shaft must be removed from the rear axle housing. With the retainer plate-type rear axle, the bearing and the retaining ring are press fit onto the axle and the bearing cup (outer race) is also tightly fitted into the axle housing tube. ● **SEE FIGURE 97–28**. ● **SEE FIGURE 97–29** for the method to remove the axle shaft using a rear axle puller.

C-LOCK-TYPE AXLES Vehicles that use C-locks (clips) use a straight roller bearing supporting a semi-floating axle shaft

TECH TIP

The Brake Drum Slide Hammer Trick

To remove the axle from a vehicle equipped with a retainer plate-type rear axle, simply use the brake drum as a slide hammer to remove the axle from the axle housing. ● **SEE FIGURE 97–30**. If the brake drum does not provide enough force, a slide hammer can also be used to remove the axle shaft.

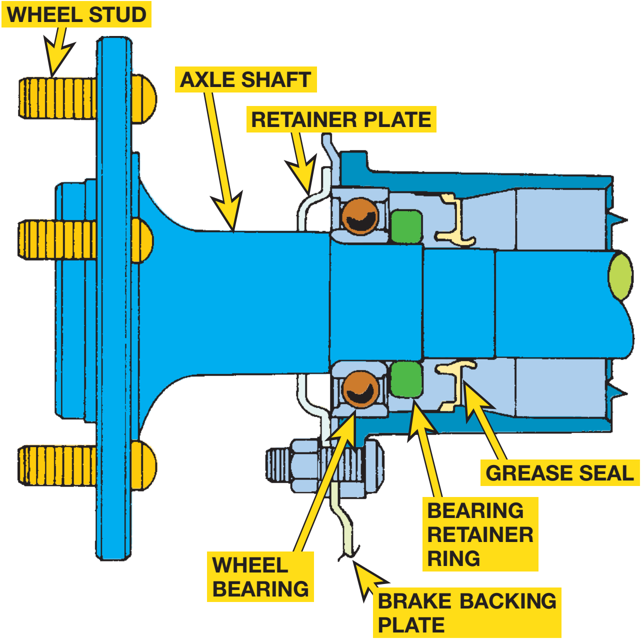


FIGURE 97–28 A retainer plate-type rear axle bearing. Access to the fasteners is through a hole in the axle flange.

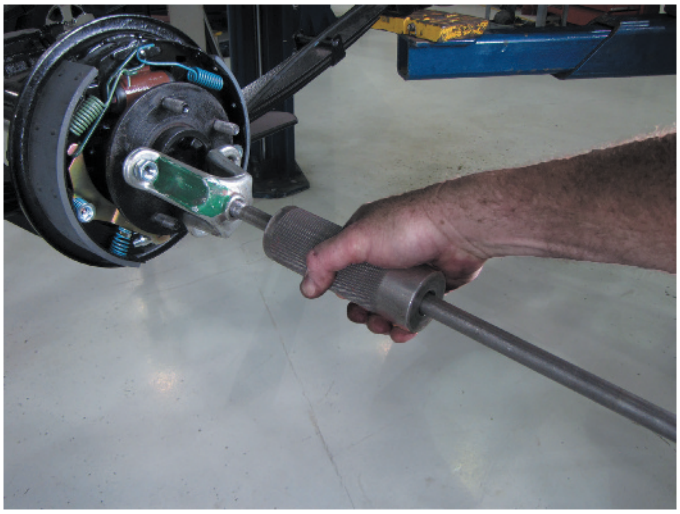


FIGURE 97–29 A slide-hammer-type axle puller can be used to remove an axle.

inside the axle housing. The straight rollers do not have an inner race. The rollers ride on the axle itself. If a bearing fails, both the axle and the bearing usually need to be replaced. The outer bearing race holding the rollers is pressed into the rear axle housing. The axle bearing is usually lubricated by the rear-end lubricant and a grease seal is located on the outside of the bearing.

NOTE: Some replacement bearings are available that are designed to ride on a fresh, unworn section of the old axle. These bearings allow the use of the original axle, saving the cost of a replacement axle.

The C-lock-type rear axle retaining method requires that the differential cover plate be removed. After removal of the cover, the differential pinion shaft has to be removed before the C-lock that retains the axle can be removed. ● **SEE FIGURES 97–31 AND 97–32**.

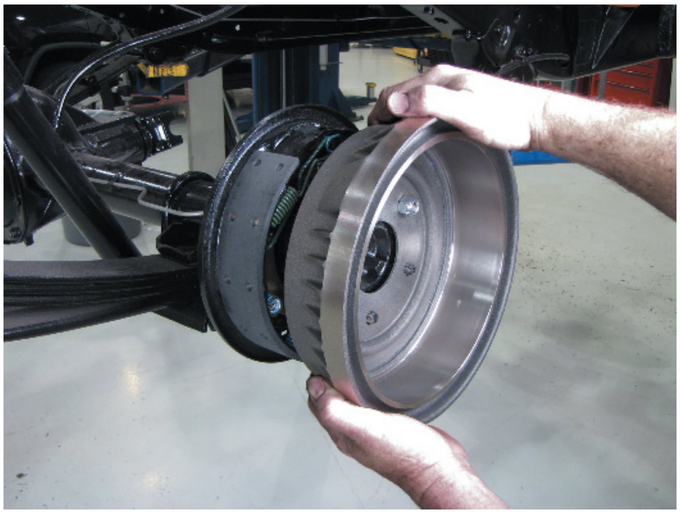


FIGURE 97–30 To remove the axle from this vehicle equipped with a retainer-plate rear axle, the brake drum was placed back onto the axle studs backward so that the drum itself can be used as a slide hammer to pull the axle out of the axle housing. After a couple of pulls, the rear axle is pulled out of the axle housing.

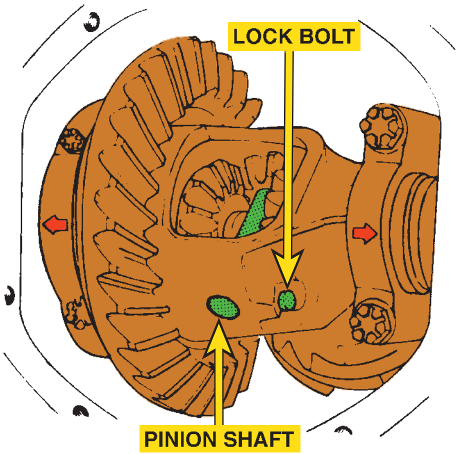


FIGURE 97–31 To remove the C-lock (clip), the lock bolt must be removed before the pinion shaft is taken out.

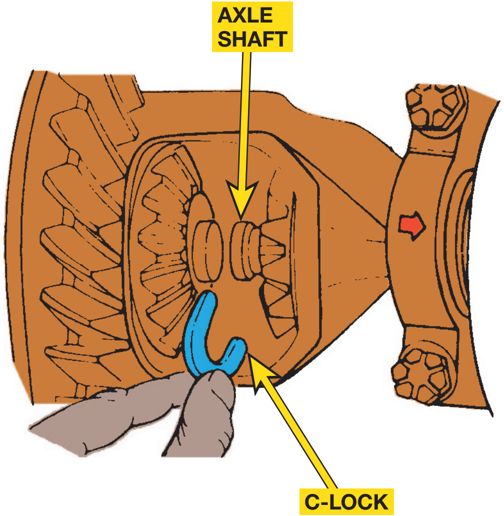


FIGURE 97–32 The axle must be pushed inward slightly to allow the C-lock to be removed. After the C-lock has been removed, the axle can be easily pulled out of the axle housing.

NOTE: When removing the differential cover, rear axle lubricant will flow from between the housing and the cover. Be sure to dispose of the old rear axle lubricant in the environmentally approved way, and refill with the proper type and viscosity (thickness) of rear-end lubricant. Check the vehicle specifications for the recommended grade.

Once the C-lock has been removed, the axle simply is pulled out of the axle tube. Axle bearings with inner races are pressed onto the axle shaft and must be pressed off using a hydraulic press. A bearing retaining collar should be chiseled or drilled into to expand the collar, allowing it to be removed. ● **SEE FIGURE 97–33**.

Always follow the manufacturer's recommended bearing removal and replacement procedures. Always replace the rear axle seal whenever replacing a rear axle bearing. ● **SEE FIGURE 97–34** for an example of seal removal.

All differentials use a vent so make sure it is clear. A clogged vent can cause excessive pressure to build up inside the differential and cause the rear axle seals to leak. If rear-end lubricant gets on the brake linings, the brakes will not have the proper friction and the linings themselves are ruined and must be replaced.

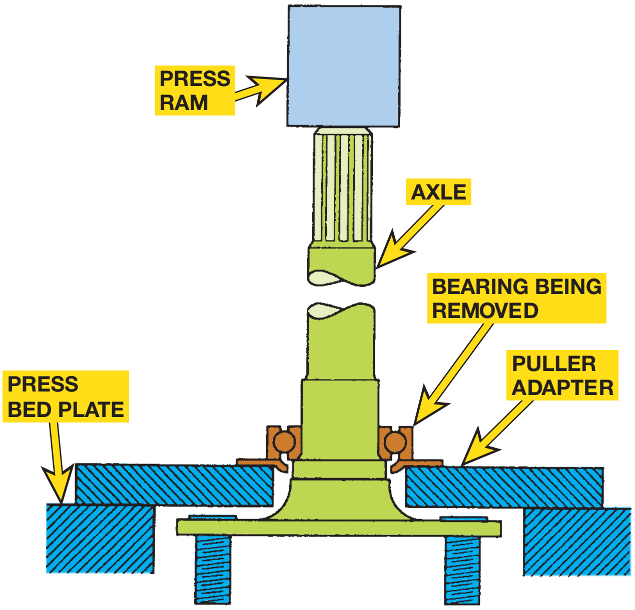


FIGURE 97–33 Using a hydraulic press to press an axle bearing from the axle. When pressing a new bearing back onto the axle, pressure should only be on the inner bearing race to prevent damaging the bearing.

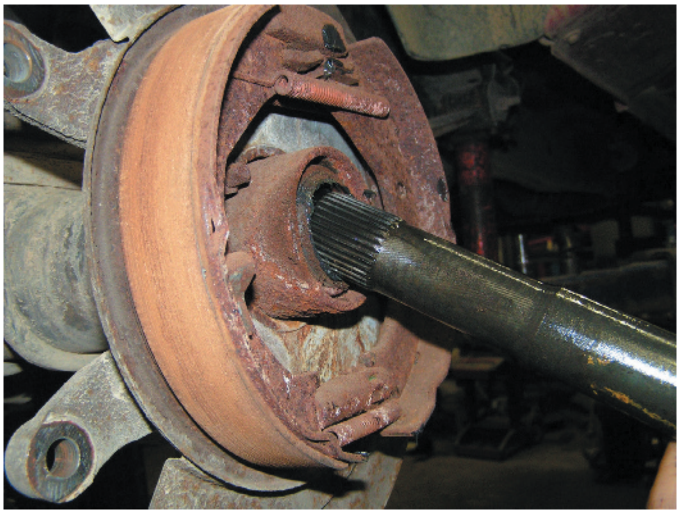


FIGURE 97–34 Removing an axle seal using the axle shaft as the tool. While this procedure is done in some shops, the preferred and specified procedure is to use a seal puller.

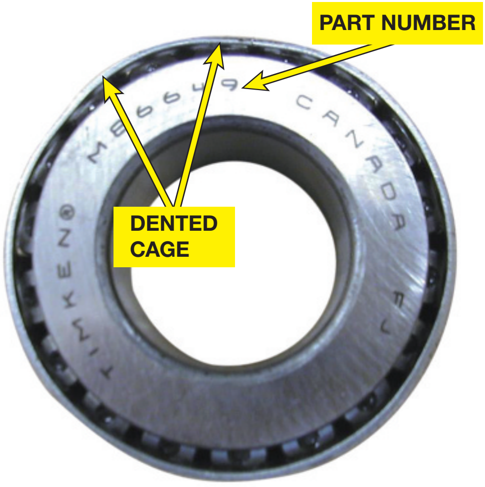


FIGURE 97–35 This bearing has a bent cage and must be replaced.

BEARING FAILURE ANALYSIS

Whenever a bearing is replaced, the old bearing must be inspected and the cause of the failure eliminated. If a bearing has a bent cage, it must be replaced. ● **SEE FIGURE 97–35**.

A wheel bearing may also fail for reasons that include the following:

METAL FATIGUE Long vehicle usage, even under normal driving conditions, causes metal to fatigue. Cracks often appear, and eventually these cracks expand downward into the metal from the surface. The metal between the cracks can break out into small chips, slabs, or scales of metal. This process of breaking up is called **spalling**.

ELECTRICAL ARCING Bearings can be damaged by poor ground wires or improper welding on the vehicle.

SHOCK LOADING Dents can be formed in the race of a bearing, which eventually leads to bearing failure. The indentations are called **brinelling** caused by the impact of loads or vibration when the bearing is not turning. It is named after Johan August Brinell, a Swedish engineer, who created the Brinell scale of hardness.

TECH TIP

Touch the Spring When Checking for Bearing Noise

Wheel bearing noises are often hard to pin down because the noise can be transmitted throughout the vehicle. Whenever diagnosing a possible defective wheel bearing, use one hand to grasp the spring while using the other hand to rotate the wheel. The roughness of a defective wheel bearing is easily detected by feeling a vibration in the coil spring. ● **SEE FIGURE 97–36**.

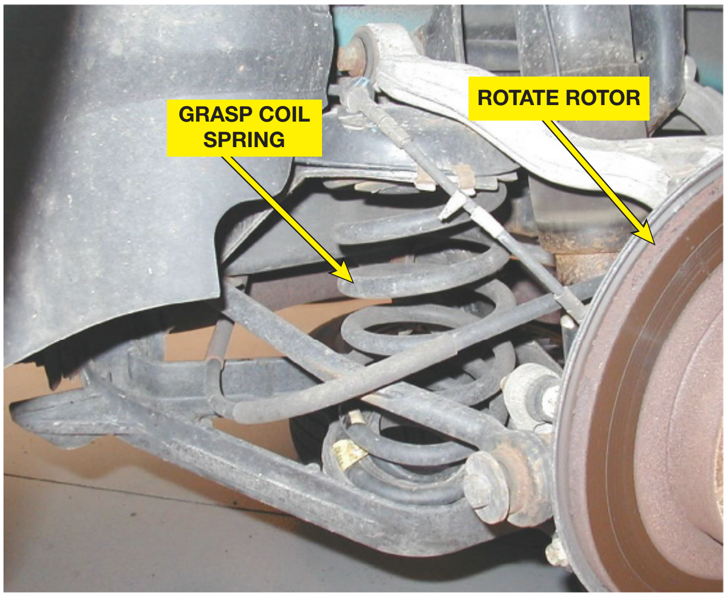


FIGURE 97–36 To detect a possible defective wheel bearing, grasp the coil spring and then rotate the wheel. If there is roughness in the bearing, a vibration will be felt in the spring.

TECH TIP

Double-Check the Bearing Part Number

Most wheel bearing/hub assemblies include the tone wheel (reluctor ring), which is used by the wheel speed sensor for use by the electronic brake control unit for electronic stability control and antilock brake operation. The number of notches or teeth on the bearing hub can and do vary. If the incorrect bearing is installed, it can cause the amber ABS warning lamp to come on and a wheel speed sensor diagnostic trouble code to be set. ● **SEE FIGURE 97–37**.

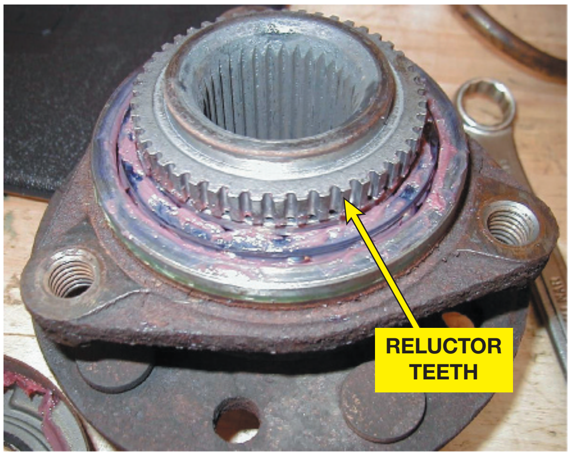


FIGURE 97–37 A bearing/hub assembly that shows the reluctor (tone wheel) teeth used by the wheel speed sensor.

CASE STUDY

The Noisy Toyota

A customer complained that a noise was heard from the rear of a Toyota Highlander SUV. During a test drive, the service technician did notice a slight noise and thought it might be due to a tire. Driving over various types of road surfaces did not change the level or the pitch (frequency) of the noise indicating that the noise was due to a bearing rather than a tire. As a double check that a tire was not the issue, the technician rotated tires placing the front tires in the rear and the rear tires on the front. Another test drive resulted in the same results.

The technician then recommended that the right rear wheel bearing (bearing hub assembly) be replaced and the customer agreed to the estimate.

When the hub bearing was removed and checked for any roughness, the technician did not feel or hear any noise from the old bearing. However, once the new bearing was replaced, the noise was gone during a test drive.

Summary:

Complaint—Customer complained of a noise from the right rear of the SUV.
Cause—Defective wheel bearing.
Correction—Replacing the right rear bearing/hub assembly fixed the noise concern.

TECH TIP

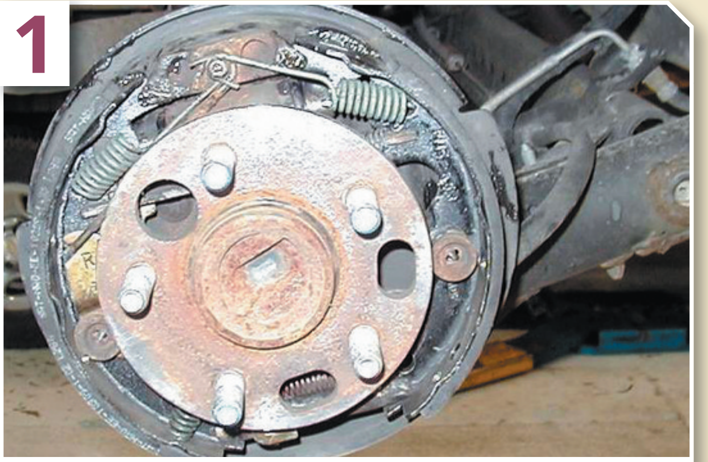
"Bearing Overload"

It is not uncommon for vehicles to be overloaded. This is particularly common with pickup trucks and vans. Whenever there is a heavy load, the axle bearings must support the entire weight of the vehicle, including its cargo. If a bump is hit while driving with a heavy load, the balls of a ball bearing or the rollers of a roller bearing can make an indent in the race of the bearing. This dent or imprint is called brinelling, named after Johann A. Brinell, a Swedish engineer who developed a process of testing for surface hardness by pressing a hard ball with a standard force into a sample material to be tested.

Once this imprint is made, the bearing will make noise whenever the roller or ball rolls over the indent. Continued use causes wear to occur on all of the balls or rollers and eventual failure. While this may take months to fail, the *cause* of the bearing failure is often overloading of the vehicle. Avoid shock loads and overloading for safety and for longer vehicle life.

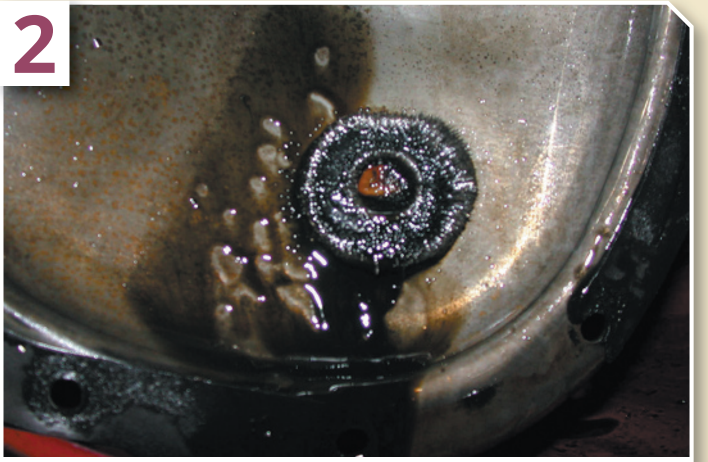
REAR AXLE BEARING SERVICE

1



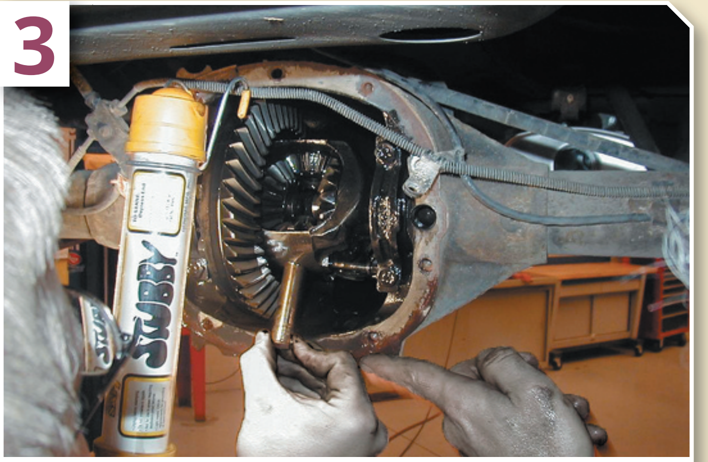
After safely hoisting the vehicle, remove the rear wheels and brake drums.

2



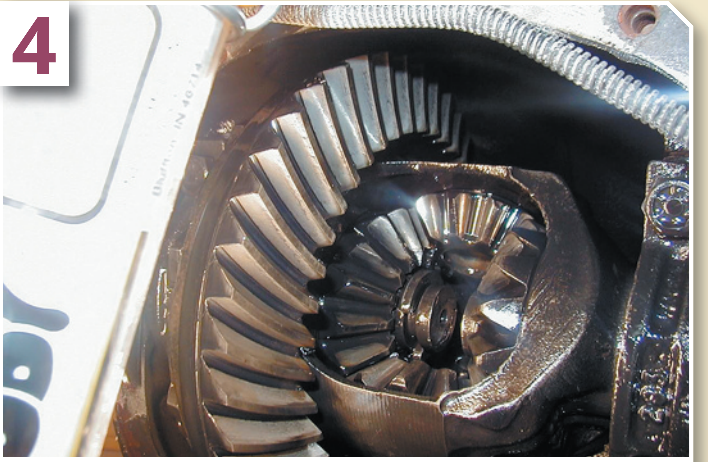
Remove the rear differential cover and inspect the magnet for metal particles that would indicate serious wear or damage.

3



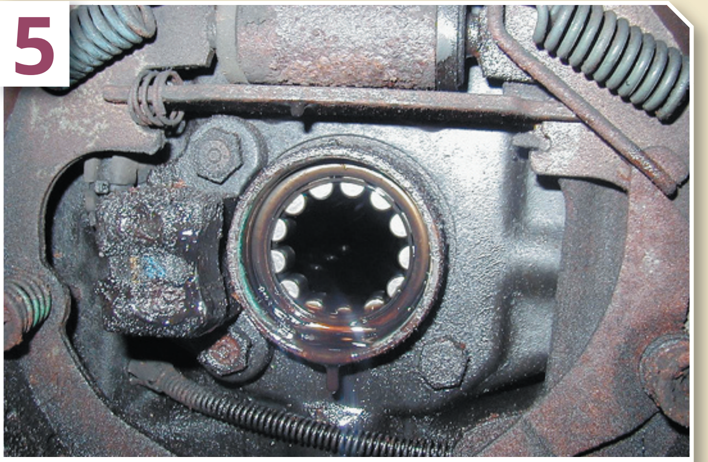
Remove the retaining bolt and allow the pinion shaft to be removed.

4



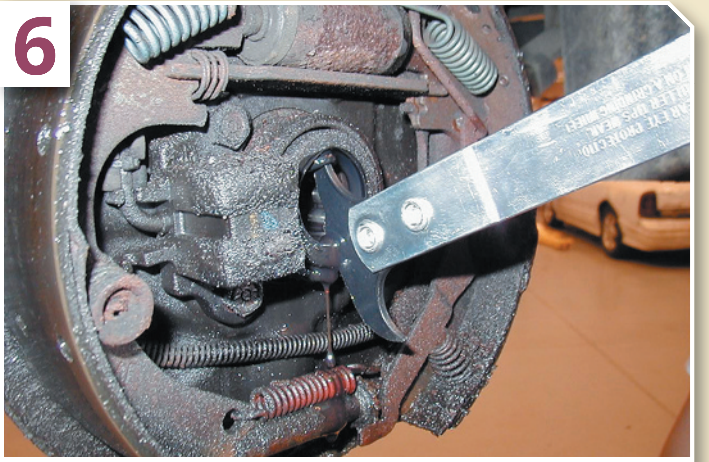
Push the axle inward toward the center of the vehicle to free the axle clip.

5



After removing the clip, the axle can then be removed. Note that the backing plate is wet, indicating that the axle seal has been leaking.

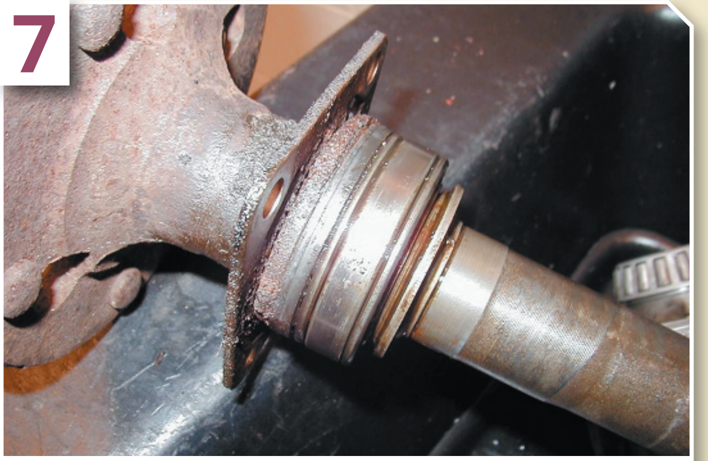
6



A seal removal tool being used to remove the axle seal.

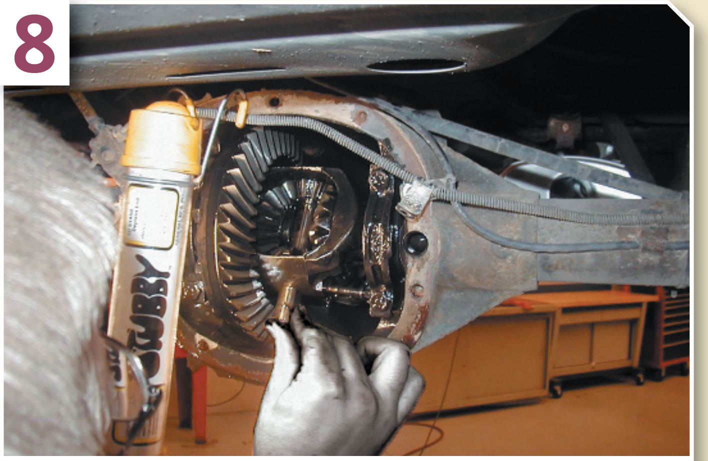
STEP BY STEP

7



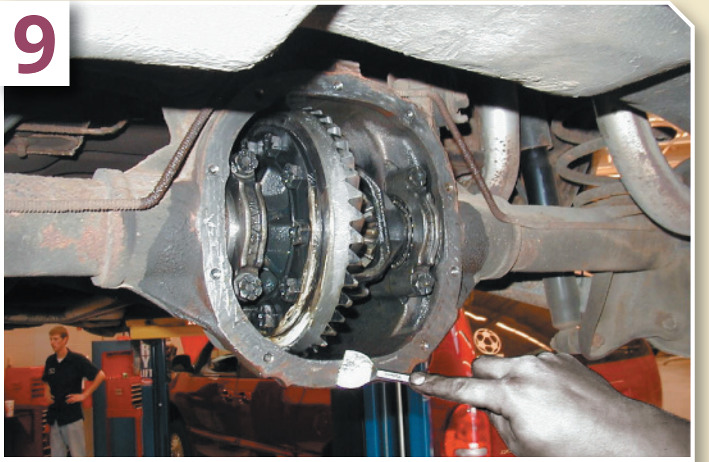
If a retainer-type axle is being serviced, the bearing and seal need to be pressed off of the axle.

8



After installing a new bearing and seal, insert the axle and install the clip, then the pinion shaft.

9



Clean the differential housing before installing the cover gasket and cover. Refill the differential with the specified fluid.

REVIEW QUESTIONS

1. List three common types of automotive antifriction bearings.
2. Explain the adjustment procedure for a typical tapered roller wheel bearing.
3. List four symptoms of a defective wheel bearing.
4. Describe how the rear axle is removed from a C-lock-type axle.
5. What is the meaning of the different colors of grease?

CHAPTER QUIZ

1. Which type of automotive bearing can withstand radial and thrust loads, yet must be adjusted for proper clearance?
   - **a.** Roller bearing
   - **b.** Tapered roller bearing
   - **c.** Ball bearings
   - **d.** Needle roller bearing
2. Which type of sealed bearings are mostly used on the front wheels of front-wheel-drive vehicles?
   - **a.** Roller bearing
   - **b.** Single tapered roller bearing
   - **c.** Double-row ball bearing
   - **d.** Needle roller bearing
3. The bearing grease most often specified is rated NLGI ___________.
   - **a.** #00
   - **b.** #0
   - **c.** #1
   - **d.** #2
4. Technician A says that a defective wheel or axle bearing often makes a growling or rumbling noise. Technician B says that a defective wheel or axle bearing often makes a noise similar to a tire with an aggressive mud or snow design. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. After a non-drive-wheel bearing has been properly adjusted, how much end play should the wheel have?
   - **a.** Zero
   - **b.** 0.001 to 0.005 inch
   - **c.** 0.10 to 0.30 inch
   - **d.** 1/16 to 3/32 inch
6. What part(s) should be replaced when servicing a wheel bearing on a non-drive wheel?
   - **a.** The bearing cup
   - **b.** The grease seal
   - **c.** The cotter key
   - **d.** Both the grease seal and the cotter key
7. Two technicians are discussing differentials. Technician A says all differentials are vented. Technician B says that a clogged vent can cause the rear axle seal to leak. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Which type of drive axle would a heavy-duty truck tractor have?
   - **a.** Full-floating
   - **b.** Semi-floating
   - **c.** Three-quarter floating
   - **d.** Any of these
9. The differential cover must be removed before removing the rear axle on which type of axle?
   - **a.** Retainer plate
   - **b.** C-lock
   - **c.** Press fit
   - **d.** Welded tube
10. On a bearing that has been shock loaded, the race (cup) of the bearing can be dented. This type of bearing failure is called ___________.
    - **a.** spalling
    - **b.** arcing
    - **c.** brinelling
    - **d.** fluting

Chapter

98

DRUM BRAKES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Identify drum brake component parts.
- Discuss the advantages of drum brakes.
- Discuss the disadvantages of drum brakes.
- Explain the function of the backing plate and wheel cylinders.
- Explain the function of drum brake shoes.
- Describe the operation of non-servo brakes.
- Explain the operation of dual-servo brakes.
- Discuss automatic brake adjusters.

KEY TERMS:

Anchor eyes 1149 • Beehive hold-down 1151 • Bonded linings 1150 • Brake fade 1145 • Brake shoe hold-downs 1151 • Brake shoe return springs 1150 • Brake shoes 1148 • Core charge 1149 • Double-trailing brake 1152 • Dual-servo brake 1153 • Duo-Servo 1153 • Gas fade 1146 • Labyrinth seal 1147 • Leading shoe 1152 • Leading-trailing brake 1152 • Ledges 1148 • Lining fade 1146 • Lining table 1149 • Mechanical fade 1146 • Nibs 1149 • Non-servo brake 1151 • Over-travel spring 1155 • Pawl 1154 • Piston stops 1147 • Platform 1149 • Primary shoe 1153 • Riveted linings 1150 • Secondary shoe 1153 • Self-energizing action 1151 • Shoe anchors 1147 • Shoe contact areas 1148 • Shoe rim 1149 • Shoe support pads 1148 • Shoe web 1149 • Trailing shoe 1152 • Water fade 1147

DRUM BRAKES

BACKGROUND Drum brakes were the first type of brakes used on motor vehicles. Even today, over 100 years after the first "horseless carriages," drum brakes are still used on the rear of many vehicles, as shown in ● **FIGURE 98–1**. The drum brake has been more widely used than any other automotive brake design. ● **SEE FIGURE 98–2**.

Although the disc brake has proven its superiority in extreme braking conditions, and has replaced the drum brake on the front axle of vehicles, the drum brake continues to have a number of advantages that contribute to its use on the rear axle of many trucks, vans, SUVs, and cars.

DRUM BRAKE ADVANTAGES

SELF-ENERGIZING AND SERVO ACTION The primary advantage of drum brakes is that they can apply more stopping power for a given amount of force applied to the brake pedal than can disc brakes. This is possible because the drum brake design offers a self-energizing action that helps force the brake linings tightly against the drum. In addition, some drum brake designs use an effect called servo action that enables one brake shoe to help apply the other for increased stopping power. Both self-energizing and servo action are explained in detail later in the chapter.

PARKING BRAKE SERVICE One advantage of drum brakes is that they make excellent parking brakes. A simple linkage fitted to the brake assembly allows relatively low effort from the driver to hold a heavy vehicle in place when parked. Disc brakes, which do not benefit from self-energizing or servo action, require a complex set of extra parts to provide enough force to work well as parking brakes.

DRUM BRAKE DISADVANTAGES

BRAKE FADE Drum brakes are not very efficient at dissipating heat. The brake drum covers the linings, and most of the heat produced during braking must pass through the drum, from the inside out into the air.

The greatest drawback of drum brakes is that they are susceptible to fade. **Brake fade** is the loss of stopping power that occurs when excessive heat reduces the friction between the

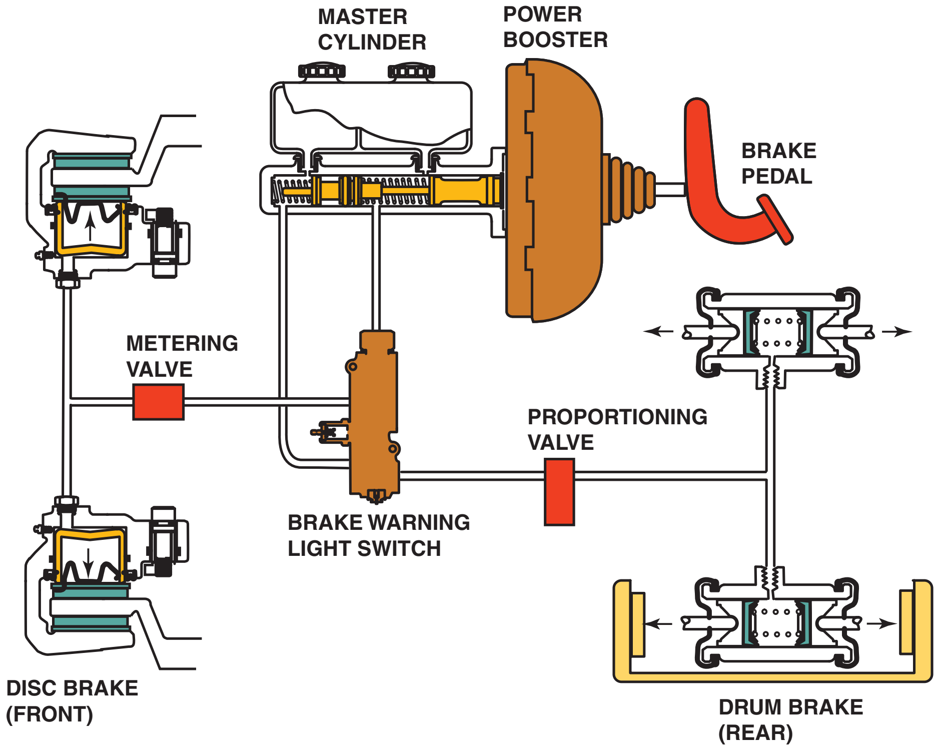

MASTER CYLINDER
POWER BOOSTER
BRAKE PEDAL
METERING VALVE
PROPORTIONING VALVE
BRAKE WARNING LIGHT SWITCH
DISC BRAKE (FRONT)
DRUM BRAKE (REAR)

FIGURE 98–1 Typical brake system components showing disc brakes on the front and drum brakes on the rear.

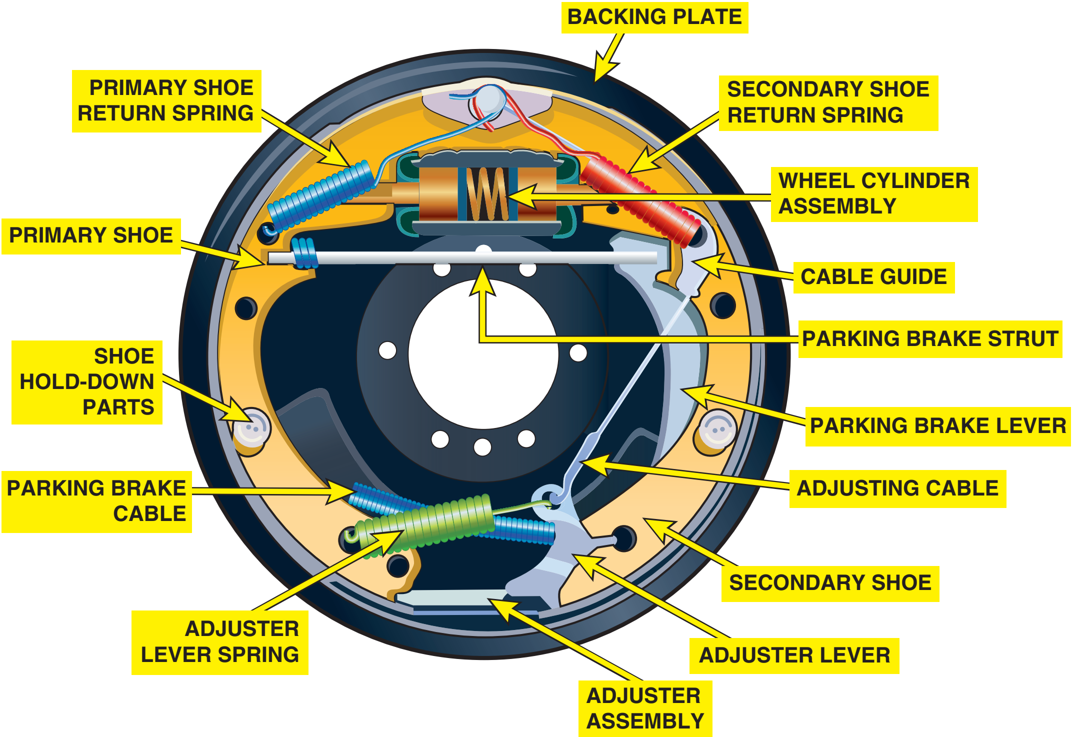

BACKING PLATE
PRIMARY SHOE RETURN SPRING
SECONDARY SHOE RETURN SPRING
WHEEL CYLINDER ASSEMBLY
PRIMARY SHOE
CABLE GUIDE
PARKING BRAKE STRUT
SHOE HOLD-DOWN PARTS
PARKING BRAKE LEVER
PARKING BRAKE CABLE
ADJUSTING CABLE
SECONDARY SHOE
ADJUSTER LEVER SPRING
ADJUSTER LEVER
ADJUSTER ASSEMBLY

FIGURE 98–2 A typical drum brake assembly showing the relationship of the all of the individual parts.

brake shoe linings and the drum. The four types of brake fade include the following:

1. **Mechanical fade. Mechanical fade** occurs when the brake drum gets so hot that it expands away from the brake linings. The brake shoes then move outward to maintain contact with the drum, causing the brake pedal to drop toward the floor as additional brake fluid moves into the hydraulic system.
2. **Lining fade. Lining fade** occurs when the friction coefficient of the brake lining material drops off sharply because intense heat makes it "slippery." Unlike mechanical fade, brake pedal travel does not increase when lining fade occurs. Instead, the pedal becomes hard and there is a noticeable loss of braking power.
3. **Gas fade. Gas fade** occurs under extended hard braking from high speeds. A thin layer of hot gases and dust particles

TECH TIP

Quick-and-Easy Drum Brake Adjustment Check

Tap the brake drum lightly with a hammer or wrench. If the brake shoes are not contacting the drum, the drum will ring like a bell. If the shoes are contacting the drum, the sound will be muffled.

can build up between the brake shoe linings and drum. The gas layer acts as a lubricant and reduces friction. As with the lining fade, the brake pedal becomes hard, and greater application force is required to maintain a constant level of stopping power.

4. **Water fade. Water fade** occurs when moisture is trapped between the shoes and drum, where it acts as a lubricant. This lowers braking efficiency until friction creates enough heat to evaporate the water.

BRAKE ADJUSTMENT Another disadvantage of the drum brake design is its need for an adjusting mechanism. As the brake shoe lining material wears, the clearance between the linings and drum increases, resulting in longer brake pedal travel. To maintain a high brake pedal, a mechanism must be included in the brake assembly for adjustment of the clearance between the brake shoe and drum. Most vehicles have automatic adjusters that maintain the proper clearance between the brake linings and the drum.

BRAKE PULL Brake pull occurs when the friction assemblies on opposite sides of the vehicle have different amounts of stopping power. These differences can be caused by brake fade or misadjustment of the clearance between the brake linings and drum.

BACKING PLATE AND WHEEL CYLINDERS

BACKING PLATE The foundation of every drum brake is the backing plate that mounts to the steering knuckle on the front brakes, or to the suspension or axle housing on the rear brakes. ● **SEE FIGURE 98–3.**

The backing plate serves as the mounting surface for all the other friction assembly parts. The backing plate also functions as a dust and water shield to keep contaminants out of the brake assembly. The edge of the backing plate curves outward to form a lip that strengthens the backing plate and fits inside the brake drum to help prevent water entry. The lip fits into a machined groove in the open edge of the brake drum to provide an even better water barrier or seal. This type of seal is called a **labyrinth seal**. ● **SEE FIGURE 98–4.**

In addition to mounting holes for the various brake parts, the backing plate may also have openings that are used to inspect the wear of the brake linings, or adjust the lining-to-drum clearance. These openings are sometimes sealed with metal plugs that must be punched out the first time inspection or adjustment is needed. Rubber plugs are available to seal the holes and prevent water entry once the metal plugs have been removed.

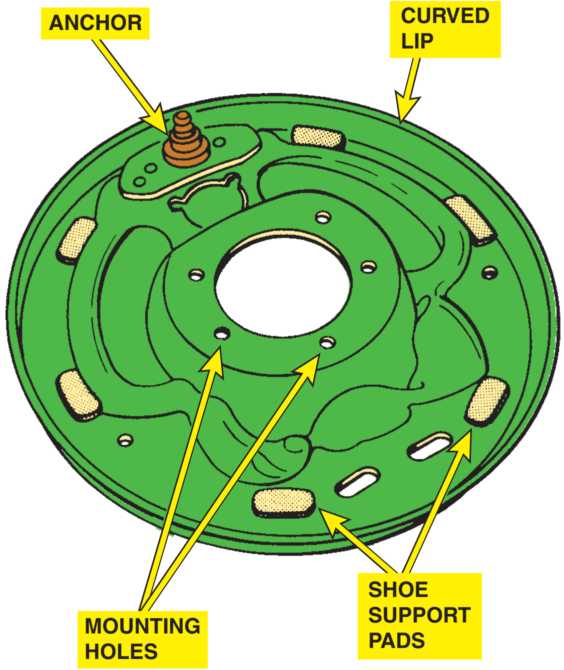


FIGURE 98–3 The backing plate is the foundation of every drum brake. There are normally six pads where the brake shoes contact the backing plate.

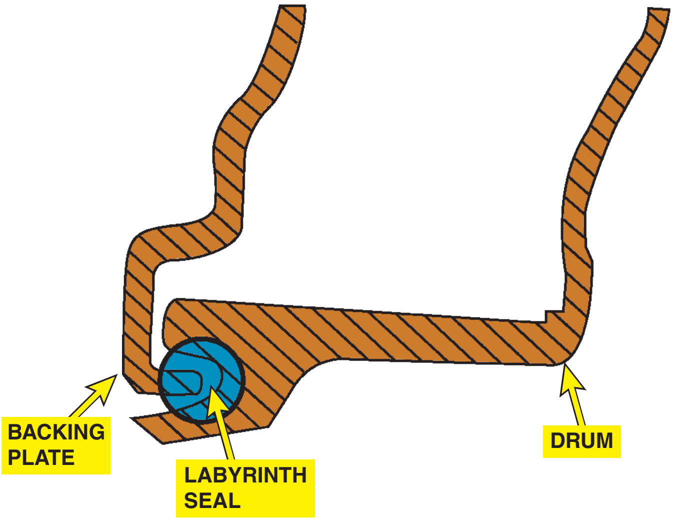


FIGURE 98–4 A labyrinth seal is created between the lip of the backing plate and the groove in the brake drum.

SHOE ANCHORS **Shoe anchors** prevent the brake shoes from rotating with the drum when the brakes are applied. The majority of drum brakes have a single anchor, but some drum brake designs use two or more.

Many anchors are a simple round post that is permanently mounted on the backing plate. The brake shoes have semicircular cutouts where they contact the anchor, and the anchor positively locates the shoe on the backing plate. Another type of anchor is the self-centering or keystone anchor. ● **SEE FIGURE 98–5.** It is called a keystone anchor because of the angled shape similar to a keystone used on the top center of a stone arch.

PISTON STOPS Some backing plates incorporate **piston stops** that prevent the wheel cylinder pistons from coming out of their bores when the friction assembly is disassembled for servicing. The stops may be part of a reinforcing plate positioned under the anchor or they can be stamped directly into the shape of the backing plate itself. ● **SEE FIGURE 98–6.**

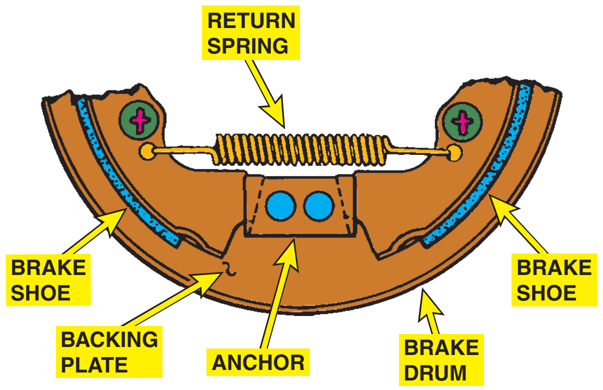

RETURN SPRING
BRAKE SHOE
BRAKE SHOE
BACKING PLATE
ANCHOR
BRAKE DRUM

FIGURE 98–5 A keystone anchor allows the brake shoes to self-center in the drum.

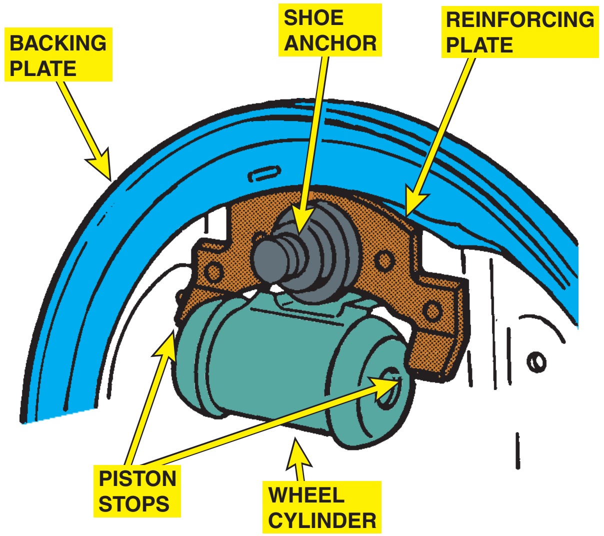

BACKING PLATE
SHOE ANCHOR
REINFORCING PLATE
PISTON STOPS
WHEEL CYLINDER

FIGURE 98–6 Piston stops prevent the wheel cylinder from coming apart.

When piston stops are used, the wheel cylinder must be removed from the backing plate before it can be taken apart for servicing.

SHOE SUPPORT PADS The **shoe support pads** are stamped into the backing plate and contact the edges of the brake shoes to keep the linings properly aligned with the center of the friction surface inside the brake drum. These pads are also called **ledges** or **shoe contact areas**. The support pads are slightly coated with special high-temperature silicone brake grease to minimize wear, prevent rust, and eliminate squeaking that can occur when the shoes move slightly on the pads during a stop.

WHEEL CYLINDERS Hydraulic pressure is transferred from the master cylinder to each wheel cylinder through brake fluid. The force exerted on the brake fluid by the driver forces the piston inside the wheel cylinder to move outward. ● **SEE FIGURE 98–7.** Through pushrods or links, this movement acts on the brake shoes, forcing them outward against the brake drum. ● **SEE FIGURE 98–8.**

DRUM BRAKE SHOES

TERMINOLOGY The linings of drum brakes are attached to curved metal assemblies called **brake shoes**. Most shoes are made of two pieces of sheet steel welded together in a T-shaped cross section. ● **SEE FIGURE 98–9.**

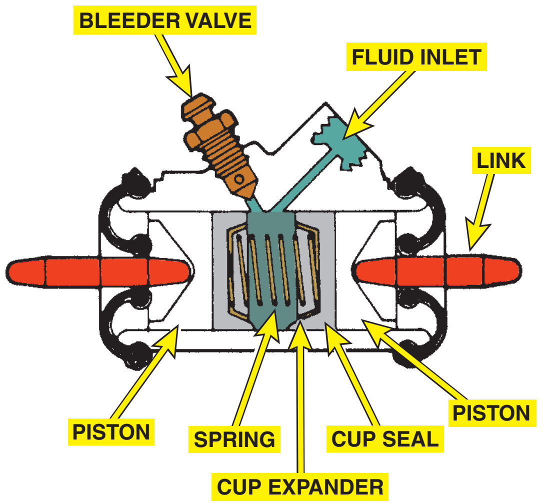

BLEEDER VALVE
FLUID INLET
LINK
PISTON
SPRING
CUP SEAL
PISTON
CUP EXPANDER

FIGURE 98–7 Cross section of a wheel cylinder that shows all of its internal parts. The brake line attaches to the fluid inlet. The cup expander prevents the cup seal lip from collapsing when the brakes are released.

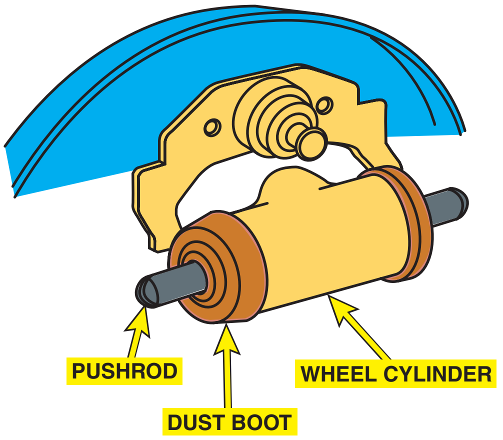

PUSHROD
WHEEL CYLINDER
DUST BOOT

FIGURE 98–8 The pushrods are held in place by the rubber dust boots. As the wheel cylinder pistons move outward, the pushrods transfer the movement to the brake shoes.

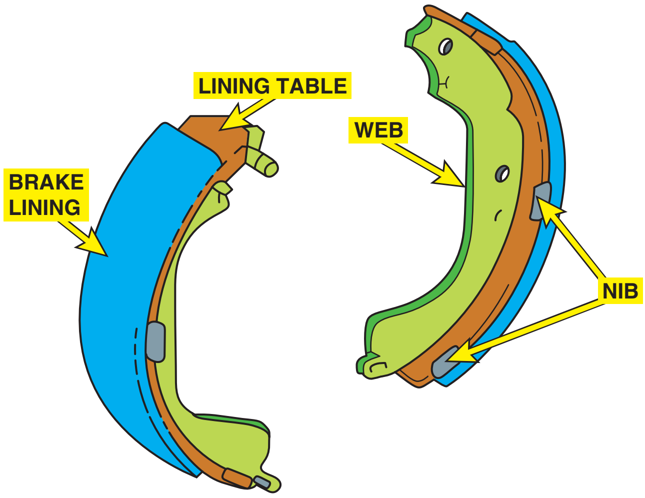

LINING TABLE
WEB
BRAKE LINING
NIB

FIGURE 98–9 Steel brake shoes are made from two stampings welded together—the web and the lining table.

The outer edge is lined with a friction material that contacts the brake drum to generate the actual stopping power. The ends of the linings on most brake shoes are tapered to prevent vibration and brake noise as shown in ● **FIGURE 98–10.**

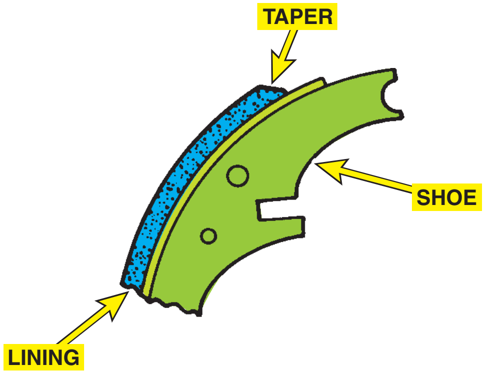


FIGURE 98–10 Tapered ends on the linings help to reduce brake noise.

The curved metal piece on the outer portion of the shoe is called the **lining table**, the **shoe rim**, or **platform**. The lining table supports the block of friction material that makes up the brake lining. On some shoes, the edge of the lining table contains small V- or U-shaped notches called **nibs**. The nibs rest against the shoe support pads on the backing plate when the shoe is installed.

The metal piece of the shoe positioned under the lining table and welded to it is called the **shoe web**. All of the application force that actuates the shoe is transferred through the web to the lining table. The web usually contains a number of holes in various shapes and sizes for the shoe return springs, hold-down hardware, parking brake linkage, and self-adjusting mechanism.

One end of the web usually has a notch where the wheel cylinder touches the shoe, while the other end commonly has a flat or curved surface where the shoe meets an anchor or adjusting link. The upper ends of the webs on dual-servo brake shoes have semicircular cutouts called **anchor eyes**. ● **SEE FIGURE 98–11**.

Brake shoes are parts that can be relined and reused many times if the web and lining table are not damaged. Brake shoes for any given application are usually available in both "new" and "relined" versions from suppliers. Relined brake shoes are usually sold on an exchange basis. At the time of purchase, a **core charge** is added to the cost of the relined parts. This charge is refunded when the old shoes are returned in rebuildable condition.

PRIMARY AND SECONDARY BRAKE SHOES In a dual-servo drum brake system, the shoes in a dual-servo brake perform different jobs. The primary shoe (forward-facing shoe) is self-energized by drum rotation to create a servo action that forces the secondary shoe more firmly against the drum. Because of this, the two shoes have physical differences and cannot be interchanged.

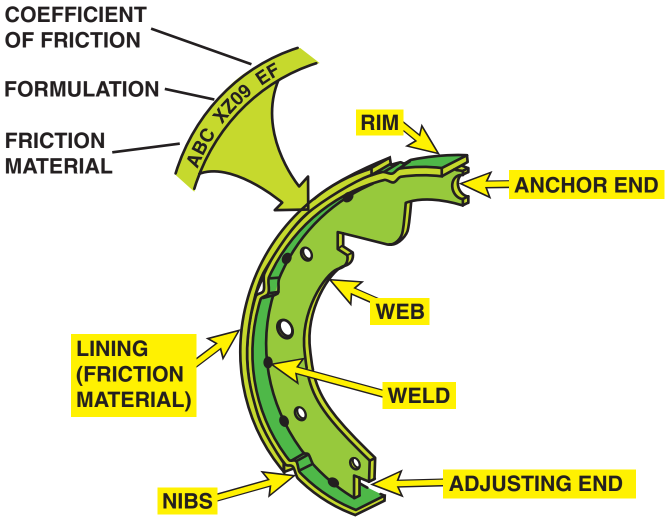


FIGURE 98–11 Typical drum brake shoe and the names of the parts.

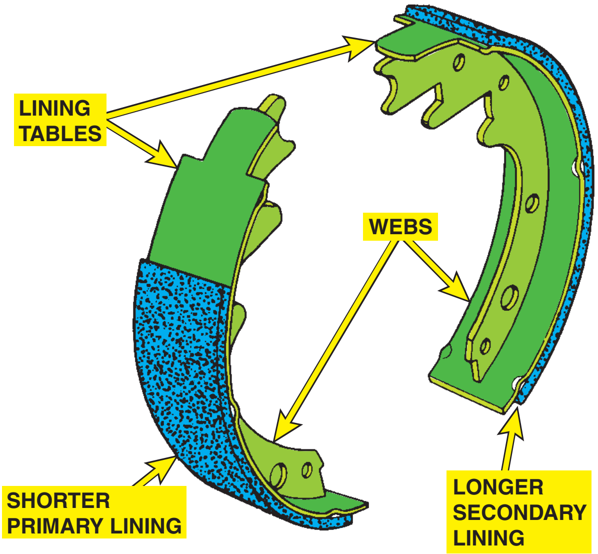


FIGURE 98–12 The primary (forward facing) brake shoe often has a shorter lining than the secondary shoe (rearward facing).

To help deal with the added friction, heat, and wear it undergoes, the lining of the secondary shoe extends nearly the full length of the shoe lining table. ● **SEE FIGURE 98–12**. The secondary shoe lining material also has a high coefficient of friction to provide good stopping power. The primary shoe undergoes far less stress than the secondary shoe, and its lining is often shorter—sometimes less than half the length of the lining table. In addition, the lining material usually has a lower coefficient of friction. This prevents the shoe from engaging the drum too quickly or harshly, which could cause the brakes to grab or lock.

On most dual-servo brake primary shoes, the lining is positioned near the center of the lining table. However, in some cases, the lining may be positioned above or below the lining table centerline. Higher or lower lining positions provide better braking action, or prevent noise, in some vehicles. ● **SEE FIGURE 98–13**.

LINING ASSEMBLY METHODS There are two main methods used to mount brake linings to the brake shoe.

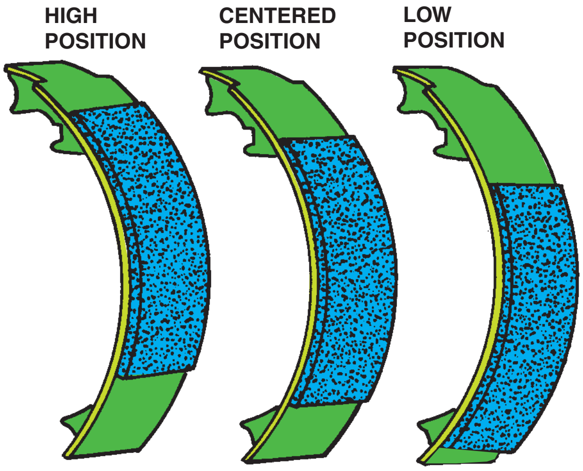


FIGURE 98–13 Primary shoe lining may vary depending on the application.

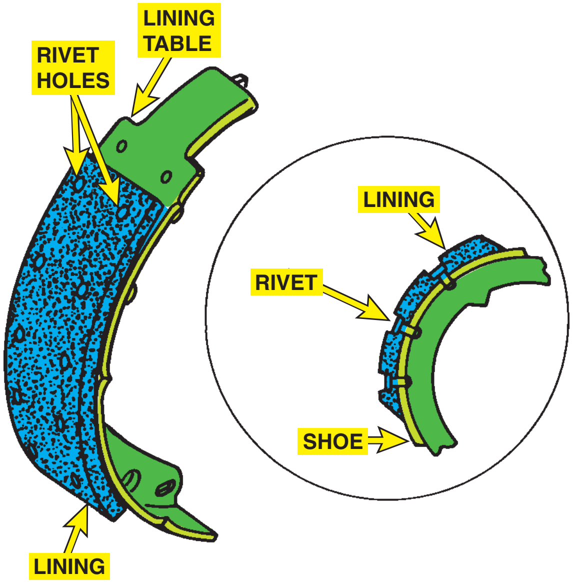

RIVET HOLES
LINING TABLE
LINING
RIVET
SHOE
LINING

FIGURE 98–14 Riveted brake linings are quiet and reliable at high temperatures.

RIVETING The brake block is attached to the lining table or backing plate with copper or aluminum rivets. ● **SEE FIGURE 98–14.** Riveting has the following advantages:

- The major advantage of riveting is that it allows a small amount of flex between the brake block and lining table or backing plate. This play enables the assembly to absorb vibration, and the result is that **riveted linings** operate more quietly than bonded linings.
- Rivets are also very reliable and will not loosen at high temperatures.

Riveting has the following disadvantages:

- Rivet holes, however, do create stress points in the lining where cracks are likely to occur.
- Riveted lining has a reduced service life because the linings must be replaced before the rivet head contacts the brake drum.
- The rivet can cause deep grooves to be cut into the drum, often requiring replacement if the worn brakes are not detected early enough to prevent damage.

BONDING **Bonded linings** use high-temperature adhesive to glue the brake block directly to the shoe lining table or pad backing plate as shown in ● **FIGURE 98–15**. Heat and pressure are then applied to cure the assembly. Bonding is a common form of shoe and pad assembly and is most often used to mount organic friction materials.

Bonding has several advantages including the following:

- Without rivets, bonded linings can wear closer to the lining table or backing plate and provide a longer service life. If the linings wear too far, bonding adhesive is not as destructive to drums or rotors as rivets.
- Bonded linings also have fewer problems with cracking because they have no rivet holes to weaken the brake block.

Bonded linings have the following disadvantages:

- If a bonded lining gets too hot, the bonding adhesive will fail and allow the brake block to separate from the lining table or backing plate.

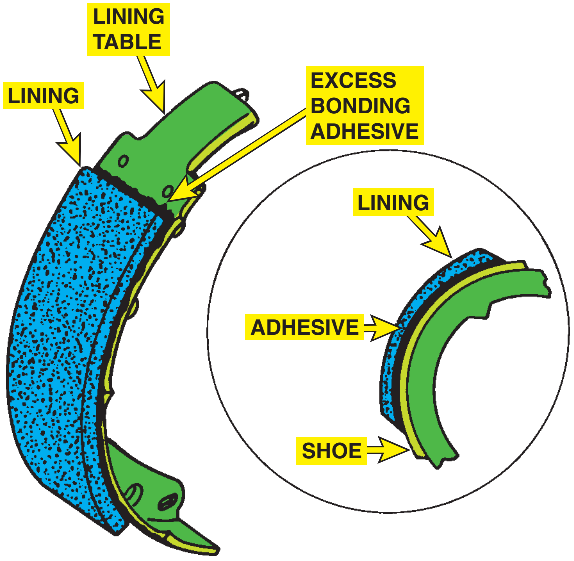

LINING TABLE
LINING
EXCESS BONDING ADHESIVE
LINING
ADHESIVE
SHOE

FIGURE 98–15 Many brake linings are bonded.

- Bonded linings are also more prone to be noisy because they do not allow any vibration absorbing flex between the brake block and lining table or backing plate.

RETURN SPRINGS

The **brake shoe return springs** retract the shoes to their unapplied positions when the brake pedal is released. This helps prevent brake drag and aids the return of brake fluid to the master cylinder reservoir. Most brakes use closed-coil return springs to retract the brake shoes. ● **SEE FIGURE 98–16.**

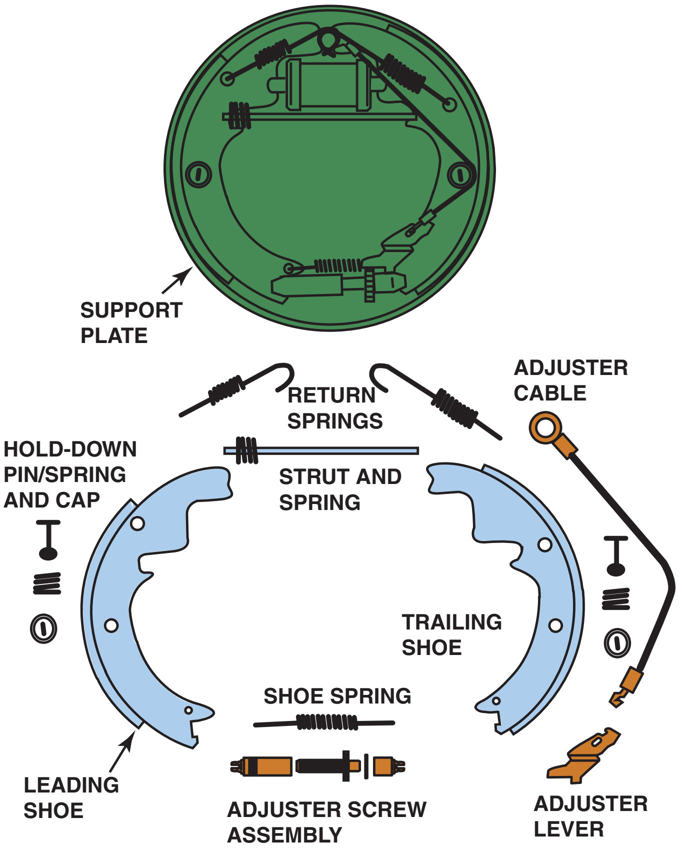

SUPPORT PLATE
RETURN SPRINGS
ADJUSTER CABLE
HOLD-DOWN PIN/SPRING AND CAP
STRUT AND SPRING
TRAILING SHOE
SHOE SPRING
LEADING SHOE
ADJUSTER SCREW ASSEMBLY
ADJUSTER LEVER

FIGURE 98–16 A typical drum brake assembly showing the support plate (backing plate), anchor pin, and springs.

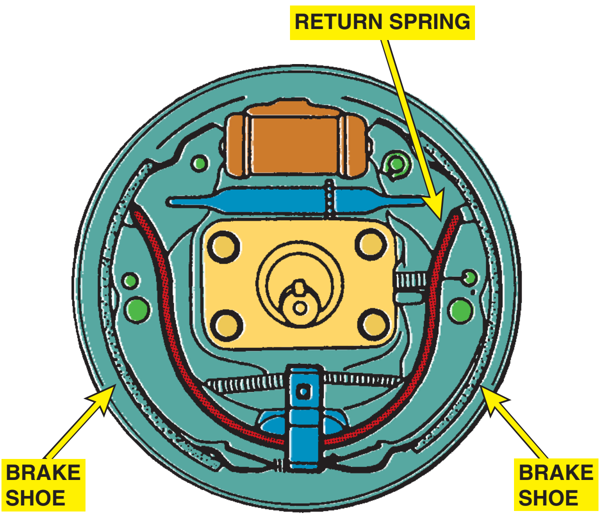


FIGURE 98–17 A single spring-steel spring is used on some drum brakes. The spring also takes the place of the shoe hold-down springs.

The coils on these springs are very tightly wound and contact one another when the spring is relaxed. Some vehicles have a single, large, horseshoe-shaped return spring. ● **SEE FIGURE 98–17.**

The type, location, and number of return springs vary from one brake design to the next. All springs are installed in one of two ways. Some connect directly from shoe to shoe, while others connect from one shoe to the anchor post.

BRAKE SHOE HOLD-DOWNS While the return springs retract the brake shoes to their unapplied positions, the **brake shoe hold-downs** keep the shoes securely against the support pads on the backing plate. The hold-downs prevent noise, vibration, and wear, but still allow the shoes to move out and back as the brakes are applied and released. The hold-downs also provide enough freedom of movement to allow adjustments of the shoes outward as the linings wear. Shoe hold-downs take many forms, as shown in ● **FIGURE 98–18.**

The most common design is a steel pin installed through a hole in the backing plate and a corresponding hole in the brake shoe web. A spring fits over the end of the pin against the shoe web, and a special washer compresses the spring and locks onto the flattened end of the pin.

Another type of hold-down is a taper-wound coil spring with a hook formed on its end. Because of its shape, this part is sometimes called a **beehive hold-down**. The hook end of the spring is installed through a hole in the brake shoe web and attached into a retaining clip that fits into a corresponding hole in the backing plate.

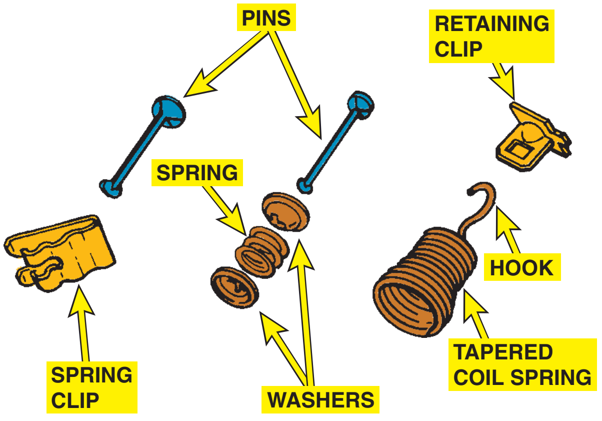


FIGURE 98–18 Various types and styles of hold-down springs.

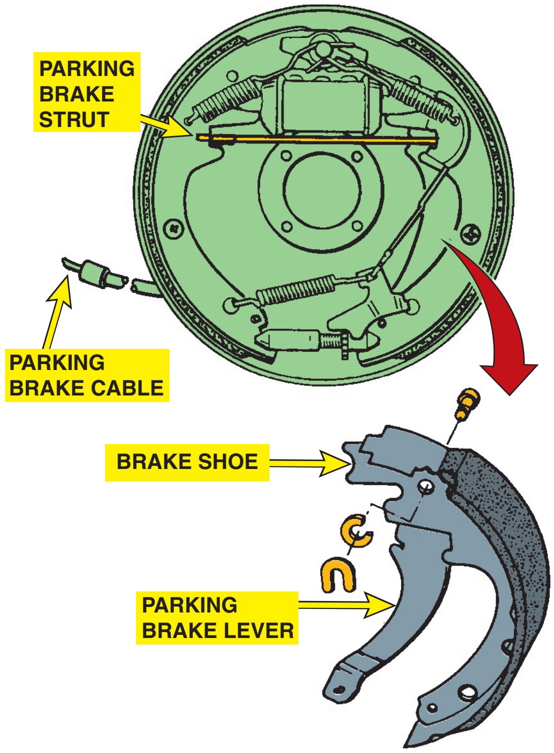


FIGURE 98–19 A mechanical brake linkage is part of most drum brake assemblies.

TECH TIP

Purchase Quality Brake Linings for Best Performance

While many brands of replacement brake lining provide acceptable stopping power and long life, purchasing factory brake lining from a dealer is usually the best opportunity to get lining material that meets all vehicle requirements. Aftermarket linings are not required by federal law to meet performance or wear standards that are required of original factory brake linings.

PARKING BRAKE LINKAGE Most rear drum brake friction assemblies include a parking brake linkage. The linkage commonly consists of a cable, lever, and strut system that spreads the brake shoes apart to apply the brake mechanically. The parking brake strut plays a large part in many of the automatic brake adjusters. ● **SEE FIGURE 98–19.**

BRAKE DRUMS The brake drum is not connected to the backing plate, but turns with the wheel. The drum mounts on the hub or axle, and covers the rest of the brake assembly. Brake drums are made of cast iron or cast aluminum with a cast-iron liner. Many of these drum types may have ribs or fins on their outer edge to help dissipate heat. ● **SEE FIGURE 98–20.**

NON-SERVO BRAKE DESIGN

PURPOSE AND FUNCTION A **non-servo brake** feature is that each brake shoe is applied individually. The action of one shoe has no effect on the action of the other. Many non-servo drum brakes use **self-energizing action** to improve their braking performance.

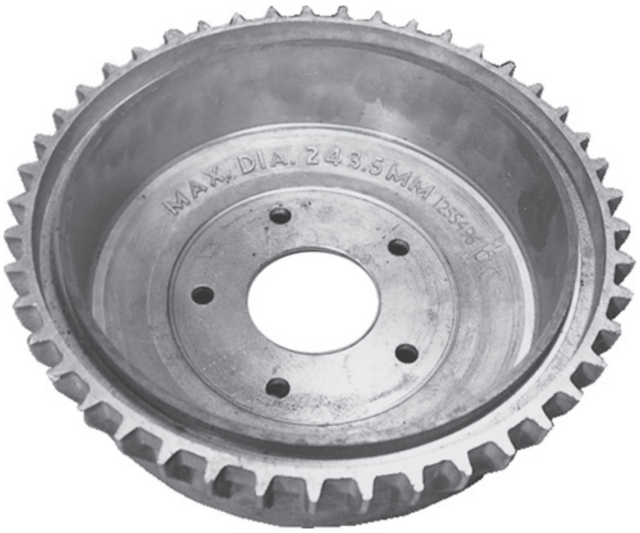


FIGURE 98–20 An aluminum brake drum with a cast-iron friction surface. The cooling fins around the outside help dissipate the heat from the friction surface to the outside air.

PARTS AND OPERATION

Self-energizing action occurs when the forward or **leading shoe** contacts the drum and the drum attempts to rotate the shoe along with it. However, the shoe cannot rotate because its far end (relative to drum rotation) is fixed in place by an anchor. As a result, drum rotation *energizes* the shoe by forcing it outward and wedging it tightly against the brake drum.

The drum also attempts to rotate the reverse or **trailing shoe** as it contacts the drum. However, in this case, the far end of the shoe (relative to drum rotation) is not solidly anchored. As a result, drum rotation *de-energizes* the shoe by forcing it inward away from the brake drum.

When this type of brake is applied with the vehicle backing up, the roles of the forward and reverse shoes are switched. The reverse shoe becomes the leading shoe, which is self-energized by drum rotation, while the forward shoe becomes the trailing shoe, which is de-energized. *A leading shoe is always energized by drum rotation. A trailing shoe is always de-energized by drum rotation.* The simple drum brake assembly in ● **FIGURE 98–21** shows how the self-energizing process works.

The first shoe from the wheel cylinder in the direction of drum rotation is the leading shoe. If the piston of a wheel cylinder moves in the same direction as drum rotation when the brakes are applied, the shoe it actuates is a leading shoe. If the piston moves opposite the direction of drum rotation, the shoe actuated is the trailing shoe.

Leading shoes generally wear at a faster rate than trailing shoes because they are applied with greater force. Where a brake uses one leading and one trailing shoe, the leading shoe will sometimes have a thicker lining or one with a larger surface area than that of the trailing shoe. The thicker or larger lining balances the wear between the two shoes so that they will both need replacement at about the same time.

DOUBLE-TRAILING BRAKE

The least powerful non-servo drum brake is the **double-trailing brake**. ● **SEE FIGURE 98–22.** This design has two trailing shoes and does not use any self-energization. Both shoes have the same size and shaped linings that are applied with equal force by a pair of single-piston wheel cylinders. Each shoe is anchored at the end opposite the wheel cylinder that applies it. In many double-trailing brakes, the backside of one-wheel cylinder serves as the anchor for the brake shoe actuated by the other wheel cylinder.

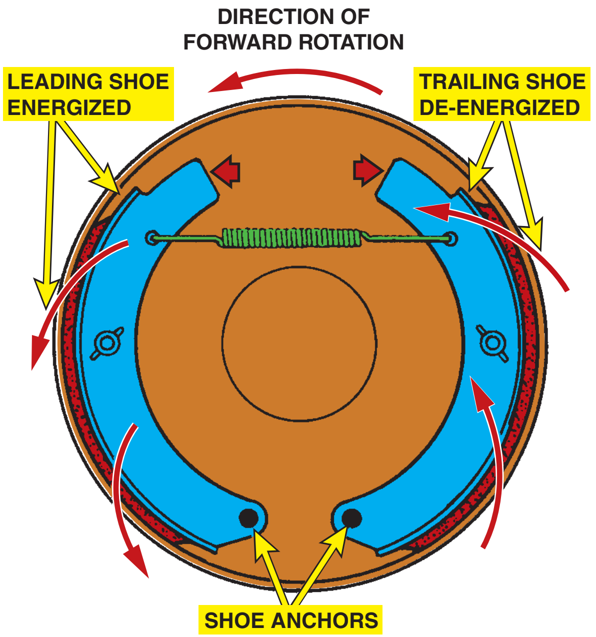


FIGURE 98–21 Self-energizing action can increase or decrease the stopping power of a brake shoe.

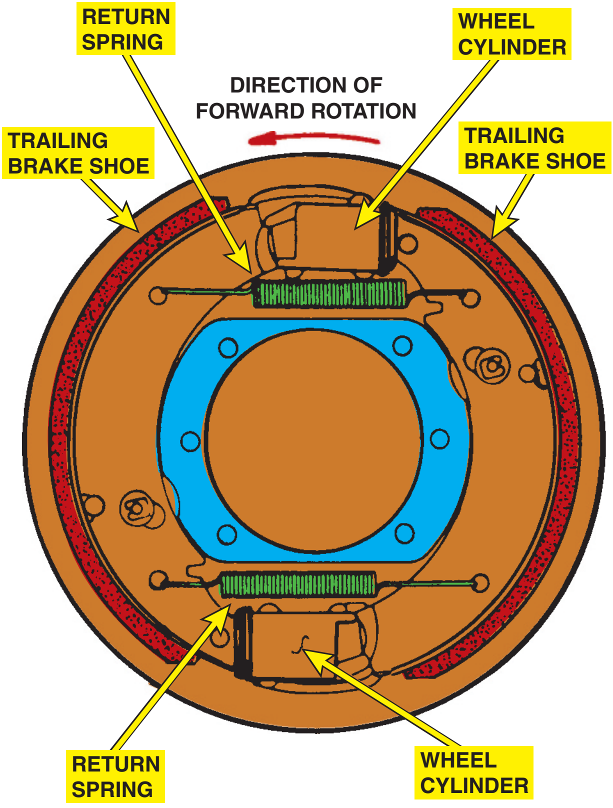


FIGURE 98–22 A double-trailing non-servo drum brake.

LEADING-TRAILING BRAKE DESIGN

The non-servo **leading-trailing brake** has one leading shoe and one trailing shoe. ● **SEE FIGURE 98–23.** Typically, a single, two-piston wheel cylinder is mounted at the top of the backing plate and the two brake shoes are anchored at the bottom of the backing plate.

The brake design has one energized and one de-energized shoe regardless of whether it is applied while the vehicle is

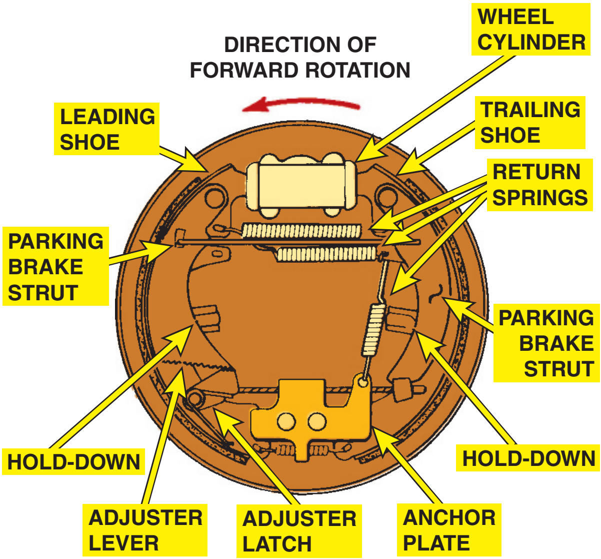


FIGURE 98–23 A leading-trailing non-servo brake.

traveling forward or in reverse. This allows the leading-trailing brake to work equally well in either direction. The leading shoe usually wears more than the trailing shoe.

Leading-trailing brakes are popular on the rear wheels of many small and front-wheel-drive vehicles because, although they are not as powerful as a servo brake, they are less prone to lockup. They have the further benefit of making a good parking brake in both directions.

DUAL-SERVO BRAKE DESIGN

PURPOSE AND FUNCTION The **dual-servo brake** is the most common drum brake design. The name "servo" comes from the fact that one shoe "serves" the other to increase application force. All servo brakes used on automobiles are of the dual-servo design that works with equal force in both directions.

The primary advantage of the dual-servo brake is that it is more powerful than any of the non-servo designs. Another advantage of the dual-servo brake is that it makes a good parking brake. Dual-servo action not only makes the brake very powerful, it allows the brake to hold equally well in both directions.

Dual-servo brakes are more susceptible to pull than other brake designs, and their greater application force can lead to faster fade under extreme braking conditions.

NOTE: Dual-servo brakes are also called Duo-Servo, which is a brand name of the Bendix Corporation.

DUAL-SERVO BRAKE CONSTRUCTION The basic dual-servo brake uses one anchor and a single two-piston wheel cylinder. ● **SEE FIGURE 98–24**. The anchor is usually mounted at the top of the backing plate with the wheel cylinder directly beneath it. The tops of the brake shoes are held against the anchor by individual return springs. The bottoms of the shoes are spaced apart by an adjusting link held in position by a third return spring that connects the two shoes.

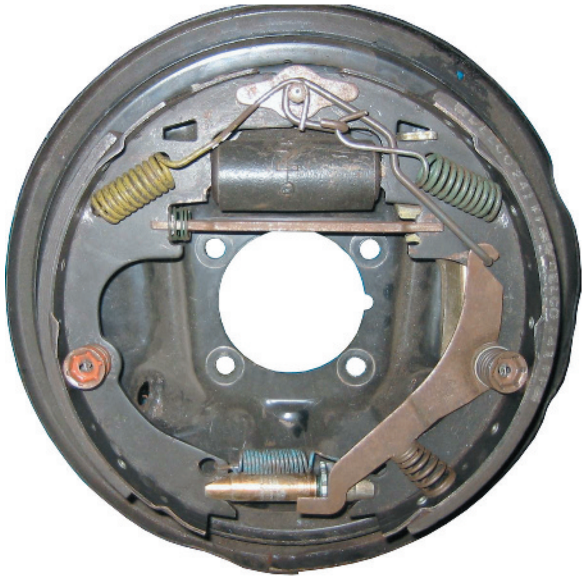


FIGURE 98–24 A typical dual-servo drum brake.

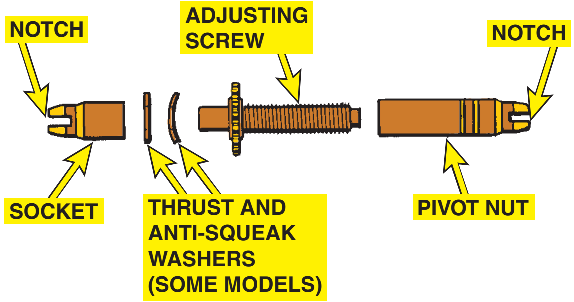


FIGURE 98–25 A typical dual-servo brake adjusting link assembly.

ADJUSTING LINK The adjusting link consists of a starwheel that is part of an adjusting screw, a pivot nut that one end of the adjusting screw threads into, and a socket that rotates freely on the opposite end of the adjusting screw. ● **SEE FIGURE 98–25**. The outer ends of the pivot nut and socket are notched to fit over the brake shoe webs. Some adjusting links have a steel thrust washer and/or spring washer installed between the socket and the starwheel. These washers allow easier rotation of the starwheel and help reduce brake squeal.

NOTE: Adjusting links generally have specific left- or right-hand threads and must be installed on the correct side of the vehicle.

PRIMARY AND SECONDARY BRAKE SHOES Although dual-servo brakes make use of self-energizing action to help provide servo action, the two brake shoes are not called leading and trailing parts as in non-servo brakes. Instead, they are identified as the **primary shoe** and the **secondary shoe**. To identify the primary shoe on a dual-servo brake with a single two-piston wheel cylinder, point to the wheel cylinder, and then move your finger in the direction of drum rotation. The first shoe reached is the primary shoe and the other shoe is the secondary shoe.

The secondary brake shoe provides approximately 70% of the total braking power in a dual-servo brake. For this reason, the lining is usually somewhat larger than that of the primary shoe. In addition, some manufacturers use different types of friction materials on the primary and secondary shoes to help equalize wear.

DUAL-SERVO BRAKE OPERATION When a dual-servo brake is applied, the wheel cylinder attempts to force the tops of both brake shoes outward against the drum. ● **SEE FIGURE 98–26**.

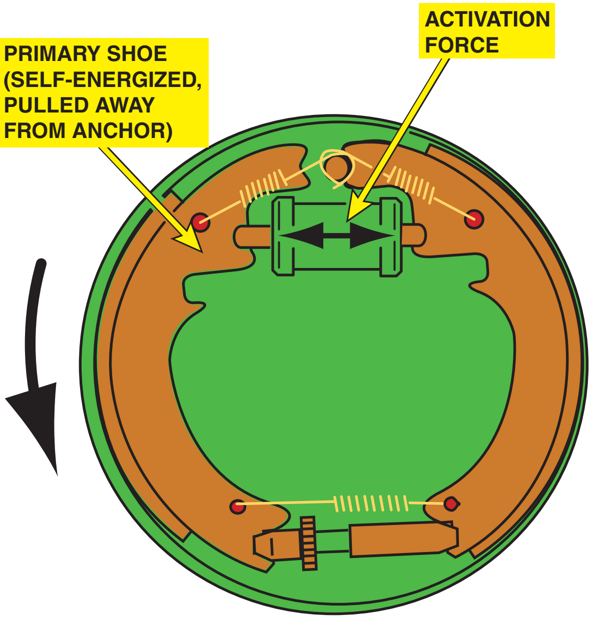


FIGURE 98–26 Dual-servo brake operation. The primary shoe on the left exerts a force on the secondary shoe on the right.

As the primary shoe makes contact, it rotates with the drum because its far end (relative to the direction of drum rotation) is not directly anchored to the backing plate. As the primary shoe rotates, it forces the adjusting link and the secondary shoe to also rotate until the secondary shoe seats firmly against the anchor.

Although the wheel cylinder attempts to push the top of the secondary shoe outward, the rotational force developed by friction between the brake shoes and drum is much greater than the force developed by hydraulic pressure in the wheel cylinder. As a result, the secondary shoe is held against the anchor. In effect, only one-half of the wheel cylinder is used to apply the brakes.

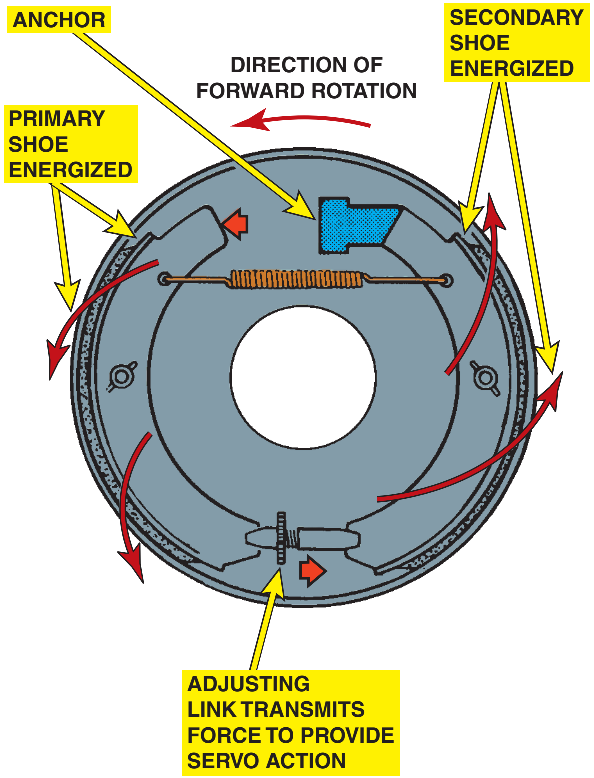

ANCHOR
DIRECTION OF FORWARD ROTATION
SECONDARY SHOE ENERGIZED
PRIMARY SHOE ENERGIZED
ADJUSTING LINK TRANSMITS FORCE TO PROVIDE SERVO ACTION

FIGURE 98–27 Dual-servo action greatly increases the application force on the secondary shoe.

SERVO ACTION Once all clearance is taken up between the brake shoes, adjusting link, and anchor, both brake shoes become self-energized like the leading shoes in a non-servo brake. The anchor pin prevents the secondary shoe from rotating, and the adjusting link (held in position by the secondary shoe) serves as the anchor for the primary shoe. Servo action then occurs as a part of the braking force generated by the primary shoe is transferred through the adjusting link to help apply the secondary shoe. ● **SEE FIGURE 98–27**.

When a dual-servo brake is applied with the vehicle moving in reverse, the primary and secondary shoes switch roles. The primary shoe is forced against the anchor while the secondary shoe moves outward and rotates with the drum to apply the primary shoe with a greater force.

TECH TIP

Rear-Wheel Lockup? Check the Adjustment

Servo action enables a drum brake to provide increased stopping power, but it can also cause the brakes to grab and lock if they get too far out of adjustment. As clearance between the shoes and drum increases, the primary brake shoe is allowed a greater range of movement. The farther the shoe moves, the more speed it picks up from the rotating brake drum. At the moment the slack is taken up between the brake shoes, adjusting link, and anchor, the speed of the primary shoe is converted into application force by servo action. If the primary shoe is moving too quickly, it will apply the secondary shoe very hard and fast, causing the brakes to grab and possibly lock the wheels.

AUTOMATIC BRAKE ADJUSTERS

SERVO BRAKE STARWHEEL AUTOMATIC ADJUSTERS Servo brakes use three styles of starwheel adjusters:

- **Cable.** ● **SEE FIGURE 98–28.**
- **Lever.** ● **SEE FIGURE 98–29.**
- **Link.** ● **SEE FIGURE 98–30.**

All three adjusters mount on the secondary brake shoe and adjust only when the brakes are applied while the vehicle is moving in reverse.

As the brakes are applied on a vehicle with a cable or link automatic adjuster, the wheel cylinder and drum rotation combine to move the secondary shoe away from the anchor. Movement of the shoe causes the cable or linkage to pull up on the adjuster **pawl**. ● **SEE FIGURE 98–31**. If the brake lining has worn far enough, the pawl engages the next tooth on the starwheel. When the brakes are released, the pawl return spring pulls the pawl down, rotating the starwheel and moving the brake shoes apart to reduce the lining-to-drum clearance.

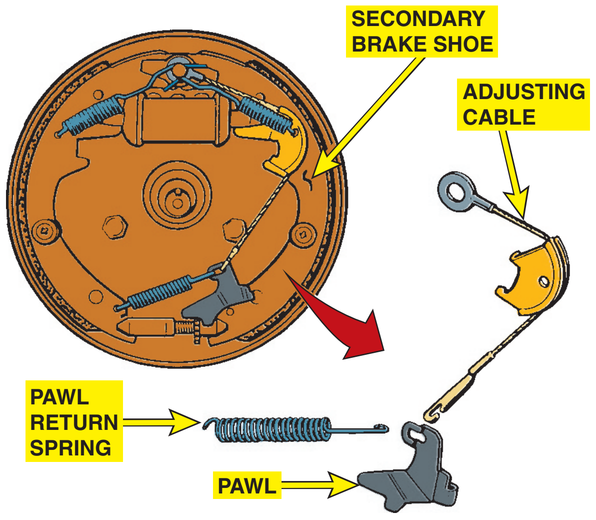

SECONDARY BRAKE SHOE
ADJUSTING CABLE
PAWL RETURN SPRING
PAWL

FIGURE 98–28 A cable-actuated starwheel adjuster. This type of adjuster makes the adjustment as the brakes are released.

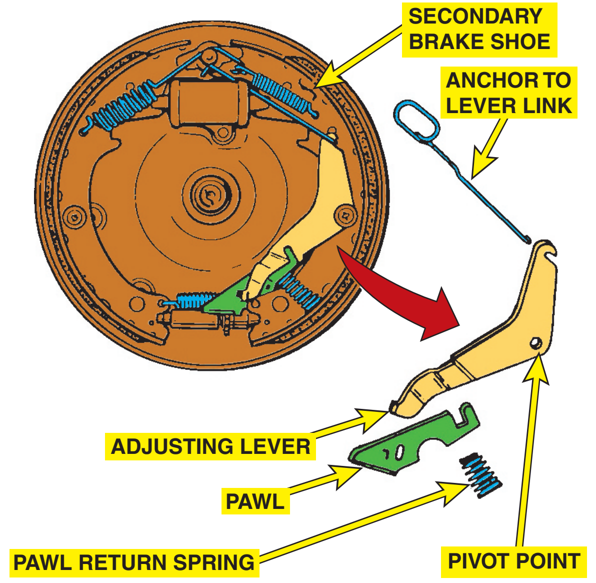

SECONDARY BRAKE SHOE
ANCHOR TO LEVER LINK
ADJUSTING LEVER
PAWL
PAWL RETURN SPRING
PIVOT POINT

FIGURE 98–29 A lever-actuated starwheel automatic adjuster. This type of adjuster makes the adjustment when the brakes are applied.

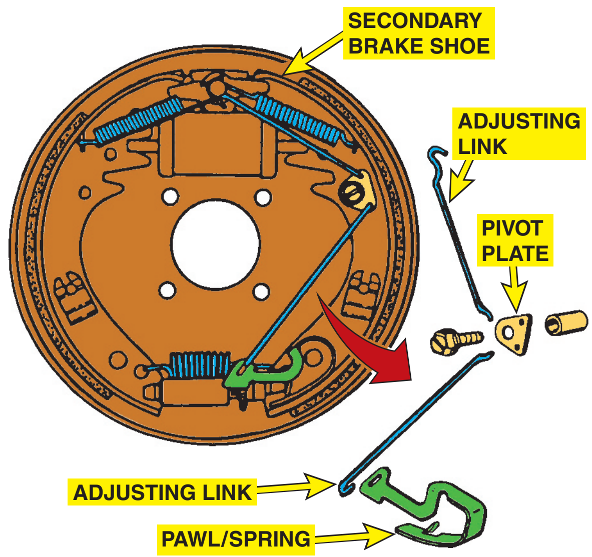

SECONDARY BRAKE SHOE
ADJUSTING LINK
PIVOT PLATE
ADJUSTING LINK
PAWL/SPRING

FIGURE 98–30 A link-actuated starwheel adjuster. This type of adjuster makes the adjustment when the brakes are released.

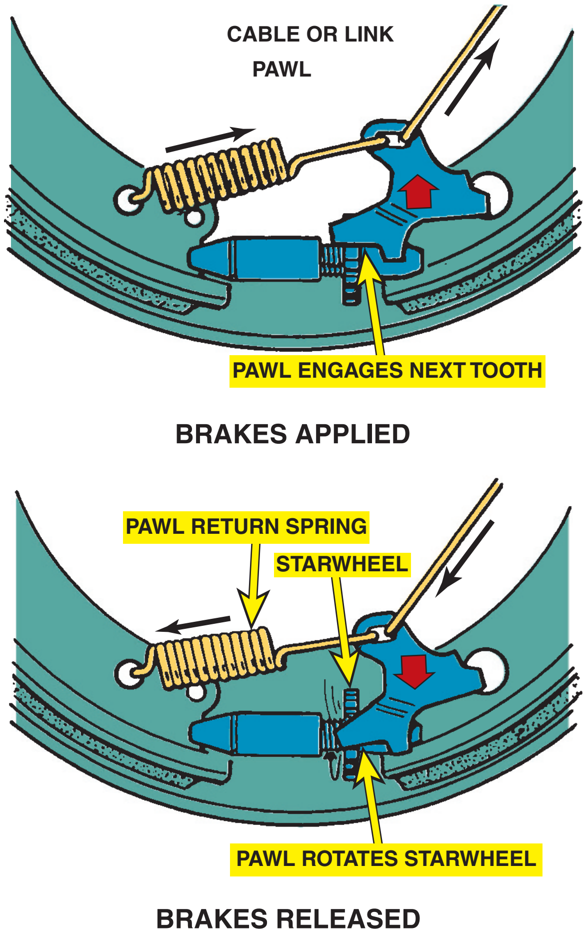

CABLE OR LINK
PAWL
PAWL ENGAGES NEXT TOOTH
BRAKES APPLIED
PAWL RETURN SPRING
STARWHEEL
PAWL ROTATES STARWHEEL
BRAKES RELEASED

FIGURE 98–31 The operation of a typical self-adjuster. Notice that the adjuster actually moves the starwheel. The starwheel adjuster use left-hand and right-hand threads and must be installed on the correct side of the vehicle to function as designed.

Some servo brakes with cable-actuated starwheel automatic adjusters have an **over-travel spring** assembly on the end of the cable. ● **SEE FIGURE 98–32**. In this design, the adjuster pawl is mounted *under* the starwheel, and adjustment is made as the brakes are applied rather than released. The over-travel spring dampens the movements of the adjuster mechanism and prevents overadjustment if the brakes are applied very hard and fast. It also prevents damage to the adjusting mechanism if the starwheel seizes or is otherwise unable to rotate.

The lever starwheel adjuster makes the adjustment as the brakes are applied rather than released. The operation includes the following actions:

- As the secondary shoe moves away from the anchor, the solid link between the anchor and the top of the adjuster lever forces the lever to rotate around the pivot point where it attaches to the brake shoe.
- This moves the bottom half of the lever downward, which causes the pawl to rotate the starwheel and make the adjustment.
- The separate pawl piece is free to pivot on the lever to prevent damage if the starwheel will not rotate.
- When the brakes are released, the return springs lift the lever. If the brakes have worn enough, the end of the lever engages the next tooth on the starwheel and additional adjustment will be made the next time the brakes are applied.

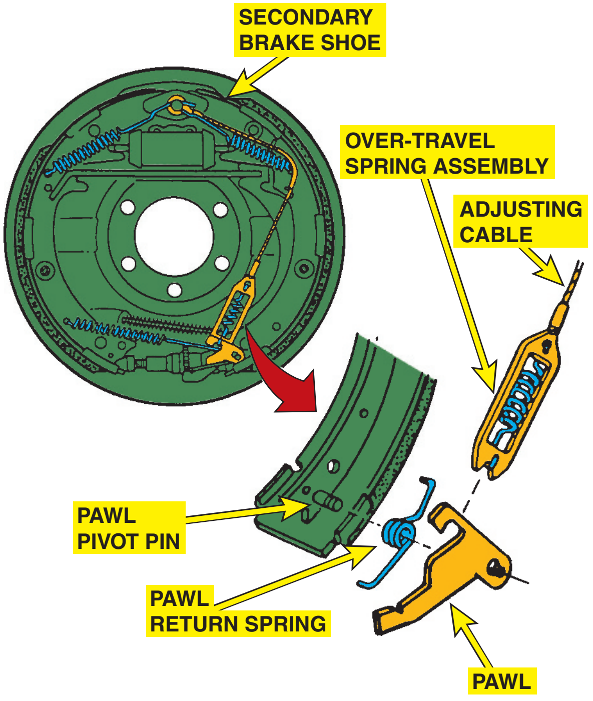


FIGURE 98–32 A cable-actuated starwheel adjuster with an over-travel spring.

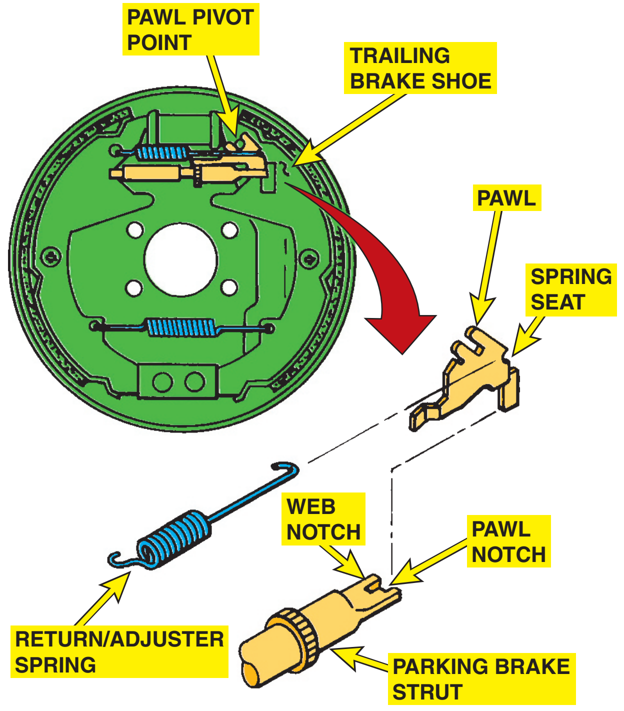


FIGURE 98–34 A non-servo brake with a lever-actuated starwheel automatic adjuster on the trailing shoe. This type of adjuster makes the adjustment as the brakes are released.

NON-SERVO STARWHEEL AUTOMATIC ADJUSTERS

OPERATION The starwheel automatic adjusters used on non-servo brakes may be mounted on either the leading or trailing shoe. These types of adjusters work whenever the brakes are applied—in either the forward or reverse direction. A leading-shoe design is shown in ● **FIGURE 98–33**.

When the brakes are not applied, the adjuster pawl is held in position by the parking brake strut. When the brakes are applied and the primary shoe moves out toward the brake drum (away from the parking brake strut), the pawl spring pivots the pawl downward where it mounts on the brake shoe and rotates the starwheel to adjust the brake. When the brakes are released, the return springs retract the shoes and the pawl is levered back into its resting position by the parking brake strut. If the linings have worn far enough, the lever engages the next tooth on the starwheel and further adjustment will occur the next time the brakes are applied.

The trailing-shoe non-servo starwheel adjuster shown in ● **FIGURE 98–34** works somewhat like the leading-shoe design, but it makes the adjustment as the brakes are released rather than applied. The upper shoe return spring in this design returns the brake shoes and operates the automatic adjuster, as follows:

- When the brakes are not applied, spring tension holds the trailing shoe and the adjuster pawl tightly against the parking brake strut.

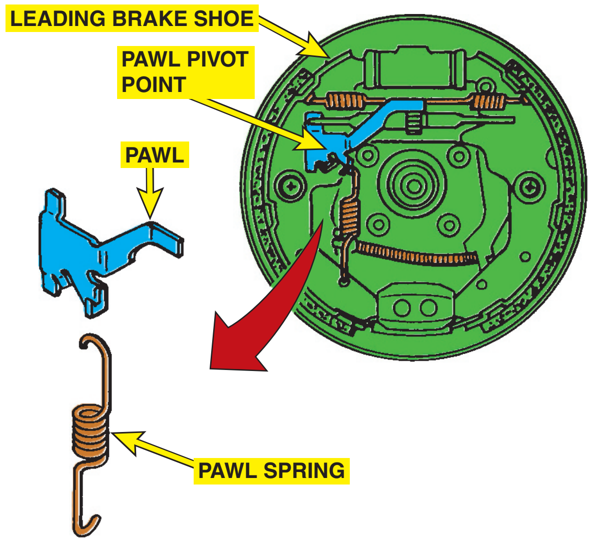


FIGURE 98–33 A non-servo brake with a lever-actuated starwheel automatic adjuster on a leading shoe. This type of adjuster makes an adjustment as the brakes are applied.

TECH TIP

Cool the Brakes before Backing

Self-adjusters can overadjust the rear drum brakes if the brake drums are hot and have increased in diameter due to the heat. For example, if a pickup truck towing a boat had to brake while backing down a long, steep grade to the boat ramp, the rear brake drums could become larger in diameter due to the heat created during braking. The brakes could over-adjust if the driver repeatedly depresses and releases the brake pedal while backing the trailer down the boat ramp. Then, after the boat has been removed from the trailer and the rear brakes have cooled, the drums will shrink and keep the rear brakes from releasing, preventing the truck from moving up the ramp.

NOTE: Some drum brakes are equipped with a bimetallic heat sensor that prevents the self-adjusters from working if the brakes are hot.

- When the brakes are applied, the trailing shoe moves out toward the drum and away from the parking brake strut. This allows the adjuster pawl, which is restrained by the return spring, to pivot where it attaches to the brake shoe, causing the adjuster arm to move upward.
- If the brakes have worn far enough, the arm will engage the next tooth of the starwheel.
- When the brakes are released, the return spring pulls the brake shoes back together and the parking brake strut levers the adjuster pawl downward to rotate the starwheel and adjust the brakes.

REVIEW QUESTIONS

1. Describe the difference between a dual-servo and a leading-trailing drum brake system.
2. List all the parts of a typical drum brake.
3. Explain how a self-adjusting brake mechanism works.
4. Why should a driver allow the brakes to cool before backing a long distance?
5. What is a labyrinth seal?

CHAPTER QUIZ

1. A vehicle with drum brakes on the rear wheels will usually have ________ brakes on the front wheels.
   a. expanding shoe
   b. disc
   c. banded
   d. internal shoe
2. Technician A says that drum brakes can fail to slow the vehicle if driven through deep water. Technician B says that when drum brakes get hot, the brake pedal will drop because the drum expands away from the shoes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Two technicians are discussing drum brake shoes. Technician A says that forward and rearward facing shoes are the same and can be installed in either position on any drum brake system. Technician B says that the longer lining should always be placed toward the front of the vehicle. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Which part of the drum brake shoe contacts the ledges on the backing plate?
   a. Anchor eye
   b. Nib
   c. Web
   d. Lining table
5. A typical drum brake backing plate has how many shoe support pads (also called ledges)?
   a. 3
   b. 4
   c. 6
   d. 8
6. Which lining does most of the braking on a dual-servo brake?
   a. Front (forward facing)
   b. Rear (rearward facing)
   c. Both contribute equally
   d. Depends on the speed of the vehicle
7. Which lining wears the most on a leading-trailing brake?
   a. Leading (forward facing)
   b. Trailing (rearward facing)
   c. Both contribute equally
   d. Depends on the speed of the vehicle
8. Technician A says that starwheel adjusters use different threads (left- and right-handed) for the left and right sides of the vehicle. Technician B says that a pawl contacts the teeth of the starwheel adjuster. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Technician A says that self-adjusters used on most drum brakes work when the brakes are applied, then release while traveling in reverse. Technician B says that some adjusters can over-adjust if the brake drums are hot. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Two technicians are discussing drum brake self-adjusters. Technician A says that a frozen starwheel adjuster can cause the brakes to lock up due to the adjusting lever being unable to move the adjuster causing the linkage to bind. Technician B says that some brakes self-adjust when the brakes are applied rather than when released. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

Chapter

99

DRUM BRAKE DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss drum brake diagnosis and brake drum removal.
- Discuss brake drum removal.
- Explain the procedure for drum brake disassembly and inspection of parts.
- Describe how to reassemble the drum brake.
- Describe how to adjust drum brakes.
- Describe the symptoms of a faulty drum brake.

KEY TERMS:

Bearingized 1162 • Brake hardware kits 1163 • Speed nuts 1159 • Tinnerman nuts 1159

DRUM BRAKE DIAGNOSIS

DIAGNOSTIC STEPS Diagnosing brake concerns includes the following steps:

STEP 1 Verify the customer complaint (concern). For example, common drum brake concerns include the following:

- Low brake pedal
- Parking brake does not hold the vehicle on a hill
- Noise while braking
- Noise when the vehicle is moving, but the brakes are not applied

STEP 2 Perform a visual inspection of the brakes and related parts, such as the wheels, tires, and suspension system.

STEP 3 Determine the root cause. For example, this could include determining that the parking brake is corroded causing the brake shoes to wear. Replacing just the brake shoes will not correct the root cause.

STEP 4 Restore the brake system to like-new operation, which is the purpose of any repair.

STEP 5 Test-drive the vehicle to verify that the service has corrected the customer's complaint.

Drum brake service usually involves the following steps:

STEP 1 Remove the brake drums.

STEP 2 Inspect the brake drums for damage and measure the inside diameter and compare to specifications.

STEP 3 Inspect brake linings and hardware for wear or damage.

STEP 4 Inspect the wheel cylinder and brake lines for leakage.

STEP 5 Check the backing plate for excessive rust or wear.

BRAKE DRUM REMOVAL

MARK DRUMS The drum has to be removed before inspection or repair of a drum brake can begin. There are two basic types of drums, and the removal procedure depends on which type is

WARNING

Removal of the brake drum should occur inside a sealed vacuum enclosure equipped with a HEPA filter or washed with a brake washer. ● **SEE FIGURE 99–1**.

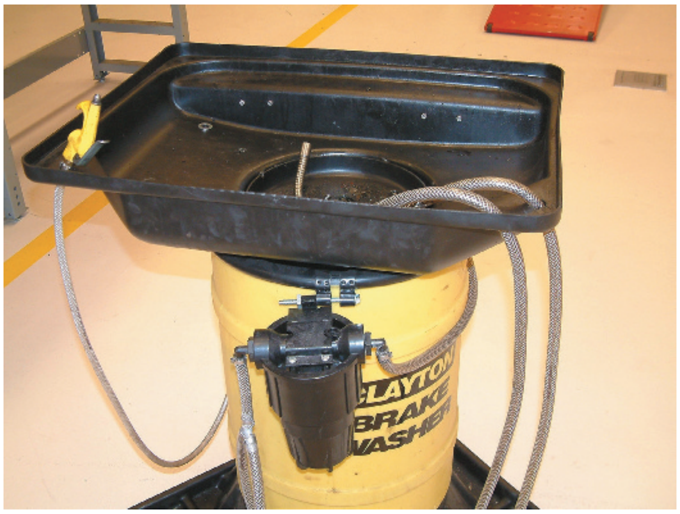


FIGURE 99–1 An aqueous-based (water-based) brake washer can be used to wet down the outside of the brake assembly before removing the drum. After the drum is removed, wash down the shoes and other parts to capture the dust into the washer.

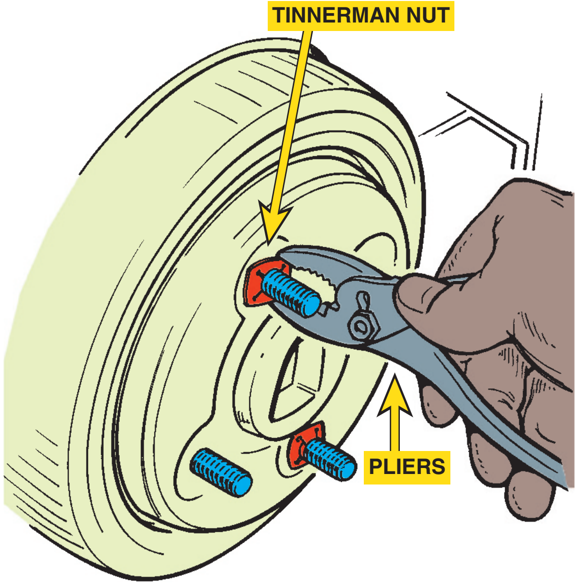


FIGURE 99–2 Tinnerman nuts are used at the assembly plant to prevent the brake drum from falling off until the wheels are installed.

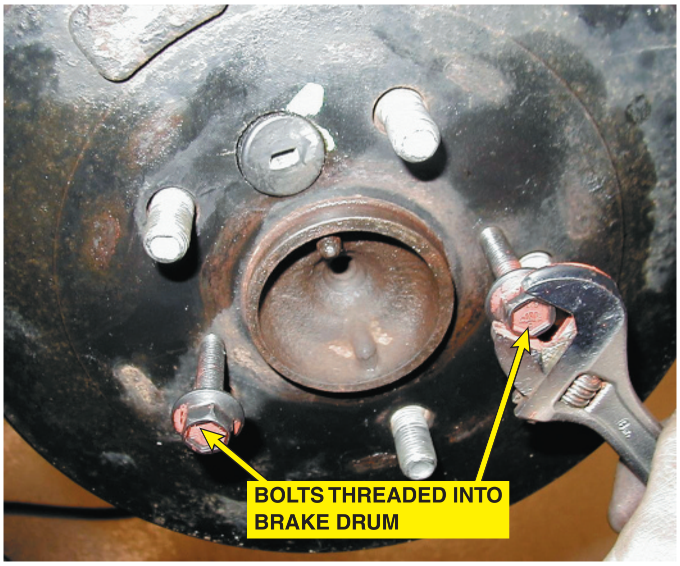


FIGURE 99–3 Turning the bolts that are threaded into the brake drum forces the drum off the hub.

being serviced. With either type, it is usually recommended that the drums be marked with an “L” for left or an “R” for right so that they can be replaced in the same location.

HUB OR FIXED DRUMS

A fixed or hub-mounted drum is often used on the rear of front-wheel-drive vehicles. The drum has a hub for inner and outer bearings and is retained by a spindle nut. To remove the brake drum, remove the dust cap and cotter key that is used to retain the spindle nut. Remove the spindle nut and washer and then the brake drum can be carefully pulled off the spindle.

HUBLESS OR FLOATING DRUMS

Floating or hubless drums are usually used on the rear of a rear-wheel-drive vehicle. The drums are secured to the axle flange by the wheel and lug nuts. New vehicles have **tinnerman nuts** (clips), also called **speed nuts,** on the stud when the vehicle is being assembled. These thin sheet-metal nuts keep the brake drum from falling off during shipping and handling prior to installation of the rear wheels. ● **SEE FIGURE 99–2**.

The tinnerman nuts can be discarded because they are not needed after the vehicle leaves the assembly plant. After removing the wheels, the drum *should* move freely on the hub and slip off over the brake shoes. Some drum brakes have two threaded holes in the drum that allow bolts to be installed. ● **SEE FIGURE 99–3**.

By tightening the bolts, the drum is forced off of the hub. Two situations that can prevent the drum from being removed include the following:

1. **The drum is rusted to the hub.** The fit between the drum and the hub is very close because it is this center pilot hole in the drum that centers the drum on the axle. Rust and corrosion often causes the drum to seize to the hub. Striking the area inside the wheel studs will usually break the drum loose from the hub. Sometimes a torch has to be used to expand the pilot hole.

NOTE: Use of an air hammer with a flat-headed driver against the hub also works well to break the drum loose from the hub.

CAUTION: Overheating or not allowing the drum to cool slowly can cause the brake drum to distort. Using a puller can also damage a drum.

2. **The brake shoes are worn into the drum.** Even if the pilot hole is loose, many brake drums cannot be removed because the inner edge of the brake drum catches on the lining. Pulling outward on the drum often bends the backing plate or breaks some of the mounting hardware. To prevent damage, remove the adjuster plug from the backing plate or drum and back off the adjuster. ● **SEE FIGURE 99–4**.

NOTE: Be sure to reinstall the adjuster opening plugs. These plugs help keep water and debris out of the brakes.

After removing the brake drums, they should be cleaned, inspected, measured, and possibly machined before being returned to service.

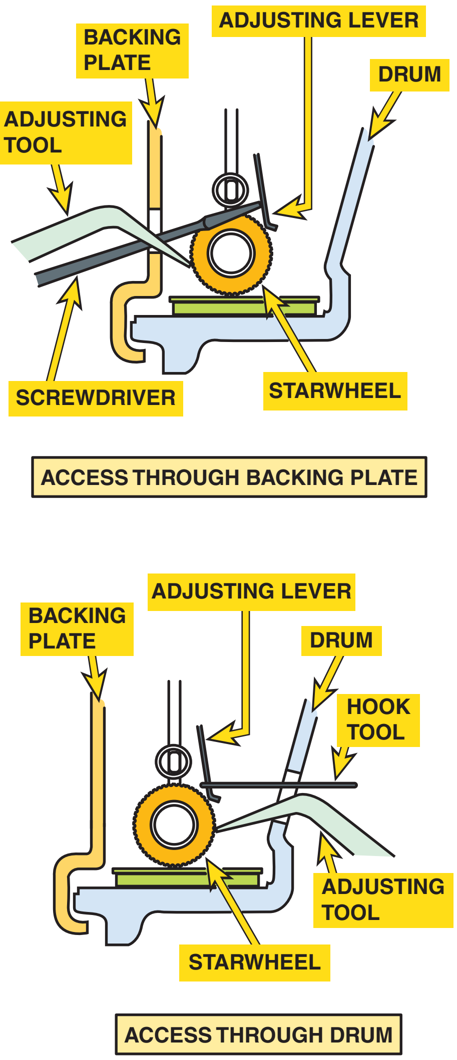

ADJUSTING LEVER
BACKING PLATE
DRUM
ADJUSTING TOOL
SCREWDRIVER
STARWHEEL
ACCESS THROUGH BACKING PLATE
ADJUSTING LEVER
BACKING PLATE
DRUM
HOOK TOOL
ADJUSTING TOOL
STARWHEEL
ACCESS THROUGH DRUM

FIGURE 99–4 If the brake shoes have worn into the drum, the adjuster can be backed in after removing the access plug. After removing the plug, use a wire or a screwdriver to move the adjusting lever away from the starwheel, then turn the starwheel with a brake adjusting tool, often called a "brake spoon."

DRUM BRAKE DISASSEMBLY AND INSPECTION

DISASSEMBLY PROCEDURE After removal of the brake drum, the brake shoes and other brake hardware should be wetted down with a solvent or enclosed in an approved evacuation system to prevent possible asbestos release into the air. Precautions should be taken to prevent any asbestos that may be present in the brake system from becoming airborne. Removal of the brake drum should occur inside a sealed vacuum enclosure equipped with a HEPA filter or washed with water or solvent. ● **SEE FIGURE 99–5**.

Usually, the first step in the disassembly of a drum brake system is removal of the return (retracting) springs. ● **SEE FIGURE 99–6**.

After the return springs have been removed, the hold-down springs and other brake hardware can be removed. ● **SEE FIGURE 99–7**.

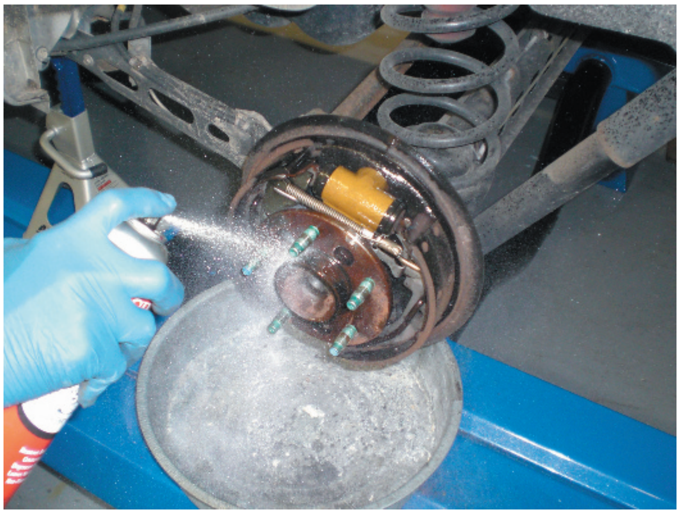


FIGURE 99–5 A liquid soaking solvent, such as brake cleaner, should be used to wet the linings. The purpose of wetting the lining material while the drum is still on the vehicle is to prevent the possibility of asbestos from the lining becoming airborne. Asbestos is only hazardous when asbestos dust is airborne and is breathed in during brake system service.

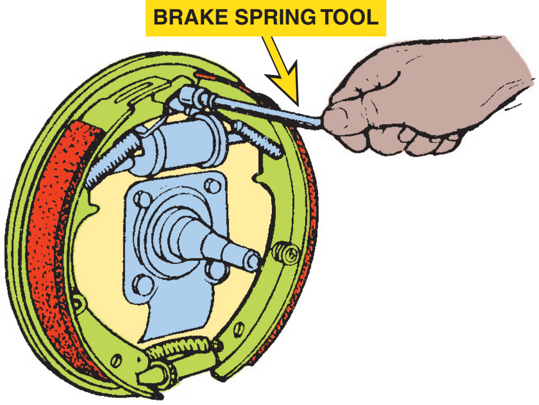

BRAKE SPRING TOOL

FIGURE 99–6 Using a brake spring tool to release a return (retracting) spring from the anchor pin.

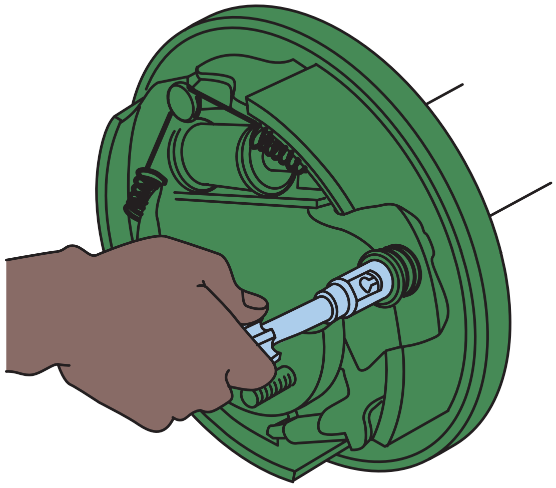


FIGURE 99–7 A special tool, called a hold-down spring tool, being used to depress and rotate the retainer.

NOTE: There are generally no "exact" disassembly or reassembly procedures specified by the manufacturer. The order in which the parts are disassembled or reinstalled is based on experience and the personal preference of the technician.

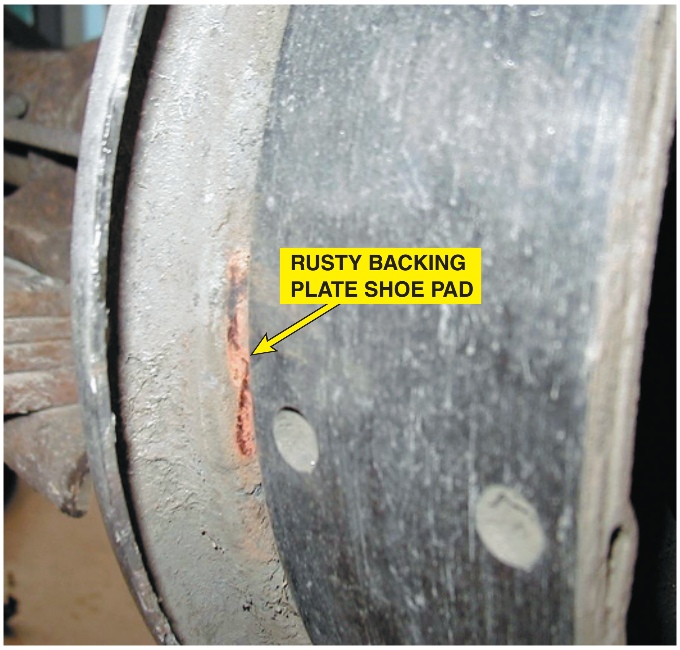


FIGURE 99–8 A typical rusting backing plate shoe pad. This can cause the brakes to squeak when the shoes move outward during a brake application and again when the brake pedal is released.

INSPECTING THE BACKING PLATE The backing plate supports the parts of the drum brake and helps to keep water from getting onto the brake shoes. The backing plate bolts to the rear axle or spindle and is made from stamped steel. Backing plates are plated (usually with cadmium) or painted to prevent rusting. To inspect the backing plate, follow these steps:

STEP 1 When brakes are serviced, the six raised contact surfaces, called pads, ledges, or shoe contact areas, of the backing plate should be inspected because they rub against the sides of the shoes. If the pads are worn more than 1/16 inch (1.5 mm), the backing plate should be replaced. ● **SEE FIGURE 99–8**.

STEP 2 The backing plate must be inspected for looseness or bending.

STEP 3 Backing plates should also be inspected to ensure that they are parallel with the axle flange.

STEP 4 The raised pads should be cleaned and lubricated. Lithium high-temperature brake grease, synthetic brake grease, silicone grease, or antiseize should be used to lubricate drum brake parts. ● **SEE FIGURE 99–9**.

DRUM BRAKE LINING INSPECTION Both primary (front facing) and secondary (rear facing) lining material must be thicker than 0.060 inch (1.5 mm). To inspect the drum brake lining, follow these steps:

STEP 1 Some vehicles are equipped with holes in the backing plate that allow for a visual inspection of the thickness of the lining. Most vehicle and brake lining manufacturers recommend replacing worn brake lining when the thickness of the riveted lining reaches 0.060 inch or less. An American nickel is about 0.060 inch thick, so simply remember that you must always have at least “a nickel’s worth of lining.” ● **SEE FIGURES 99–10 AND 99–11**.

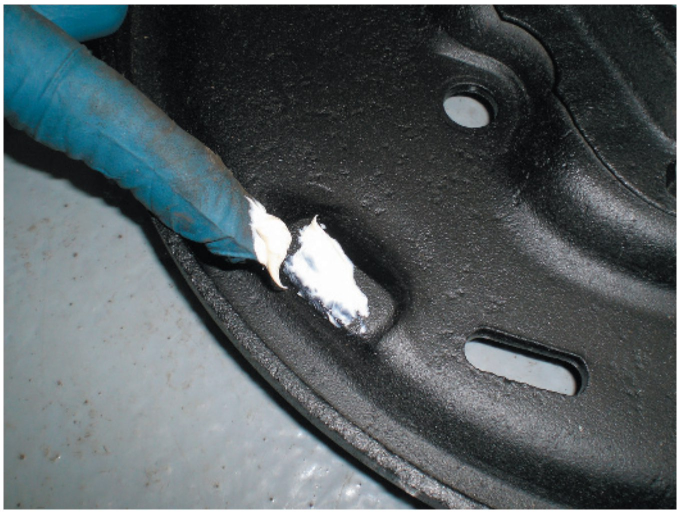


FIGURE 99–9 Applying lithium grease to the raised pads on the backing plate.

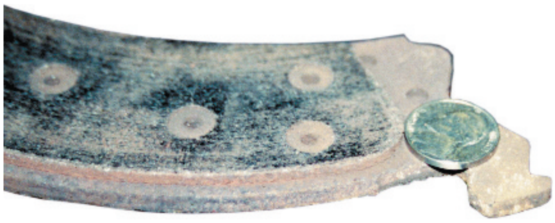


FIGURE 99–10 A rule of thumb is that the lining should be at least the thickness of a nickel.

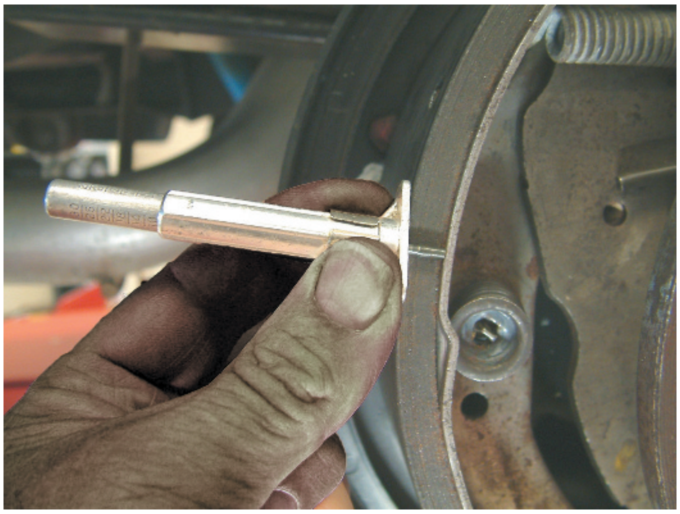


FIGURE 99–11 A tire tread depth gauge can be used to measure lining thickness. When measuring riveted linings, measure to the head of the rivets.

STEP 2 Most experts agree that the best possible inspection involves removing the brake drum and making a thorough visual inspection of the entire brake instead of just looking at the thickness of the remaining lining. If a riveted brake lining is cracked between rivets, the lining should be replaced. The lining must be replaced if cracked, as shown in ● **FIGURE 99–12**.

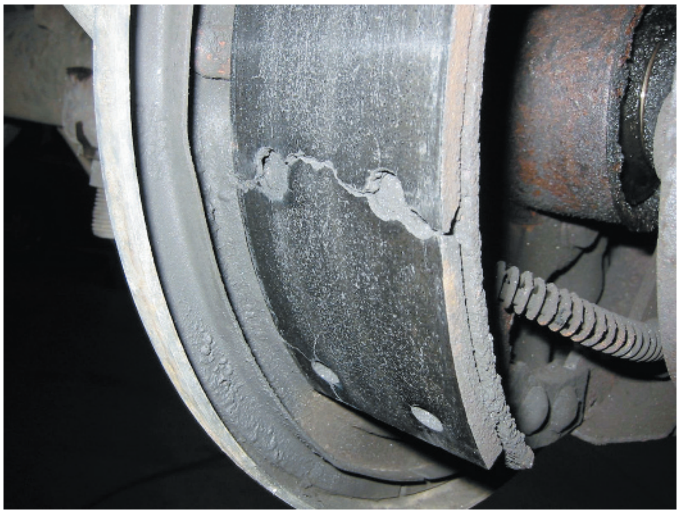


FIGURE 99–12 Cracked brake lining must be replaced.

BRAKE SPRING INSPECTION Each lining has a return spring (retracting spring) that returns the brake shoes back from the drums whenever the brakes are released. The springs are called primary and secondary return springs. The primary return spring attaches to the primary brake shoe and the secondary return spring attaches to the secondary brake shoe. These springs should be tested prior to a brake overhaul, especially when uneven lining wear is discovered.

Some drum brakes use a spring that connects the primary and secondary shoes and is commonly called a shoe-to-shoe spring. Return springs can get weak due to heat and time and can cause the linings to stay in contact with the drum when the brakes are released.

HOLD-DOWN SPRINGS Hold-down springs (one on each shoe) are springs used with a retainer and a hold-down spring pin (or nail) to keep the linings on the backing plate. Other types of hold-down springs include U-shape, flat spring steel type, and the combination return-and-hold spring. These springs still allow the freedom of movement necessary for proper braking operation.

TECH TIP

The Drop Test

Brake return (retracting) springs can be tested by dropping them to the floor. A good spring should "thud" when the spring hits the ground. This noise indicates that the spring has not stretched and that all coils of the springs are touching each other. If the spring "rings" when dropped, the spring should be replaced because the coils are not touching each other. ● **SEE FIGURE 99–13**.

Although this drop test is often used, many experts recommend replacing all brake springs every time the brake linings are replaced. Heat generated by the brake system often weakens springs enough to affect their ability to retract brake shoes, especially when hot, yet not "ring" when dropped.

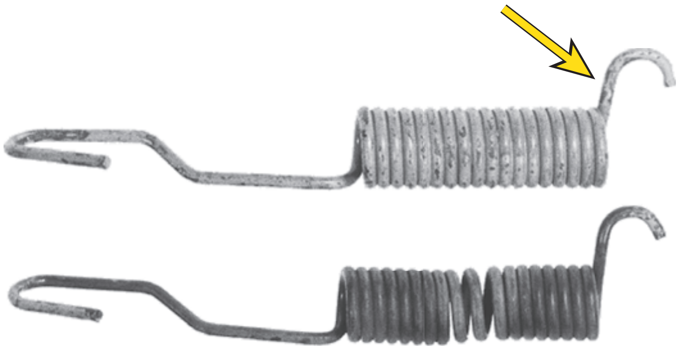


FIGURE 99–13 The top spring is a good-looking spring because all coils of the spring are touching each other. The bottom spring is stretched and should be discarded. The arrow points to the back side of the spring, which goes into a hole in the brake shoe. The open loop of the spring is not strong enough to keep from straightening out during use. Using the back side of the hook provides a strong, long-lasting hold in the brake shoe.

CONNECTING SPRING (ADJUSTING SCREW SPRING) The connecting spring attaches to the lower portion and connects the two shoes together. Check or replace at every brake lining change for best results.

WHEEL CYLINDER INSPECTION Drum brake wheel cylinders are cast iron with a bore (hole) drilled and finished to provide a smooth finish for the wheel cylinder seals and pistons. This special finish is called **bearingized.** The final step in manufacture of the wheel cylinder is to force a hardened steel ball through the bore to bend over the "grain" of the metal and to smooth the inner surface. This process provides a smooth porous-free surface for the sealing caps to travel over. It is this bearingized surface finish on the inside of the wheel cylinder that is often destroyed when a wheel cylinder is honed.

CAUTION: It is because of this bearingized surface finish that most vehicle manufacturers do not recommend that wheel cylinders be honed. Be sure to follow the vehicle manufacturer's recommended procedures. Some manufacturers state that the wheel cylinders can be overhauled using new (replacement) sealing cups and dust shields after cleaning the cylinder bore only.

Outside each wheel cylinder piston are dust boots installed to keep dirt out of the cylinder bore. Between both piston seals, there is a spring with piston seal expanders to keep the seals from collapsing toward each other and to keep pressure exerted on the lips of both seals to ensure proper sealing. ● **SEE FIGURE 99–14**.

On the back of each wheel cylinder there is a threaded hole for the brake line and a bleeder valve that can be loosened to remove (bleed) air from the hydraulic system. The wheel cylinder is bolted or clipped to the backing plate. ● **SEE FIGURES 99–15 AND 99–16**.

REASSEMBLY

DRUM BRAKE HARDWARE KIT If any spring is found to be defective, it is possible to purchase most parts individually or in pairs. However, for best results, many brake suppliers sell drum

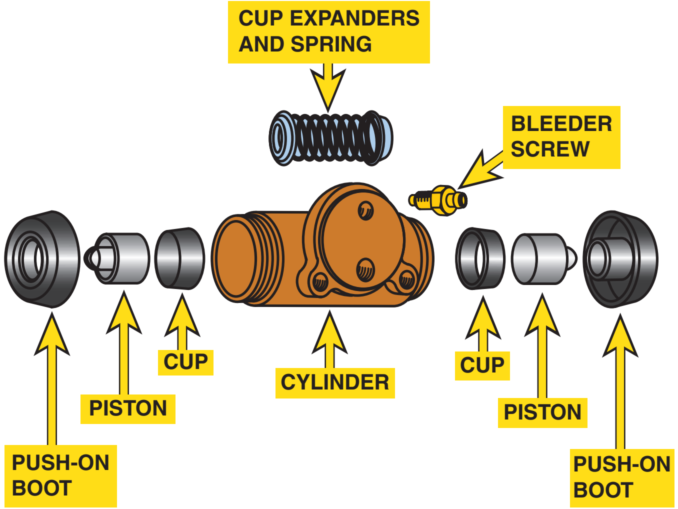


FIGURE 99–14 Exploded view of a typical wheel cylinder. Note how the flat part of the cups touches the flat part of the piston. The cup expander and spring go between the cups.

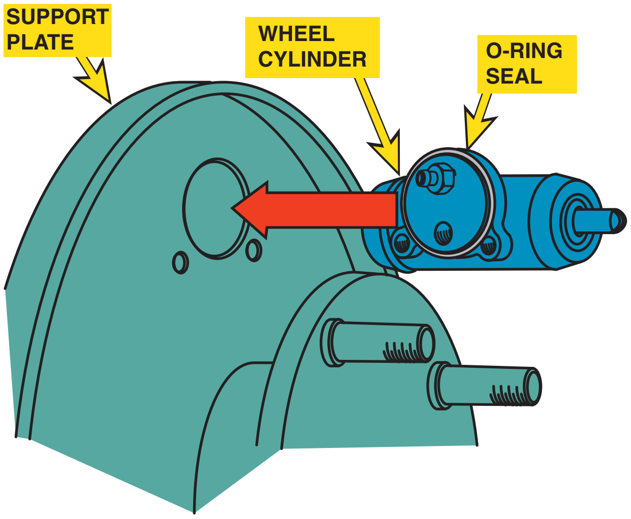


FIGURE 99–15 Many wheel cylinders are bolted to the support plate (backing plate). The O-ring seal helps keep water and dirt out of the drum brake.

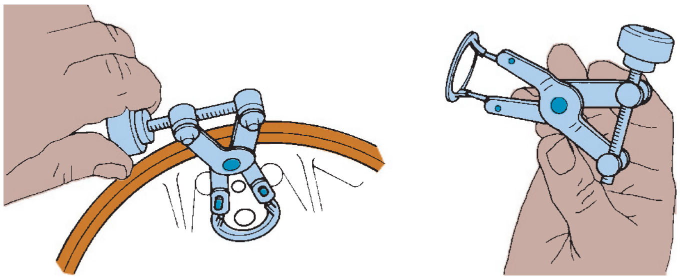


FIGURE 99–16 This special tool makes it a lot easier to remove the wheel cylinder clip. A socket (1 1/8 in. 12 point) can be used to push the clip back onto the wheel cylinder.

brake hardware kits. These kits usually include the items listed below for two drum brakes (axle set):

1. Primary and secondary return springs
2. Connecting spring
3. Hold-down springs
4. Hold-down spring retainers
5. Hold-down spring pins (nails)

TECH TIP

Time—Not Mileage—Is Important

Many brake experts recommend rebuilding or replacing wheel cylinders at every other brake job. Some experts recommend that the wheel cylinders be overhauled or replaced every time the brake linings are replaced. If the wheel cylinders are found to be leaking, they must be replaced or overhauled. The most important factor is time, not mileage, when determining when to repair or replace hydraulic components.

The longer the time, the more moisture is absorbed by the brake fluid. The greater the amount of moisture absorbed by the brake fluid, the greater the corrosion to metal hydraulic components. For example, the brakes will probably wear out much sooner on a vehicle that is used all day every day than on a vehicle driven only a short distance every week. In this example, the high-mileage vehicle may need replacement brake linings every year, whereas the short-distance vehicle will require several years before replacement brakes are needed. The service technician should try to determine the amount of time the brake fluid has been in the vehicle. The longer the brake fluid has been in the system, the greater the chances that the wheel cylinders need to be replaced or overhauled.

Self-adjuster kits are available in left- and right-handed threads for the left and right side of the vehicle. Other brake parts such as adjusters are available separately or as part of a self-adjuster kit. ● **SEE FIGURE 99–17**.

INSPECTING AND REPLACING BRAKE SHOES Carefully inspect the replacement brake shoes. Check all of the following:

1. Check that the replacements are exactly the same size (width and diameter) as the original. Hold the replacement shoes up against the old shoes to make the comparison.
2. Check for sound rivets (if rivet type). The friction material should also be snug against the metal brake shoe backing.

After checking that the replacement brake lining is okay, place the old shoes into the new linings' box. This helps ensure proper credit for the old shoes (called the core) as well as protection against asbestos contamination exposure.

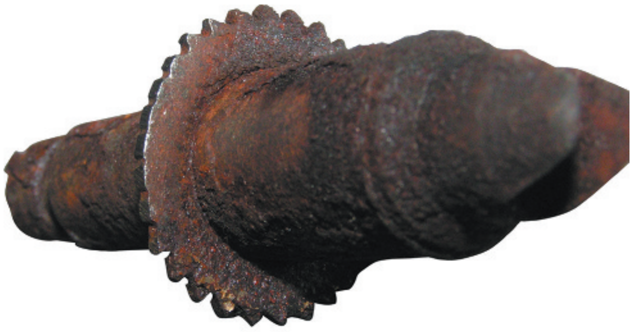


FIGURE 99–17 This starwheel adjuster is damaged and must be replaced. A lack of proper lubrication can cause the starwheel to become frozen in one place and not adjust properly.

BRAKE PARTS CLEANING Whenever cleaning brake parts or components, always use the following guidelines:

- Denatured alcohol or "brake clean" should only be used to clean brake parts that are disassembled. When individual parts are cleaned, they should be allowed to dry before being assembled.
- Never clean or flush assembled brake components with denatured alcohol or brake clean. Often, the alcohol cannot evaporate entirely from an assembled component. The trapped alcohol will evaporate inside the brake system, causing contamination. The trapped alcohol vapors also act like trapped air in the braking system and can cause a spongy brake pedal.
- Always clean assembled brake components with brake fluid.

LUBRICATION CHECKLIST For proper operation, the following points should be lubricated with approved brake lubricant:

1. The starwheel adjuster threads and under end caps
2. The backing plate contact areas (pads or ledges)
3. Anchor pins

CAUTION: Do not use wheel bearing or chassis grease on a braking system. Use only approved brake lubricant such as molybdenum disulfide (moly) grease, synthetic grease, lithium-based brake grease, or antiseize compound.

Also, be sure to check and lubricate the parking brake cable, if necessary.

REASSEMBLING THE DRUM BRAKE Reassembling the drum brake includes the following steps:

STEP 1 Carefully clean the backing plate.

STEP 2 Check the anchor pin for looseness.

STEP 3 Lubricate the shoe contact surfaces (shoe pads) with antiseize, brake grease, or synthetic grease.

STEP 4 Reassemble the primary and secondary shoes and brake strut, along with all springs.

STEP 5 Finish assembling the drum brake, being careful to note the correct location of all springs and parts.

NOTE: Many technicians preassemble the primary and secondary shoes with the connecting (lower retracting) spring as a unit before installing them onto the backing plate. ● SEE FIGURES 99–18 AND 99–19.

Most self-adjusters operate off the rear (secondary) shoe and should therefore be assembled toward the rear of the vehicle. Be sure that the star wheel adjuster is used on the correct side of the vehicle as the threads are different. ● **SEE FIGURE 99–20**.

ADJUSTING DRUM BRAKES

Most drum brakes are adjusted by rotating a starwheel or rotary adjuster. As the adjuster is moved, the brake shoes move toward the drum. If the brakes have been assembled correctly and with the parking brake fully released, both brake shoes should make contact with the anchor pin at the top. ● **SEE FIGURE 99–21** for an example where one shoe does not make contact with the anchor pin.

If the clearance between the brake shoes and the brake drum is excessive, a low brake pedal results. The wheel cylinder travel may

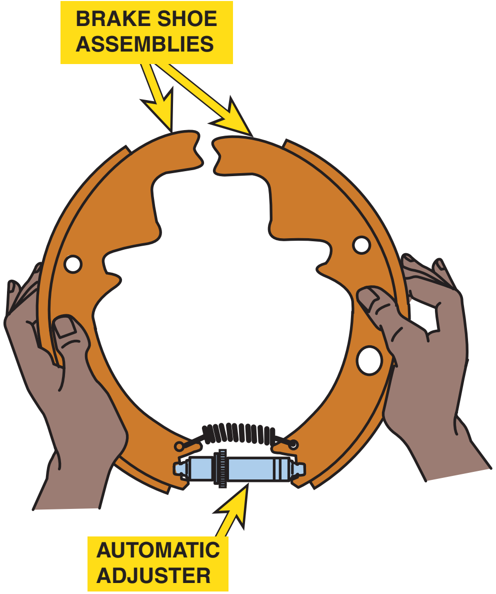


FIGURE 99–18 Pre-assembly of the starwheel adjuster with its connecting spring often helps when reassembling a drum brake. Check to make sure that the starwheel adjuster is on the correct side of the vehicle because they use different threads (left-hand and right-hand).

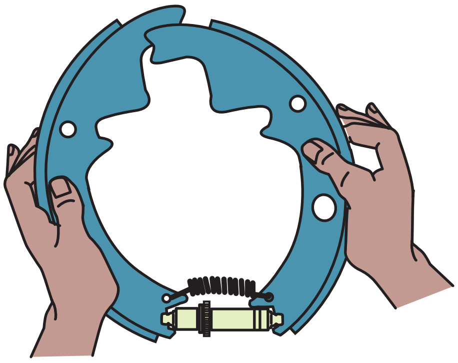


FIGURE 99–19 Sometimes it is necessary to cross the shoes when pre-assembling the starwheel adjuster and connecting spring.

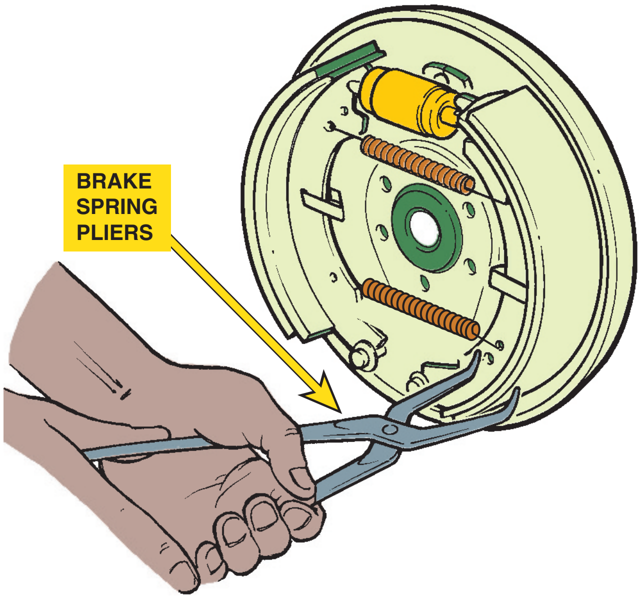


FIGURE 99–20 Brake spring pliers being used to install the connecting spring.

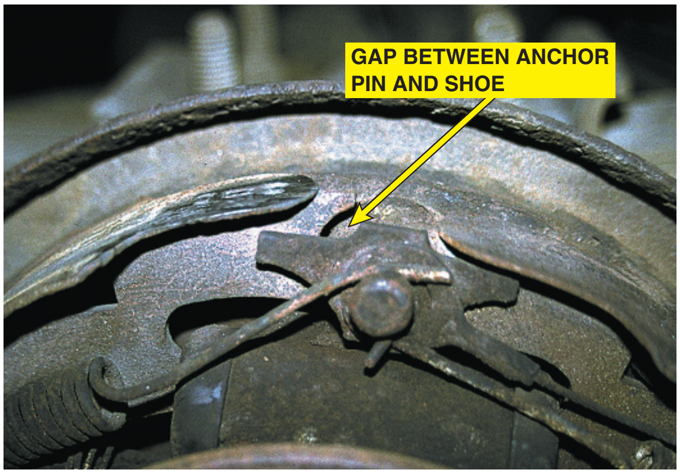


FIGURE 99–21 Notice that the brake shoe is not contacting the anchor pin. This often occurs when the parking brake cable is stuck or not adjusted properly.

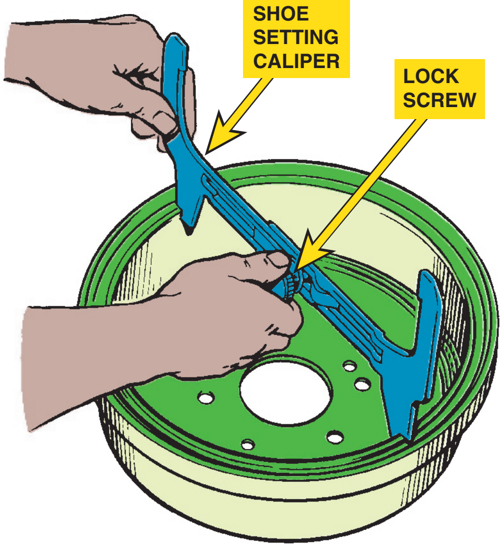


FIGURE 99–22 The first step in using a brake shoe clearance gauge is to adjust it to the drum inside diameter and tighten the lock screw.

not be adequate to cause the lining to contact the drums. Often, the driver has to pump the brakes to force enough brake fluid into the wheel cylinder to move it enough for braking action to occur.

Many technicians use a brake shoe clearance gauge to adjust the brake shoes before installing the drum. ● **SEE FIGURES 99–22 AND 99–23**.

CAUTION: Before installing the brake drum, be sure to clean any grease off the brake lining. Some experts warn not to use sandpaper on the lining to remove grease. The sandpaper may release asbestos fiber into the air. Grease on the linings can cause the brakes to grab.

TECH TIP

The Masking Tape Trick

Some technicians cover the friction material with masking tape to prevent contaminating the linings with dirt or grease during installation. After everything has been installed and double-checked, the masking tape is removed and the brake drums are installed. ● **SEE FIGURE 99–24**.

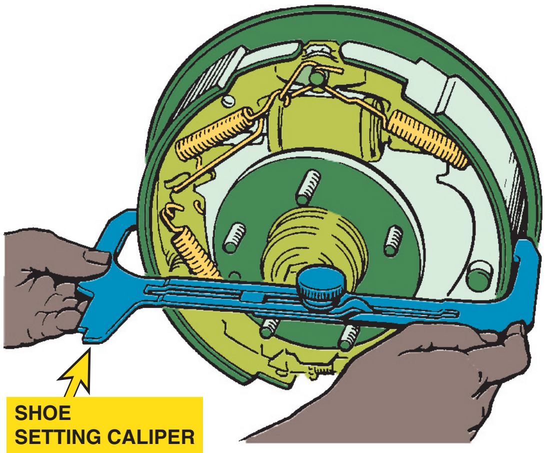


FIGURE 99–23 Place the gauge over the shoes and adjust the brakes until they contact the inside of the gauge.

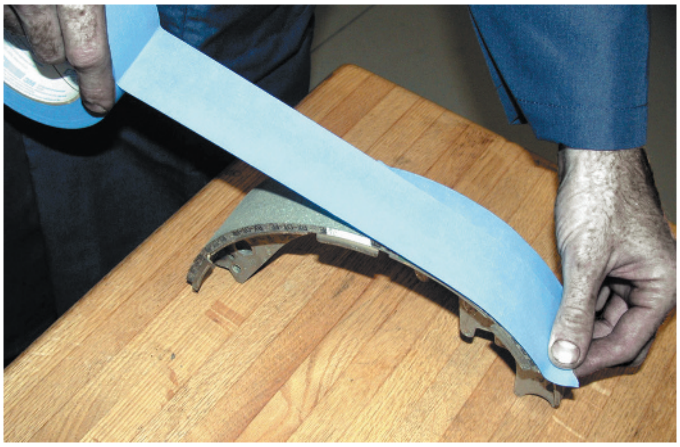


FIGURE 99–24 To prevent getting grease on the lining, the wise service technician covers the friction material with masking tape. The tape is removed after the brake shoes have been installed.

DRUM BRAKE FAULT SYMPTOM GUIDE

LOW PEDAL OR THE PEDAL GOES TO THE FLOOR Possible causes for low pedal include the following:

1. Excessive clearance between the linings and drum
2. Automatic adjusters not working
3. Leaking wheel cylinder
4. Air in the system

SPRINGY, SPONGY PEDAL Possible causes for springy, spongy pedal include the following:

1. Drums worn below specifications
2. Air in the system

EXCESSIVE PEDAL PRESSURE REQUIRED TO STOP THE VEHICLE Possible causes for excessive pedal pressure include the following:

1. Grease or fluid-soaked linings
2. Frozen wheel cylinder pistons
3. Linings installed on wrong shoes

LIGHT PEDAL PRESSURE—BRAKES TOO SENSITIVE Possible causes for light pedal pressure include the following:

1. Brake adjustment not correct
2. Loose backing plate
3. Lining loose on the shoe
4. Excessive dust and dirt in the drums
5. Scored, bell-mouthed, or barrel-shaped drum
6. Improper lining contact pattern

BRAKE PEDAL TRAVEL DECREASING Possible causes for brake pedal travel decreasing include the following:

1. Weak shoe retracting springs
2. Wheel cylinder pistons sticking

PULSATING BRAKE PEDAL (PARKING BRAKE APPLY PULSATES ALSO) Possible cause for pulsating brake pedal include the following:

1. Drums out-of-round

BRAKES FADE (TEMPORARY LOSS OF BRAKE EFFECTIVENESS WHEN HOT) Possible causes for brake fade include the following:

1. Poor lining contact
2. Drums worn below the discard dimension
3. Charred or glazed linings

SHOE CLICK NOISE Possible causes for shoe click noise include the following:

1. Shoes lift off the backing plate and snap back
2. Hold-down springs weak
3. Shoe bent
4. Grooves in the backing plate pads

THUMPING NOISE WHEN BRAKES ARE APPLIED Possible causes for thumping noise include the following:

1. Cracked drum; hard spots in the drum
2. Retractor springs unequal—weak

GRINDING NOISE Possible causes for grinding noise include the following:

1. Shoe hits the drum
2. Bent shoe web
3. Brake improperly assembled

ONE WHEEL DRAGS Possible causes for one wheel dragging include the following:

1. Weak or broken shoe retracting springs
2. Brake-shoe-to-drum clearance too tight—brake shoes not adjusted properly
3. Brake assembled improperly
4. Wheel cylinder piston cups swollen and distorted
5. Pistons sticking in the wheel cylinder
6. Drum out-of-round
7. Loose anchor pin/plate
8. Parking brake cable not free
9. Parking brake not adjusted properly

WET WEATHER: BRAKES GRAB OR WILL NOT HOLD Possible causes for brakes grabbing or not holding include the following:

1. Bent backing plate flange
2. Incorrect or abused shoe and linings

BRAKES SQUEAK Possible causes for brakes squeaking include the following:

1. Backing plate is bent or shoes twisted
2. Shoes scraping on backing plate pads
3. Weak or broken hold-down springs
4. Loose backing plate, anchor, or wheel cylinder
5. Glazed linings
6. Dry shoe pads and hold-down pin surfaces

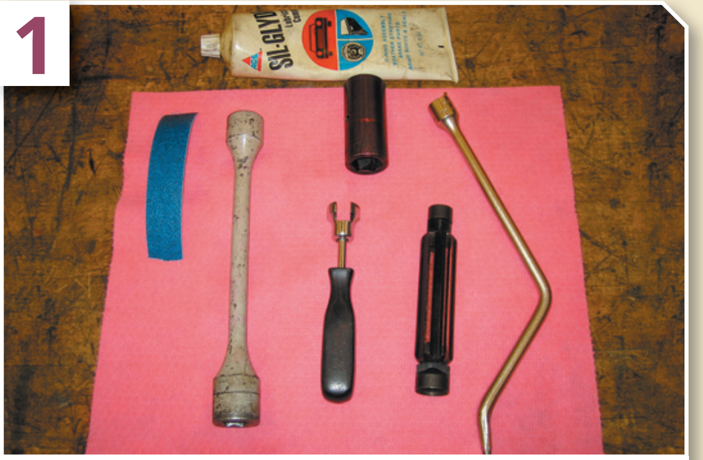
BRAKES CHATTER Possible causes for brake chattering include the following:

1. Incorrect lining-to-drum clearance
2. Loose backing plate
3. Weak or broken retractor spring
4. Drums out-of-round
5. Tapered or barrel-shaped drums
6. Improper lining contact pattern

DRUM BRAKE SERVICE

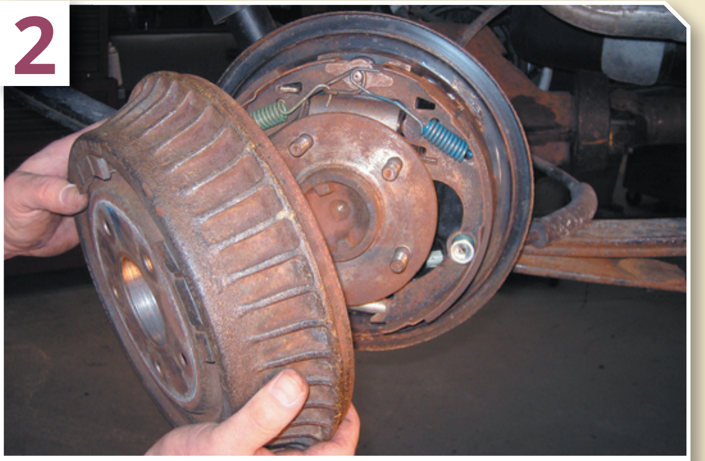
STEP BY STEP

1



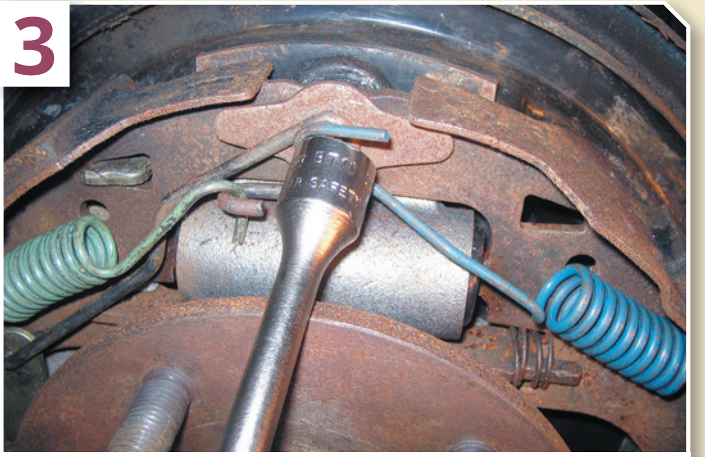
Tools needed to service a drum brake assembly include brake tools, silicone grease, lug nut wrench (socket).

2



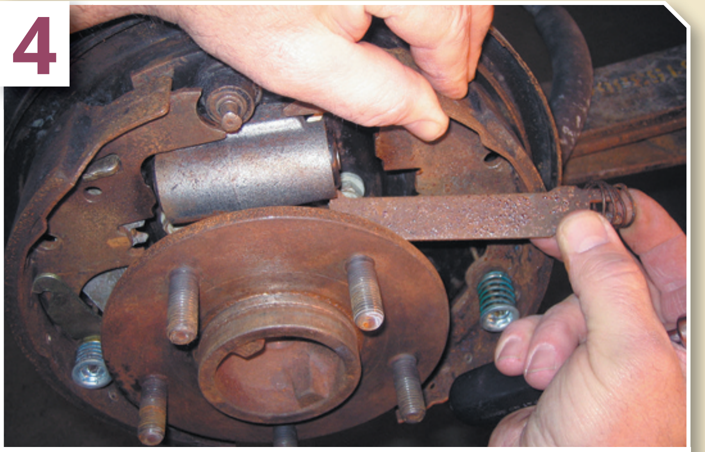
After safely hoisting the vehicle to chest height, remove the brake drum.

3



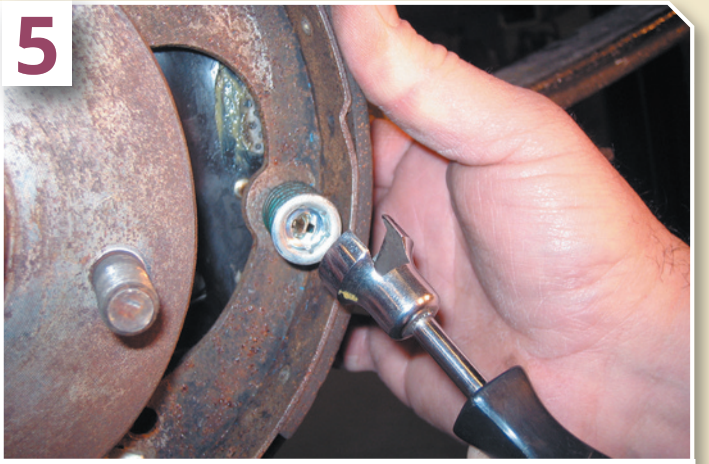
Remove the primary (forward facing) shoe return spring, using a brake tool. Then, remove the secondary return spring.

4



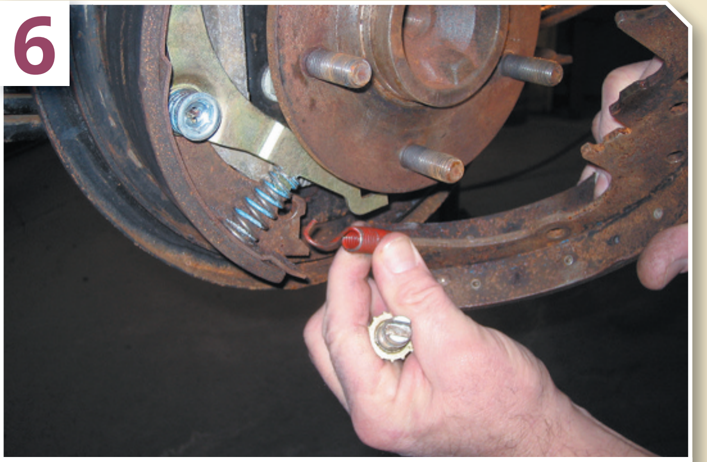
Remove the parking brake strut along with the antirattle spring.

5



Use a brake tool to depress the hold-down spring, and then rotate it until the slot in the retainer lines up with the flattened part of the hold-down pin.

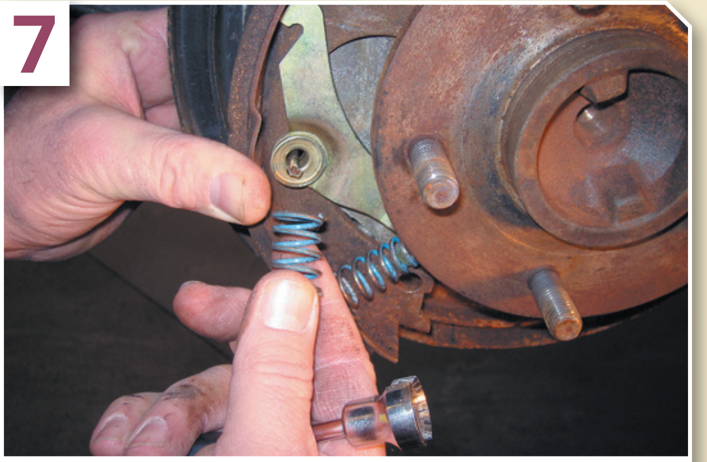
6



Removing the primary brake shoe plus the starwheel adjuster and connecting spring.

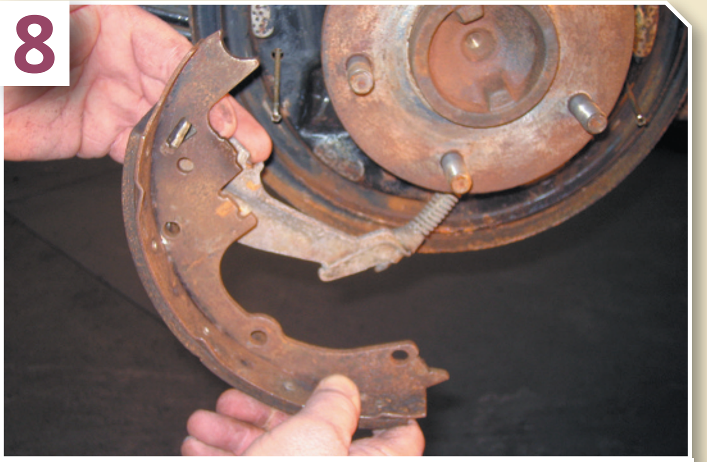
DRUM BRAKE SERVICE

7



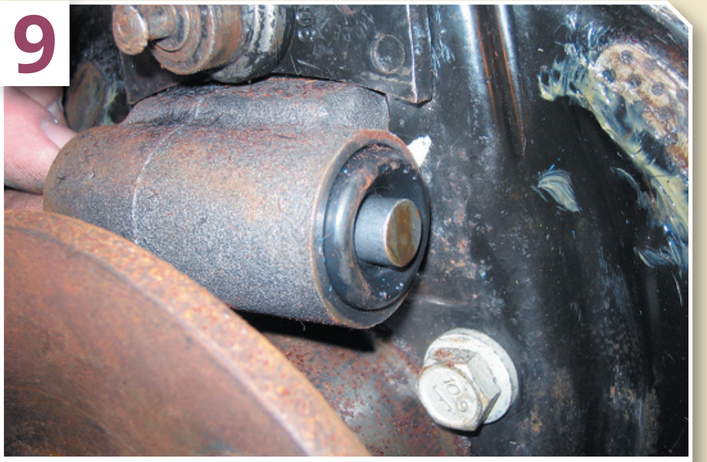
When the secondary lining hold-down spring is removed, the adjusting lever and pawl return spring can be removed.

8



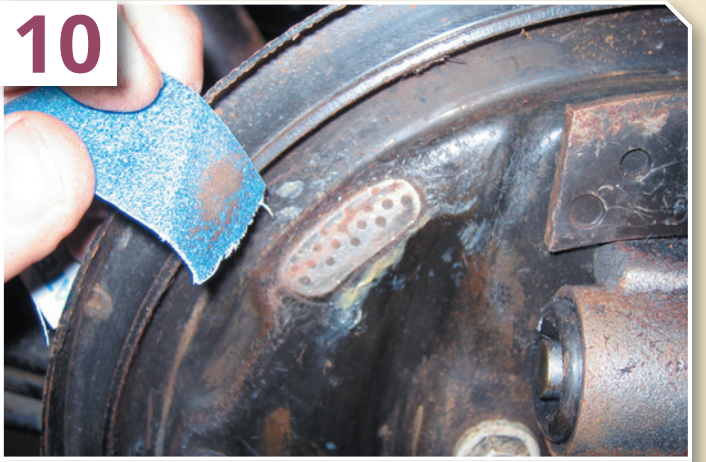
The parking brake lever can now be disconnected from the secondary brake shoe.

9



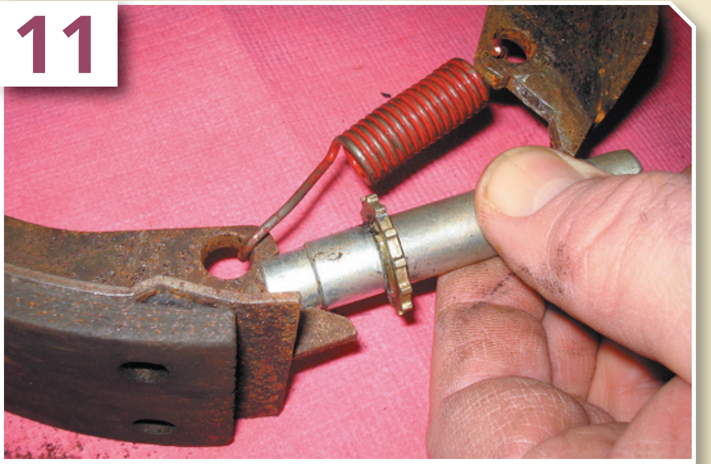
Check the wheel cylinder for leakage. This wheel cylinder is relatively new and not leaking.

10



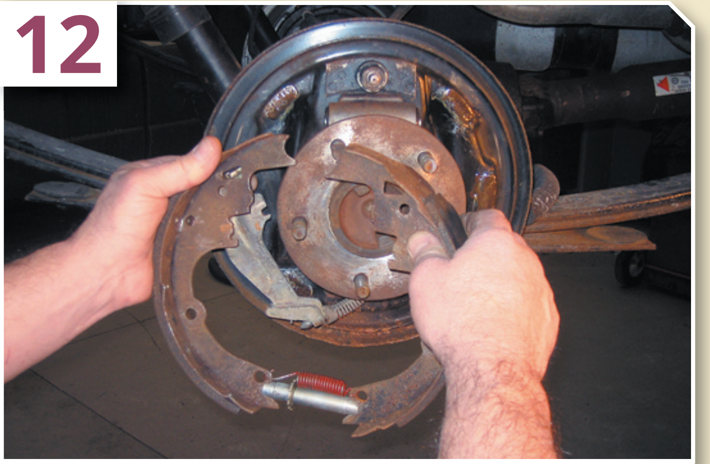
Clean all six brake shoe ledges. Lubricate the ledges with silicone brake grease.

11



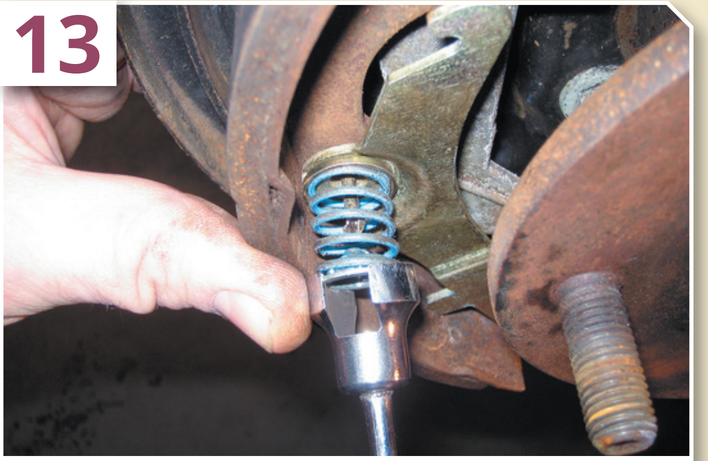
Many technicians prefer to assemble the connecting spring and starwheel adjuster to both shoes to help in the reinstallation.

12



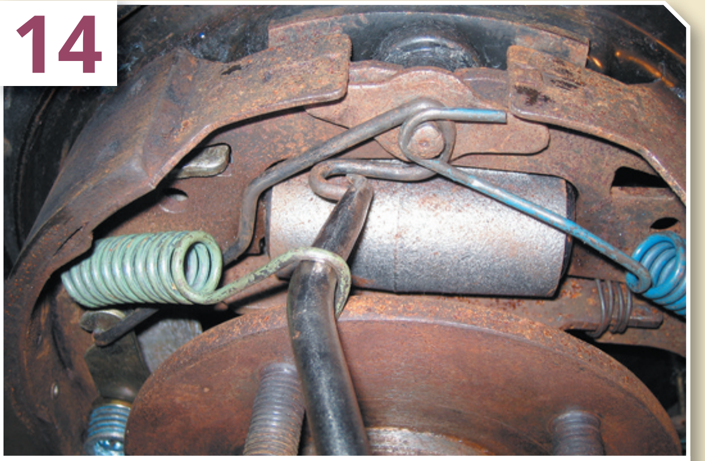
Attaching the parking brake lines to the secondary shoe. The assembled parts at the bottom help keep everything together.

13



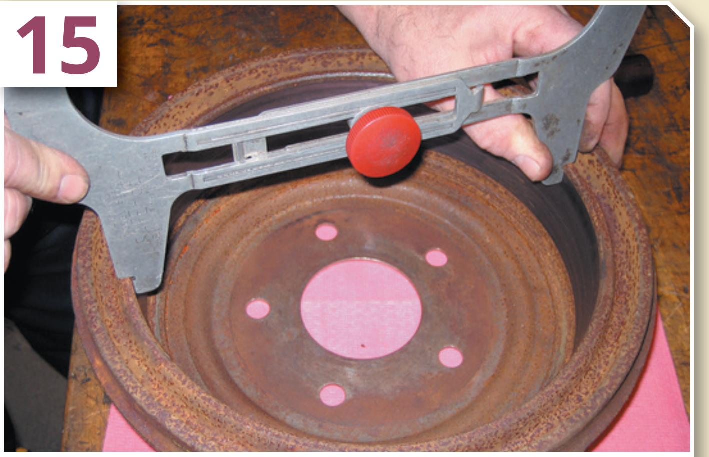
Installing the secondary shoe hold-down spring.

14



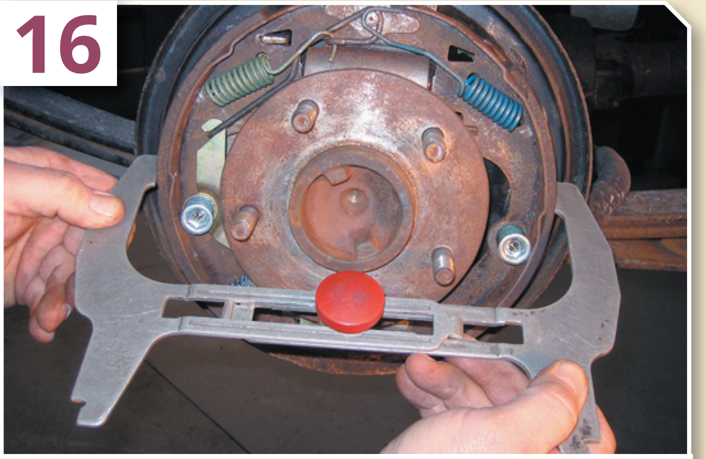
Installing the secondary shoe return spring. Note that the primary return spring has already been installed.

15



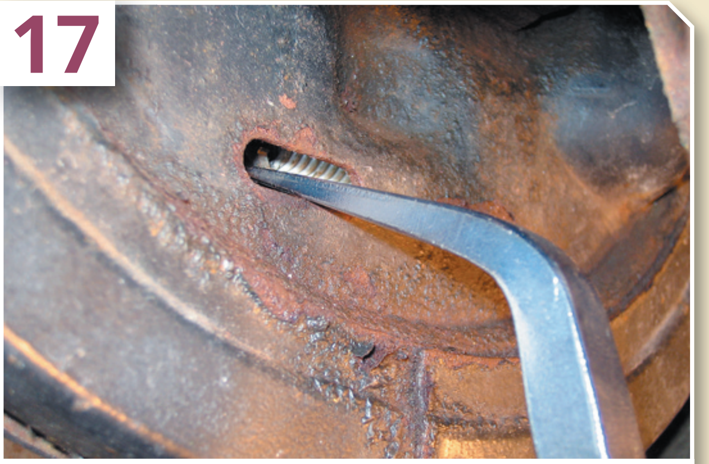
After installing the brake shoes and springs, use a drum/shoe clearance gauge and set it to the inside diameter of the drum.

16



Adjust the starwheel adjuster until the linings contact the drum brake shoe clearance gauge.

17



After installing the drum, it may be necessary to make the final adjustment using a brake adjusting tool (spoon).

18

After completing the brake service, be sure to cover the brake adjustment opening to prevent water from getting into the brake.

REVIEW QUESTIONS

1. Explain how to remove a brake drum.
2. List all items that should be lubricated on a drum brake.
3. List the steps necessary to follow when replacing drum brake linings.
4. Explain why many vehicle manufacturers do not recommend the wheel cylinder be honed.
5. What is the purpose of tinnerman nuts?

CHAPTER QUIZ

1. Technician A says that the tinnerman nuts are used to hold the brake drum on and should be reinstalled when the drum is replaced. Technician B says that a drum should be removed inside a sealed vacuum enclosure or washed with water or solvent to prevent possible asbestos dust from being released into the air. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. The backing plate should be replaced if the shoe contact areas (pads or ledges) are worn more than ____________.
   - **a.** 1/2 inch (13 mm)
   - **b.** 1/4 inch (7 mm)
   - **c.** 1/8 inch (4 mm)
   - **d.** 1/16 inch (1.5 mm)
3. Technician A says that silicone brake grease can be used to lubricate the shoe contact ledges. Technician B says that synthetic brake grease, lithium brake grease, or antiseize compound can be used as a brake lubricant. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Most brake experts and vehicle manufacturers recommend replacing brake lining when the lining thickness is ____________.
   - **a.** 0.030 inch (0.8 mm)
   - **b.** 0.040 inch (1.0 mm)
   - **c.** 0.050 inch (1.3 mm)
   - **d.** 0.060 inch (1.5 mm)
5. Technician A says that many vehicle manufacturers recommend that wheel cylinders not be honed because of the special surface finish inside the bore. Technician B says that some experts recommend that the wheel cylinders be replaced every time the brake linings are replaced. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Most manufacturers recommend that brake parts should be cleaned with ____________.
   - **a.** clean water only
   - **b.** denatured alcohol
   - **c.** stoddard solvent
   - **d.** detergent and water
7. After assembling a drum brake, it is discovered that the brake drum will not fit over the new brake shoes. Technician A says that the parking brake cable may not have been fully released. Technician B says to check to see if both shoes are contacting the anchor pin. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Technician A says to use masking tape temporarily over the lining material to help prevent getting grease on the lining. Technician B says that grease on the brake lining can cause the brakes to grab. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. Technician A says that starwheel adjusters use different threads (left- and right-handed) for the left and right sides of the vehicle. Technician B says that the threads and end caps of the adjusters should be lubricated with brake grease before being installed. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. The drum brake on one side of a vehicle is dragging. Which of the following could *not* be the cause?
    - **a.** Sticking wheel cylinder piston
    - **b.** Improper shoe adjustment
    - **c.** Broken retracting springs
    - **d.** Air in the system

Chapter

100

DISC BRAKES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the parts and operation of disc brakes.
- Describe the construction of disc brakes.
- Discuss brake pads.
- Explain the different types of disc brake designs.
- Describe rear disc parking brakes.

KEY TERMS:

Anchor plate 1178 • Antirattle clips 1174 • Bonded linings 1177 • Brake block 1177 • Brake pad 1175 • Fixed brake caliper 1177 • Floating caliper 1178 • Gas fade 1172 • Integrally molded 1177 • Lining fade 1172 • Low-drag caliper 1180 • Mechanical fade 1171 • Mold-bonded lining 1177 • Natural frequency 1174 • Pad wear indicators 1176 • Pin-slider caliper 1178 • Riveted linings 1177 • Sliding caliper 1181 • Swept area 1171 • Water fade 1173 • Ways 1181

DISC BRAKES

PARTS AND OPERATION Disc brakes use a piston(s) to squeeze friction material (pads) on both sides of a rotating disc (rotor). Disc may be spelled *disk* by some manufacturers, but *disc* is the SAE (Society of Automotive Engineers) term and the most commonly used spelling in the industry. The rotor is attached to and stops the wheel.

Disc brakes are used on the front wheels of late-model vehicles, and on the rear wheels of an increasing number of automobiles. Disc brakes were adopted primarily because they can supply greater stopping power than drum brakes with less likelihood of fade. This makes disc brakes especially well-suited for use as front brakes, which must provide 60% to 80% of the vehicle's total stopping power.

DISC BRAKE ADVANTAGES Although increased federal brake performance standards hastened the switch to disc brakes, the front drum brakes would eventually have been eliminated anyway because disc brakes are superior in almost every respect. The disc brake friction assembly has several significant strong points, and only a few relatively minor weak points. ● **SEE FIGURE 100–1**.

The main advantages of the disc brake include the following:

FADE RESISTANCE The main design feature that helps disc brakes avoid heat-induced fade is their cooling ability because all of the major parts of a disc brake are exposed to the air flowing over the friction assembly. Many brake rotors also have cooling passages cast into them to further reduce operating temperatures and have greater fade resistance than drum brakes because they have greater swept area. **Swept area** is the amount of brake drum or rotor friction surface that moves past the brake linings every time the drum or rotor completes a rotation. Disc brakes are resistant to all kinds of fade, including the following:

- **Mechanical fade** is not a problem with disc brakes because, unlike a brake drum, the disc brake rotor expands *toward* the brake linings as it heats up rather than *away* from them. This fundamental design difference makes it physically impossible for heat to cause the rotor to expand out of contact with the brake linings. Because of this, there is never the need to move the brake linings out to keep them in contact with the rotor, so brake pedal travel does not increase. If the brake pedal on a vehicle with disc brakes drops toward the floor, it is almost always a sign of vapor lock, a fluid leak, fluid bypassing the seals in the master cylinder, or mechanical fade of the rear *drum* brakes.

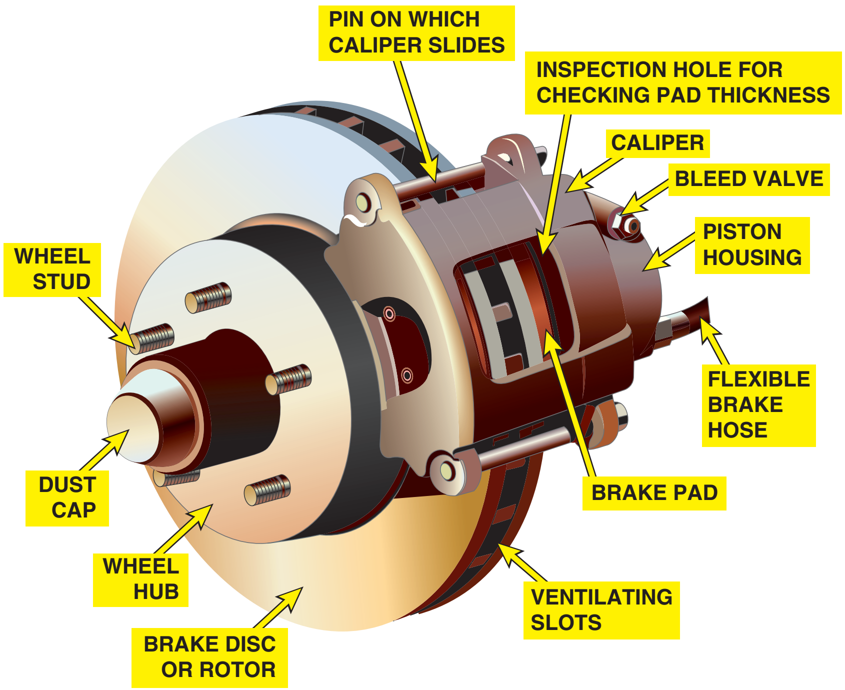

PIN ON WHICH CALIPER SLIDES
INSPECTION HOLE FOR CHECKING PAD THICKNESS
CALIPER
BLEED VALVE
PISTON HOUSING
WHEEL STUD
FLEXIBLE BRAKE HOSE
DUST CAP
BRAKE PAD
WHEEL HUB
VENTILATING SLOTS
BRAKE DISC OR ROTOR

FIGURE 100–1 A typical single-piston, floating-caliper-type disc brake assembly.

- **Lining fade** can and does occur if the brakes become overheated. A little bit of heat brings the brake pads to their operating temperature and actually increases the friction coefficient of the lining material. A warm brake performs better than a cold brake. However, when too much heat is generated by braking, the lining material overheats. Its friction coefficient drops, and lining fade occurs.

  The primary symptom of lining fade is a hard brake pedal that requires the driver to apply greater force to maintain stopping power. Unlike the similar situation in a drum brake, however, increased application force will not distort the brake rotor because the caliper applies equal force to both sides. ● **SEE FIGURE 100–2**.

  Increased pressure will, however, create even more heat, and if brake lining temperatures continue to increase, gas fade and vapor lock of the hydraulic system can occur. If the pads are overheated to the point where the lining material is physically damaged, the brakes will not recover their full stopping power until the pads are replaced. ● **SEE FIGURE 100–3**.
- **Gas fade** is a problem only under severe braking conditions when hot gases and dust particles from the linings are trapped between the brake linings and rotor, where they act as lubricants. The symptoms of gas fade are the same as those for lining fade. The pedal becomes hard and increased force is required to maintain stopping power.

  Even though disc brakes operate at higher temperatures than drum brakes, they have fewer problems with gas fade for a number of reasons.

  1. Disc brakes do not have a drum to contain gases and particles in the area around the brake linings.

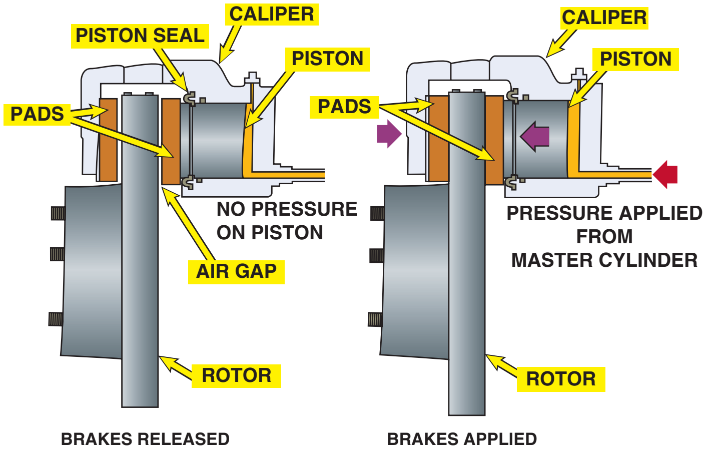

CALIPER
PISTON SEAL
PISTON
PADS
NO PRESSURE ON PISTON
AIR GAP
ROTOR
BRAKES RELEASED
CALIPER
PISTON
PADS
PRESSURE APPLIED FROM MASTER CYLINDER
ROTOR
BRAKES APPLIED

FIGURE 100–2 Braking force is applied equally to both sides of the brake rotor.

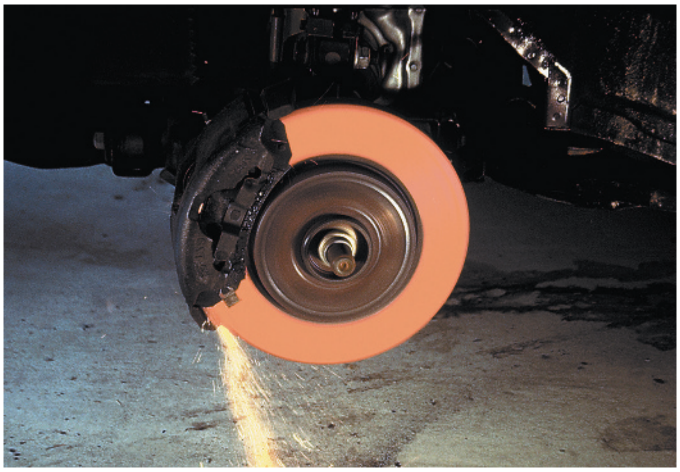


FIGURE 100–3 Disc brakes can absorb and dissipate a great deal of heat. During this demonstration, the brakes were gently applied as the engine drove the front wheels until the rotor became cherry red. During normal braking, the rotor temperature can exceed 350°F (180°C), and about 1,500°F (800°C) on a race vehicle.

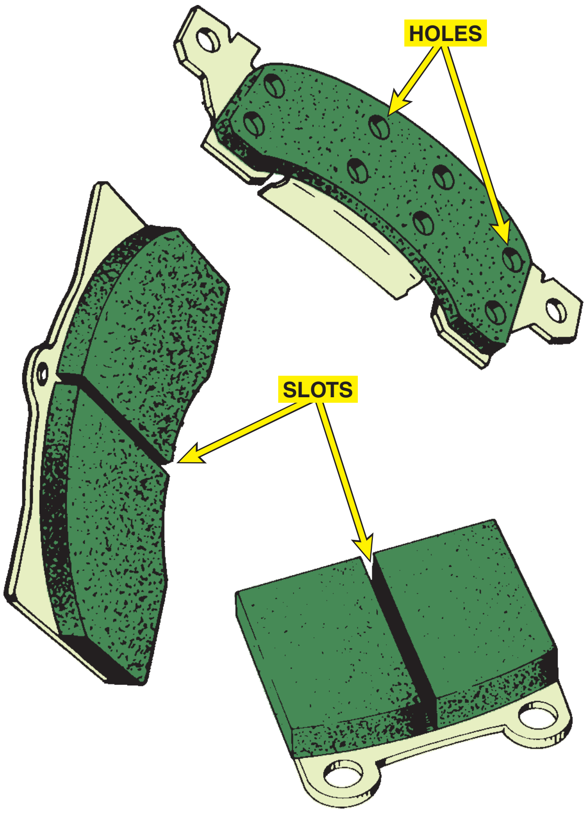


FIGURE 100–4 Slots and holes in the brake linings help prevent gas and water fade.

2. The constant flow of air over the brake carries away contaminants that might otherwise build up.
3. The surface area of the brake lining material in a disc brake is smaller than that of a comparable drum brake and this allows gases and particles to escape more easily.

To help prevent gas fade, many brake pads have slots cut in the lining material. These slots allow gases and dust particles to escape. ● **SEE FIGURE 100–4**. The holes required in riveted linings also perform this function. For even greater protection against gas fade, high-performance vehicles and motorcycles sometimes have holes or slots cut into the rotor. These openings allow gases and water to escape, and their sharp edges continually wipe loose particles off the linings.

- **Water fade** is not a big problem with disc brakes because centrifugal force created by the spinning rotor throws off most moisture, and the brake pads positioned only a few thousandths of an inch away from the rotor continuously wipe it clean. When the brakes are applied, the leading edge of the brake pad lining material wipes the last bit of water from the disc. Once good lining-to-rotor contact is established, water is unable to enter the space between the linings and rotor until the brakes are released.

Although far more resistant to water fade than drum brakes, disc brakes are not entirely free from its effects. Splash shields and the vehicle's wheels help keep water off of the rotor, and the brake lining materials specified for most vehicles minimize the effects of water fade.

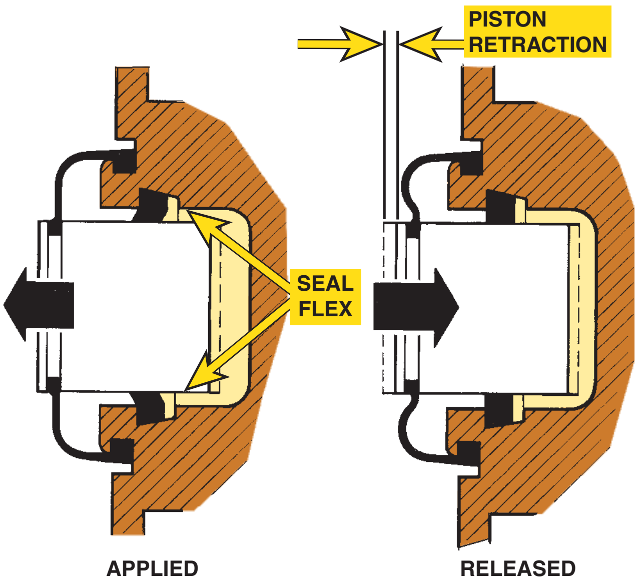


FIGURE 100–5 The square-cut O-ring not only seals hydraulic brake fluid but also retracts the caliper piston when the brake pedal is released.

SELF-ADJUSTING ABILITY Disc brakes are self-adjusting because any wear of the linings is automatically compensated for by the action of the brake caliper.

When the brakes are applied, the caliper pistons move out as far as needed to force the brake pads into contact with the rotor. When the brakes are released, the piston retracts only the small distance dictated by rotor runout and piston seal flex. ● **SEE FIGURE 100–5**. The surface finish on the piston must be clean to allow the piston to slide past this seal. Excessive friction between the caliper piston and the caliper bore can prevent the piston from retracting. If the force of the caliper seal is not strong enough, the piston stays in the applied position. Because the brake pads are still in contact with the rotor, one or both pads will show excessive wear.

FREEDOM FROM PULL A disc brake will stop straighter under a wider range of conditions than will a drum brake. A disc brake is self-cleaning, will throw off most water, and is less likely to pull.

Disc brakes do not have self-energizing or servo action. Because disc brakes do not use friction between the linings and rotor to increase their braking power, the effects of a loss of friction on one side of the vehicle are far less pronounced than with drum brakes.

TECH TIP

Check the Tire Size for a Pulling Problem

If an unequal braking problem is being diagnosed, check that the front tires match and that the rear tires match. Brakes slow and stop wheels. Unequal diameter tires create an unequal braking force. The result may be a pulling toward one side while braking. Tire diameter can vary from one tire manufacturer to another even though the size designation is the same. Even slight differences in the wear of tires can cause a different tire diameter and, therefore, a different braking force.

DISC BRAKE DISADVANTAGES The most notable fact about the disadvantages of disc brakes is that there are so few. The weaknesses of disc brakes include the following:

- **No self-energizing or servo action**—The disc brake's lack of self-energizing or servo action is a disadvantage for two reasons.
    1. It contributes to poor parking brake performance and requires the driver to push harder on the brake pedal for a given stop. However, the problem of high pedal pressures has been eliminated through the use of brake power boosters.
    2. It is easier to modulate the brakes for the exact amount of stopping power desired.
- **Brake noise**—Probably the biggest complaint about disc brakes is that they sometimes make various squeaks and squeals during a brake application. As long as the brake linings are not worn down to the backing plate, these noises are usually caused by high-frequency rattling or vibration of the brake pads. Several methods are used to quiet noisy disc brakes. Manufacturers use specific lining materials that damp vibrations, and most calipers have **antirattle clips** or springs that hold the pads in the caliper under tension to help prevent vibration. ● **SEE FIGURE 100–6**.

Some calipers use special shims between the brake pad backing plate and the caliper piston to damp vibrations. ● **SEE FIGURE 100–7**. These shims may be made of metal or fiber. Antinoise sprays and brush-on liquids are available and provide a cushion layer between the pad and the caliper piston. The bond lowers the **natural frequency** of the pad, and the cushion layer damps any vibration that may still occur.

BRAKE DUST Because the lining is exposed on a disc brake, rather than being enclosed as on a drum brake, some brake dust can accumulate on the wheels. This brake dust is often dark brown or black and can stain wheels if not cleaned often or protected from the dust.

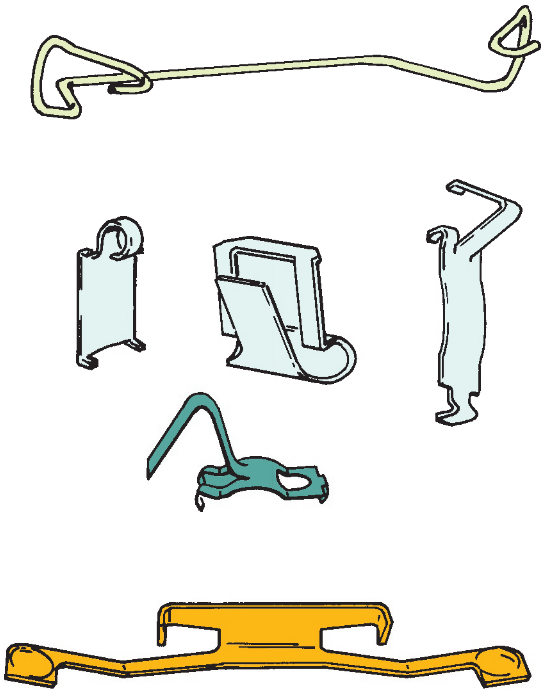


FIGURE 100–6 Antirattle clips reduce brake pad movement and vibration.

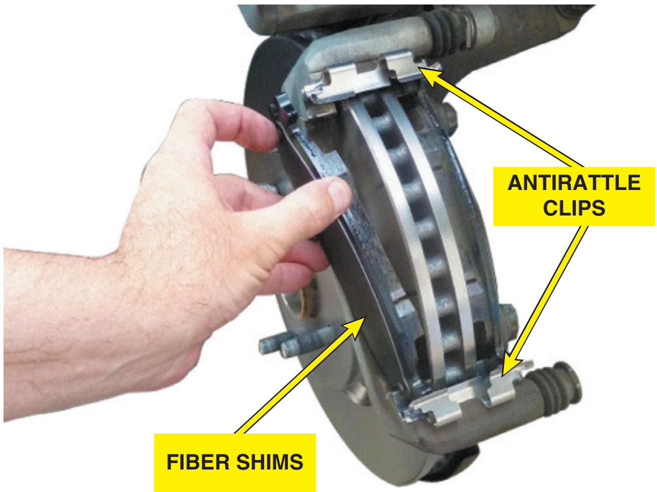


FIGURE 100–7 Antivibration shims are used behind the pads on many disc brake caliper designs.

TECH TIP

Wax the Wheels

Brake dust from semimetallic brake pads often discolors the front wheels. Customers often complain to service technicians about this problem, but it is normal for the front wheels to become dirty because the iron and other metallic and nonmetallic components wear off the front disc brake pads and adhere to the wheel covers. A coat of wax on the wheels or wheel covers helps prevent damage and makes it easier to wash off the brake dust.

POOR PARKING BRAKE PERFORMANCE The lack of self-energizing or servo action plays a large part in poor disc brake parking brake performance. The lining-to-rotor contact area of a disc brake is somewhat smaller than the lining-to-drum contact area of a drum brake. This causes the disc brake to have a lower static coefficient of friction, and therefore less holding power when the vehicle is stopped.

DISC BRAKE CONSTRUCTION

CALIPER With the exception of the rotor, the caliper is the largest part of a disc brake friction assembly. The brake caliper uses hydraulic pressure to create the mechanical force required to move the brake pads into contact with the brake rotor. At the front axle, the caliper mounts to the spindle or steering knuckle. ● **SEE FIGURE 100–8**. Rear disc brake calipers mount to a support bracket on the axle flange or suspension. ● **SEE FIGURE 100–9**.

DISC BRAKE ROTOR TYPES The brake rotor provides the friction surfaces for the brake pads to rub against. The rotor, the largest and heaviest part of a disc brake, is usually made of cast iron because that metal has excellent friction and wear properties. There are two basic types of rotors:

- **Solid**—Solid rotors are most often used on the rear of vehicles equipped with four-wheel disc brakes.
- **Vented**—Vented rotors have radial cooling passages cast between the friction surfaces. ● **SEE FIGURE 100–10**.

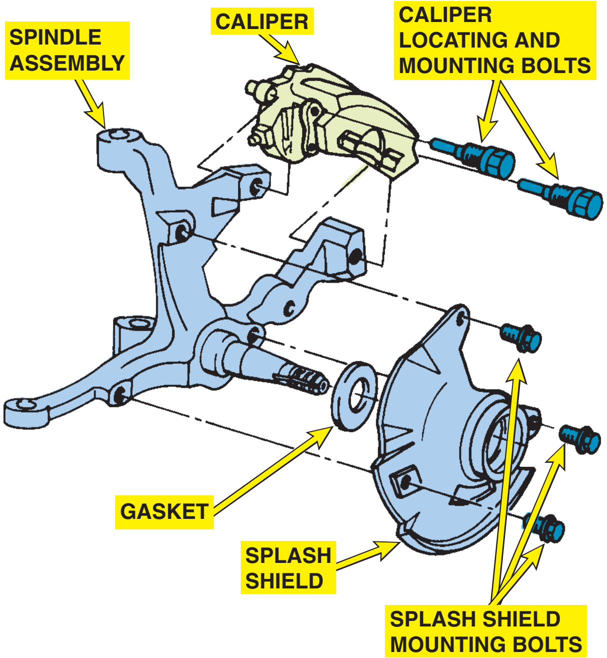

SPINDLE ASSEMBLY
CALIPER
CALIPER LOCATING AND MOUNTING BOLTS
GASKET
SPLASH SHIELD
SPLASH SHIELD MOUNTING BOLTS

FIGURE 100–8 This brake caliper attaches to the front spindle.

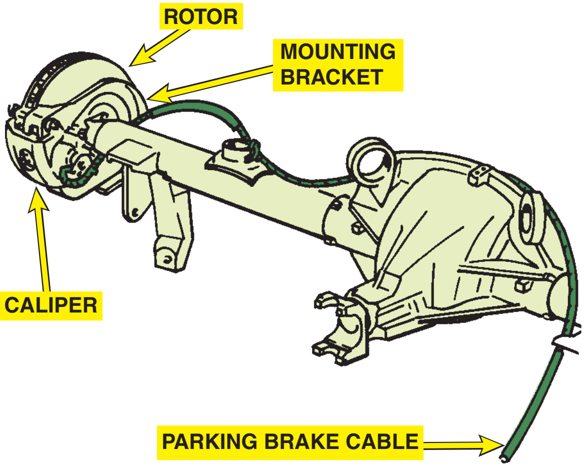

ROTOR
MOUNTING BRACKET
CALIPER
PARKING BRAKE CABLE

FIGURE 100–9 A rear disc brake caliper often attaches to a mounting bracket on the rear axle housing.

SPLASH SHIELD The splash shield bolts to the front spindle or steering knuckle, or in rear disc brake applications, to the axle flange or a suspension adapter plate. The job of the splash shield is to protect the inner side of the brake rotor from water and other contaminants, whereas the outer side of the rotor is protected by the wheel. Most splash shields are made of stamped steel or plastic.

DISC BRAKE PADS

DESIGN FEATURES The lining of a disc brake is part of an assembly called the **brake pad.** ● **SEE FIGURE 100–11**. Compared to a brake shoe, a brake pad is a relatively simple part that consists of a block of friction material attached to a stamped steel backing plate. Some pad backing plates have tabs that bend over the caliper to hold the pad tightly in place and help prevent brake noise. ● **SEE FIGURE 100–12**.

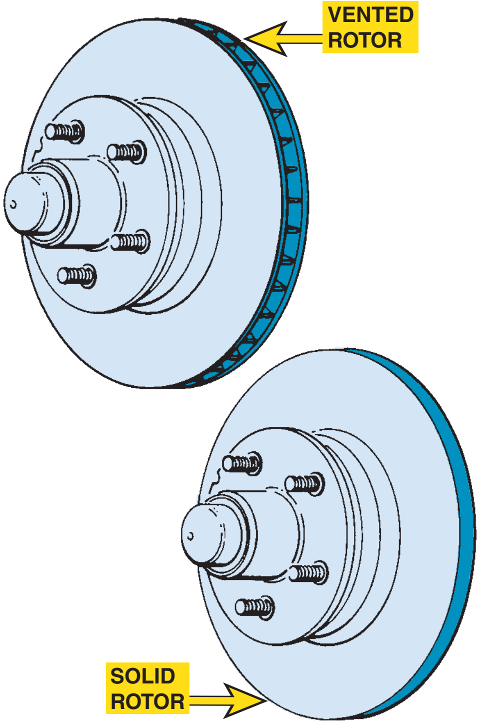

VENTED ROTOR
SOLID ROTOR

FIGURE 100–10 Disc brake rotors can be either solid or vented.

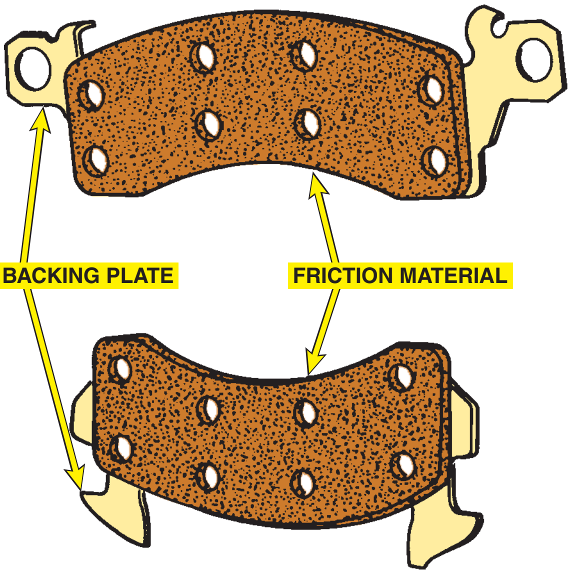

BACKING PLATE
FRICTION MATERIAL

FIGURE 100–11 A typical disc brake pad.

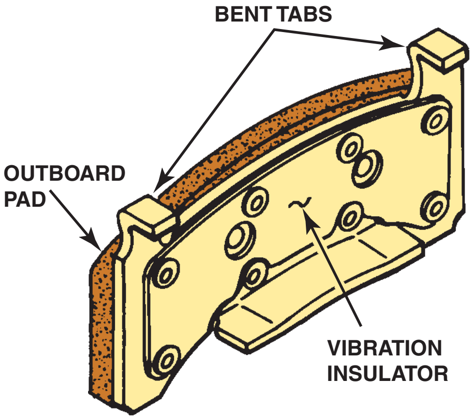

BENT TABS
OUTBOARD PAD
VIBRATION INSULATOR

FIGURE 100–12 To prevent noise, bent tabs on the backing plate hold some brake pads to the caliper housing.

FREQUENTLY ASKED QUESTION

Why Are Some Brake Pads Slotted and Others Not?

Brake pads are designed by the vehicle manufacturer for each specific application. Some are tapered at the ends and others are slotted and many are tapered and slotted. According to brake design engineers, these features are designed to help reduce brake noise. By changing the size of the pad area or by breaking it up into sections by slotting, the frequency of the sound generated during braking changes. For best results, use a replacement brake pad that has the same design features as the original brake pads.

Other pad backing plates have tabs with holes in them as shown in ● **FIGURE 100–13**. A pin slips through the holes and fastens to the caliper body to hold the pads in position. Still other pad backing plates have a retainer spring attached that locates the pad in the caliper by locking it to the caliper piston. ● **SEE FIGURE 100–14**.

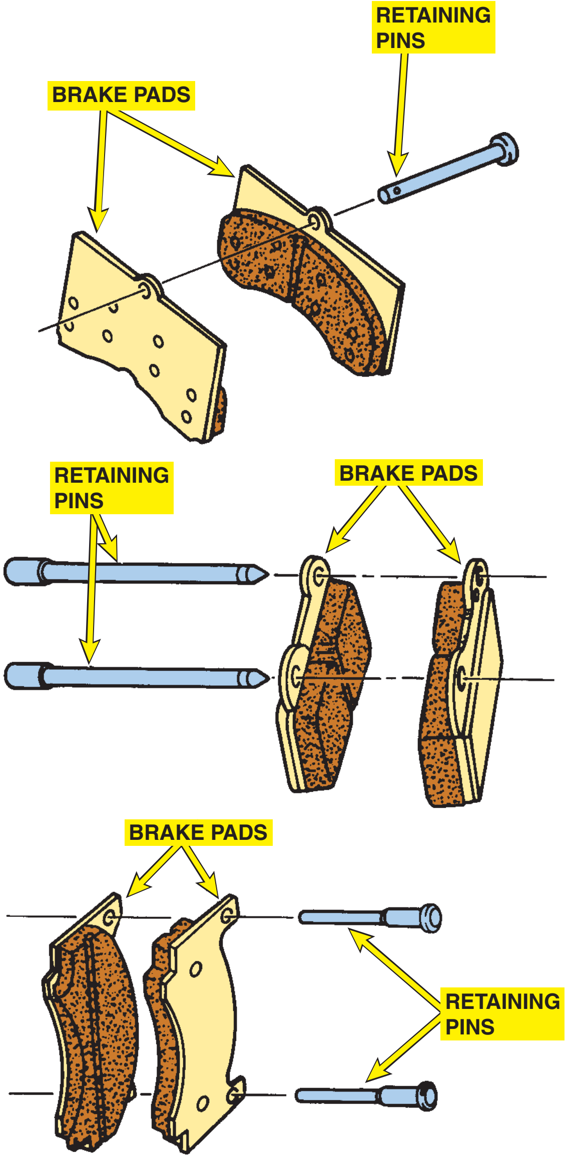


FIGURE 100–13 Holes in the backing plate are a method of locating a pad in the caliper.

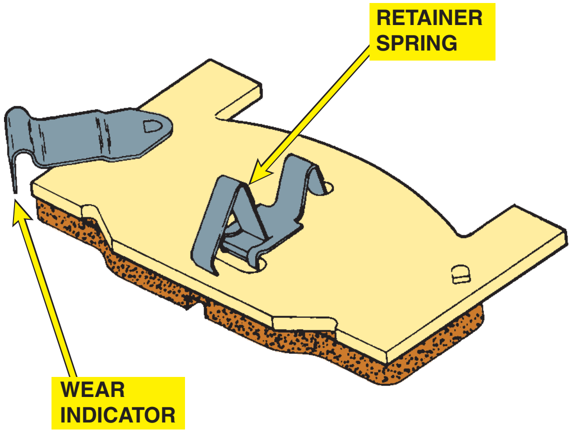


FIGURE 100–14 Retainer springs lock the pad to the caliper piston to prevent brake noise.

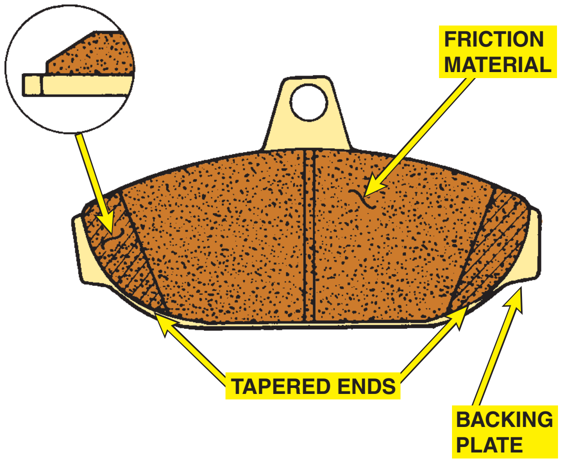


FIGURE 100–15 The lining edges of some brake pads are tapered to help prevent vibration.

As with brake shoes, the lining material of a disc pad can be any one of a number of products that can be fastened to the backing plate in several ways. The edges of the lining material on a brake pad are usually perpendicular to the rotor surface, although a few larger pads do have tapered edges to help combat vibration and noise. ● **SEE FIGURE 100–15**.

PAD WEAR INDICATORS Although not required by law, a growing number of vehicle manufacturers are fitting **pad wear indicators** to their brakes for safety reasons. Pad wear indicators are either mechanical or electrical and signal the driver when the lining material has worn to the point where pad replacement is necessary.

A mechanical wear indicator is a small spring-steel tab riveted to the pad backing plate. When the friction material wears to a predetermined thickness, the tab contacts the rotor and makes a squealing or chirping noise (when the brakes are not applied) that alerts the driver to the need for service. ● **SEE FIGURE 100–16**.

Electrical wear indicators, such as those shown in ● **FIGURE 100–17**, use a coated electrode embedded in the lining material to generate the warning signal. The electrode is wired to a warning light in the instrument panel and when the lining wears sufficiently, the electrode grounds against the rotor to complete the circuit and turn on the warning light.

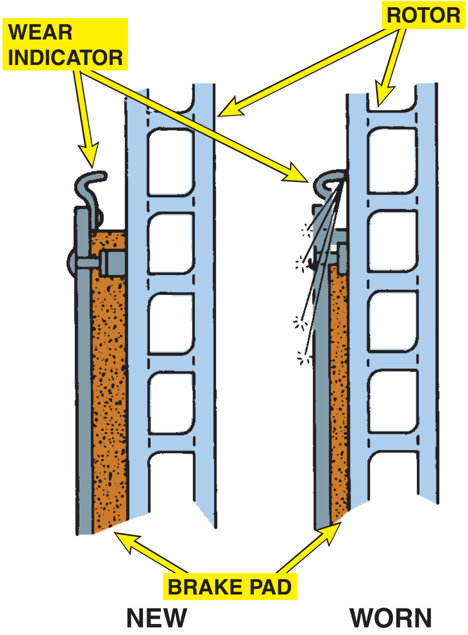


FIGURE 100–16 Typical pad wear sensor operation. It is very important that the disc brake pads are installed on the correct side of the vehicle to be assured that the wear sensor will make a noise when the pads are worn. If the pads with a sensor are installed on the opposite side of the vehicle, the sensor tab is turned so that the rotor touches it going the opposite direction. Usually the correct direction is where the rotor contacts the sensor before contacting the pads when the wheels are being rotated in the forward direction.

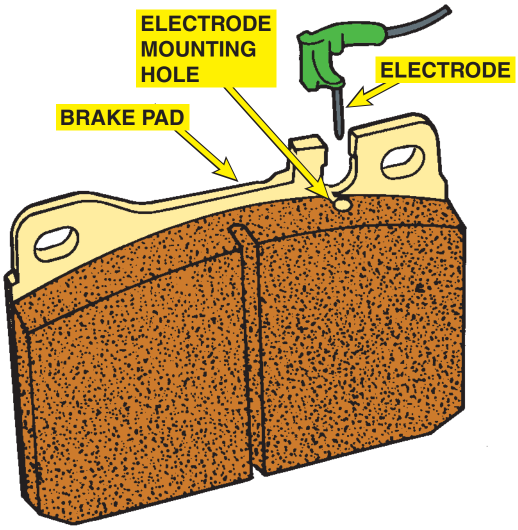


FIGURE 100–17 Electrical wear indicators ground a warning light circuit when the pads need replacement.

On newer vehicles, the pad wear sensor is a two wire input to the electronic brake control module (EBCM). The module can detect faults in the sensor wiring. When a pad sensor begins to ground out against the brake rotor, the EBCM uses the serial data link to display a warning message in the driver information center (DIC).

PAD ASSEMBLY METHODS As mentioned previously, there are several methods that are used to mount brake linings, including the following:

- **Riveted linings** take advantage of the oldest method of lining attachment still in use. In this system, the **brake block** is attached to the backing plate with copper or aluminum rivets.

  The major advantage of riveting is that it allows a small amount of flex between the brake block backing plate. This play enables the assembly to absorb vibration, and the result is that riveted linings operate more quietly than bonded linings. However, the rivet holes create stress points in the lining where cracks are likely to develop.
- **Bonded linings** use high-temperature adhesive to glue the brake block directly to the shoe pad backing plate. Heat and pressure are then applied to cure the assembly. Bonding is a common form of shoe and pad assembly, and is most often used to mount organic friction materials.

  Bonding offers several advantages. Without rivets, bonded linings can wear closer to the backing plate and provide a longer service life. If the linings wear too far, bonding adhesive is not as destructive to rotors as rivets. Bonded linings also have fewer problems with cracking because they have no rivet holes to weaken the brake block. The primary disadvantage of bonded linings is a limited ability to withstand high temperatures. If a bonded lining gets too hot, the bonding adhesive will fail and allow the brake block to separate from the backing plate. Bonded linings are also more prone to be noisy because they do not allow any vibration absorbing flex between the brake block and backing plate.
- **Mold-bonded linings** are found on some disc brake pads. Mold bonding is a manufacturing process that combines the advantages of bonding with some of the mechanical strength of riveting. Instead of riveting and/or bonding a cured brake block to a separate backing plate, the friction material in a mold-bonded pad is cured on the backing plate during manufacture. This process is also called **integrally molded.** Most high-performance disc brake pads are made in this way.

  To make a mold-bonded pad, one or more holes are punched in the pad backing plate, and a high-temperature adhesive is applied to it. The backing plate is then installed in a molding machine where uncured friction material is formed onto the plate and forced into the holes. ● **SEE FIGURE 100–18**. Once the pad is cured under heat and pressure, the bonding adhesive combines with the portions of the lining that extend into the backing plate holes to solidly lock the brake block in place.

DISC BRAKE DESIGNS

There are three types of calipers:

1. Fixed
2. Floating
3. Sliding

FIXED CALIPER DESIGN The **fixed brake caliper** is the earliest design. ● **SEE FIGURE 100–19**. The fixed caliper has a body manufactured in two halves, and uses two, four, or six pistons to apply the brake pads. The fixed caliper gets its name from the fact that the caliper is rigidly mounted to the suspension. When the brakes are applied, the pistons extend from the caliper bores and apply the brake pads with equal force from both sides of the rotor. No part of the caliper body moves when the brakes are applied.

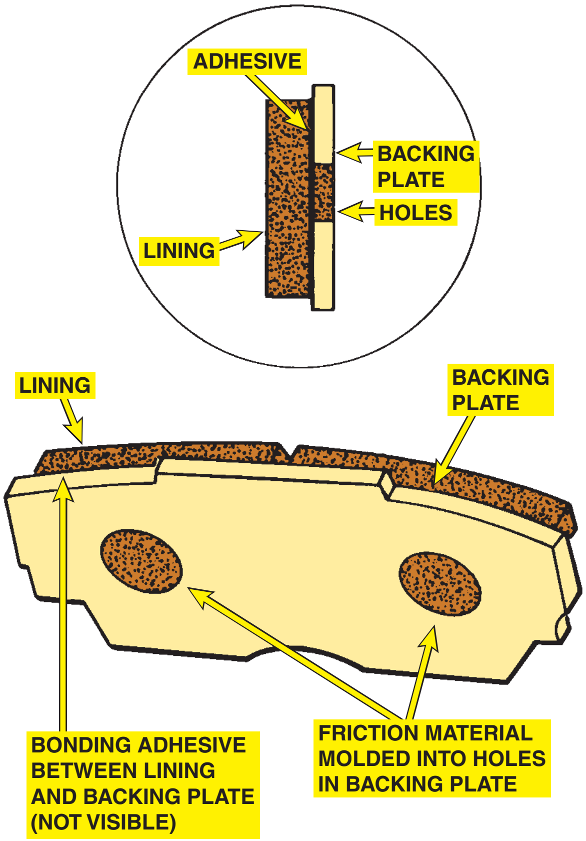

ADHESIVE
BACKING PLATE
HOLES
LINING
LINING
BACKING PLATE
BONDING ADHESIVE BETWEEN LINING AND BACKING PLATE (NOT VISIBLE)
FRICTION MATERIAL MOLDED INTO HOLES IN BACKING PLATE

FIGURE 100–18 Mold-bonded linings are commonly used in many applications.

FIXED CALIPER ADVANTAGES Fixed calipers are relatively large and heavy, which enables them to absorb and dissipate great amounts of heat. This allows the brake rotor and pads to run cooler, and reduce the amount of heat transferred to the brake fluid. Compared with other caliper designs, a fixed caliper is able to withstand a greater number of repeated hard stops without heat-induced fade or vapor lock of the hydraulic system.

The size and rigid mounting of a fixed caliper also means it does not flex as much as other designs. A caliper that is flexing is usually felt by the driver as a spongy brake pedal. Fixed calipers are very strong and provide a firm and linear brake pedal feel.

The strength and heat-dissipating abilities of fixed calipers make them best suited for heavy-duty use such as in most race vehicles.

FIXED CALIPER DISADVANTAGES The size and weight of fixed calipers are advantages in heavy-duty use, but they add weight to the vehicle.

Another disadvantage of fixed calipers is that with multiple pistons and split bodies, service is more difficult and allows greater opportunity for leaks. The drilled passages that route fluid through the inside of the caliper body also contribute to cracking as miles accumulate and the caliper goes through hundreds of thousands of heating and cooling cycles.

FLOATING AND SLIDING CALIPER DESIGN

The front brakes of most vehicles are fitted with either floating or sliding calipers, which are *not* rigidly mounted. The caliper is free to move within a limited range on an **anchor plate** that *is* solidly mounted to the vehicle suspension. The anchor plate may be cast into a suspension member (often the front spindle) or it can be a separate piece that bolts to the suspension. ● **SEE FIGURE 100–20**.

When the brakes are applied, the caliper piston moves out of its bore and applies the inner brake pad. At the same time, the caliper body moves in the opposite direction on the anchor plate and applies the outer brake pad. With a floating or sliding caliper, the caliper body moves every time the brakes are applied. ● **SEE FIGURE 100–21**.

NORMAL CALIPER OPERATION The piston moves just enough to distort the caliper seal and returns to the original position when the brake pedal is released.

WEAR COMPENSATION The piston moves more than the caliper seal can distort. It moves through the seal until the pad contacts the rotor. The caliper piston returns to the released position by the seal distortion, the same as during normal operation, except now in a different, more applied position.

As the wear occurs and the piston moves, additional brake fluid is needed behind the piston. This additional brake fluid comes from the master cylinder and the brake fluid level drops as the disc brake pads wear.

FLOATING AND SLIDING CALIPER ADVANTAGES The biggest advantages of floating and sliding calipers are lower cost, simple construction, and compact size. Most floating and sliding calipers are single-piston designs. Because they have fewer pieces, floating and sliding calipers are cheaper to build and service, and have fewer places where leaks can develop.

The smaller size of floating and sliding calipers also allows better packaging of the caliper on the vehicle. A single-piston caliper with the piston located on the inboard side of the brake rotor fits easily within the diameter of a small wheel. The inboard position of the caliper piston also contributes to better cooling because the bulk of the caliper body is exposed to the passing airflow.

Like any disc brake, floating and sliding calipers have poor parking brake performance. Unlike a fixed caliper, a floating or sliding caliper can be mechanically actuated by applying the single piston with a cable and lever mechanism.

FLOATING AND SLIDING CALIPER DISADVANTAGES The movable caliper body allows a certain degree of flex, which can contribute to a spongy brake pedal. Caliper flex also allows the caliper body to twist slightly when the brakes are applied, causing tapered wear of the brake pad lining material. ● **SEE FIGURE 100–22**.

Although the inboard piston location of floating and sliding calipers provides good cooling, these designs can never absorb as much heat (and therefore have the fade resistance) as a fixed caliper with similar stopping power. Floating and sliding calipers simply do not have the mass of fixed calipers, and their flexible mounting systems slow the transfer of heat from the caliper body to the anchor plate and other suspension components that aid in the cooling process.

FLOATING CALIPER OPERATION

The body of a **floating caliper** does not make direct metal-to-metal contact with the anchor plate. ● **SEE FIGURE 100–23**. Instead, the caliper body is supported by bushings and/or O-rings that allow it to "float" or slide on metal guide pins or locating sleeves attached to the anchor plate. For this reason, some automakers call the floating caliper a **pin-slider caliper.**

The bushings that support floating calipers are made from a number of materials including rubber, Teflon, and nylon. The O-rings are generally made from high-temperature synthetic rubber. ● **SEE FIGURE 100–24**. The guide pins and sleeves are

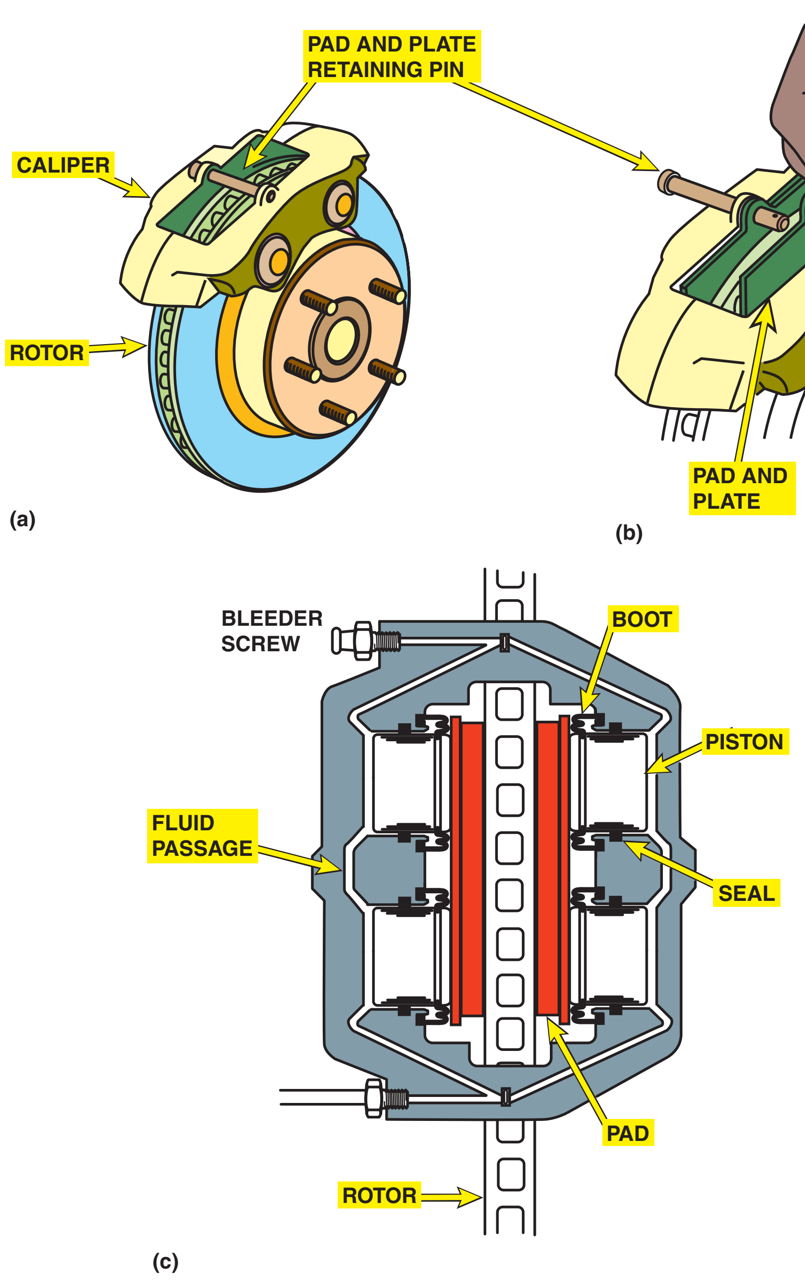

PAD AND PLATE RETAINING PIN
CALIPER
ROTOR
(a)
PAD AND PLATE
(b)
BLEEDER SCREW
BOOT
PISTON
FLUID PASSAGE
SEAL
PAD
ROTOR
(c)

FIGURE 100–19 (a) Many fixed caliper disc brakes use a simple retaining pin to hold the disc brake pads. (b) Removing the retainer pin allows the brake pads to be removed. (c) Notice the cross-over hydraulic passage that connects both sides of the caliper. Most fixed calipers use four (two on each side) or six pistons (three on each side) of the rotor.

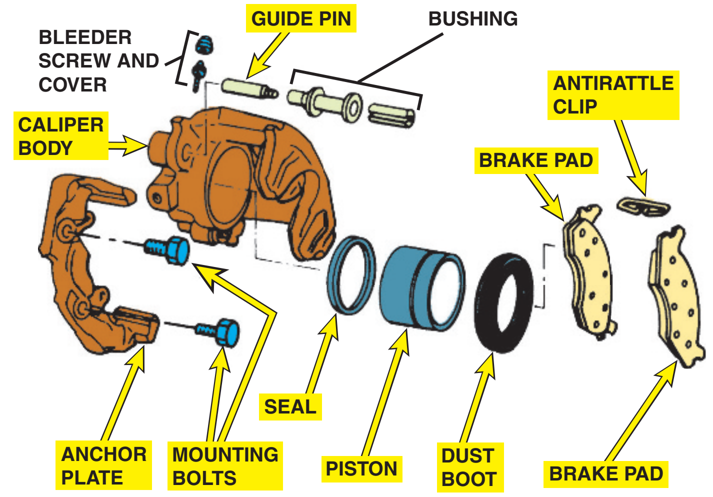

BLEEDER SCREW AND COVER
GUIDE PIN
BUSHING
CALIPER BODY
ANTIRATTLE CLIP
BRAKE PAD
SEAL
ANCHOR PLATE
MOUNTING BOLTS
PISTON
DUST BOOT
BRAKE PAD

FIGURE 100–20 This floating caliper mounts on a separate anchor plate that bolts to the vehicle suspension.

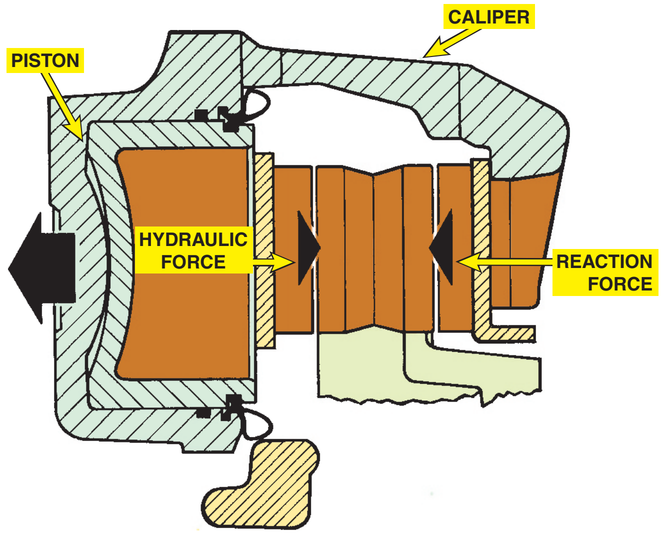

CALIPER
PISTON
HYDRAULIC FORCE
REACTION FORCE

FIGURE 100–21 Hydraulic force on the piston (left) is applied to the inboard pad and the caliper housing itself. The reaction of the piston pushing against the rotor causes the entire caliper to move toward the inside of the vehicle (large arrow). Since the outboard pad is retained by the caliper, the reaction of the moving caliper applies the force of the outboard pad against the outboard surface of the rotor.

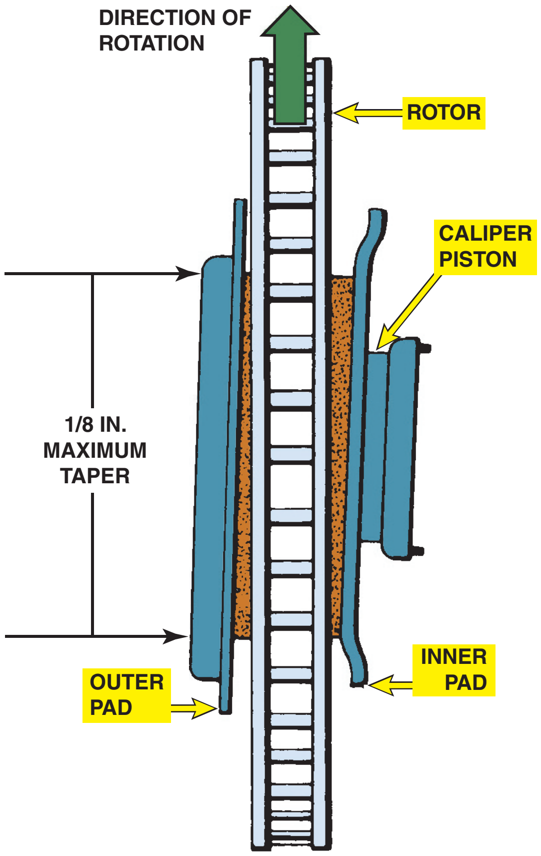


FIGURE 100–22 Caliper flex can cause tapered wear of the brake lining.

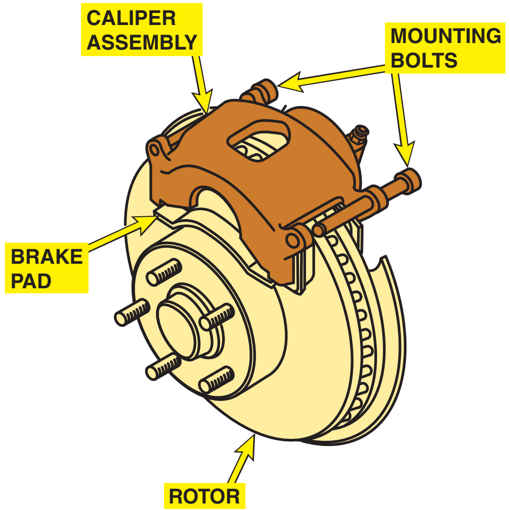


FIGURE 100–23 A typical single-piston floating caliper. In this type of design, the entire caliper moves when the single piston is pushed out of the caliper during a brake application. When the caliper moves, the outboard pad is pushed against the rotor.

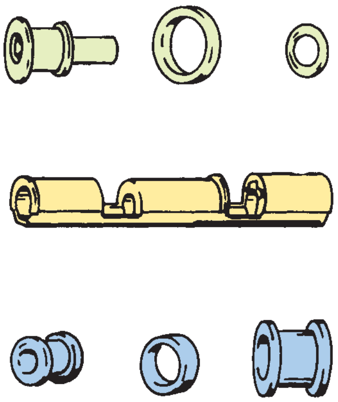


FIGURE 100–24 Floating calipers are supported by rubber O-rings or plastic bushings.

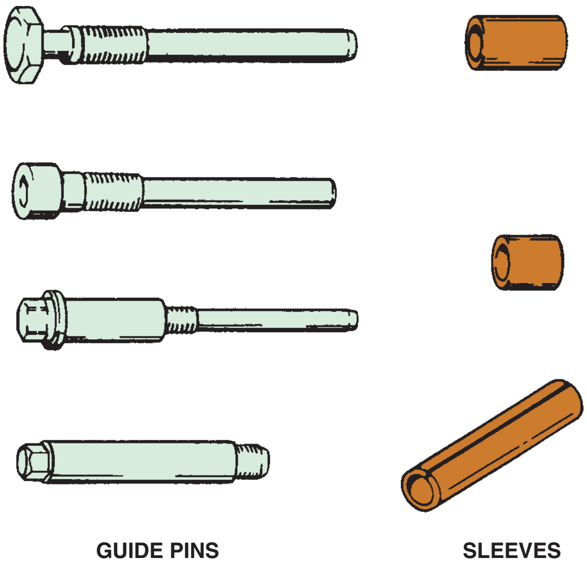


FIGURE 100–25 Metal guide pins and sleeves are used to retain and locate floating calipers.

FREQUENTLY ASKED QUESTION

What Is a Low-Drag Caliper?

A **low-drag caliper** differs from a standard caliper in the area of the square-cut O-ring. A V-shaped cutout allows the O-ring to deflect more and, as a result, is able to pull the caliper piston back into the bore when the brakes are released. Because of this further movement, the brake pads are pulled farther from the rotor and are less likely to drag. The negative aspect of this design is that greater volume of brake fluid is needed to achieve a brake application. To compensate for this need for greater brake fluid volume, a quick-take-up master cylinder was designed and is used whenever low-drag calipers are used. ● **SEE FIGURE 100–26**.

made of steel and come in a variety of shapes and sizes for different caliper designs. ● **SEE FIGURE 100–25**.

Floating calipers depend on proper lubrication of their pins, sleeves, bushings, and O-rings for smooth operation. If these parts become rusted or corroded, the caliper will bind and stick, causing loss of braking power that is usually accompanied by rapid and unusual wear of brake pads. Special high-temperature brake grease must be used to lubricate these parts any time the caliper is disassembled. Many manufacturers recommend that floating caliper pins, sleeves, bushings, and O-rings be replaced whenever the caliper is serviced. These parts come in a "small parts kit" available from brake part suppliers.

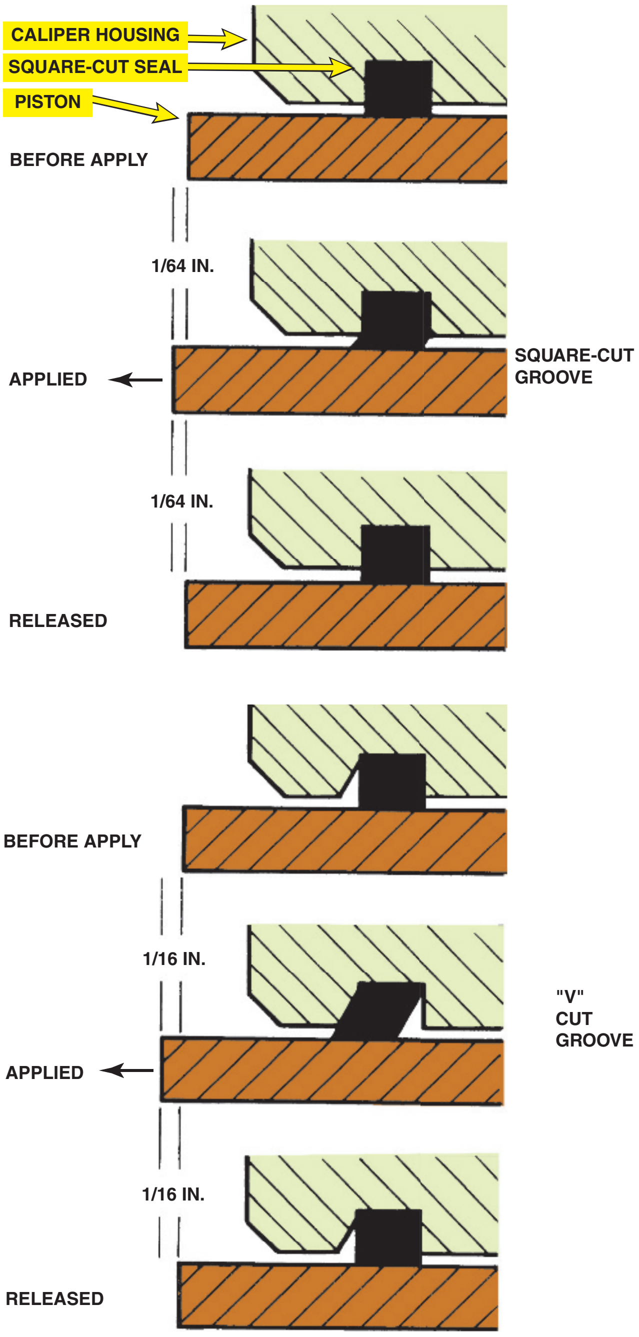

CALIPER HOUSING
SQUARE-CUT SEAL
PISTON
BEFORE APPLY
1/64 IN.
APPLIED
SQUARE-CUT GROOVE
1/64 IN.
RELEASED
BEFORE APPLY
1/16 IN.
"V" CUT GROOVE
APPLIED
1/16 IN.
RELEASED

FIGURE 100–26 In a standard disc brake caliper, the square-cut O-ring deforms when the brakes are applied and returns the piston to its original (released) position due to the elastic properties of the rubber seal. In a low-drag caliper design, the groove for the square-cut O-ring is V-shaped, allowing for more retraction. When the brake pedal is released, the piston is moved away from the rotor further, resulting in less friction between the disc brake pads and the rotor when the brakes are released.

SLIDING CALIPERS Unlike a floating caliper, the body of a **sliding caliper** mounts in direct metal-to-metal contact with the anchor plate. ● **SEE FIGURE 100–27**.

Instead of pins and bushings, sliding calipers move on **ways** cast and machined into the caliper body and anchor plate. ● **SEE FIGURE 100–28**. Retaining clips and the design of the caliper prevent the body from coming out of the ways once the caliper is assembled. On some calipers, the ways may have to be filed for proper clearance between the caliper body and anchor plate if the caliper is replaced.

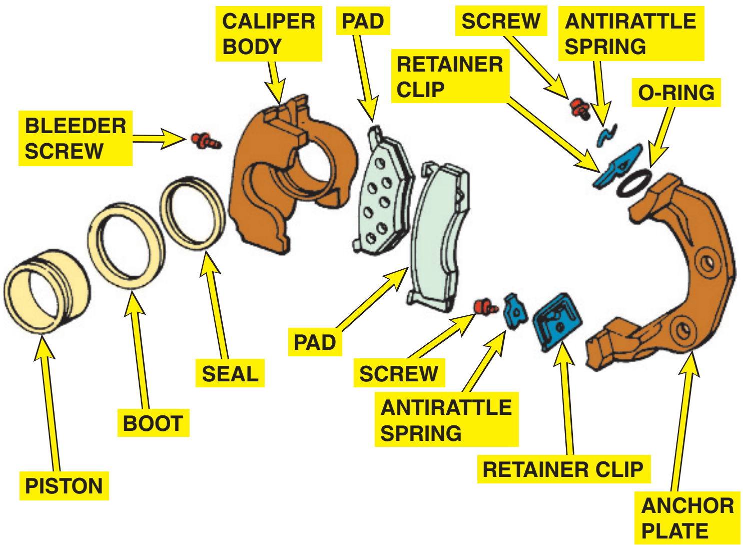

CALIPER BODY
PAD
SCREW
ANTIRATTLE SPRING
RETAINER CLIP
O-RING
BLEEDER SCREW
PAD
SEAL
SCREW
BOOT
ANTIRATTLE SPRING
RETAINER CLIP
PISTON
ANCHOR PLATE

FIGURE 100–27 Exploded view of a typical sliding brake caliper.

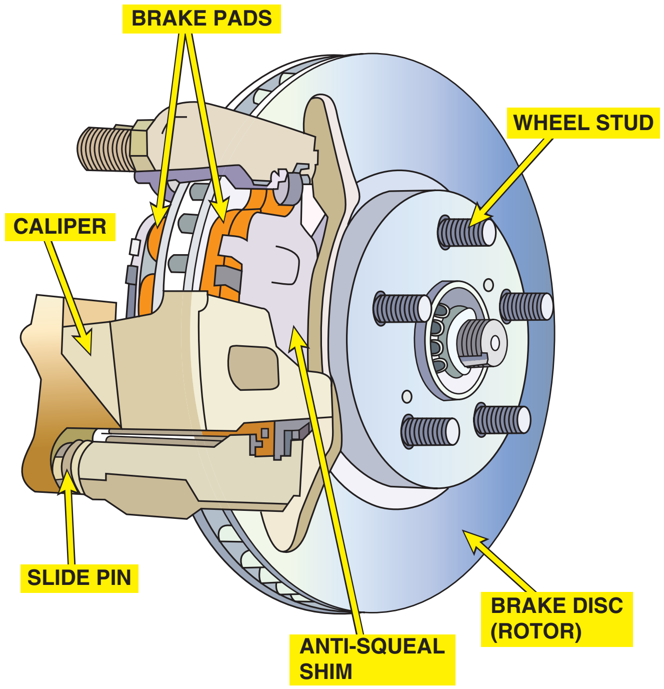

BRAKE PADS
WHEEL STUD
CALIPER
SLIDE PIN
BRAKE DISC (ROTOR)
ANTI-SQUEAL SHIM

FIGURE 100–28 Sliding calipers move on slide (guide) pins.

Like floating calipers, sliding calipers depend on good lubrication of their ways for proper operation. If not properly coated with high-temperature brake grease, the ways can rust or corrode, causing the caliper to drag or seize.

REAR DISC BRAKES

REAR DISC PARKING BRAKES There are two methods of providing parking brakes when rear discs are installed on a vehicle.

1. Adapt the disc brake to also function as the parking brake. This is done by installing a series of cables, levers, and internal parts to mechanically actuate the brake caliper. ● **SEE FIGURES 13–29 AND 13–30**.
2. Use mechanically actuated drum brakes inside the rear rotors. ● **SEE FIGURE 100–31**.

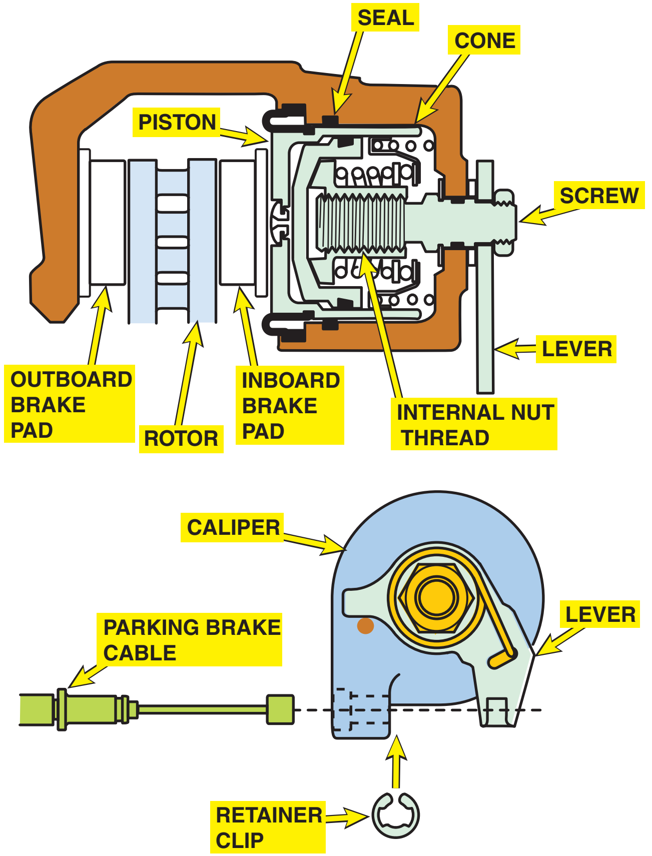

SEAL
CONE
PISTON
SCREW
LEVER
OUTBOARD BRAKE PAD
ROTOR
INBOARD BRAKE PAD
INTERNAL NUT THREAD
CALIPER
PARKING BRAKE CABLE
LEVER
RETAINER CLIP

FIGURE 100–29 Exploded view of a typical rear disc brake with an integral parking brake. The parking brake lever mechanically pushes the caliper piston against the rotor.

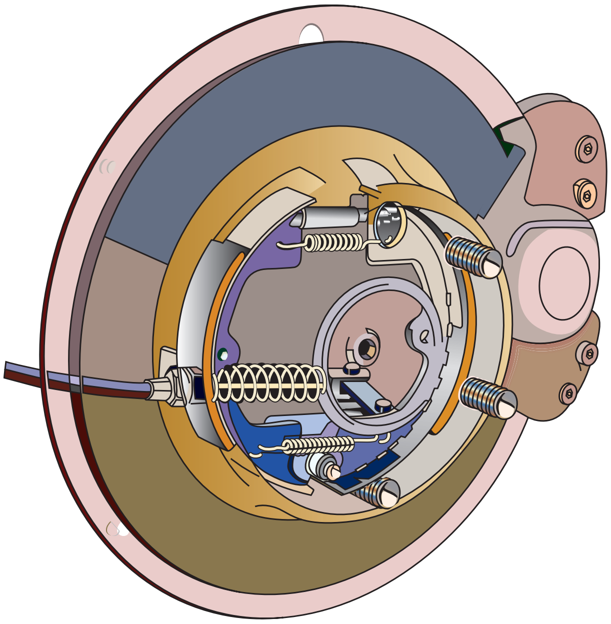


FIGURE 100–31 Drum parking brakes are fitted inside the rotors on this vehicle equipped with rear disc brakes.

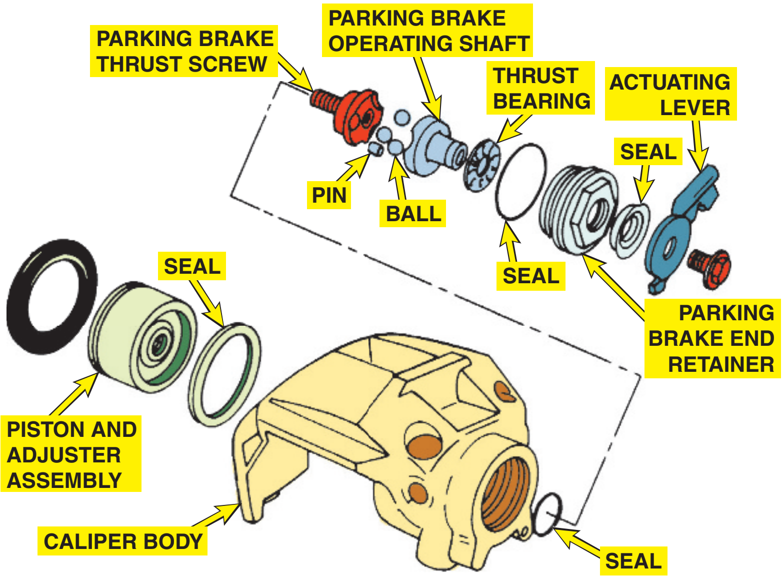

PARKING BRAKE THRUST SCREW
PARKING BRAKE OPERATING SHAFT
THRUST BEARING
ACTUATING LEVER
SEAL
PIN
BALL
SEAL
SEAL
PARKING BRAKE END RETAINER
PISTON AND ADJUSTER ASSEMBLY
CALIPER BODY
SEAL

FIGURE 100–30 This single-piston brake caliper is mechanically actuated to serve as a parking brake.

REVIEW QUESTIONS

1. What are the advantages and disadvantages of disc brakes?
2. What parts are included in a typical disc brake?
3. How does a low-drag caliper work?
4. What mechanism is used to apply the parking brake on a vehicle equipped with rear disc brakes?
5. Where are antirattle clips used?

CHAPTER QUIZ

1. What part causes the disc brake caliper piston to retract when the brakes are released?
- **a.** Return (retracting) spring
- **b.** The rotating rotor (disc) that pushes the piston back
- **c.** The square-cut O-ring
- **d.** The caliper bushings

2. Slots are often used in brake pads because they __________.
- **a.** reduce brake noise
- **b.** increase brake life
- **c.** reduce brake fade
- **d.** improve braking performance

3. Which of the following is *not* a component of a disc brake system?
- **a.** Backing plate
- **b.** Splash shield
- **c.** Caliper
- **d.** Brake pads

4. Technician A says that riveted disc brake pads are often quieter than bonded disc brake pads. Technician B says integrally molded disc brake pads are molded into holes in the steel backing of the pads. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

5. Two technicians are discussing the reason that the brake fluid level in the master cylinder drops. Technician A says that it may be normal due to the wear of the disc brake pads. Technician B says that this is part of the wear compensation feature of disc brakes. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

6. Two technicians are discussing a floating-type disc brake caliper. Technician A says that if the caliper slides are corroded, one pad may wear more than the other pad on the same wheel brake. Technician B says that if a caliper slide is corroded, reduced braking may occur. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

7. Technician A says that disc brakes are self-adjusting and the brake pedal height should not become lower as the disc brake pads wear. Technician B says that as the disc brake pads wear, the level of brake fluid in the master cylinder reservoir drops. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

8. Which type of disc brake caliper may leak brake fluid more often?
- **a.** Sliding
- **b.** Fixed
- **c.** Floating
- **d.** Single-piston

9. Technician A says that all vehicles equipped with rear disc brakes use a parking brake that is integrated in the caliper. Technician B says that all vehicles equipped with rear disc brakes use a small drum brake inside the rear rotor for a parking brake. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

10. A four-piston caliper is used in what type of caliper design?
- **a.** Floating
- **b.** Fixed
- **c.** Sliding
- **d.** Either fixed or floating

Chapter 101

DISC BRAKE DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss how to diagnose problems with disc brakes.
- Explain visual inspection of disc brakes and pads.
- Describe disc brake caliper service.
- Describe caliper installation.
- Explain disc brake squeal correction.
- State the symptoms of a faulty disc brake.

KEY TERMS:

Abutments 1187 • Antiseize compound 1190 • Bedded-in 1189 • Burnished 1189 • Constrained layer shims (CLS) 1190 • Lithium-based brake grease 1190 • Loaded calipers 1187 • Molybdenum disulfide (MOS_2) grease 1190 • Polyalphaolefin (PAO) 1190 • Reaction pads 1187 • Silicone grease 1190 • Synthetic grease 1190 • Ways 1187

DISC BRAKE DIAGNOSTIC PROCEDURES

When diagnosing disc brake concerns, perform the following steps:

STEP 1 The first step is to verify the customer complaint. This step usually includes test-driving the vehicle to see if the complaint can be duplicated. If the problem cannot be duplicated, then the repair or service cannot be verified.

CAUTION: Do not test-drive the vehicle on public roads if the red brake warning light is on. Perform a visual inspection to determine the reason for the warning light being on and correct before test-driving the vehicle.

STEP 2 Check the brake pedal height and verify proper operation. If the brake pedal is low, check the parking brake and count the number of "clicks." There should be 3 to 7 clicks. If there are over 10 clicks, check the rear brakes.

STEP 3 Safely hoist the vehicle and remove the wheels. Visually check the following:

- Flexible brake lines for wear or damage
- Disc brake rotors for excessive rust or scoring
- Disc brake calipers for leakage or damage

STEP 4 Remove disc brake calipers and check the disc brake pads for proper lining thickness and check for cracks or other damage.

TECH TIP

Let the Owner Drive

When verifying the customer complaint, ask the owner or driver of the vehicle to drive. Often, the problem is best discovered if the vehicle is being driven exactly the same way as when the complaint first occurred. For example, the technician may brake harder or softer than the driver; so, the problem may not be detected.

STEP 5 Replace all components that do not meet factory specifications.

STEP 6 Test-drive the vehicle to verify that the repairs did correct the customer concern.

VISUAL INSPECTION

Even with operating wear-indicating sensors, a thorough visual inspection is very important. ● **SEE FIGURE 101–1**. A lining thickness check alone should not be the only inspection performed on a disc brake. *A thorough visual inspection can only be accomplished by removing the friction pads.* ● **SEE FIGURE 101–2** for an example of a disc brake pad that shows usable lining thickness, but is severely cracked and *must* be replaced.

NOTE: Some disc brake pads use a heat barrier (thermo) layer between the steel backing plate and the friction material. The purpose of the heat barrier is to prevent heat from transferring into the caliper piston where it may cause the brake fluid to boil. Do not confuse the thickness of the barrier as part of the thickness of the friction lining material. The barrier material is usually a different color and can be distinguished from the lining material.

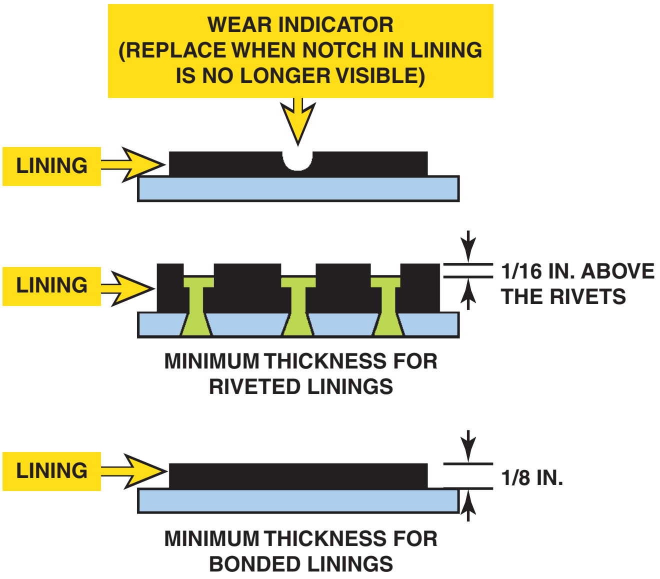


FIGURE 101–1 Minimum thickness for various types of disc brake pads. Pad wear sensors often make a "chirping" sound when the vehicle is moving if the pads are worn. Do not confuse that noise for a defective wheel bearing or other fault.

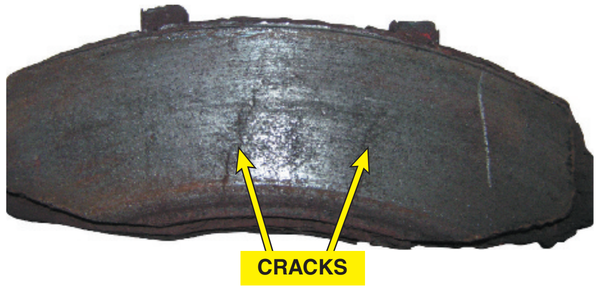


FIGURE 101–2 This cracked disc brake pad must be replaced even though it is thicker than the minimum allowed by the vehicle manufacturer.

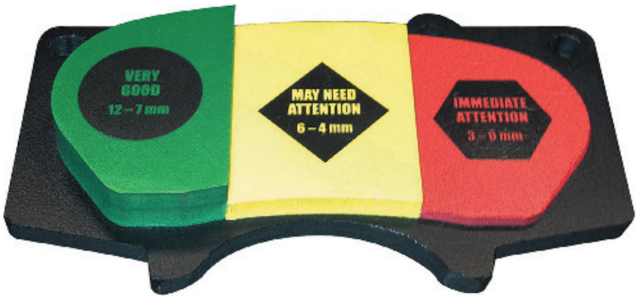


FIGURE 101–3 A brake pad display used by shops to help customers visualize the measurements taken when their brakes were inspected.

Green—Good is 0.25 to 0.50 inch (7–12 mm)

Yellow—May need attention is 0.16 to 0.24 inch (4–6 mm)

Red—Immediate attention required is less than 0.12 inch (3 mm)

TECH TIP

The Bleed and Squirt Test

If you suspect a brake is not being fully released, simply loosen the bleeder valve. If brake fluid squirts out under pressure, then the brake is being kept applied. Look for a defective flexible brake hose.

If the vehicle is off the ground, the wheels should be able to be rotated with the brakes off. If a wheel is difficult or hard to turn by hand and is easy to turn after opening the bleeder valve, then there is a brake fluid restriction between the master cylinder and the brake.

Some disc brake pads may show more wear on the end of the pad that first contacts the rotor as compared to the trailing end of the pad. This uneven wear is caused by the force between the pad and the abutment (slide area). In designs that place the caliper piston exactly in the center of the leading edge of the pad that first contacts the rotor as it is revolving through the caliper, pressures are often one-third higher than the average pressure exerted on the entire pad. The result of this higher pressure is greater wear. ● **SEE FIGURES 101–3 AND 101–4**.

DISC BRAKE CALIPER SERVICE

REMOVAL Hoist the vehicle and remove the wheel(s). Note the caliper mount position as shown in ● **FIGURE 101–5** before removing the caliper. Knowing whether the caliper is "rear-mount" position or "forward-mount" position is often needed when purchasing replacement calipers. Following the procedure specified in service information, remove the caliper assembly and the rotor. ● **SEE FIGURES 101–6 THROUGH 101–10**.

INSPECTION Caliper replacement is indicated if any of these conditions are found:

- brake fluid is in and around the piston boot area
- boot is damaged or a fluid leak is visible

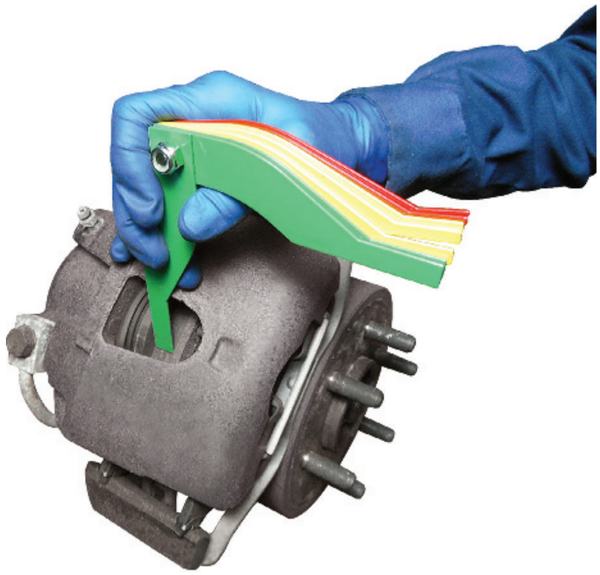
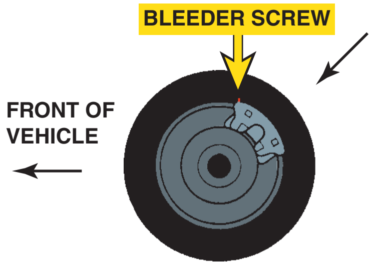
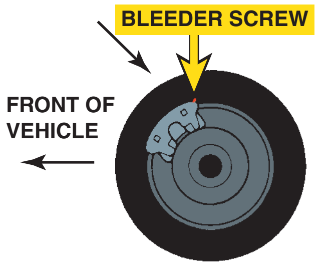


FIGURE 101–4 Most disc brake calipers have a brake inspection opening. For a thorough inspection, however, the caliper should be removed and the entire braking system thoroughly inspected. This inspection opening does allow the use of a brake pad thickness gauge so that the pad thickness can be documented on the work order.



REAR-MOUNT CALIPER POSITION



FORWARD-MOUNT CALIPER POSITION

FIGURE 101–5 Both rear- and forward-mounted calipers have the bleeder valve at the top. Some calipers will fit on the wrong side of the vehicle, yet not be able to be bled correctly because the bleeder valve would point down, allowing trapped air to remain inside the caliper bore. If both calipers are being removed at the same time, mark them “left” and “right.”

- caliper piston is frozen or stuck
- bleeder screw is stripped or broken off
- mounting threads on the caliper are damaged or stripped

NOTE: Uneven disc brake pad wear (inside pad compared to the outside pad) can be caused if the caliper is unable to “float.”

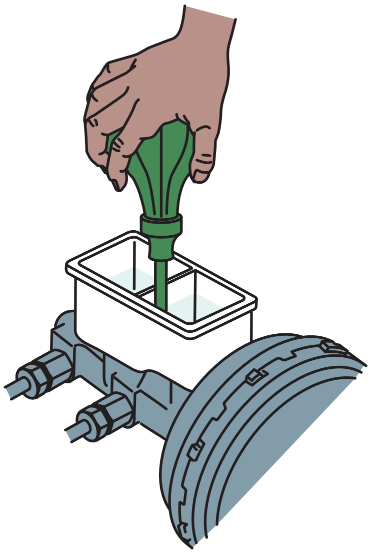


FIGURE 101–6 Many manufacturers recommend removing one-half of the brake fluid from the master cylinder before servicing disc brakes. Use a squeeze bulb and dispose of the used brake fluid properly.

CASE STUDY

Three Brake Jobs in 40,000 Miles

A service technician was asked to replace the front disc brake pads on a Chevrolet Malibu because the sensors were touching the rotors and making a squealing sound. This was the third time that the front brakes needed to be replaced. Previous brake repairs had been limited to replacement of the front disc brake pads only.

When the caliper was removed and the pads inspected, it was discovered that a part of one pad had broken and a piece of the lining was missing. ● **SEE FIGURE 101–11**.

Then the technician spotted something at the rear of the vehicle that told the whole story—a trailer hitch.

The owner confirmed that a heavy jet ski was towed in hilly terrain. The technician recommended overhauling the front disc brake calipers to prevent the possibility of the front pads dragging. The technician also recommended an inspection of the rear brakes. The rear brakes were glazed and out of adjustment. The technician received permission to replace the rear brakes, replace both front calipers, and install quality disc brake pads. When the customer returned, the technician advised the customer to use a lower gear in the transmission on long downhill roads to help keep the brakes from overheating and failing prematurely.

Summary:

Complaint—The front calipers needed replacement more often than expected.
Cause—The front calipers were not retracting and the rear brakes were not working as designed.
Correction—Front calipers were replaced and the rear brakes were serviced. Plus the owner was advised to use the gear selector when descending long grades to reduce the load on the brakes.

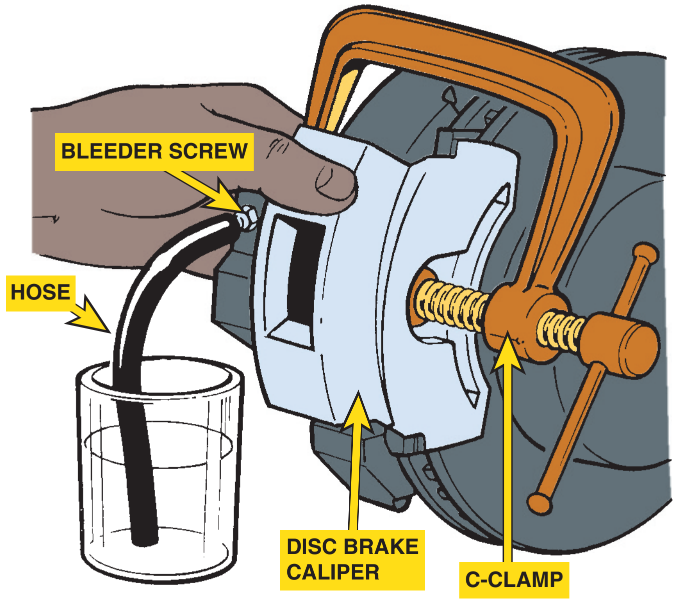


FIGURE 101–7 Most manufacturers recommend that the bleeder valve be opened and the brake fluid forced into a container rather than back into the master cylinder reservoir. This helps prevent contaminated brake fluid from being forced into the master cylinder where the dirt and contamination could cause problems.

TECH TIP

Using "Loaded Calipers" Saves Time

Many technicians find that disassembly, cleaning, and rebuilding calipers can take a lot of time. Often the bleeder valve breaks off or the caliper piston is too corroded to reuse. This means that the technician has to get a replacement piston, caliper overhaul kit (piston seal and boot), plus the replacement friction pads and hardware kit.

To save time (and sometimes money), many technicians are simply replacing the old used calipers with "loaded calipers." **Loaded calipers** are remanufactured calipers that include (come loaded with) the correct replacement friction pads and all the necessary hardware. ● **SEE FIGURE 101–12**.

Therefore, only one part number is needed for each side of the vehicle for a complete disc brake overhaul.

CALIPER INSTALLATION

CALIPER MOUNT SERVICE When the hydraulic force from the master cylinder applies pressure to the disc brake pads, the entire caliper tends to be forced in the direction of rotation of the rotor. All calipers are mounted to the steering knuckle or axle housing. ● **SEE FIGURE 101–13**.

All braking force is transferred through the caliper to the mount. The places where the caliper contacts the caliper mount are called the **abutments**, **reaction pads**, or **ways**. The sliding surfaces of the caliper support should be cleaned with a wire brush and coated with a synthetic grease or antiseize compound according to manufacturer's recommendations. ● **SEE FIGURE 101–14**.

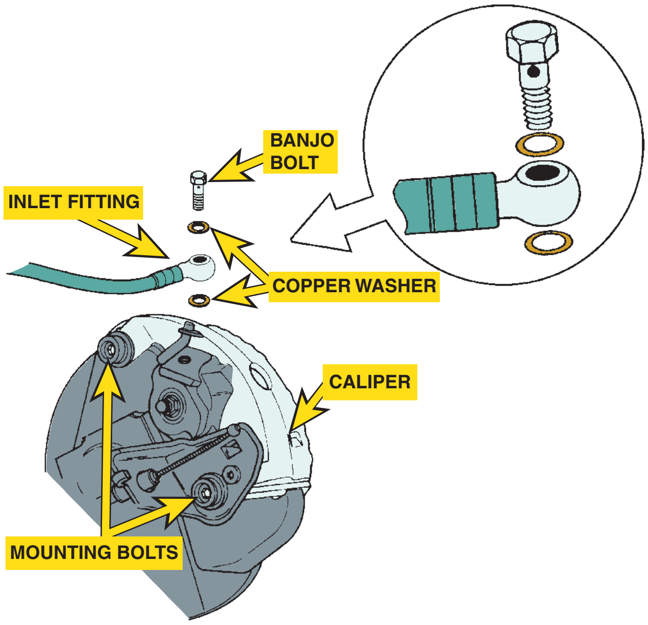


FIGURE 101–8 Many calipers use a hollow "banjo bolt" to retain the flexible brake line to the caliper housing. The fitting is usually round like a banjo. The copper washers should always be replaced and not reused.

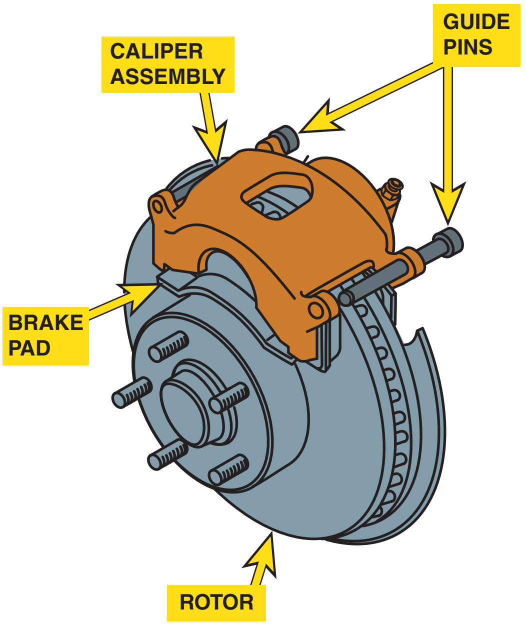


FIGURE 101–9 Caliper retaining bolts are often called guide pins. These guide pins are used to retain the caliper to the steering knuckle. These pins also slide through metal bushings and rubber O-rings.

As the vehicle ages and the brakes are used thousands of times, these abutments (pads) can wear, causing too much clearance between the caliper and the mounting. When this occurs, the caliper often rotates against the abutment when the brakes are first applied, making a loud "knocking" noise. If this occurs, the service technician can repair this type of wear in two ways:

METHOD 1 Replace the entire steering knuckle or caliper mount. This is the recommended method and also the most expensive. Replacement caliper mounts or knuckles may also be difficult to locate.

METHOD 2 Some aftermarket brake supply companies offer "abutment repair kits" that include oversize slides.

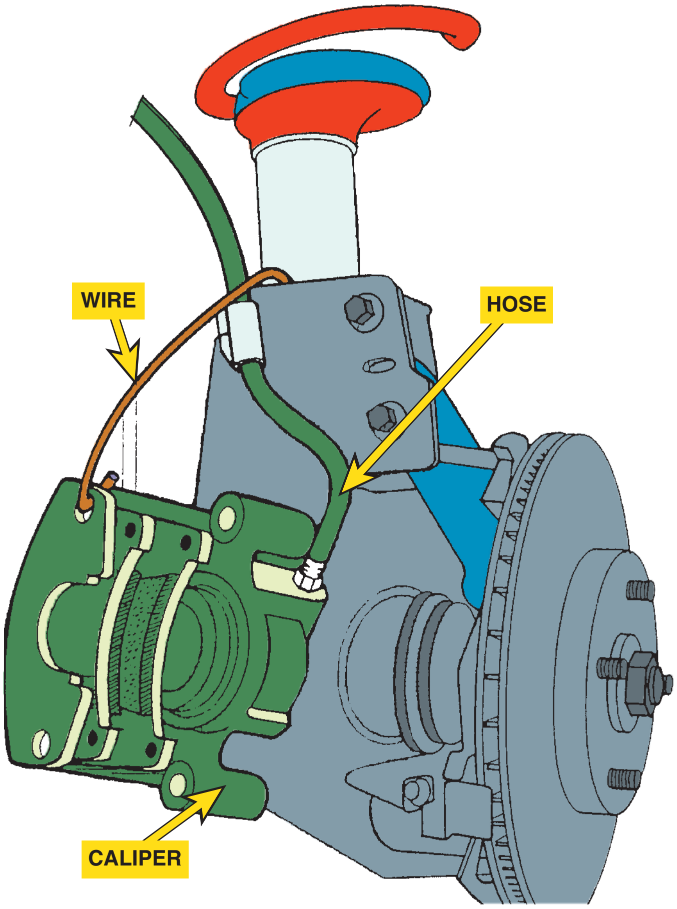

WIRE
HOSE
CALIPER

FIGURE 101–10 If the caliper is not being removed, it must be supported properly so that the weight of the caliper is not pulling on the flexible rubber brake line. A suitable piece of wire, such as a coat hanger, may be used.

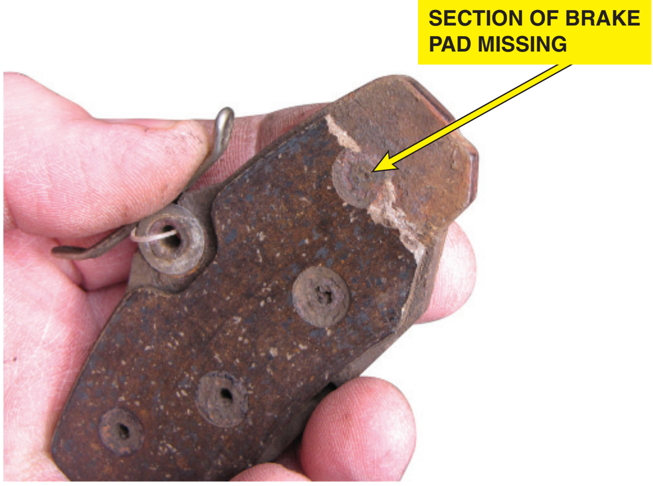

SECTION OF BRAKE PAD MISSING

FIGURE 101–11 These pads were found to be cracked and a section was missing from a part of one pad.

ROTATING PISTONS BACK INTO THE CALIPER Many disc brake calipers used on the rear wheels require that the piston be rotated to reseat the pistons. When the parking brake is applied, the actuating screw moves the piston outward, forcing the pads against the disc brake rotor. The piston is kept from rotating because of an antirotation device or notches on the inboard pad and piston.

When the disc brake pads are being replaced, use a special tool to rotate the piston back into the brake calipers. Insert the tip of the tool in the holes or slots in the piston. Exert inward

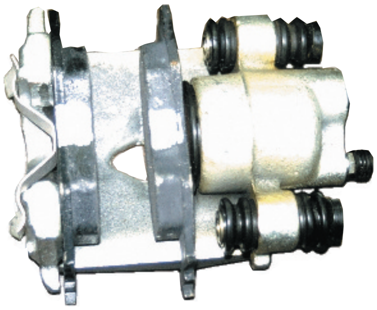


FIGURE 101–12 A loaded caliper includes all hardware and shims with the correct pads all in one convenient package, ready to install on the vehicle.

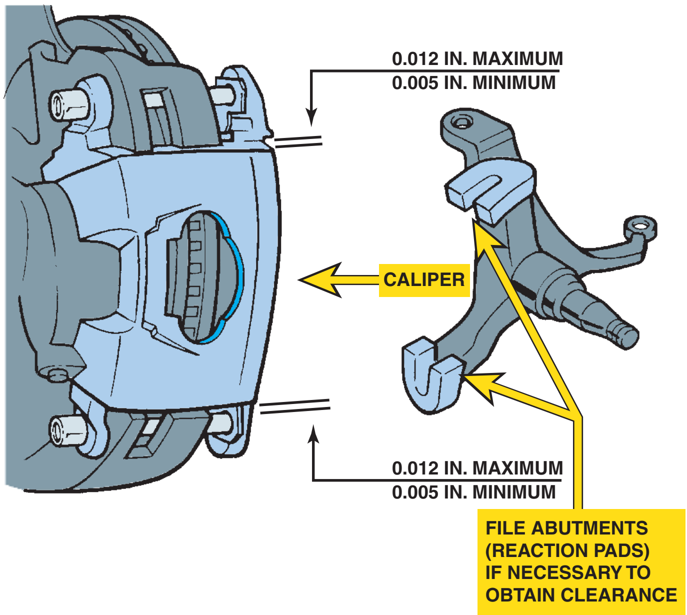

0.012 IN. MAXIMUM
0.005 IN. MINIMUM
CALIPER
0.012 IN. MAXIMUM
0.005 IN. MINIMUM
FILE ABUTMENTS (REACTION PADS) IF NECESSARY TO OBTAIN CLEARANCE

FIGURE 101–13 Floating calipers must be able to slide during normal operation. Therefore, there must be clearance between the caliper and the caliper mounting pads (abutments). Too little clearance will prevent the caliper from sliding and too much clearance will cause the caliper to make a clunking noise when the brakes are applied.

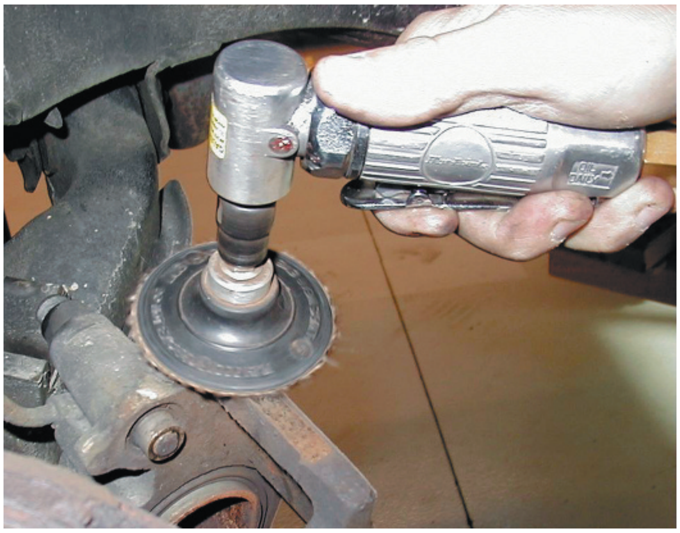


FIGURE 101–14 Using an air-powered sanding disc to clean the caliper mount pads.

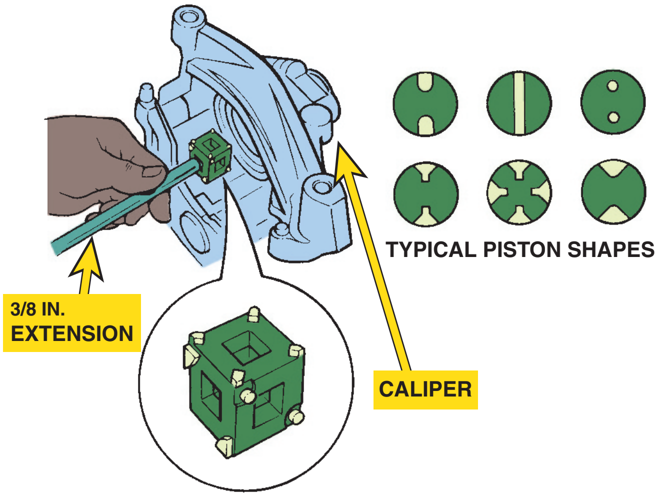


FIGURE 101–15 Determine which face of the special tool best fits the holes or slots in the piston. Sometimes needle-nose pliers can be used to rotate the piston back into the caliper bore.

pressure while turning the piston. Make sure that the piston is retracting into the caliper and continue to turn the piston until it bottoms out.

NOTE: Some pistons are activated with left-handed threads.

After replacing the pads back into the caliper, check that the clearance does not exceed 1/16 inch (1.5 mm) from the rotor. Clearance greater than 1/16 inch may allow the adjuster to be pulled out of the piston when the service brake is applied. If the clearance is greater than 1/16 inch, readjust by rotating the piston outward to reduce the clearance. ● **SEE FIGURE 101–15**.

TEST-DRIVE AFTER BRAKE REPLACEMENT After installing replacement disc brake pads or any other brake work, depress the brake pedal several times before driving the vehicle. This is a very important step! New brake pads are installed with the caliper piston pushed all the way into the caliper. The first few brake pedal applications usually result in the brake pedal going all the way to the floor. The brake pedal must be depressed ("pumped") several times before enough brake fluid can be moved from the master cylinder into the calipers to move the piston tight against the pads and the pads against the rotors.

CAUTION: Never allow a customer to be the first to test-drive the vehicle after brake work has been performed.

BEDDING-IN REPLACEMENT BRAKE PADS Some manufacturers recommend that their replacement brake pads be **bedded-in** or **burnished** before returning the vehicle to the owner.

TECH TIP

Always Double-Check Your Work

Whenever reassembling brakes, it is easy to twist the flexible brake hose as shown in ● **FIGURE 101–16**. To prevent possible brake hose failure and possibly an accident, always double-check that the ribs on the brake hose are straight. The ribs allow the service technician to easily spot if the hose has been twisted.

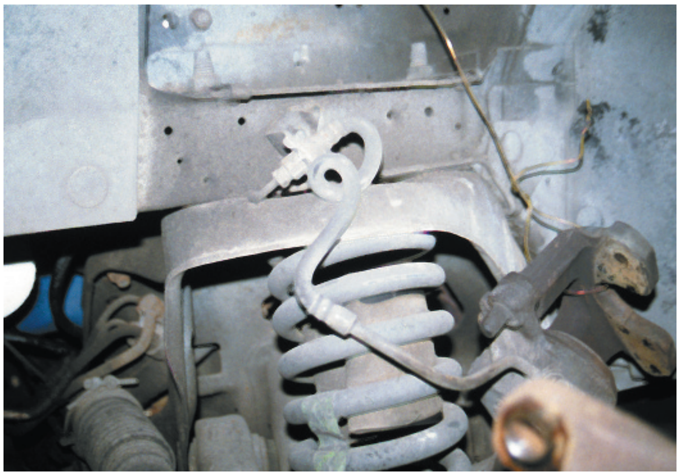


FIGURE 101–16 Note the twisted flexible brake line. This was caught by an automotive instructor before the brake work on the vehicle was completed. The twisted brake line can cause brake hose failure if not corrected.

TECH TIP

Increasing Pad Life

Many vehicles seem to wear out front disc brakes more often than normal. Stop-and-go city-type driving is often the cause. Driving style, such as rapid stops, also causes a lot of wear to occur.

The service technician can take some actions to increase brake pad life that are easier than having to cure the driver's habits. These steps include the following:

1. Make sure the rear brakes are properly adjusted and working correctly. If the rear brakes are not functioning, all of the braking is accomplished by the front brakes alone.

NOTE: Remind the driver to apply the parking brake regularly to help maintain proper rear brake clearance on the rear brakes.

2. Use factory brake pads or premium brake pads from a known manufacturer. Tests performed by vehicle manufacturers show that many aftermarket replacement brake pads fail to deliver original equipment brake pad life.

After installing new pads, perform the following steps:

STEP 1 Make 6 to 10 brake applications from approximately 35 MPH (56 km/h) with moderate brake pedal force.

STEP 2 Make an additional two to three hard brake applications from approximately 45 MPH (72 km/h).

NOTE: Do not allow the vehicle to come to a complete stop. After preforming these brake applications, allow the brakes to cool completely before driving again.

This break-in procedure helps the replacement pads to conform to the rotor and helps cure the resins used in the manufacture of the pads. Failure to properly break in new pads according to the manufacturer's recommended procedure could result in a hard brake pedal complaint from the driver and/or reduced braking effectiveness.

Even if the brake pad manufacturer does not recommend a break-in procedure, high-speed stops and overheating of the brakes should be avoided as much as possible during the first 50 to 100 stops.

DISC BRAKE SQUEAL CORRECTION

CAUSES OF BRAKE SQUEAL Disc brakes tend to create brake noise (squeal). The cause and correction of brake noise is a major concern for both the vehicle manufacturers and the service technicians. The greatest customer complaint about brake work involves brake noise. Noise is caused by moving air, which is a result of moving brake components.

CORRECTING DISC BRAKE SQUEAL Brake squeal can best be *prevented* by careful attention to details whenever servicing any disc brake. Some of these precautions include the following:

- **Keep the disc brake pads clean.** Grease on brake lining material causes the friction surface to be uneven. When the brakes are applied, this uneven brake surface causes the brake components to move.
- **Use factory-type clips and anti-squeal shims.** The vehicle manufacturer has designed the braking system to be as quiet as possible. To assure that the brakes are restored to like-new performance, all of the original hardware should be used. Many original equipment brake pads use **constrained layer shims (CLS)** on the back of the brake pads. These shims are constructed with dampening material between two layers of steel. ● **SEE FIGURE 101–17**.

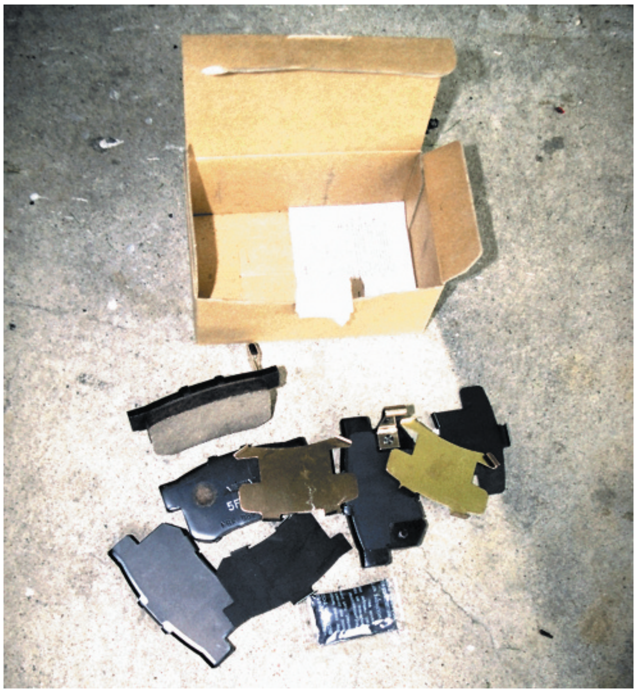


FIGURE 101–17 For best braking performance, purchase replacement disc brake pads that include all clips and shims specified by the vehicle manufacturer. Some pads even come with a package of the specified grease to use on the shims to reduce the possibility of brake noise.

NOTE: Many aftermarket disc brake pads do *not* include replacement hardware that usually includes noise-reducing shims and clips. One of the advantages of purchasing original equipment (OE) disc brake pads is that they usually come equipped with all necessary shims and often with special grease that is recommended to be used on metal shims.

- **Lubricate all caliper slide points as per manufacturer's recommendation.** Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend one or more of the following greases:
  1. **Lithium-based brake grease**
  2. **Silicone grease**
  3. **Molybdenum disulfide (MOS_2) grease** ("Molykote"), often referred to as "moly" grease
  4. **Synthetic grease** (usually **polyalphaolefin [PAO]**) sometimes mixed with graphite, Teflon, and/or MOS_2
  5. **Antiseize compound**

  The grease should be applied on both sides of shims used between the pad and the caliper piston.

CAUTION: Grease should only be applied to the nonfriction (steel) side of the disc brake pads.

- **Machine the brake rotor as little as possible and with the correct surface finish.** Machining the brake rotor reduces its thickness. A thinner rotor will vibrate at a different frequency than a thicker rotor. For factors that can help or hurt brake squeal. ● **SEE CHART 101–1**.

Vehicle manufacturers also change brake pad (lining) composition and the shape of the pads to help eliminate brake noise. The change of shape changes the frequency of the sound. Noise is vibration, but much of the vibration generated is not heard because the noise is beyond the normal frequency to be heard. Most people can hear from 20 to 20,000 cycles per second (called hertz). To stop brake noise, the manufacturer can change the frequency of the vibration to above or below the hertz range that can be heard. ● **SEE FIGURE 101–18**.

FACTOR	INCREASE NOISE	REDUCE NOISE
Brake pad thickness	Thinner (worn) pads	Thicker (new) pads
Rotor (disc) thickness	Thinner (worn) rotor	Thicker (new) rotor
Brake pad material	Harder	Softer
Lubrication of parts	Dry—not lubricated	Properly lubricated
Dampening	No dampening	Dampening material behind the pads
Pad mounting	Pad tabs not bent over	Pad tabs securely crimped
Antirattle clips	Worn, defective, or not lubricated	New and properly lubricated

CHART 101–1

The causes of brake noise can have many reasons and corrections.

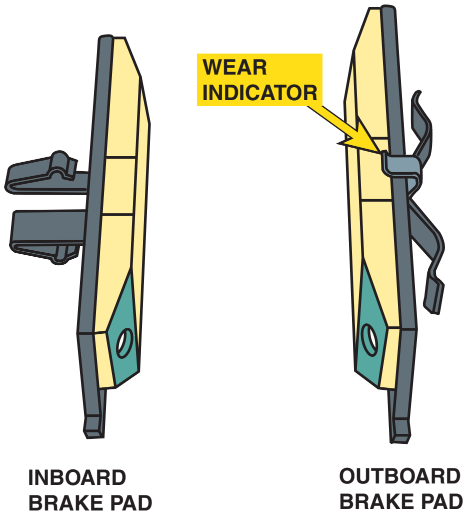


FIGURE 101–18 Notice the beveled pads. The shape of the pad helps reduce brake noise.

NOTE: All metal-to-metal contacts *must* be lubricated to help prevent brake noise.

DISC BRAKE SYMPTOM GUIDE

PULLS TO ONE SIDE DURING BRAKING Possible causes of this include the following:

1. Incorrect or unequal tire pressures
2. Front end out of alignment
3. Unmatched tires on the same axle
4. Restricted brake lines or hoses
5. Stuck or seized caliper or caliper piston
6. Defective or damaged shoe and lining (grease or brake fluid on the lining, or a bent shoe)
7. Malfunctioning rear brakes
8. Loose suspension parts
9. Loose calipers

BRAKE ROUGHNESS OR CHATTER (PEDAL PULSATES) Possible causes of this include the following:

1. Excessive lateral runout of rotor
2. Parallelism of the rotor not within specifications
3. Wheel bearings not adjusted correctly
4. Rear drums out of round
5. Brake pads worn to metal backing plate

EXCESSIVE PEDAL EFFORT Possible causes of this include the following:

1. Binding or seized caliper mounting
2. Binding brake pedal mechanism
3. Improper rotor surface finish
4. Malfunctioning power brake
5. Partial system failure
6. Excessively worn shoe and lining
7. Piston in the caliper stuck or sluggish
8. Fading brakes due to incorrect lining

EXCESSIVE PEDAL TRAVEL Possible causes of this include the following:

1. Partial brake system failure
2. Insufficient fluid in the master cylinder
3. Air trapped in the system
4. Bent shoe and lining
5. Excessive pedal effort
6. Excessive parking brake travel (four-wheel disc brakes, except Corvette)

DRAGGING BRAKES Possible causes of this include the following:

1. Pressure trapped in the brake lines (to diagnose, momentarily open the caliper bleeder valve to relieve the pressure)
2. Restricted brake tubes or hoses
3. Improperly lubricated caliper mounting system
4. Improper clearance between the caliper and torque abutment surfaces
5. Check valve installed in the outlet of the master cylinder to the disc brakes

FRONT DISC BRAKES VERY SENSITIVE TO LIGHT BRAKE APPLICATIONS Possible causes of this include the following:

1. Metering valve not holding off the front brake application
2. Incorrect lining material
3. Improper rotor surface finish
4. Check other causes listed under "PULLS"

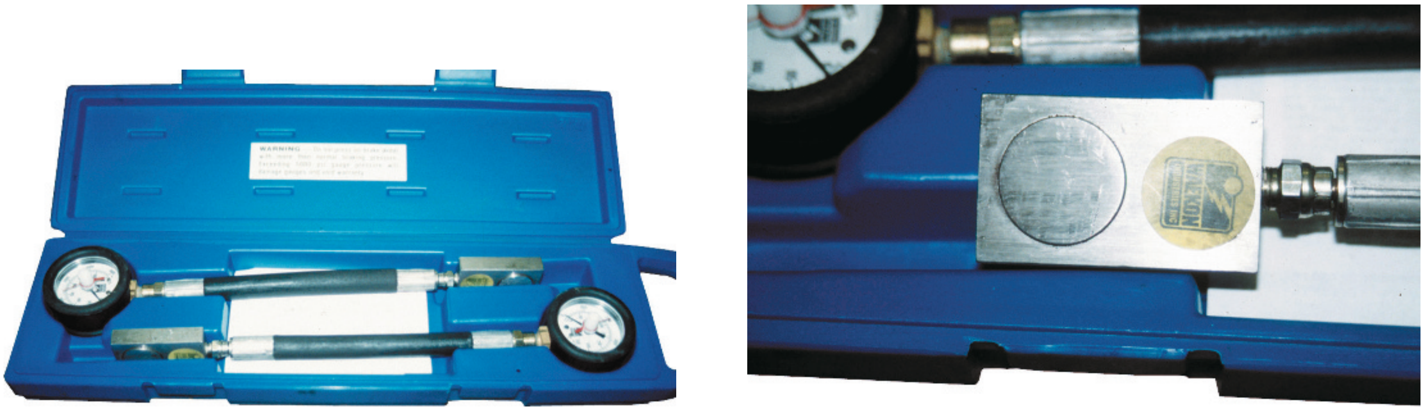
REAR DRUM BRAKES SKIDDING UNDER HARD BRAKE APPLICATIONS Possible causes of this include the following:

1. Proportioning valve
2. Contaminated rear brake lining
3. Caliper or caliper piston stuck or corroded

TECH TIP

Pressure Testing Can Help Find Problems

A stuck caliper or caliper slide is often difficult to see or diagnose as a problem because the movement of the broken pads is so little. Using a pressure gauge between the caliper piston and the rotor (inboard) or between the rotor and the caliper (outboard) can tell the service technician if there is a difference between the left and the right side brakes. ● **SEE FIGURE 101–19**.



(a)

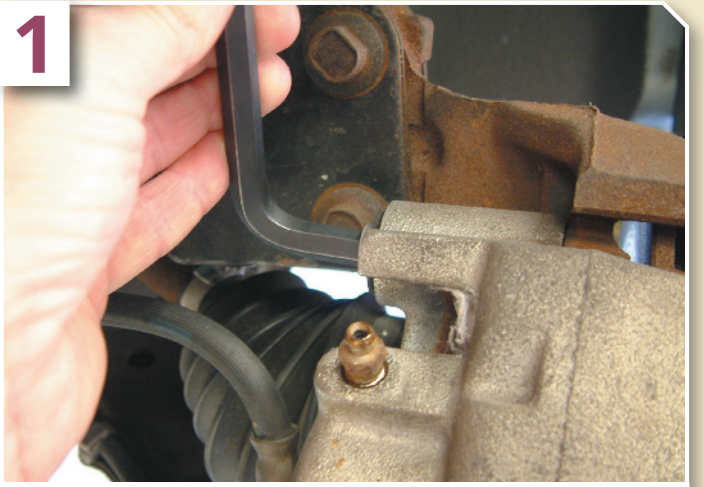
(b)

FIGURE 101–19 (a) A brake pressure tester. (b) The small "pads" can be placed between the caliper piston and the rotor to check for applied pressure and inserted between the caliper and the rotor on the outside of the rotor to test the pressure—the pressure should be the same if the caliper is able to slide on its pins or slides.

DISC BRAKE SERVICE

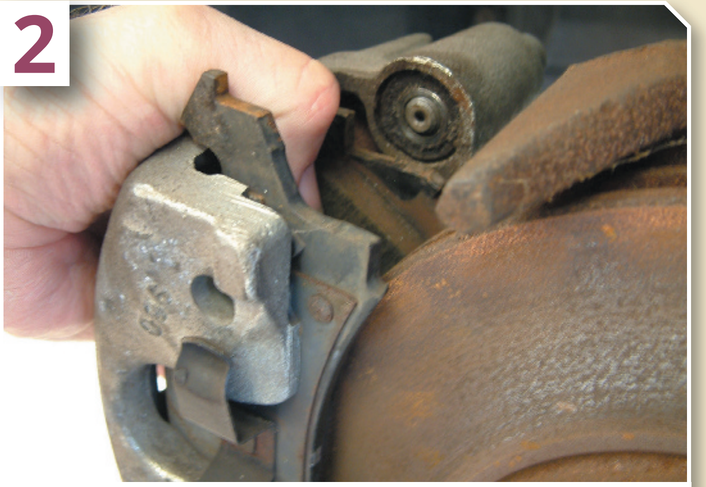
STEP BY STEP

1



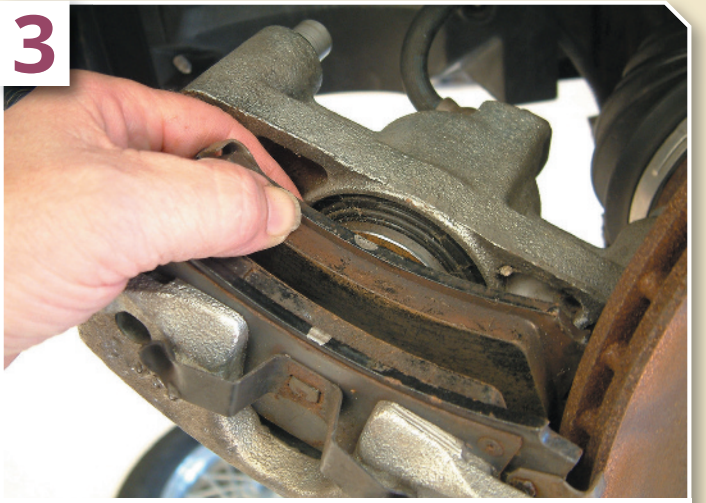
Use a hex wrench to remove the caliper mounting bolts.

2



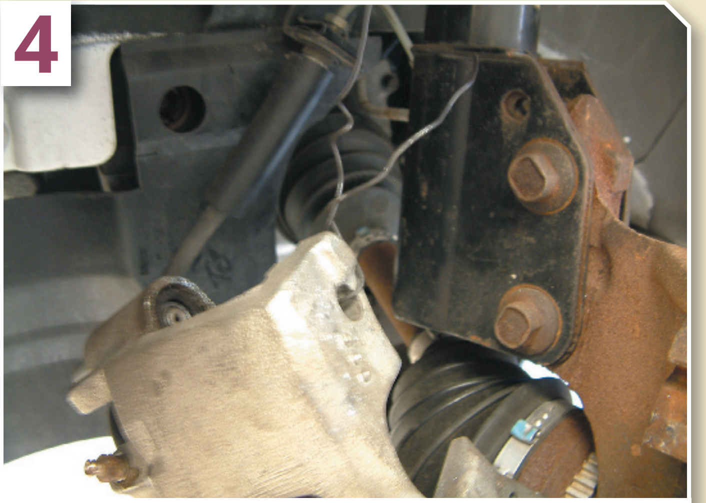
Remove the caliper and pads from the brake rotor.

3



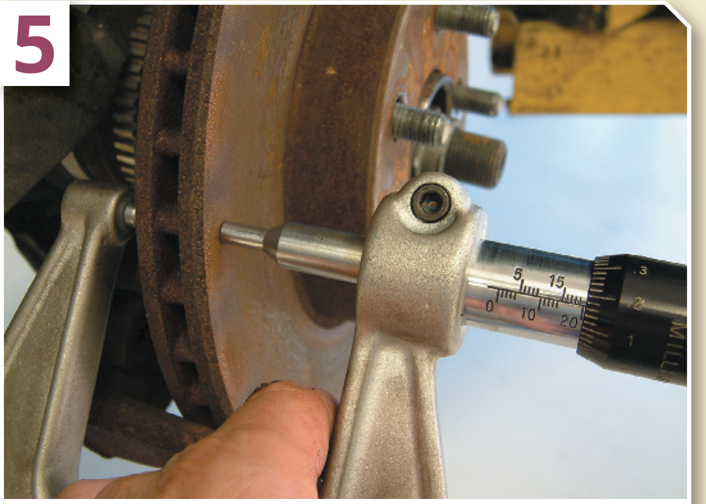
Remove the brake pads from the caliper.

4



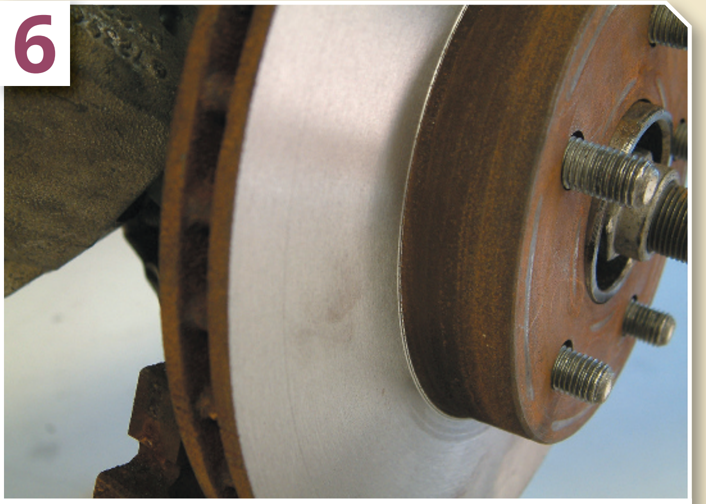
Hang the caliper with wire or a hook. Do not let the caliper hang from the brake hose.

5



Measure the rotor thickness and machine or replace, if necessary.

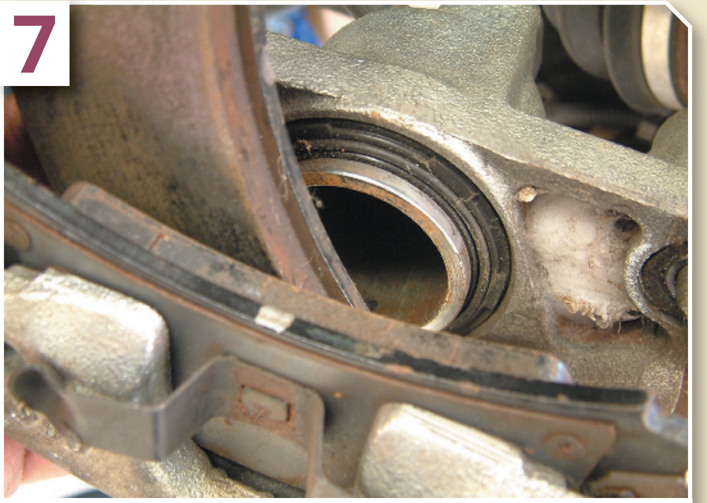
6



Clean the rotor and install it on the hub.

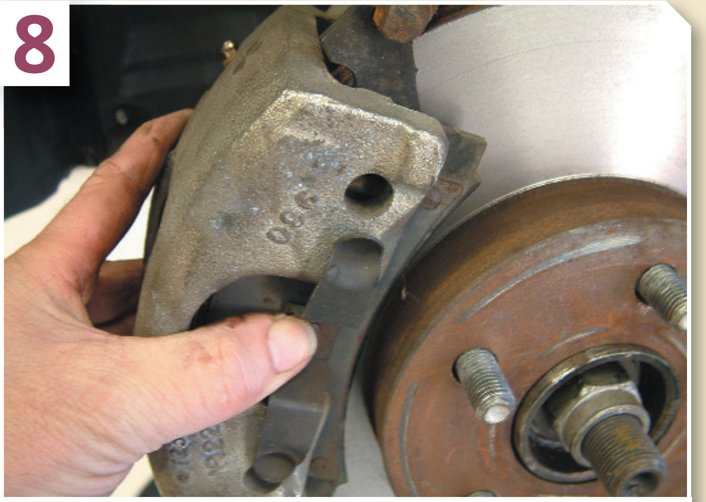
DISC BRAKE SERVICE

7



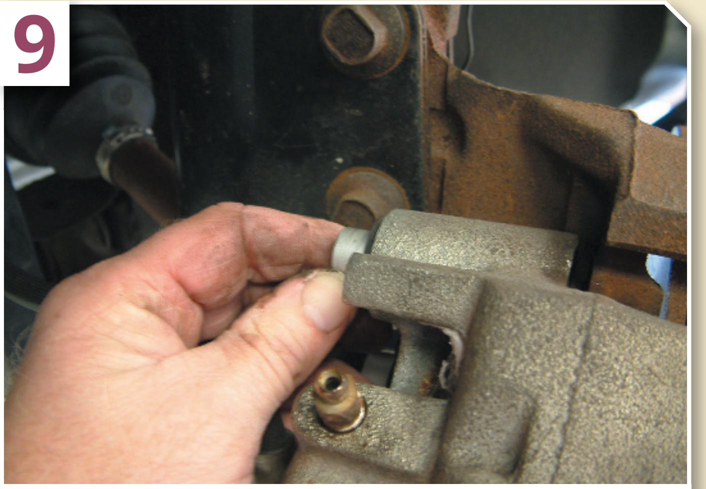
Bottom the piston and install the new brake pads.

8



Slide the caliper and new pads into position on the rotor and steering knuckle.

9



Install and torque the caliper mounting bolts to factory specifications.

REVIEW QUESTIONS

1. Describe how to do a disc brake visual inspection.
2. What is a banjo bolt?
3. Explain what causes disc brake squeal and list what a technician can do to reduce or eliminate the noise.
4. Why should the bleeder valve be opened before pushing the piston back into the caliper when replacing brake pads?
5. What factors increase the possibility of brake noise?

CHAPTER QUIZ

1. A vehicle is in for a brake inspection and the red brake warning light is ON. Which of the following actions should the technician *not* take?
   - **a.** Inspect the system for leaks
   - **b.** Test-drive the vehicle
   - **c.** Check brake pedal height
   - **d.** Check the parking brake
2. Uneven disc brake pad wear is being discussed. Technician A says the caliper piston may be stuck. Technician B says the caliper may be stuck on the slides and unable to "float." Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. A "chirping" noise is heard while the vehicle is moving forward, but stops when the brakes are applied. Technician A says that the noise is likely caused by the disc brake pad wear sensors. Technician B says the noise is likely a wheel bearing because the noise stops when the brakes are applied. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Technician A says that disc brake pads should be replaced when worn to minimum allowable thickness. Technician B says the pads should be removed and inspected whenever there is a brake performance complaint. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Two technicians are discussing brake pedal pulsation. Technician A says to check the rotor parallelism. Technician B says to check the metering valve. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Technician A says that a loaded caliper includes an overhauled caliper assembly but no brake pads or hardware. Technician B says that a loaded caliper includes the pads and all needed hardware. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Technician A says that brake squeal can be prevented by spraying the disc with lubricant. Technician B says that using factory-type shims can prevent pad squeal. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Technician A says that a lack of lubrication on the back of the disc brake pads can cause brake noise. Technician B says that pads that are not correctly crimped to the caliper housing can cause brake noise. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. What should be done after installing new disc brake pads?
   - **a.** Pump the brake pedal several times
   - **b.** Test-drive the vehicle
   - **c.** Replace the rotors
   - **d.** Rotate the piston back into the caliper
10. Which of the following lubricants should be used to lubricate moving or sliding disc brake components?
    - **a.** Silicone grease
    - **b.** Molybdenum disulfide (MOS_2) grease
    - **c.** Synthetic grease
    - **d.** Any of the above

Chapter

102

PARKING BRAKE OPERATION, DIAGNOSIS, AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss parking brake standards.
- Describe parking brake pedals, levers, and handles.
- Explain parking brake linkages.
- Explain front and rear entry parking brake cables.
- Describe drum parking brakes.
- Describe caliper-actuated disc parking brakes.
- Explain how to adjust a parking brake properly.
- Discuss electric parking brakes.

KEY TERMS:

Application cables 1199 • Control cables 1199 • Electric parking brake (EPB) 1204 • Equalizer 1200 • Intermediate lever 1199 • Red brake warning lamp 1198 • Transfer cable 1199 • Vacuum servo 1198

PARKING BRAKE STANDARDS

BACKGROUND Before 1967, most vehicles had only a single master cylinder operating all four brakes. If the fluid leaked at just one wheel, the operation of all brakes was lost. This required the use of a separate method to stop the vehicle in case of an emergency. This alternative method required that a separate mechanical method be used to stop the vehicle using two of the four wheel brakes. After 1967, federal regulations required the use of dual or tandem master cylinders where half of the braking system has its own separate hydraulic system. In case one-half of the system fails, a dash brake warning lamp lets the driver know that a failure has occurred. The term *parking brake* has replaced the term *emergency brake* since the change to dual master cylinder design.

FMVSS 135 According to Federal Motor Vehicle Safety Standard (FMVSS) 135, the parking brake must hold a fully loaded (laden) vehicle stationary on a slope of 20% up or down grade. The hand force required cannot exceed 80 pounds (18 N) or a foot force greater than 100 pounds (22 N). ● **SEE FIGURE 102–1** for a typical parking brake system.

PEDALS, LEVERS, AND HANDLES

Parking brakes are applied by a pedal, a lever, or a handle from inside the vehicle. Foot pedals and floor-mounted levers are the most common means of applying parking brakes. ● **SEE FIGURES 102–2 AND 102–3**. All parking brake controls incorporate a *ratchet* mechanism to lock the brake in the applied position. ● **SEE FIGURE 102–4**.

When service brake friction assemblies are used as the parking brakes, the service brake pedal should be depressed while the parking brake control is set. Applying the service brake increases parking brake holding power because the brake hydraulic system provides the actual application force, which is far greater than the force that can be developed mechanically. The parking brake mechanism simply locks the brakes in position. If the parking brake is operated only by the pedal, lever, or handle, holding power will be reduced, and the cables in the linkage will tend to stretch.

Most parking brakes are applied manually and the release procedure varies with the design of the parking brake control.

PARKING BRAKE PEDALS A parking brake pedal is applied by depressing it with a foot. The ratchet engages automatically

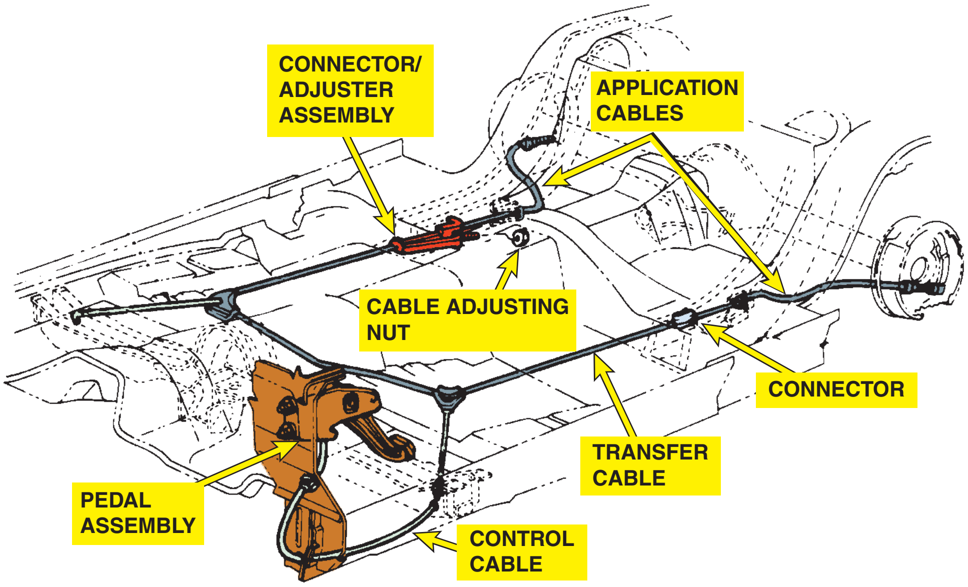

CONNECTOR/
ADJUSTER
ASSEMBLY
APPLICATION
CABLES
CABLE ADJUSTING
NUT
CONNECTOR
TRANSFER
CABLE
PEDAL
ASSEMBLY
CONTROL
CABLE

FIGURE 102–1 Typical parking brake cable system showing the foot-operated parking brake lever and cable routing.

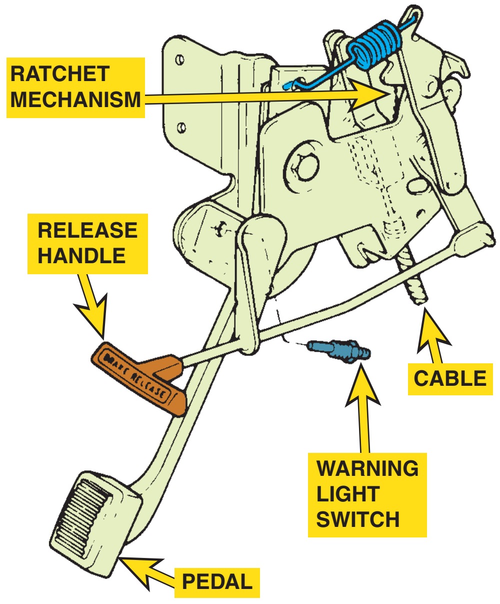

RATCHET
MECHANISM
RELEASE
HANDLE
CABLE
WARNING
LIGHT
SWITCH
PEDAL

FIGURE 102–2 A typical parking brake pedal assembly.

and the pedal remains in the depressed position. The pedal is released by a pull or a small T-handle or lever under the dash. This disengages the ratchet mechanism, and allows a return spring to move the pedal to the unapplied position. On some vehicles, the release lever is integrated into the underside of the dash and connects to the release mechanism through a rod or cable. ● **SEE FIGURE 102–5**.

Some vehicles were equipped with a special pedal design that enabled them to meet federal regulations on parking brake holding power while keeping maximum pedal application force within legal limits. This type of pedal had a high leverage ratio and a special ratchet mechanism that locked the brake pedal in the applied position, but allowed the pedal to return after it had been depressed. Two full pedal strokes, or several partial strokes, were required to fully apply the parking brake. The brake was released by a single pull on a T-handle or release lever.

Some vehicles were equipped with a system that required the driver to depress the parking brake pedal to release the parking brake once it was set. The rubber pad on the parking brake pedal usually states “push to release.”

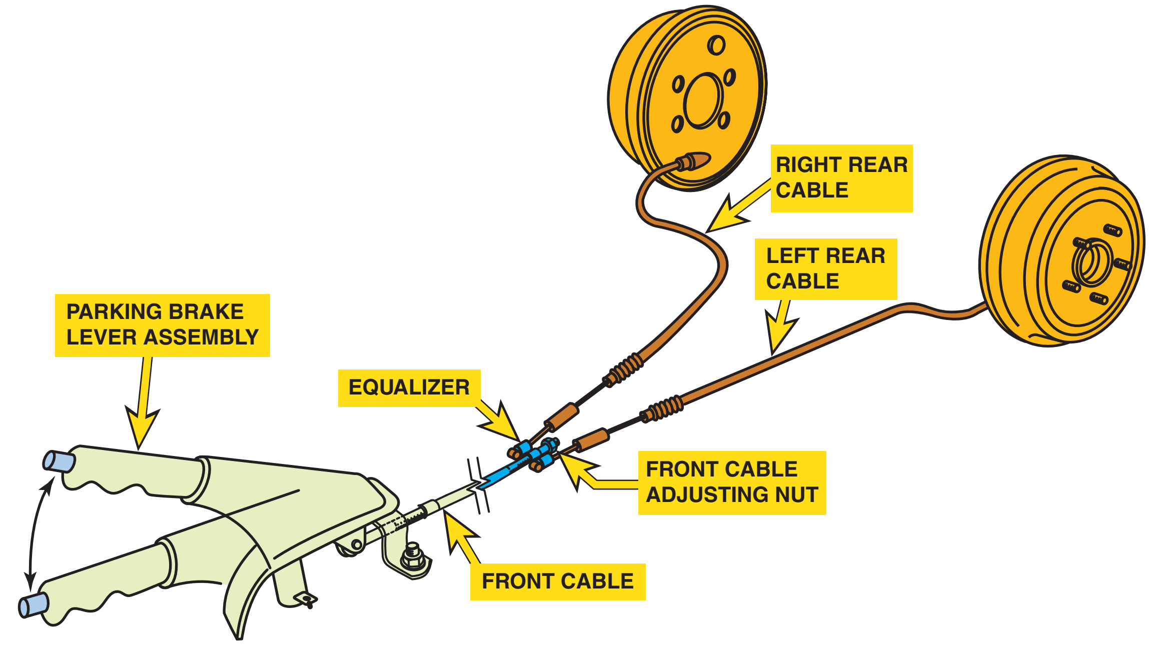

RIGHT REAR
CABLE
LEFT REAR
CABLE
PARKING BRAKE
LEVER ASSEMBLY
EQUALIZER
FRONT CABLE
ADJUSTING NUT
FRONT CABLE

FIGURE 102–3 Typical hand-operated parking brake. Note that the adjustment for the cable is underneath the vehicle at the equalizer.

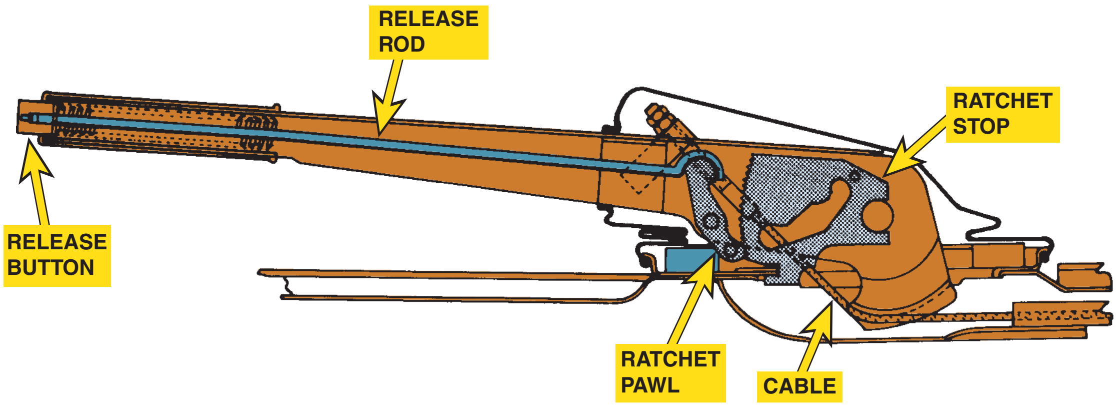


FIGURE 102–4 A ratchet mechanism is used to lock parking brakes in the applied position.

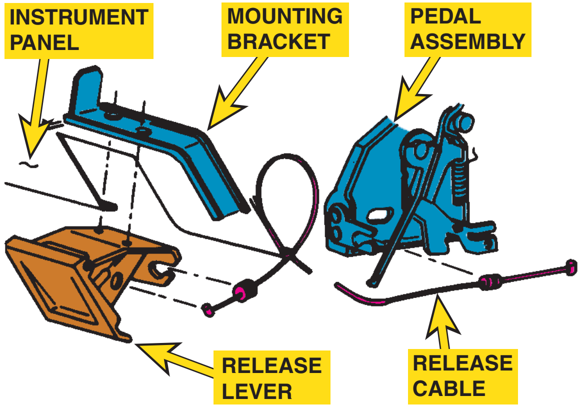


FIGURE 102–5 A remote-mounted parking brake release lever.

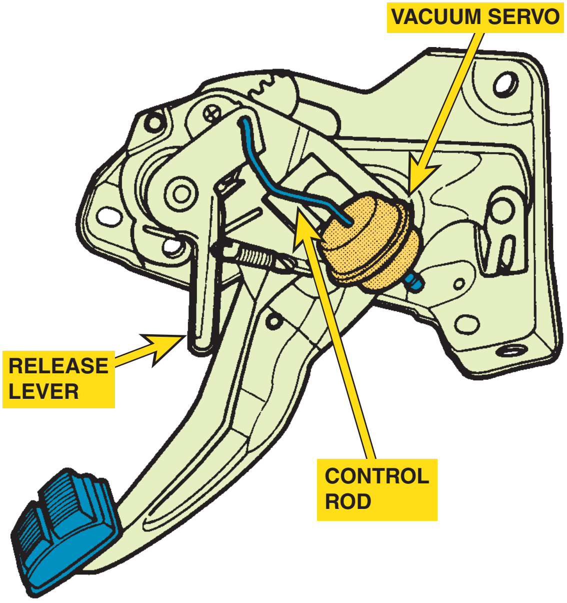


FIGURE 102–6 Automatic parking brake release mechanisms usually use a vacuum servo to operate the release lever.

CASE STUDY

Pump to Release?

A customer called and asked a dealer for help because the parking brake could not be released. The service technician discovered that the customer was attempting to release the parking brake by depressing the parking brake pedal, as was done on the customer's previous vehicle. The service technician simply pulled on the release lever and the parking brake was released.

Summary:

Complaint—Customer called the service department and asked for help releasing the parking brake as it would not release.

Cause—The service technician simply pulled on the parking brake release lever to disengage the parking brake.

Correction—No repair was needed except to inform the customer that the parking brake on the new vehicle was released using a release lever and not by depressing the foot-operated parking brake pedal as was used in the owner's previous vehicle.

AUTOMATIC PARKING BRAKE RELEASE Some vehicles with pedal-operated parking brakes have an automatic release mechanism that disengages the parking brake using a **vacuum servo** controlled by an electrical solenoid. ● **SEE FIGURE 102–6**.

A metal rod connects the vacuum servo to the upper end of the parking brake release lever. When the engine is running (to provide vacuum) and the shifter is placed in gear, an electrical contact closes to energize the solenoid and route vacuum to the servo. The servo diaphragm then retracts the rod, which releases the parking brake. ● **SEE FIGURE 102–7**.

PARKING BRAKE WARNING LAMP A **red brake warning lamp** lights on the dash if any of the following events occur:

- On most vehicles, this is the same lamp that lights when there is a hydraulic or brake fluid level problem.
- The warning lamp for the parking brake warns the driver that the parking brake is applied or partially applied. This warning helps prevent damage or overheating to the brake drums and linings that could occur if the vehicle was driven with the parking brake applied.

If the red 'brake' warning lamp is on, check the parking brake to see if it is fully released. If the 'brake' lamp is still on, the parking brake switch may be defective or out of adjustment, the fluid level may be low, or there may be a hydraulic problem.

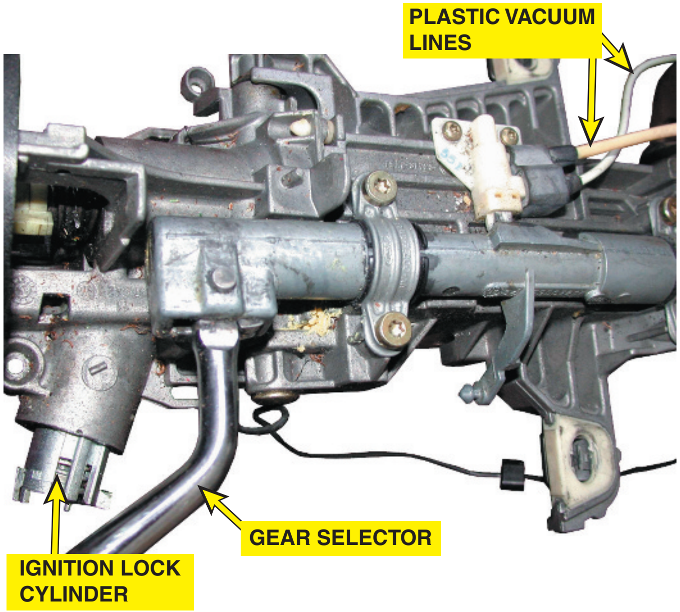


FIGURE 102–7 The two plastic vacuum tubes on the steering column are used to release the parking brake when the gear selector is moved from park into a drive gear.

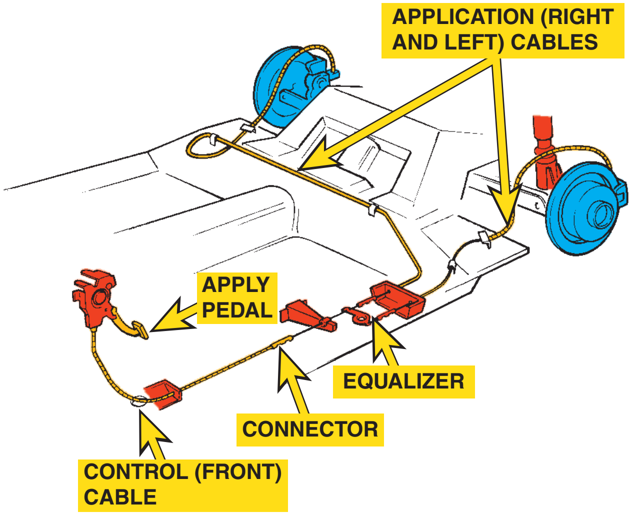


FIGURE 102–8 The cable from the activating lever to the equalizer is commonly called the control cable. From the equalizer, the individual brake cables are often called application cables. These individual cables can usually be purchased separately.

PARKING BRAKE LINKAGES

Parking brake linkages transmit force from the pedal, lever, or handle inside the vehicle to the brake friction assemblies.

LINKAGE RODS Parking brake linkage rods made from solid steel are commonly used with floor-mounted actuating levers to span the short distance to an intermediate lever or an equalizer.

LINKAGE CABLES The typical parking brake cable is made of woven-steel wire encased in a reinforced rubber or plastic housing. The housing is fixed in position at both ends, and is routed under the vehicle through mounting brackets that hold the cable in position, yet allow a small amount of movement. The cable slides back and forth inside the housing to transmit application force, and depending on the linkage design, the outer housing may play a part in parking brake application as well.

Parking brake linkages use control cables, transfer cables, and application cables.

- **Control cables** attach to the parking brake pedal, lever, or handle inside the vehicle.
- A **transfer cable** transmits force to an intermediate lever or equalizer to the application cables.
- The **application cables** use the force passed through the linkage to apply the rear-wheel brake assembly. ● **SEE FIGURE 102–8**.

Parking brake cables are subject to damage from water, dirt, and other debris thrown up under the vehicle by the tires. Most parking brake cables do not require lubrication because they are lined with nylon or Teflon, and any cable housing ends located under the vehicle are protected by rubber or nylon seals.

LINKAGE LEVERS Unfortunately, the amount of physical force a driver can apply to the parking brake control is often not enough to apply the parking brake. For this reason, all parking brake linkages contain one or more levers that increase application force.

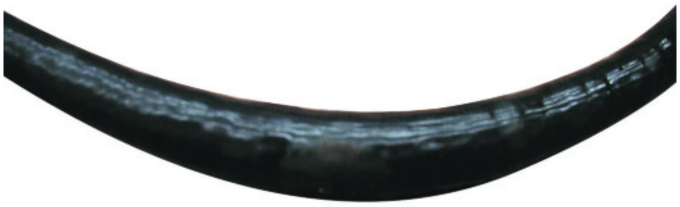


FIGURE 102–9 Notice how rust inside the covering of this parking brake cable has caused the cable to swell.

TECH TIP

Look for Swollen Parking Brake Cables

Always inspect parking brake cables for proper operation. A cable that is larger in diameter in one section indicates that it is rusting inside and has swollen. ● **SEE FIGURE 102–9**.

A rusting parking brake cable can keep the rear brake applied even though the parking brake lever has been released. This can cause dragging brakes, reduced fuel economy, and possible vehicle damage due to overheated brakes.

The parking brake pedals, floor-mounted levers, and pivoting under dash handles described earlier are all types of levers used to increase parking brake application force. A lever in the parking brake linkage under the vehicle is called an **intermediate lever**. ● **SEE FIGURE 102–10**.

To further increase parking brake application force, intermediate levers provide leverage in addition to that supplied by the parking brake control.

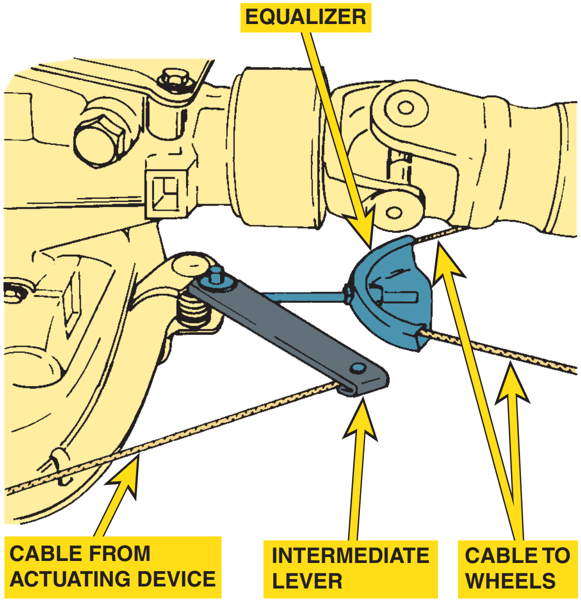

EQUALIZER
CABLE FROM ACTUATING DEVICE
INTERMEDIATE LEVER
CABLE TO WHEELS

FIGURE 102–10 Intermediate levers in the parking brake linkage increase the application force.

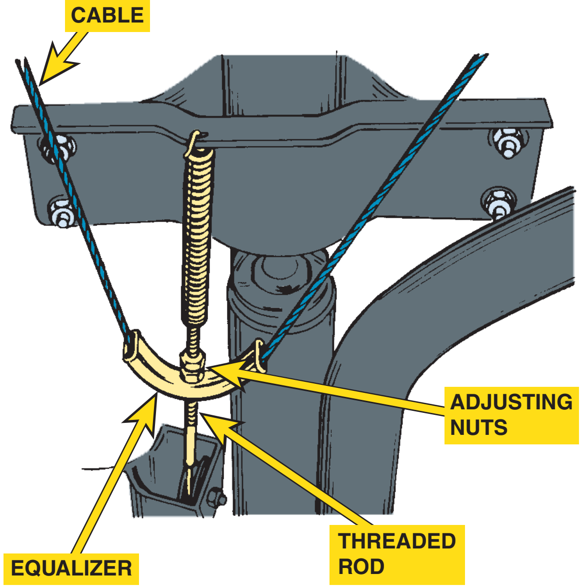

CABLE
ADJUSTING NUTS
THREADED ROD
EQUALIZER

FIGURE 102–11 A cable guide is a common type of parking brake linkage equalizer.

LINKAGE EQUALIZERS

In some parking brake linkages, the rods or cables to the two friction assemblies are adjusted separately. If the adjustments are unequal, one brake will apply before the other, preventing full lining-to-drum contact at the opposite wheel and greatly reducing the holding power of the parking brake. To prevent unequal application, most parking brake linkages use an **equalizer** to balance the force from the parking brake control and transmit an equal amount to each friction assembly.

Equalizers come in many shapes and sizes, but the simplest is the cable guide attached to a threaded rod. ● **SEE FIGURE 102–11**. This type of equalizer pivots or allows the inner cable to slide back and forth to even out application force.

Another type of equalizer installs in a long application cable that runs from the linkage at the front of the vehicle to one rear brake. ● **SEE FIGURE 102–12**.

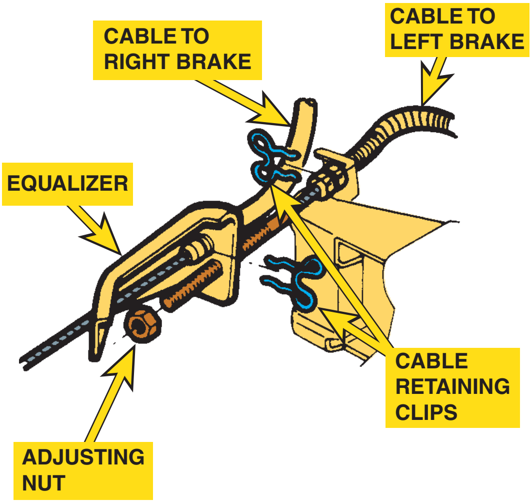

CABLE TO RIGHT BRAKE
CABLE TO LEFT BRAKE
EQUALIZER
CABLE RETAINING CLIPS
ADJUSTING NUT

FIGURE 102–12 Some parking brake equalizers are installed in the brake cable.

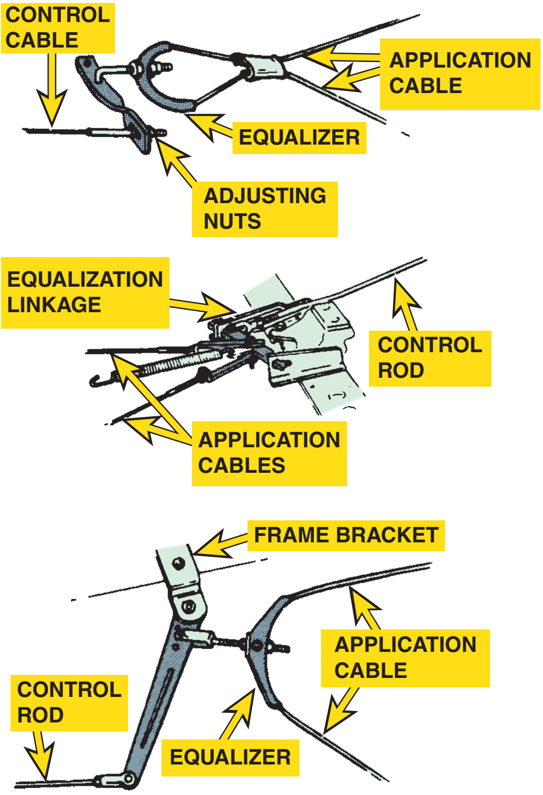

CONTROL CABLE
APPLICATION CABLE
EQUALIZER
ADJUSTING NUTS
EQUALIZATION LINKAGE
CONTROL ROD
APPLICATION CABLES
FRAME BRACKET
APPLICATION CABLE
CONTROL ROD
EQUALIZER

FIGURE 102–13 Many parking brake linkages use both an intermediate lever and an equalizer.

LINKAGE DESIGN

The number of different parking brake linkage designs is almost as great as the number of vehicle models on the road. Most linkages combine intermediate levers and equalizers in various ways and use from one to four cables to actuate the friction assemblies. ● **SEE FIGURE 102–13**.

FRONT AND REAR ENTRY PARKING BRAKE CABLES

The parking brake standard requires that the vehicle be held stationary on a 20% grade facing either uphill or downhill. Many drum parking brake systems attach the parking brake lever on the secondary (rearward) shoe and push the primary (forward facing) brake shoe against the drum. The parking brake cable enters the backing plate from the front of the vehicle (front entry). Because the primary shoe is attached to the secondary shoe on dual-servo brakes, any forward motion of the vehicle tends to wedge the primary shoe into the brake drum *and* force the rear secondary lining also against the drum.

Applying only the forward brake shoe tends to hold the vehicle best when it is being held on a hill with the front pointing downward. To help provide the same holding power for a vehicle being held from backing up, some vehicles reverse the parking brake arrangement for the right side. Instead of having the parking brake cable enter the backing plate from the front, this style has the cable entering from the rear (rear entry). In this case, the right rear brake has the parking brake lever installed on the *primary* shoe.

NOTE: An easy way to remember how to reassemble a drum brake is to realize that the parking brake lever is usually attached to the secondary (rearward) brake shoe. The parking brake strut attaches between the shoes with the spring toward the front of the vehicle (remember, "spring forward").

DRUM PARKING BRAKES

Drum parking brakes are the most common types on vehicles and light trucks. Drum brakes make excellent parking brakes because they have a high static coefficient of friction combined with self-energizing action and, in the case of dual-servo brakes, servo action that increases their application force.

INTEGRAL DRUM PARKING BRAKES

Integral drum parking brakes mechanically apply the rear drum service brakes to serve as the parking brakes. ● **SEE FIGURE 102–14**.

Integral drum parking brakes are the most common type not only because of their natural superiority in this application, but because it is simple and inexpensive to design a parking brake linkage into a drum brake.

The typical integral drum parking brake has a pivoting lever mounted on one brake shoe, and a strut placed between the lever and the other shoe. The strut may be fitted with a spring that takes up slack to prevent noise when the parking brake is not applied. The end of the lever opposite the pivot is moved by the parking brake cable, which enters through an opening in the backing plate. All integral drum parking brakes operate in essentially the same manner. ● **SEE FIGURE 102–15**.

When the parking brake control is operated, the cable pulls the end of the lever away from the shoe it is attached to. The lever pivots at the attaching point and moves the strut to apply the forward shoe. Once the forward brake shoe lining contacts the drum, the strut can travel no farther. The lever then pivots on the strut and forces the lining of the reverse shoe against the drum.

REAR DISC AUXILIARY DRUM PARKING BRAKES

Rear disc service brakes with fixed calipers commonly have a parking brake drum formed into the hub of the brake rotor. ● **SEE FIGURE 102–16**. Inside the drum is a small dual-servo drum brake friction assembly that serves as the parking brake. The rotor splash shield, or a special mounting bracket, provides the backing plate for the friction assembly. Rear disc auxiliary drum parking brakes use the dual-servo friction assembly design because it provides the most holding power, and does so equally in both forward and reverse directions. Dual-servo parking brake friction assemblies operate in essentially the same manner as service brakes except that the wheel cylinder is eliminated and the friction assembly is actuated mechanically. ● **SEE FIGURE 102–17**.

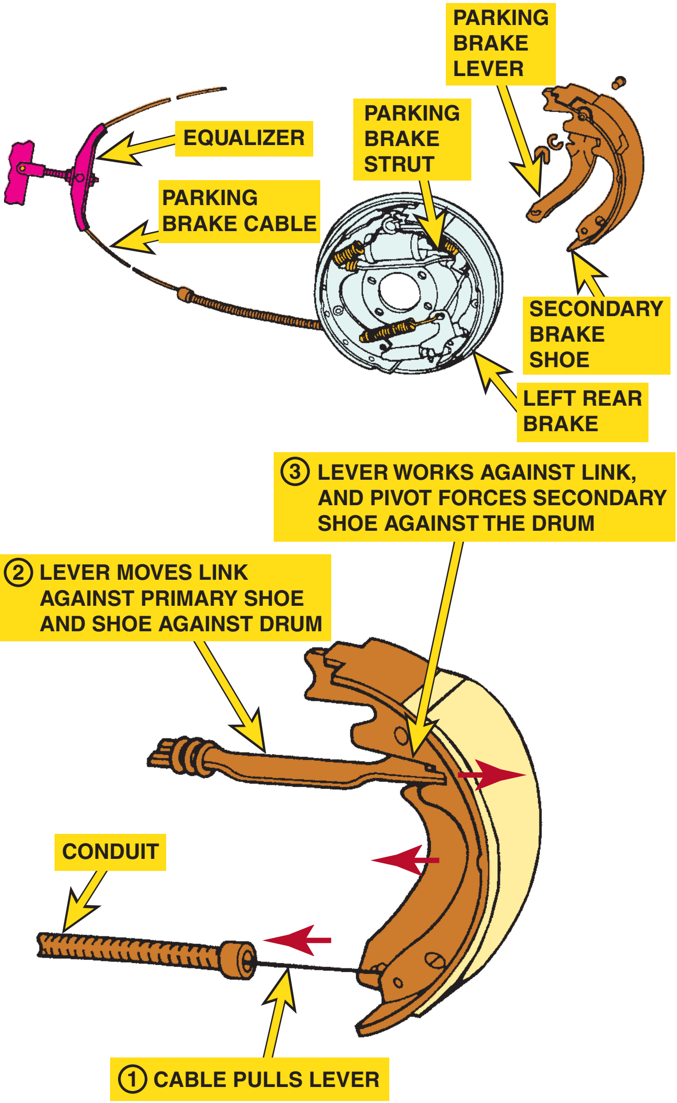

PARKING BRAKE LEVER
EQUALIZER
PARKING BRAKE STRUT
PARKING BRAKE CABLE
SECONDARY BRAKE SHOE
LEFT REAR BRAKE
③ LEVER WORKS AGAINST LINK, AND PIVOT FORCES SECONDARY SHOE AGAINST THE DRUM
② LEVER MOVES LINK AGAINST PRIMARY SHOE AND SHOE AGAINST DRUM
CONDUIT
① CABLE PULLS LEVER

FIGURE 102–14 Notice the spring at the end of the parking brake strut. This antirattle spring keeps tension on the strut. The parking brake lever is usually attached with a pin and spring (wavy) washer and retained by a horseshoe clip.

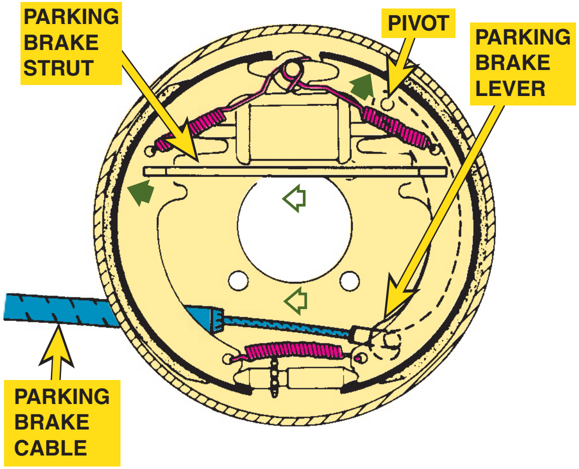


FIGURE 102–15 The parking brake cable pulls on the parking brake lever, which in turn forces the brake shoe against the drum.

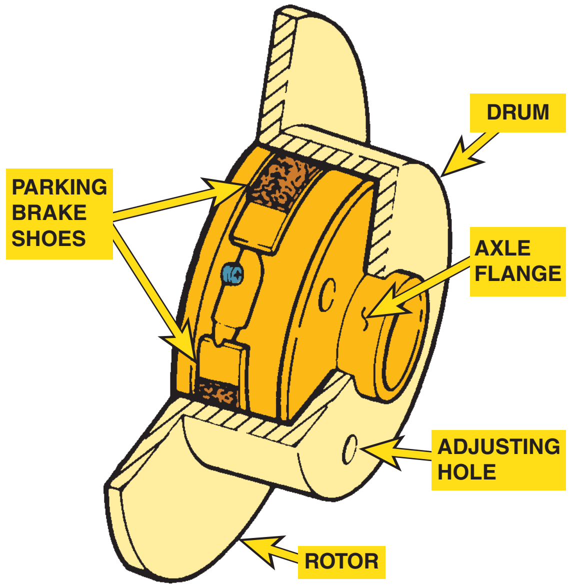


FIGURE 102–16 The inside "hat" of the disc brake rotor is the friction surface for the parking brake shoes.

All rear disc auxiliary drum parking brakes are adjusted manually using a starwheel adjuster, which is reached through an opening in the outside of the drum.

CALIPER-ACTUATED DISC PARKING BRAKES

Caliper-actuated disc parking brakes are used on vehicles whose rear disc brakes are equipped with floating or sliding brake calipers. The single-piston construction of these calipers makes them easier to mechanically actuate than multiple-piston fixed calipers. In this design, a special mechanism in the caliper applies the caliper piston mechanically. The mechanism is operated by a parking brake cable attached to a lever that protrudes from the inboard side of the caliper.

TECH TIP

The Parking Brake "Click" Test

When diagnosing any brake problem, apply the parking brake and count the "clicks." This method works for both hand- and foot-operated parking brakes. Most vehicle manufacturers specify a maximum of 10 clicks. If the parking brake travel exceeds this amount, the rear brakes may be worn or out of adjustment.

CAUTION: Do not adjust the parking brake cable until the rear brakes have been thoroughly inspected and adjusted.

If the rear brake lining is usable, check for the proper operation of the self-adjustment mechanism. If the rear brakes are out of adjustment, the service brake pedal will also be low. This 10-click test is a fast and easy way to determine if the problem is due to rear brakes.

BALL AND RAMP ACTUATION The ball and ramp actuating system found in Ford rear brake calipers has three steel balls located in ramp-shaped detents between two plates. ● **SEE FIGURE 102–18**. One plate has a thrust screw attached that is threaded into an adjuster mechanism in the caliper piston. The other plate is part of the operating shaft that extends out of the caliper. The actuating lever is mounted to the end of this shaft.

As the parking brake cable moves the lever and rotates the operating shaft, the balls ride up the ramps and force the two plates apart. The operating shaft plate cannot move because it butts against the caliper body. The thrust screw plate, which is pinned to the caliper body to prevent it from rotating, is driven away from the operating shaft and toward the rotor where the thrust screw moves the caliper piston to apply the brake. ● **SEE FIGURE 102–19**.

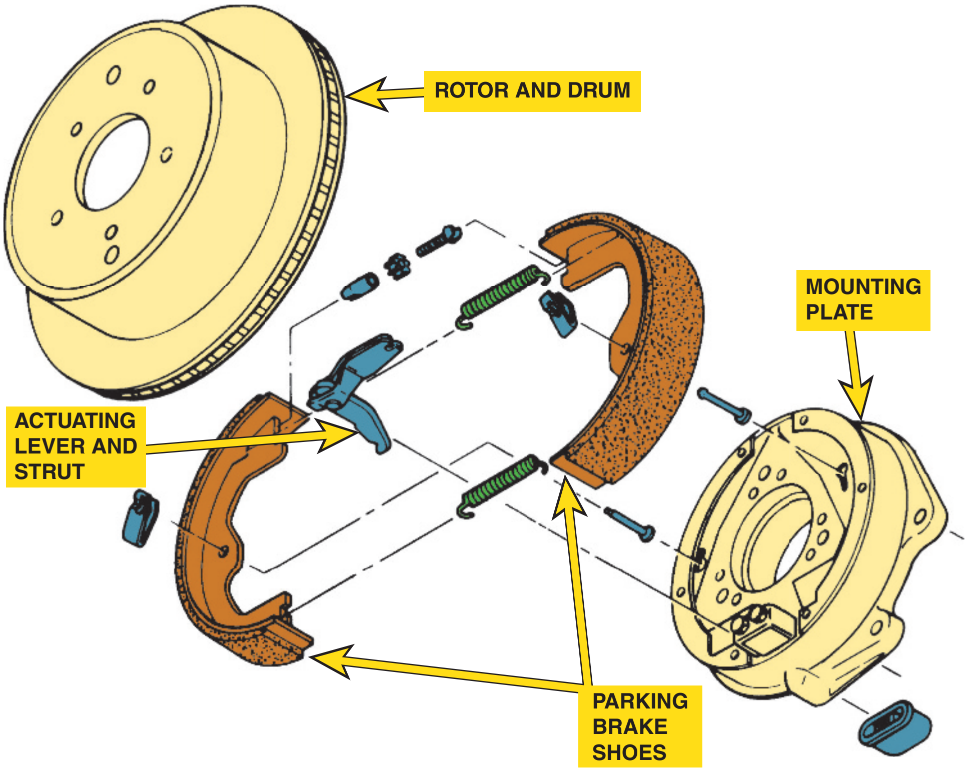


FIGURE 102–17 A typical rear disc brake auxiliary drum brake friction assembly.

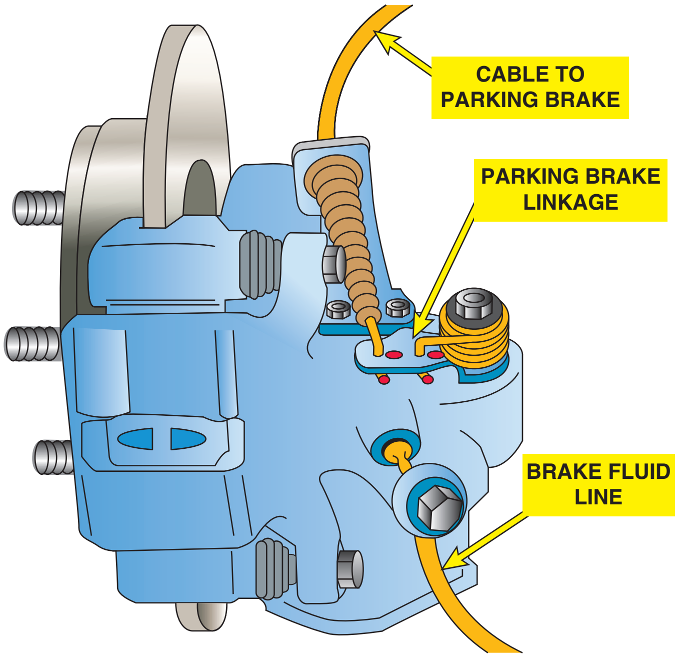


FIGURE 102–18 A typical rear disc brake showing the parking brake cable used to apply the caliper piston against the disc brake rotor.

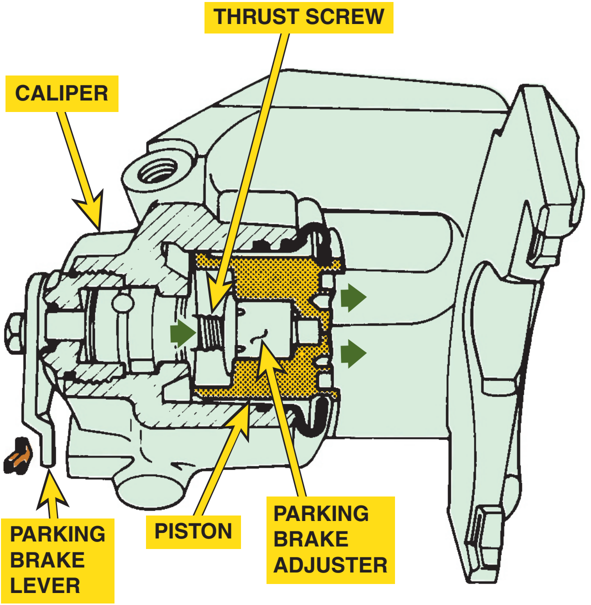


FIGURE 102–19 Operation of a ball and ramp-type rear disc brake caliper parking brake.

PARKING BRAKE CABLE ADJUSTMENT

PROCEDURE Most manufacturers specify a minimum of three or four and a maximum of eight to ten clicks when applying the parking brake. Check service information for the vehicle being serviced for the exact specifications and adjustment procedures. Most vehicle manufacturers specify that the rear brakes be inspected and adjusted correctly before attempting to adjust the parking brake cable. Always follow the manufacturer's recommended procedure exactly.

Below is a general procedure for parking brake adjustment:

1. Make certain that the rear service brakes are adjusted correctly and the lining is serviceable.

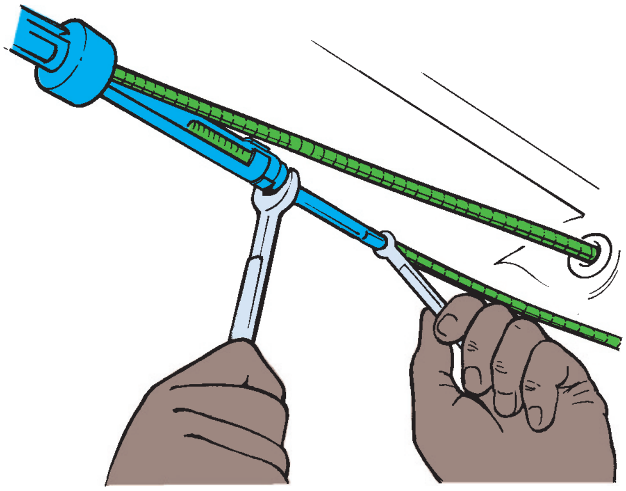


FIGURE 102–20 After checking that the rear brakes are okay and properly adjusted, the parking brake cable can be adjusted. Always follow the manufacturer's recommended procedure.

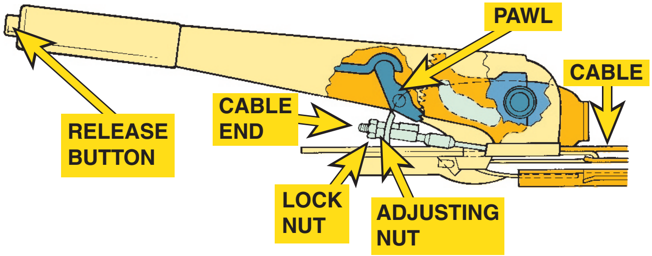


FIGURE 102–21 Many hand-operated parking brakes are adjusted inside the vehicle.

2. With the drums installed, apply the parking brake three or four clicks. There should be a slight drag on both rear wheels.
3. Adjust the cable at the equalizer (equalizes one cable's force to both rear brakes) if necessary until there is a slight drag on both rear brakes. ● **SEE FIGURES 102–20 AND 102–21.**
4. Release the parking brake. Both rear brakes should be free and not dragging. Repair or replace rusted cables or read-just as necessary to ensure that the brakes are not dragging.

NOTE: The rear parking brake adjustment should always be checked whenever replacing the rear brake linings. It may be necessary to loosen the parking brake cable adjustment to allow clearance to get the drum over the new linings. This could happen because someone may have adjusted the parking brake cable during the life of the rear linings. ● SEE FIGURE 102–22.

With new thicker linings, the parking brake adjustment can keep the brake shoes pushed outward toward the drum.

To prevent possible parking brake cable adjustment problems when installing new rear brakes, always observe the following:

1. Both brake shoes should make contact with the anchor pin at the top. If not, check the parking brake cable for improper adjustment or improper installation of the brake shoes.
2. Feel the tension of the parking brake cable underneath the vehicle. It should be slightly loose (with the parking brake "off").
3. Lubricate the parking brake cable to ensure that water or ice will not cause rust or freezing of the cable. This is necessary because even though the parking brake lever is released inside the vehicle, a stuck parking brake cable could cause the linings to remain out against the drums.

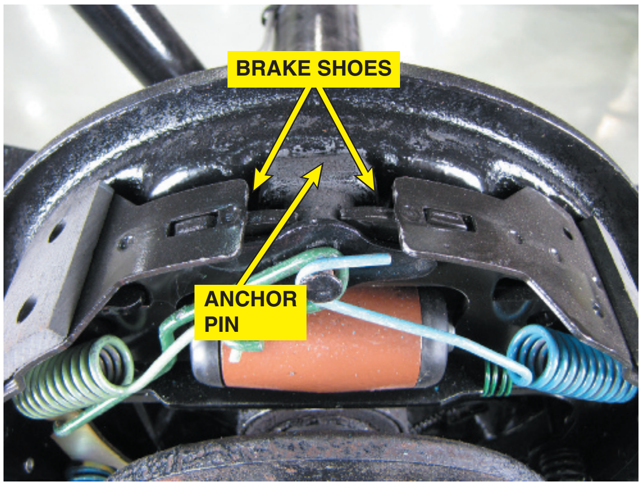


FIGURE 102–22 Always check that the brake shoes contact the anchor pin.

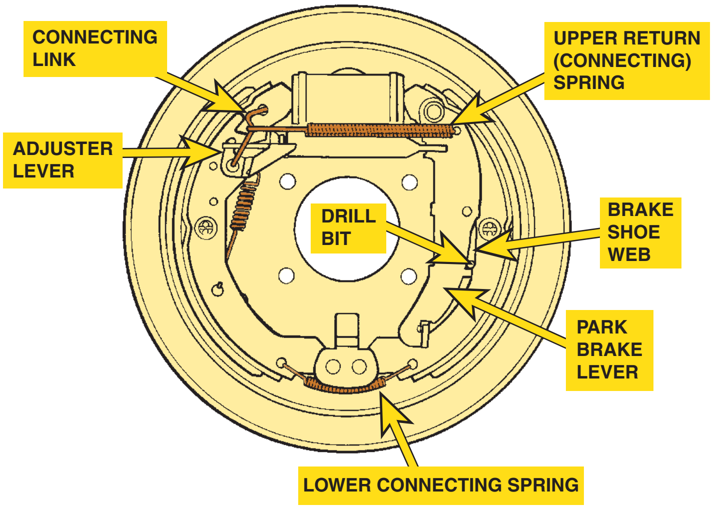


FIGURE 102–23 A 1/8 inch (3 mm) drill bit is placed through an access hole in the backing plate to adjust this General Motors leading-trailing rear parking brake. Adjust the parking brake cable until the drill can just fit between the shoe web and the parking brake lever.

4. If the parking brake needs to be adjusted (will not hold on a hill or requires excessive lever movement), always check and adjust the rear brake adjustment before adjusting the parking brake cable. ● **SEE FIGURE 102–23**.

NOTE: Some vehicles are equipped with an automatic adjusting parking brake lever/cable. Simply cycling the parking brake on/off/on three times is often all that is required to adjust the parking brake cable.

5. Replace any stuck, corroded, or broken parking brake cable.

TECH TIP

The Hose Clamp or Wrench Trick

It is often difficult to remove a parking brake cable from the backing plate due to the design of the retainer. The many fingers used to hold the cable to the backing plate can be squeezed all at once if a hose clamp is used to compress the fingers. A wrench as shown in ● **FIGURE 102–24** can also be used.

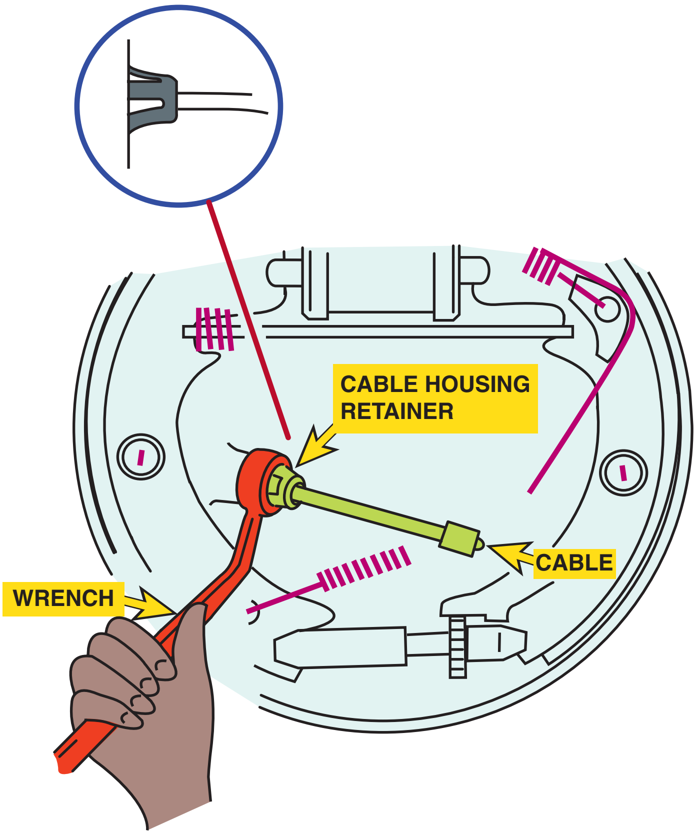


FIGURE 102–24 Many parking brake cables can be removed easily from the backing plate using a 1/2 inch (13 mm) box-end wrench. The wrench fits over the retainer finger on the end of the parking brake cable.

ELECTRIC PARKING BRAKE

TYPES **Electric parking brake (EPB)** systems are available using two different designs including the following:

1. A cable-pulling type that uses an electric motor to pull the parking brake cable rather than a mechanical handle or foot pedal. ● **SEE FIGURES 102–25 THROUGH 102–27**.
2. A more advanced unit uses a computer-controlled motor attached to the brake caliper to activate it.

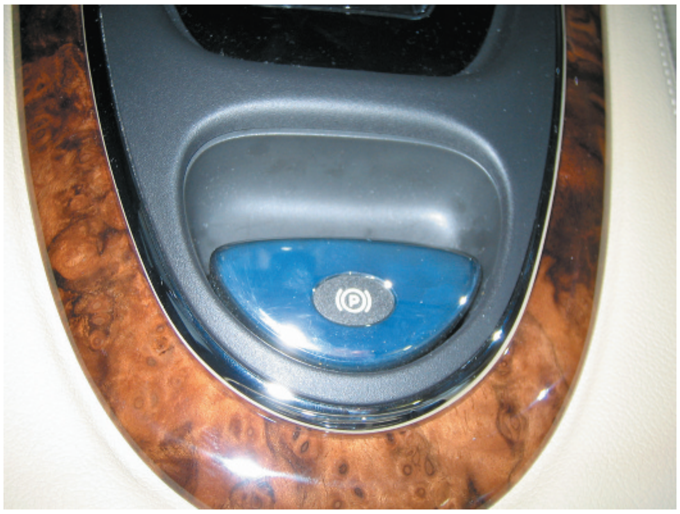


FIGURE 102–25 An electric parking brake button on the center console of a Jaguar.

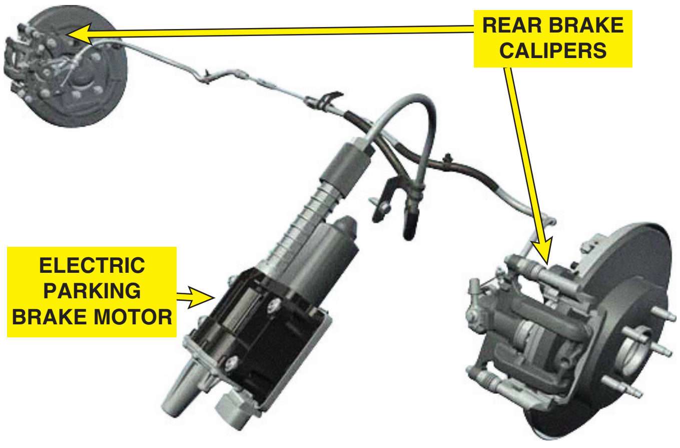

REAR BRAKE CALIPERS
ELECTRIC PARKING BRAKE MOTOR

FIGURE 102–26 A type of electric parking brake that uses an electric motor to pull on the parking brake cable to each rear wheel.

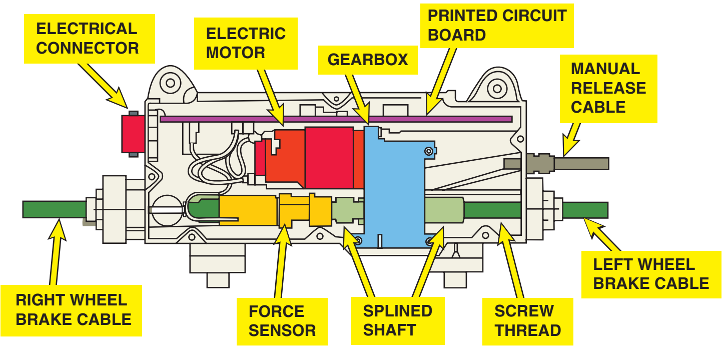

ELECTRICAL CONNECTOR
ELECTRIC MOTOR
GEARBOX
PRINTED CIRCUIT BOARD
MANUAL RELEASE CABLE
LEFT WHEEL BRAKE CABLE
RIGHT WHEEL BRAKE CABLE
FORCE SENSOR
SPLINED SHAFT
SCREW THREAD

FIGURE 102–27 A DC electric motor is used to apply the cable running to the left and right parking brake.

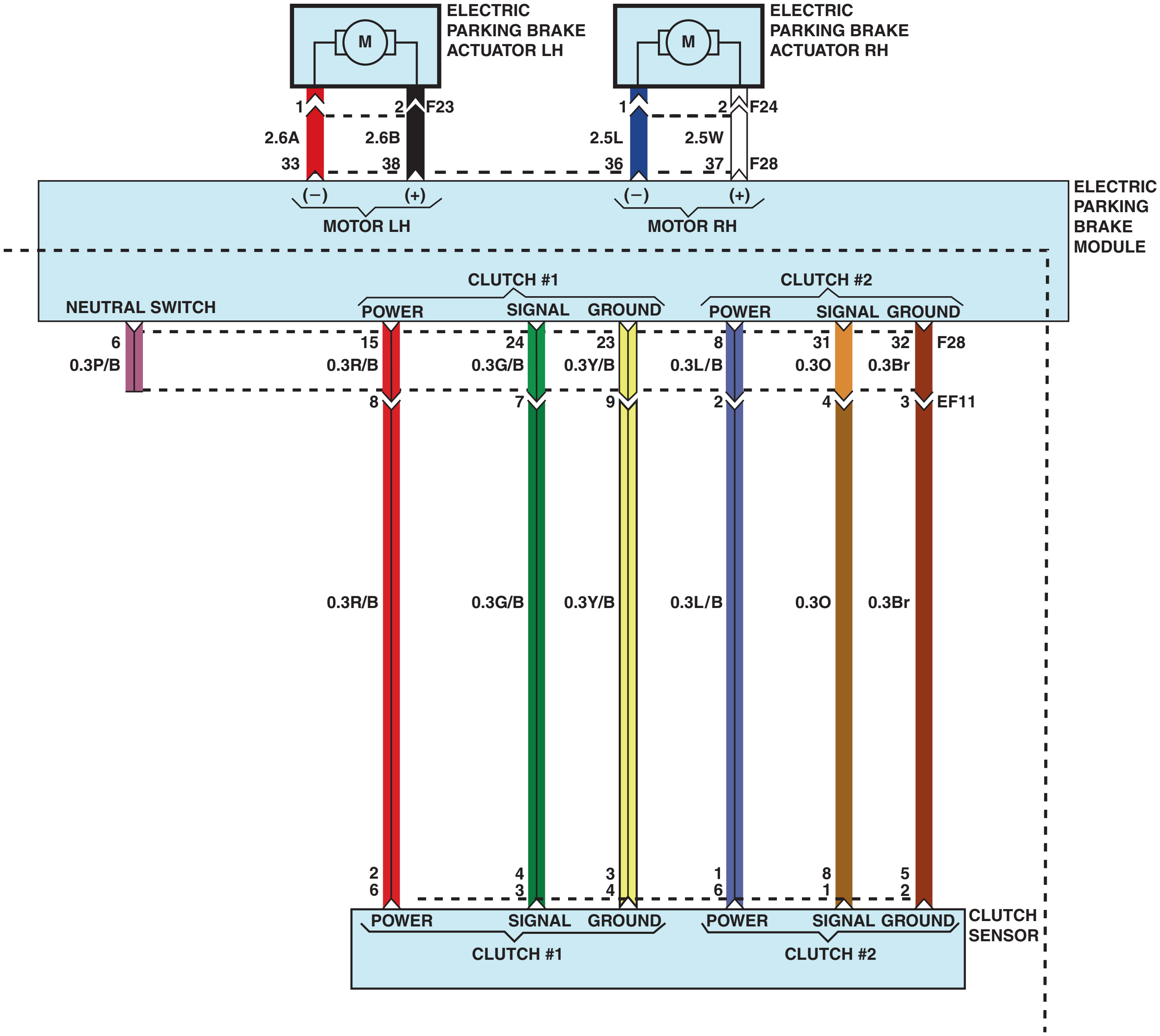

M
ELECTRIC PARKING BRAKE ACTUATOR LH
M
ELECTRIC PARKING BRAKE ACTUATOR RH
1
2
F23
1
2
F24
2.6A
2.6B
2.5L
2.5W
33
38
36
37
F28
(–)
(+)
MOTOR LH
(–)
(+)
MOTOR RH
ELECTRIC PARKING BRAKE MODULE
CLUTCH #1
CLUTCH #2
NEUTRAL SWITCH
POWER
SIGNAL
GROUND
POWER
SIGNAL
GROUND
6
0.3P/B
15
0.3R/B
24
0.3G/B
23
0.3Y/B
8
0.3L/B
31
0.3O
32
0.3Br
F28
8
7
9
2
4
3
EF11
0.3R/B
0.3G/B
0.3Y/B
0.3L/B
0.3O
0.3Br
2
6
4
3
3
4
1
6
8
1
5
2
POWER
SIGNAL
GROUND
POWER
SIGNAL
GROUND
CLUTCH #1
CLUTCH #2
CLUTCH SENSOR

FIGURE 102–28 The electric parking brake (EPB) control module is used to control the operation of the electric parking brake actuator at each rear wheel.

Some vehicles already use an electric parking brake (EPB) that can be activated when the vehicle stops and then goes off as soon as the gas pedal is pressed, preventing the vehicle from moving while stopped. ● **SEE FIGURE 102–28**.

EPB SERVICE If the vehicle being serviced is equipped with a cable-actuated system, then no special service procedures are needed when replacing rear brakes. However, in many vehicles, the electric parking brake (EPB) is automatically applied when the vehicle is placed in park. There are two ways that a technician can release the EPB including

1. Manually follow a release procedure such as:
   - Place transmission in park (P) or neutral in a vehicle equipped with a manual transmission.
   - Press and hold the EPB switch for five seconds.
   - When the EPB warning light starts to flash, release the EPB switch to deactivate the parking brake.
2. Use a scan tool and follow the on-screen instructions to deactivate the electric parking brake. ● **SEE FIGURE 102–29.**

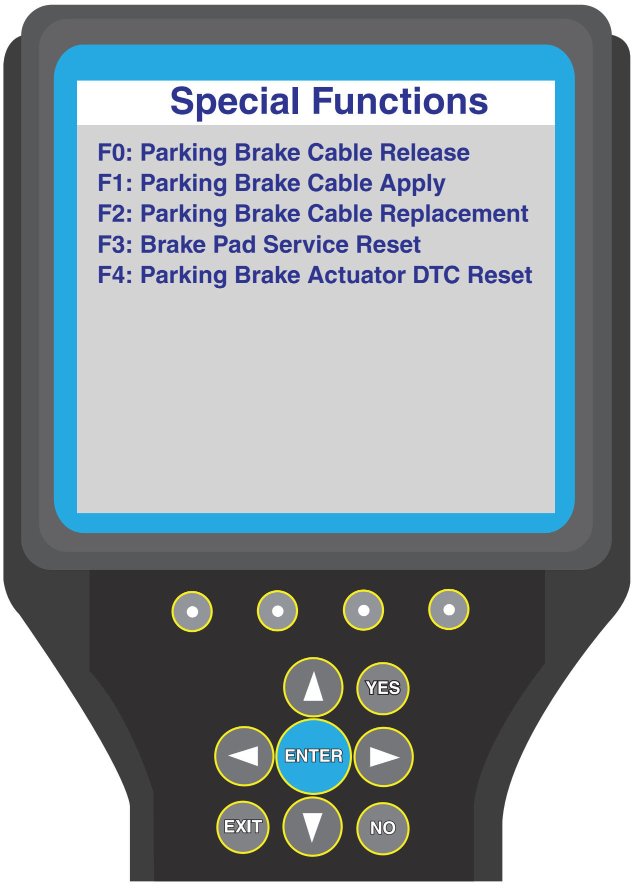

Special Functions
F0: Parking Brake Cable Release
F1: Parking Brake Cable Apply
F2: Parking Brake Cable Replacement
F3: Brake Pad Service Reset
F4: Parking Brake Actuator DTC Reset
YES
ENTER
EXIT
NO

FIGURE 102–29 A scan tool can be used when servicing the rear brakes on a vehicle equipped with an electric parking brake.

REVIEW QUESTIONS

1. Describe how a typical parking brake functions on a vehicle equipped with rear drum brakes.
2. Describe how a typical parking brake functions on a vehicle equipped with an integral rear disc brake system.
3. Explain how to adjust a parking brake cable properly.
4. What are the two types of electric parking brakes?
5. What is wrong when the parking brake cable is swollen?

CHAPTER QUIZ

1. Technician A says that the parking brake hand lever can turn on the red brake warning lamp. Technician B says that a foot-operated parking brake can turn on the red brake warning lamp. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that if the parking brake cable is adjusted too tight, the rear brakes may drag and overheat. Technician B says that the parking brake is adjusted properly if the cable is tight when in the released position. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. On most drum brake systems, the _______________ attaches to the parking brake lever or handle inside the vehicle.
   a. transfer cables
   b. control cables
   c. application cables
   d. foot pedal
4. In a typical integral rear disc brake caliper, the parking brake cable moves the _______________.
   a. caliper
   b. actuator screw
   c. auxiliary piston
   d. rotor
5. On most vehicles, the _______________ transmit the force passed through the linkage to apply the rear brakes.
   a. transfer cables
   b. control cables
   c. application cables
   d. foot pedal

6. The rear brakes should be inspected, and adjusted if necessary, if the parking brake requires more than _____________.
   a. 5 clicks
   b. 10 clicks
   c. 15 clicks
   d. 20 clicks

7. Technician A says that the parking brake cable should be adjusted at each wheel. Technician B says that the parking brake cable adjustment is usually done after adjusting the rear brakes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. A rear drum brake is being inspected. The primary shoe is not contacting the anchor pin at the top. Technician A says that this is normal. Technician B says that the parking brake cable may be adjusted too tight or is stuck. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Technician A says that the parking brake must comply with FMVSS performance standards. Technician B says that that the vehicle is tested on a 20% up or down grade. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Technician A says that an electric parking brake (EPB) uses an electric motor to pull on the parking brake cable. Technician B says that some electric parking brake systems use a computer-controlled motor attached to the caliper. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

Chapter

103

MACHINING BRAKE DRUMS AND ROTORS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the types of brake drums.
- Explain the factors that cause drum and rotor damage.
- Discuss brake drum distortion.
- Discuss brake drum removal.
- Discuss “machine to” versus “discard.”
- Explain how to machine a brake drum.
- Discuss disc brake rotors.
- Discuss disc brake rotor distortion.
- Discuss carbon-ceramic rotors.
- Discuss disc brake rotor thickness.
- Discuss when the rotors should be machined.
- Describe rotor surface finish.
- Explain the procedure for qualifying a brake lathe.
- Discuss machining a disc brake rotor.
- Discuss on-the-vehicle rotor machining.

KEY TERMS:

Bellmouth 1210 • Chill spots 1210 • Composite rotors 1215 • Convection 1208 • Discs (disks) 1213 • Disc thickness variation (DTV) 1217 • Eccentric distortion 1211 • Elastic limit 1211 • Hard spots 1210 • Heat checking 1209 • Lateral runout (LRO) 1217 • Microinches (μin) 1219 • Out-of-round 1211 • Parallelism 1217 • Ra 1220 • Scoring 1208 • Scratch cut 1213 • Self-aligning spacer (SAS) 1213 • Tinnerman nuts 1212 • Thickness variation (TV) 1217

BRAKE DRUMS

CAST-IRON DRUMS Brake drums are constructed of cast iron where the lining contacts the drum, with mild steel centers. The drum is drilled for the lug studs. Cast iron contains approximately 3% carbon, which makes the drum hard, yet brittle. For this reason, it is recommended that any pounding needed to remove drums be done on the center mild steel portion, which, due to its material characteristics, can take this force without damage. This 3% carbon content of the cast iron also acts as a lubricant, which prevents noise during braking. Also, the rubbing surface can be machined without the need of a coolant (as would be required if constructed of mild steel). Because of these properties, cast iron is used on the friction surface of all drums. ● **SEE FIGURE 103–1**.

ALUMINUM DRUMS Even aluminum brake drums use cast iron for the friction surface area. Besides saving weight, aluminum brake drums transfer heat to the surrounding air faster than cast iron or steel.

Brake drums and rotors are the major energy-absorbing parts of the braking system. Friction between the friction material and the drum or rotor creates heat. This heat is absorbed by the drum or rotor and travels from the friction surface to the remainder of the drum or rotor by heat **convection**. As energy continues to be absorbed, the drum or rotor increases in temperature. Airflow across the drum or rotor helps to dissipate the heat and keep the temperature rise under control. ● **SEE FIGURE 103–2**.

BRAKE DRUM AND ROTOR DAMAGE

Besides wear, drums and rotors often experience damage to their friction surfaces. Because drum and rotor damage is caused by extremes of operation, it is most commonly found on front brakes, which experience more severe use than rear brakes.

SCORING **Scoring** is an extreme form of drum and rotor wear consisting of scratches, deep grooves, and a generally rough finish on the friction surface. ● **SEE FIGURE 103–3**.

There are a number of causes for scoring including the following:

1. The most common is brake linings that have worn to the point where a rivet, lining table, or pad backing plate contacts the drum or rotor.

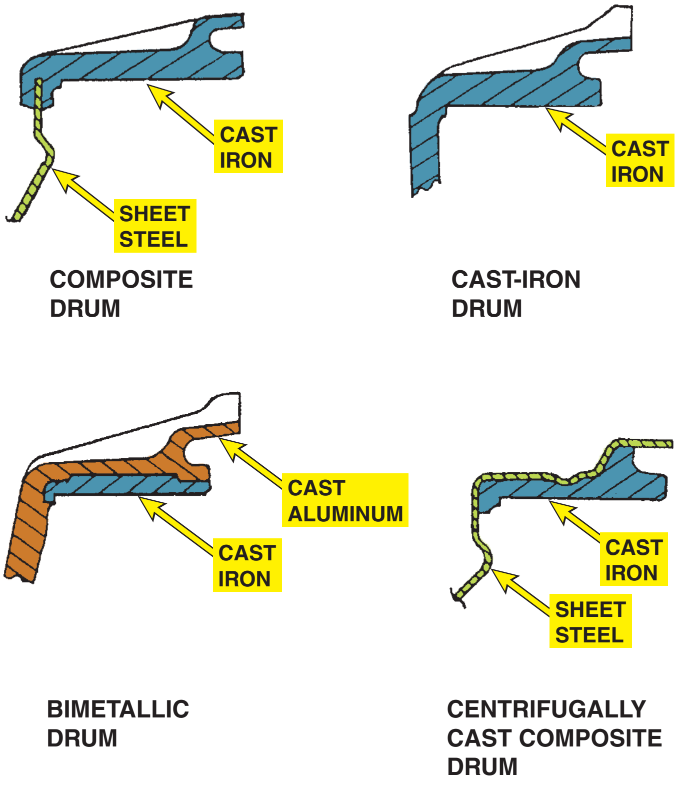


FIGURE 103–1 Types of brake drums. Regardless of the design, all types use cast iron as a friction surface.

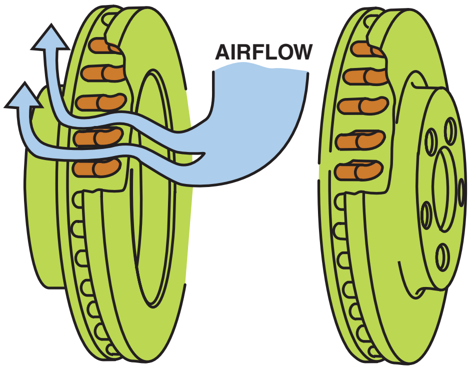


FIGURE 103–2 The airflow through cooling vents helps brakes from overheating.

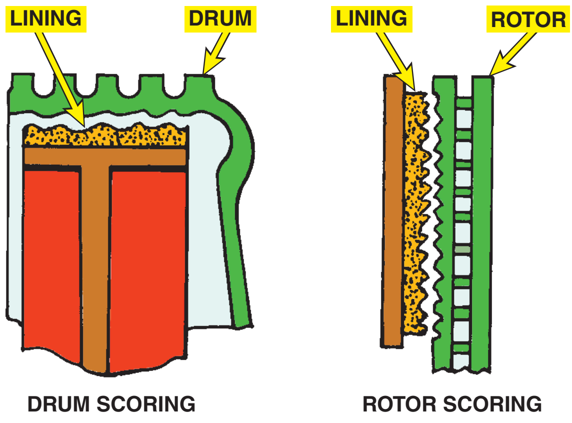


FIGURE 103–3 Scored drums and rotors often result in metal-to-metal contact.

TECH TIP

The Tap Test

Using a steel hammer, lightly tap a brake drum or rotor. It should ring if it is not cracked. If a dull thud is heard, the drum or rotor is likely cracked and should be replaced.

2. Certain friction materials are more likely to score drums and rotors than others, and glazed linings that have hardened from exposure to extreme heat can also cause scoring.
3. Drum brakes are more likely to become scored than disc brakes because their closed construction holds dirt, sand, and abrasive dust inside the friction assembly. This allows the contaminants to be scrubbed repeatedly between the linings and drum.
4. Severe drum scoring often results when metal parts of the friction assembly fatigue, break loose, and are trapped between the linings and drum.

A scored drum or rotor will cause very rapid lining wear, often accompanied by a growling or grinding noise, particularly if there is metal-to-metal contact between the shoe and drum or pad and rotor. Scoring can be machined out of a drum or rotor so long as the amount of metal removed is within the allowable limits.

CRACKING Cracks in a brake drum or rotor are caused by the stress of severe braking or an impact during an accident. ● **SEE FIGURE 103–4**. Generally, drums and rotors that have been previously machined are more susceptible to cracking than new parts. Cracks can appear anywhere on a drum or rotor, although on drums they are most often found near the bolt circle on the web, or at the open edge of the friction surface. Rotors generally crack first at the edge of their friction surfaces.

HEAT CHECKING A lesser form of drum and rotor cracking is called **heat checking**, which consists of many small, interlaced cracks on the friction surface. ● **SEE FIGURE 103–5**. These cracks typically penetrate only a few thousandths of an inch into the metal and seldom pass through the structure of the drum or rotor. Heat checking is usually caused by a driver who leaves one foot on the brake pedal while applying the accelerator with the

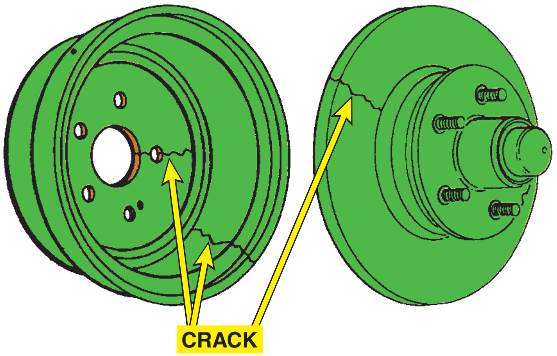


FIGURE 103–4 Cracked drums or rotors must be replaced.

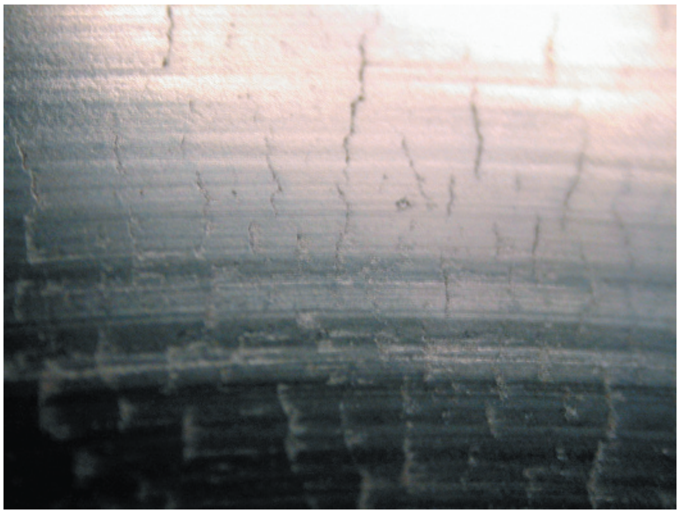


FIGURE 103–5 A heat-checked surface of a disc brake rotor.

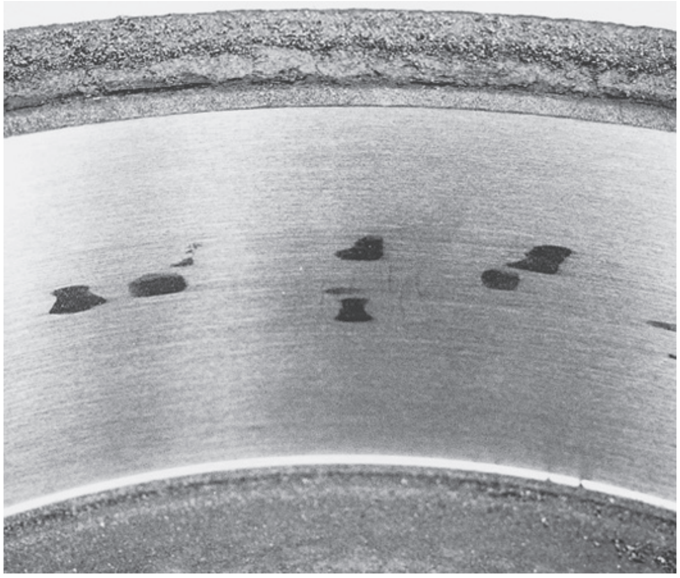


FIGURE 103–6 These dark hard spots are created by heat that actually changes the metallurgy of the cast-iron drum. Most experts recommend replacement of any brake drum that has these hard spots.

other. Heat checking can also be caused by repeated heavy braking or numerous panic stops made in rapid succession.

Light heat checking can often be machined away. In more severe cases, the drum or rotor must be replaced.

HARD OR CHILL SPOTS Earlier it was stated that cast-iron drums and rotors are durable because the friction, heat, and pressure of braking cause a tough "skin" to form on their friction surfaces. However, if brake temperatures become too great, localized impurities in the metal can be burned away, altering the structure of the metal and causing **hard spots**, also called **chill spots**, to appear. Hard spots are roughly circular, bluish gold, glassy-appearing areas on the friction surface. ● **SEE FIGURE 103–6**.

Hard spots create a number of problems including the following:

- They are harder than surrounding areas of the friction surface and do not wear at the same rate. Once the spots begin to stand out from the rest of the friction surface, they cause rapid brake lining wear.
- The friction coefficient of hard spots is less than that of surrounding areas so braking power is reduced or becomes uneven. This can cause the brakes to chatter, or result in a hard or pulsating brake pedal.
- A drum or rotor is more likely to crack in the area of hard spots than elsewhere.

Most vehicle manufacturers recommend that the drum or rotor should be replaced if hard spots are found.

TECH TIP

Storing Drums and Rotors

A common cause of distortion in new brake drums and rotors is improper storage. Drums and rotors should always be stored lying flat; they should never be stood on edge. Distortion of new drums and rotors is common, so they should be routinely checked before installation.

BRAKE DRUM DISTORTION

To ensure smooth brake application without pedal pulsation or other problems, brake drum friction surfaces must remain a fixed position in relation to the shoes. In some cases, a position variation of less than a thousandth of an inch will create braking problems. Distortion puts the drum friction surfaces out of proper alignment with the shoes.

DRUM DISTORTION The friction surface of a brake drum in perfect condition is parallel to the axis of the axle and rotates in a precise circle centered on the axle or hub. All brake drums suffer from distortion during brake operation, but they usually return to their original shape once the brakes are released. When the friction surface does not return to its proper shape, is no longer parallel to the axle, or does not rotate in a precise circle around the axle, the drum is distorted.

BELLMOUTH DRUMS When an open edge of a brake drum friction surface has a larger diameter than the closed edge, the drum is suffering from **bellmouth** distortion. ● **SEE FIGURE 103–7**. Bellmouth distortion is caused by poor drum rigidity combined with high heat and brake application force.

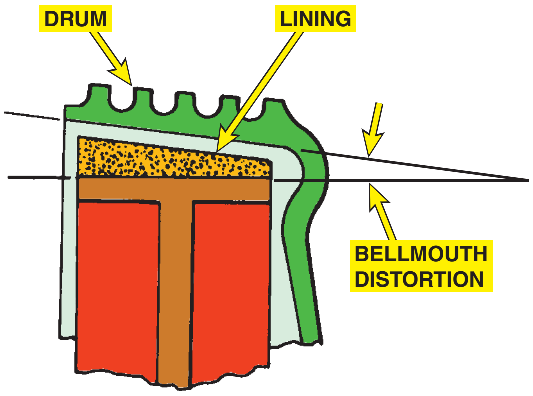


FIGURE 103–7 Bellmouth brake drum distortion.

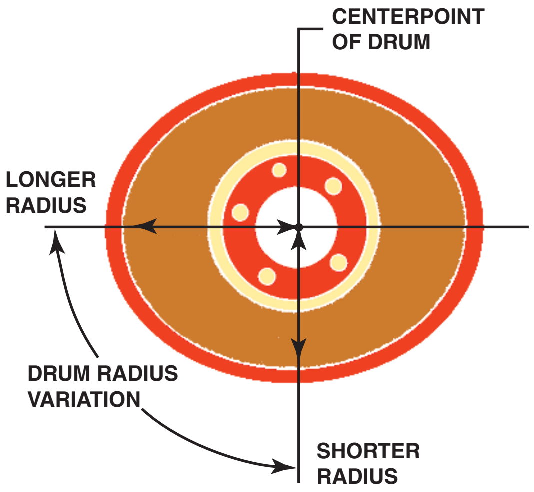


FIGURE 103–8 Out-of-round brake drum distortion.

Bellmouth distortion occurs when a drum suffers mechanical fade and its open edge, unsupported by the drum web, expands more than its closed edge. When the brakes are applied harder to compensate for the fade, the shoes distort the open edge of the drum so far outward that the **elastic limit** of its metal is exceeded. Once this happens, the drum will not return to its original shape after it cools. Repeated occurrences of this process eventually cause the drum to take on a bellmouth shape.

Bellmouth distortion is especially common on wide drums and occurs when a drum has had too much metal machined from it. If new shoes are installed in a bellmouthed drum, brake fade and unusual lining wear will result.

OUT-OF-ROUND DRUMS Uneven heat distribution can sometimes cause **out-of-round** distortion in which the drum radius varies when measured at different points around its circumference. ● **SEE FIGURE 103–8**. Out-of-round distortion can take place when a vehicle drives through a puddle after a series of hard stops and cold water splashed on the brakes causes rapid and uneven cooling of the drums. It can also result if the parking brake is firmly applied after a series of hard stops before the drums have had a chance to cool. In this case, the shoes extend out against the heat-expanded drum and prevent it from contracting to its original circular shape as it cools. Instead, the extended shoes force the drum into an out-of-round shape.

The most common symptom of an out-of-round drum is a pulsating brake pedal when the brakes are applied at all speeds. Out-of-round drums can also cause a vibration or brake chatter at speeds above approximately 40 MPH (60 km/h). In more extreme cases, an out-of-round drum can result in erratic braking action and possibly cause the brakes to grab with every revolution of the wheel.

ECCENTRIC DRUMS **Eccentric distortion** exists when the geometric center of the circle described by the brake drum friction surface is other than the center of the axle or the bolt circle of the drum web. ● **SEE FIGURE 103–9**. This type of distortion causes the drum to rotate with a camlike motion. An eccentric drum will result in a pulsating brake pedal similar to that caused by an out-of-round drum.

Eccentric distortion is often caused by overtightened or unevenly tightened lug nuts or bolts. Not only will this cause an immediate problem, but it can lead to additional problems later. If a vehicle is driven for an extended time with an eccentric drum, the linings may slowly wear the friction surface "round" again. However, as soon as tension on the lug nuts or bolts is released, the drum will relax back to its original shape creating an out-of-round condition that was not apparent before the wheel was removed.

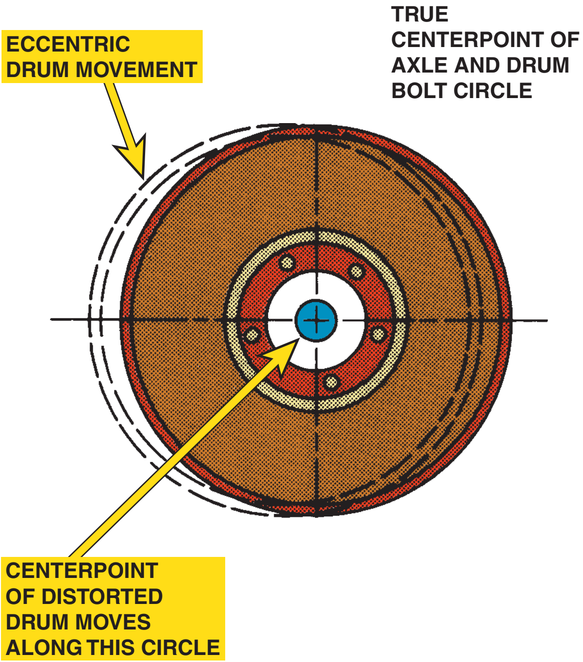

ECCENTRIC DRUM MOVEMENT
TRUE CENTERPOINT OF AXLE AND DRUM BOLT CIRCLE
CENTERPOINT OF DISTORTED DRUM MOVES ALONG THIS CIRCLE

FIGURE 103–9 Eccentric brake drum distortion.

TECH TIP

The Parking Brake Trick

Whenever attempting to diagnose a brake pedal pulsation, drive to a deserted area or parking lot and try stopping the vehicle using the parking brake. If a vibration occurs, the problem is due to a fault with the rear brakes. If a vibration does not occur except when using the service brakes, the problem is most likely due to a fault with the front brakes.

TECH TIP

Mark It to Be Sure

Most experts recommend that brake rotors, as well as drums and wheels, be marked before removing them for service. Many disc brake rotors are directional and will function correctly only if replaced in the original location. A quick-and-easy method is to use correction fluid. This alcohol-based liquid comes in small bottles with a small brush inside, making it easy to mark rotors with an "L" for left and an "R" for right. Correction fluid (also called "white-out" or "liquid paper") can also be used to make marks on wheel studs, wheels, and brake drums to help ensure reinstallation in the same location.

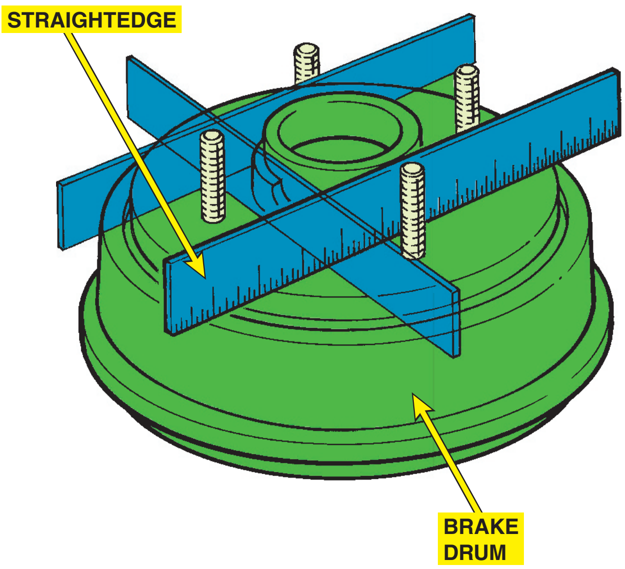


FIGURE 103–10 A straightedge can be used to check for brake drum warpage.

REMOVING DRUMS

Metal clips called **Tinnerman nuts** are installed at the factory to keep the brake drums from falling off during vehicle assembly. These clips can be removed and do not need to be reinstalled since the wheel lug nuts hold onto the brake drum.

The first inspection step after removing a brake drum is to check it for warpage using a straightedge, as shown in ● **FIGURE 103–10**.

A warped drum is often a source of vibration. A brake drum that is out-of-round can cause a brake pedal pulsation during braking.

NOTE: To help diagnose if the front brakes or rear brakes are the cause of the vibration, try slowing the vehicle using the parking brake. If vibration occurs, the problem is due to the rear brakes.

"MACHINE TO" VERSUS "DISCARD"

Brake drums can usually be machined a maximum of 0.060 inch (1.5 mm) oversize (e.g., a 9.500 in. drum could wear or be machined to a maximum inside diameter of 9.560 in.) unless otherwise stamped on the drum. Most brake experts recommend that both drums on the same axle be within 0.010 inch (0.25 mm) of each other. The maximum specified inside diameter (ID) means the maximum wear inside diameter. ● **SEE FIGURE 103–11**.

Always leave at least 0.015 inch (0.4 mm) after machining (resurfacing) for wear. Many manufacturers recommend that 0.030 inch (0.8 mm) be left for wear.

REASONS FOR EQUAL DRUM INSIDE DIAMETER There are several reasons why the service technician should check and make sure that both brake drums on the same axle are close to the same inside diameter (ID).

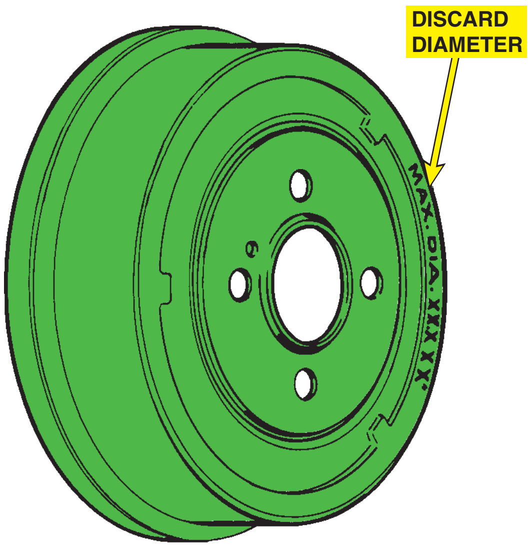


FIGURE 103–11 Discard diameter and maximum diameter are brake drum machining and wear limits.

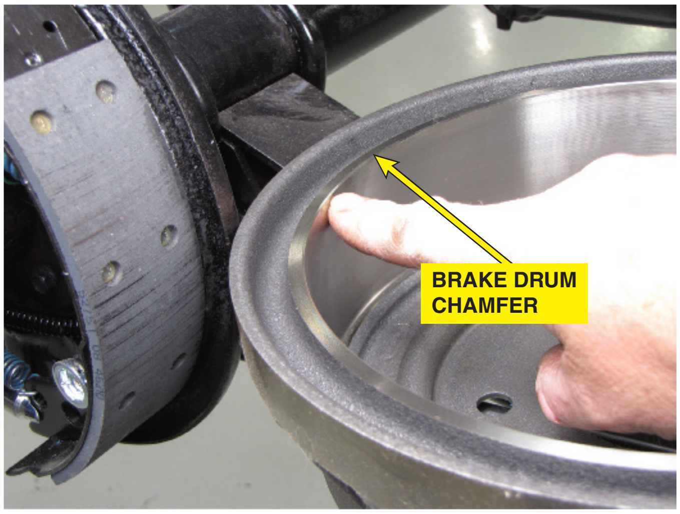


FIGURE 103–12 Most brake drums have a chamfer around the edge. If the chamfer is no longer visible, the drum is usually worn (or machined) to its maximum allowable ID.

TECH TIP

Brake Drum Chamfer

Look at the chamfer on the outer edge of most brake drums. When the chamfer is no longer visible, the brake drum is usually at or past its maximum ID. ● **SEE FIGURE 103–12**. Although this chamfer is not an accurate gauge of the ID of the brake drum, it still is a helpful indicator to the technician.

- **Reason 1.** Since heat is generated by braking, if there is less material (larger ID), the drum will tend to expand more rapidly than a drum with more material (smaller ID).
- **Reason 2.** If one drum expands more than the drum on the other side of the vehicle, unequal braking forces result.
- **Reason 3.** The drum that is larger in ID will expand away from the brake linings more than the other side.

For example:

LEFT DRUM	RIGHT DRUM
9.500 inch	9.560 inch

In this example, when the drums get hot (heavy braking), the vehicle will tend to pull to the left.

MACHINING BRAKE DRUMS

MEASURING A DRUM Before measuring a brake drum, be sure it is not cracked by tapping it with a steel hammer. The brake drum should ring like a bell. If the brake drum makes a dull thud sound, discard the drum. Brake drums are usually measured using a micrometer especially designed for brake drums. ● **SEE FIGURE 103–13**.

Compare the micrometer reading to the discard diameter. Both drums should be measured whenever they are removed for any brake service or inspection.

MACHINING A DRUM PROCEDURE Always start any machining operation by making certain that the brake drum is clean and that excess grease is removed from the hub. If the drum has a hub with bearings, check the outer bearing races (cups) for wear and replace as necessary before placing the drum on the brake lathe. Also, carefully inspect and clean the lathe spindle shaft and cones before use. Use a **self-aligning spacer (SAS)** to be assured of even force being applied to the drum by the spindle nut. Always follow the instructions for the lathe you are using.

Hubless drums use a hole in the center of the brake drum for centering. Always check that the center hole is clean and free of burrs or nicks. Typical drum brake machining steps include the following:

STEP 1 Mount the drum on the lathe and install the silencer band as shown in ● **FIGURES 103–14 AND 103–15**.

STEP 2 Turn the drum by hand before turning on the lathe to be sure everything is clean. Advance the tool bit manually until it just contacts the drum. This is called a **scratch cut**. ● **SEE FIGURE 103–16**.

STEP 3 Stop the lathe and back off the tool bit. Loosen the arbor nut, rotate the drum one-half turn (180 degrees) on the arbor, and retighten the arbor nut. ● **SEE FIGURE 103–17**. Turn the lathe on and make a second scratch cut.

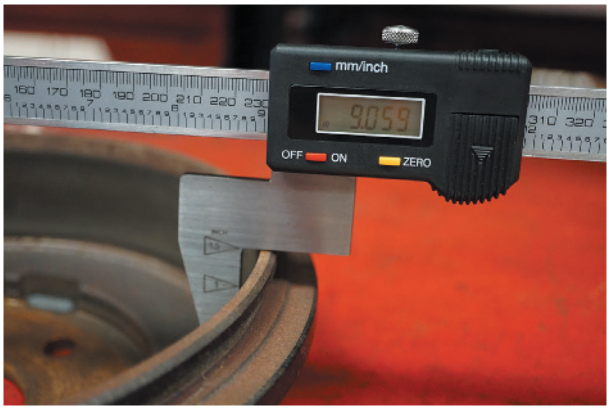


FIGURE 103–13 A digital drum micrometer makes measuring brake drums easy and accurate.

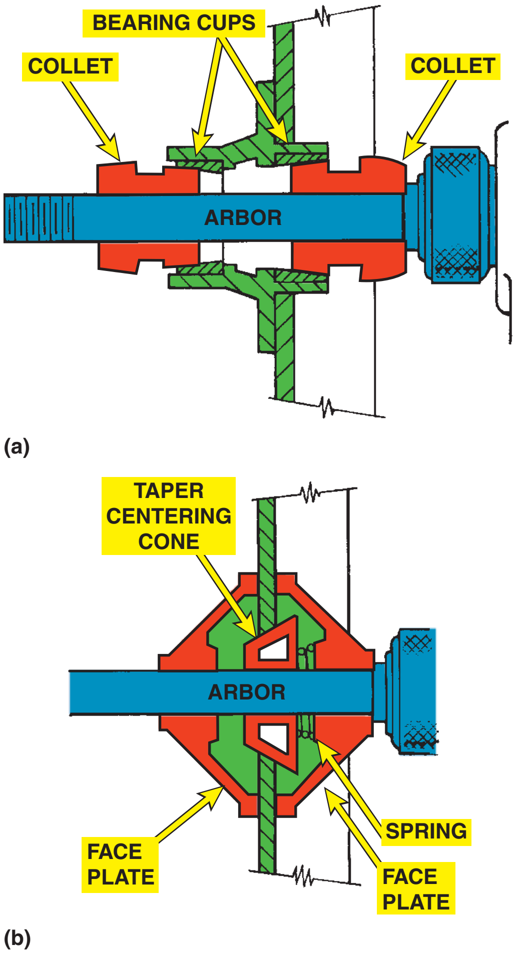


FIGURE 103–14 (a) A rotor or brake drum with a bearing hub should be installed on a brake lathe using the appropriate size collet that fits the bearing cups (races). (b) A hubless rotor or brake drum requires a spring and a tapered centering cone. A faceplate should be used on both sides of the rotor or drum to provide support.

a. If the scratch cuts are side-by-side, the lathe is okay and machining can begin.

b. If the scratch cuts are opposite, remove the drum and check for nicks, burrs, or chips on the mounting surfaces.

STEP 4 Start the lathe and set the depth of the cut. ● **SEE FIGURES 103–18 AND 103–19**.

The maximum rough cut depends on the lathe type. The minimum cut is usually specified as no less than 0.002 inch (0.05 mm). A shallower cut usually causes the tool bit to slide over the surface of the metal rather than cut into the metal.

● **SEE FIGURE 103–20** for an example of a drum machined without properly positioning the antichatter (vibration) strap.

DISC BRAKE ROTORS

CONSTRUCTION Disc brake rotors use cast gray iron at the area that contacts the friction pad. Rotors, also called **discs or disks**, have mass (weight) that absorbs heat. The heavier the rotor, the more heat can be absorbed. Vehicle downsizing has resulted in the use of thinner- and lighter-weight rotors. As

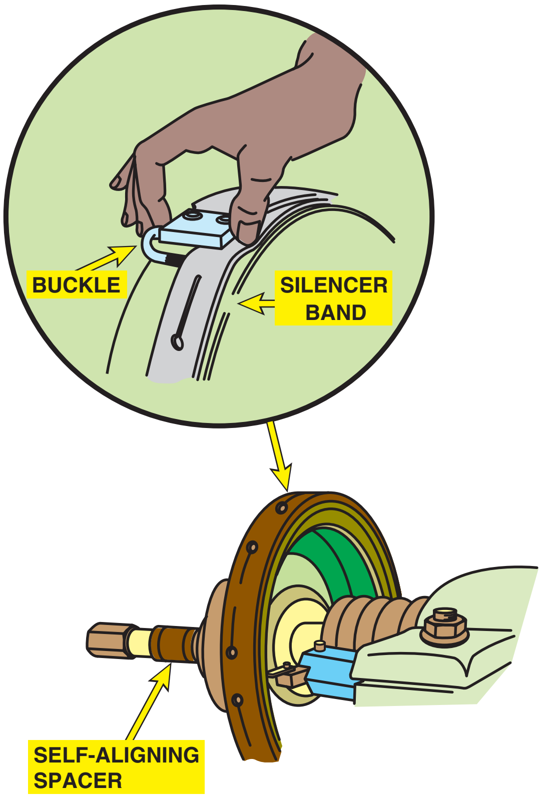

BUCKLE
SILENCER BAND
SELF-ALIGNING SPACER

FIGURE 103–15 A self-aligning spacer (SAS) should always be used between the drum or rotor and the spindle retaining nut to help ensure an even clamping force and to prevent the adapters and cone from getting into a bind. A silence band should always be installed to prevent turning-tool chatter and to ensure a smooth surface finish.

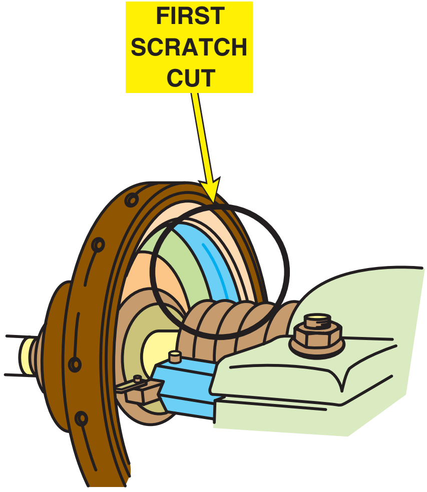

FIRST SCRATCH CUT

FIGURE 103–16 After installing a brake drum on the lathe, turn the cutting tool outward until the tool just touches the drum. This is called a scratch cut.

the weight of the rotor decreases, the less heat the rotor can "store" or absorb, resulting in the rotor getting hotter. As the rotor gets hotter, the rotor expands and "grows" larger where it is the hottest. If the rotor is allowed to cool gradually, the rotor simply returns to its original shape. If, however, the rotor is exposed to water, it may cool rapidly, causing the rotor to distort.

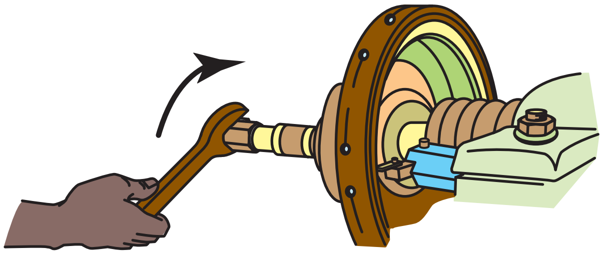


FIGURE 103–17 After making a scratch cut, loosen the retaining nut, rotate the drum on the lathe, and make another scratch cut. If both cuts are in the same location, the drum is installed correctly on the lathe and drum machining can begin.

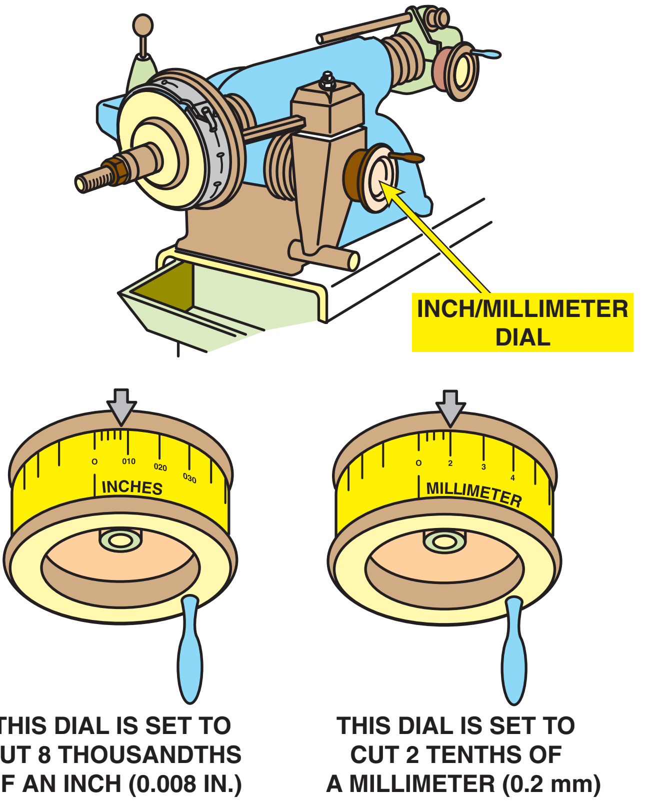

INCH/MILLIMETER DIAL
0
010
020
030
INCHES
0
2
3
4
MILLIMETER
THIS DIAL IS SET TO CUT 8 THOUSANDTHS OF AN INCH (0.008 IN.)
THIS DIAL IS SET TO CUT 2 TENTHS OF A MILLIMETER (0.2 mm)

FIGURE 103–18 Set the depth of the cut indicator to zero just as the turning tool touches the drum.

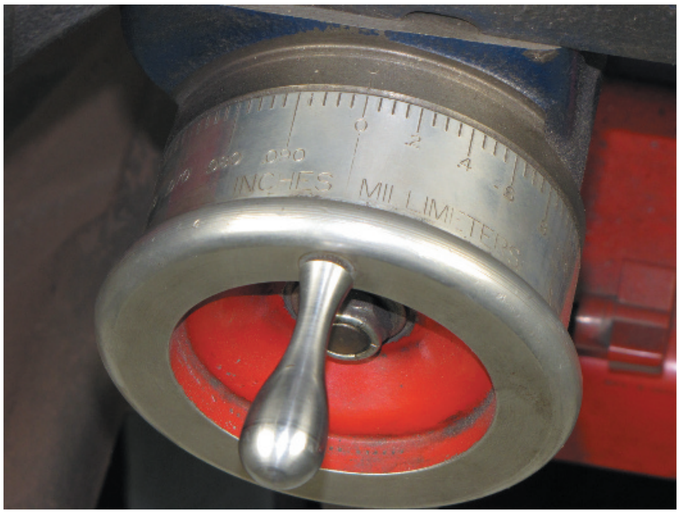


FIGURE 103–19 This lathe has a dial that is "diameter graduated." This means that a reading of 0.030 inch indicates a 0.015 inch cut that increases the inside diameter of the brake drum by 0.030 inch.

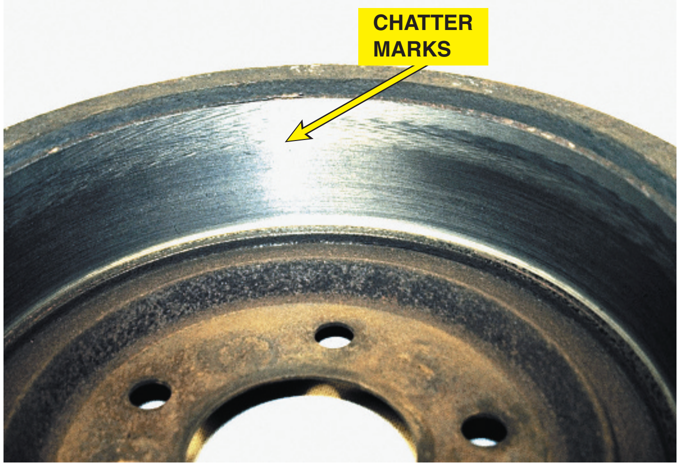


FIGURE 103–20 Notice the chatter marks at the edge of the friction-area surface of the brake drum. These marks were caused by vibration of the drum because the technician failed to wrap the dampening strap (silencer band) over the friction-surface portion of the brake drum.

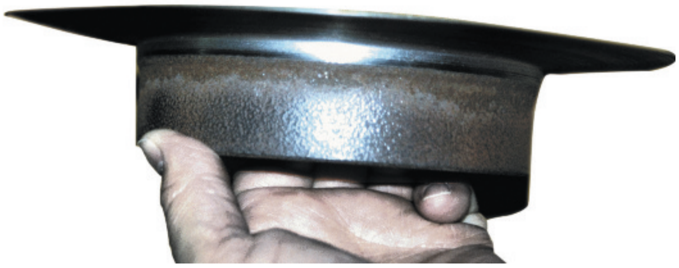


FIGURE 103–21 This excessively worn (thin) rotor was removed from the vehicle in this condition. It is amazing that the vehicle was able to stop with such a thin rotor.

STYLES OR ROTORS Rotors are made in several styles, including the following:

1. **Solid.** These are used on the rear of many vehicles equipped with rear disc brakes and on the front of some small and midsize vehicles. Solid rotors are usually used on the rear where only 20% to 40% of the braking occurs. Solid rotors are much thinner than vented rotors. ● **SEE FIGURE 103–21** for an example of an excessively worn solid rotor.
2. **Vented.** These are used on the front of most vehicles. The internal vanes allow air to circulate between the two friction surfaces of the rotor. Rotors can either be straight vane design, as shown in ● **FIGURE 103–22**, or directional vane design, as shown in ● **FIGURE 103–23**.

COMPOSITE ROTORS **Composite rotors** use a steel center section with a cast-iron wear surface. These composite rotors are lighter in weight than conventional cast-iron rotors. ● **SEE FIGURE 103–24**.

The light weight of composite rotors makes them popular with vehicle manufacturers. However, technicians should be aware that full-contact adapters that simulate the actual wheel

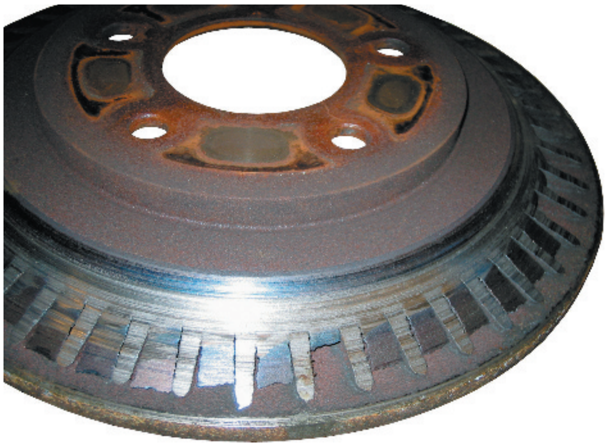


FIGURE 103–22 Severely worn vented disc brake rotor. The braking surface has been entirely worn away exposing the cooling fins. The owner brought the vehicle to a repair shop because of a "little noise in the front." Notice the straight vane design.

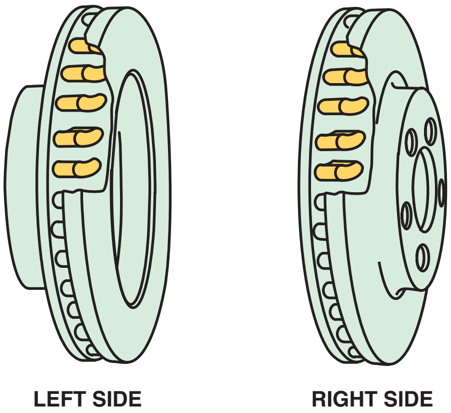


FIGURE 103–23 Directional vane vented disc brake rotors. Note that the fins angle toward the rear of the vehicle. It is important that this type of rotor be reinstalled on the correct side of the vehicle.

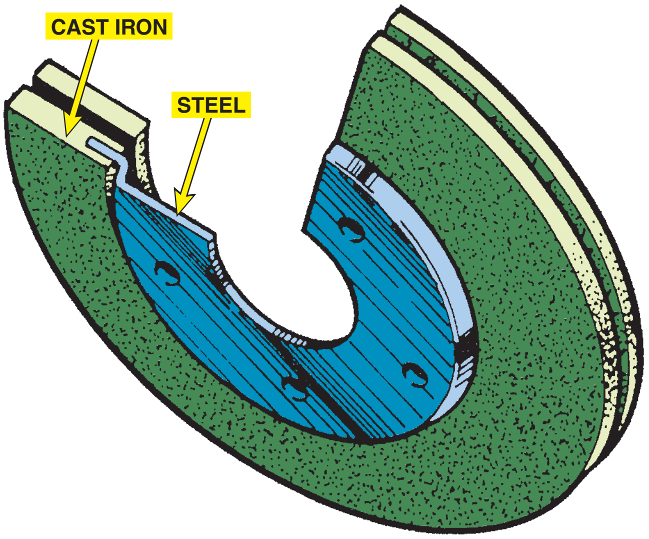


FIGURE 103–24 Typical composite rotor that uses cast-iron friction surfaces and a steel center section.

FREQUENTLY ASKED QUESTION

What Does the SAE J2928 Brake Rotor Test Mean?

The society of automotive engineers (SAE) has established a testing procedure that test aftermarket rotors called the SAE J2928 Brake Rotor Thermal Cracking Procedure. During this test, the rotor is subjected to 150 heat cycles from cold to high temperature. The heat cycles are used to test for possible cracking of the rotor. While this test is not mandatory, it can be used to verify that the rotor is able to meet the measurement and thermal capacity of a rotor. It is not an indication that the rotor is certified or approved.

being bolted to the rotor must be used when machining composite rotors. If composite rotors are machined incorrectly, they must usually be replaced.

ALUMINUM METAL MATRIX COMPOSITE ROTORS Some disc brake rotors are manufactured from an aluminum metal matrix composite alloy reinforced with 20% silicon carbide particulate. Aluminum composites combine the light weight and thermal conductivity of aluminum with the stiffness and wear resistance of a ceramic to create a disc brake rotor with excellent heat dissipation and service life.

These rotors can be distinguished from conventional cast-iron rotors in several ways. At first glance, the rotors are silver gray with a dark gray or black transfer layer (from the brake pad) on the rubbing surface. Unlike cast iron, these rotors will show no signs of rust and are nonmagnetic. When removed from the vehicle, the aluminum composite rotors can be further distinguished by their light weight, usually under 6 pounds (2.7 kg) versus over 12 pounds (5.4 kg) for cast-iron rotors on the typical passenger vehicle.

Servicing these rotors is slightly different from cast-iron rotors. The dark transfer layer on the rubbing surface does not harm rotor performance and should not be removed unless the rotor needs to be machined due to being warped. *Aluminum composite disc brake rotors cannot be machined with steel cutting tools!* Carbide tools can be used to machine a single set of aluminum composite rotors. If a shop receives these rotors on a regular basis, a polycrystalline diamond (PCD)-tipped tool is a good investment. Although more expensive initially, the PCD tool can last 100 times longer than a carbide tool.

DISC BRAKE ROTOR DISTORTION

CAUSES OF ROTOR DISTORTION The friction surfaces of a rotor in perfect condition are perpendicular to the axle centerline and have no side-to-side movement. Unlike brake drums, rotors do not suffer distortion as a routine part of brake operation. However, distortion can occur during braking if there is a problem with the friction assembly, such as a frozen caliper piston that creates unequal application force on the two sides of the rotor.

FREQUENTLY ASKED QUESTION

What Does "Cross-Drilled" and "Slotted" Mean?

The terms "cross-drilled" and "slotted" refer to two separate processes. The first procedure involves drilling rows of holes through the friction surfaces of the rotor. The second procedure refers to milling a series of specially machined grooves from the center of the disc toward the edge. When the friction surfaces of a rotor are smooth and flat, there is no means of escape for the gases and dust, which build up between pad and rotor. This is not a huge problem in normal driving, but is an important consideration in street performance applications.

The drill holes (which are sometimes called "gas relief openings") provide an exit route for the dust and gas. The holes are also commonly labeled "cooling holes" because of the improvements they make in this area. Better cooling means less fade during repeated heavy brake application. They also help dissipate water when driving in poor weather. ● **SEE FIGURE 103–25**.

Slotting increases the bite of the pads and is even more effective than cross-drilling in combating the problem known as "out-gassing." This is when, at very high braking temperatures, the bonding agents used in some brake pads produce a gas. Under extreme conditions, this gas can create a gas cushion between pad and rotor, giving a driver a normal pedal feel but reducing the amount of friction being generated. The slots pump away gas and restore full contact. The "micro-shaving" effect of the slots also serves to deglaze the pads and this is why the edges of the slots are not chamfered or "radiused." It also tends to even out the wear across the brake pad faces, increasing the effective contact area.

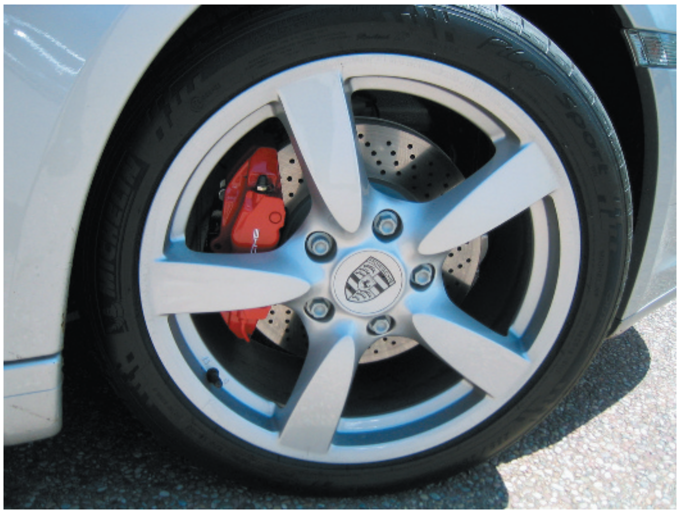


FIGURE 103–25 This Porsche is equipped with high-performance brakes including cross-drilled brake rotors.

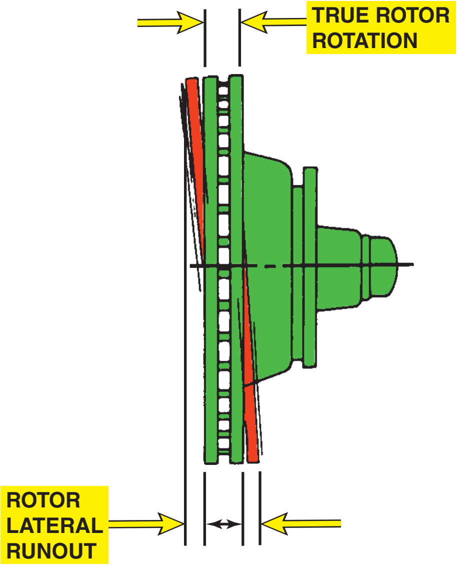


FIGURE 103–26 Brake rotor lateral-runout distortion.

Friction surface distortion is much more significant in a disc brake rotor than in a brake drum because the design of the friction assembly magnifies the effect of any wear. The hydraulic principles dictate that small movements of the large pistons in the brake calipers are converted into large movements of the small pistons in the master cylinder. Even very small amounts of distortion in a disc brake rotor can cause large amounts of pedal pulsation.

ROTOR LATERAL RUNOUT

Lateral runout, often abbreviated **LRO**, is side-to-side wobble of the rotor as it rotates on the spindle. ● **SEE FIGURE 103–26**.

A small amount of runout provides caliper piston knockback that reduces drag when the brakes are not applied. However, if the amount of runout is too great, excessive brake pedal travel and front-end vibration, felt in the steering wheel, will result. In cases of severe runout, a pulsating brake pedal may also be present.

Lateral runout can be caused by several factors. Overtightened or unevenly tightened lug nuts or bolts are a common source of runout on newer vehicles with downsized brake rotors. Extreme heat or rapid temperature variations also cause runout. Inaccurate machining at the factory or in the field is also a common cause of this distortion. Most maximum values range between 0.003 and 0.008 inch (0.05 and 0.20 mm). ● **SEE FIGURES 103–27 AND 103–28**.

ROTOR LACK OF PARALLELISM

Lack of **parallelism**, also called **thickness variation (TV)**, is a variation in the thickness of the rotor when it is measured at several places around its circumference. ● **SEE FIGURE 103–29**.

A rotor with friction surfaces that are not parallel is the most common disc brake cause of a pulsating brake pedal. A lack of rotor parallelism will cause a pedal pulsation when the brakes are applied at all speeds and can also cause front-end vibration during braking. ● **SEE FIGURE 103–30**.

Lack of parallelism can be caused by a soft spot in the rotor casting that wears more rapidly than surrounding areas, but the most common cause is rust buildup on the rotor when the vehicle is not driven for an extended period. The part of the friction surface protected by the brake pads does not rust as much as the

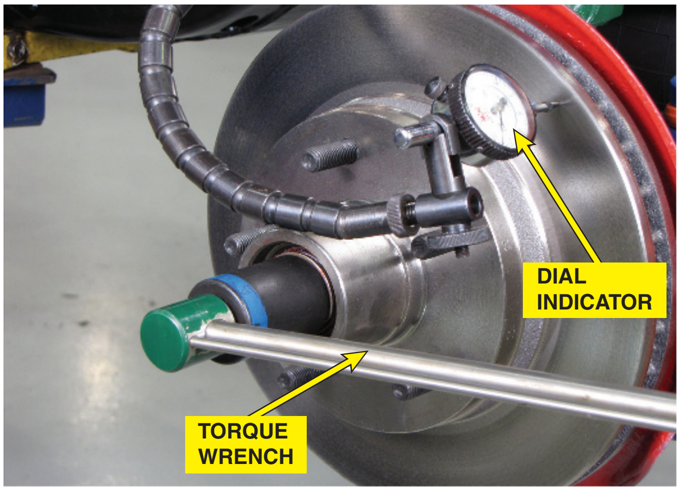


FIGURE 103–27 Before measuring lateral runout with a dial indicator (gauge), remove any wheel bearing end play by tightening the spindle nut to 10 to 20 ft-lb with a torque wrench. This step helps prevent an inaccurate reading. If the vehicle is to be returned to service, be sure to loosen the spindle nut and retighten to specifications (usually, finger tight) to restore proper bearing clearance.

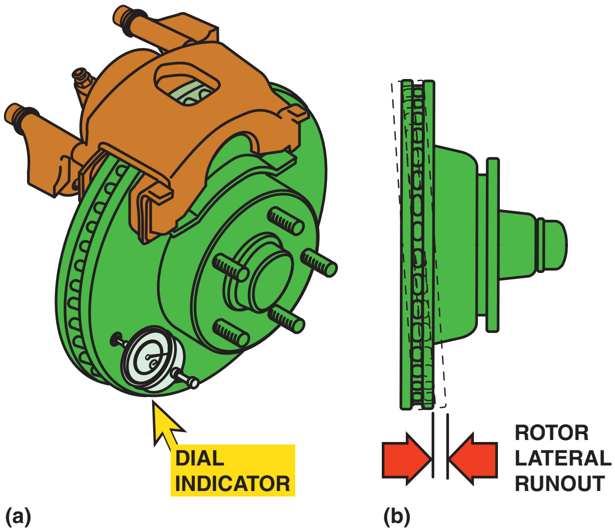


FIGURE 103–28 (a) Rotate the disc brake rotor one complete revolution while observing the dial indicator (gauge). (b) Most vehicle manufacturers specify a maximum runout of about 0.003 inch (0.08 mm).

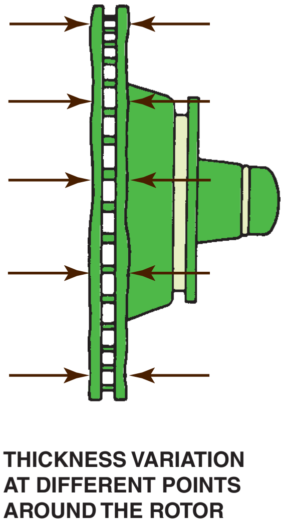


FIGURE 103–29 Brake rotor lack-of-parallelism distortion. A variation in the thickness of the rotor, commonly called **disc thickness variation (DTV)** can cause brake pedal pulsation during braking.

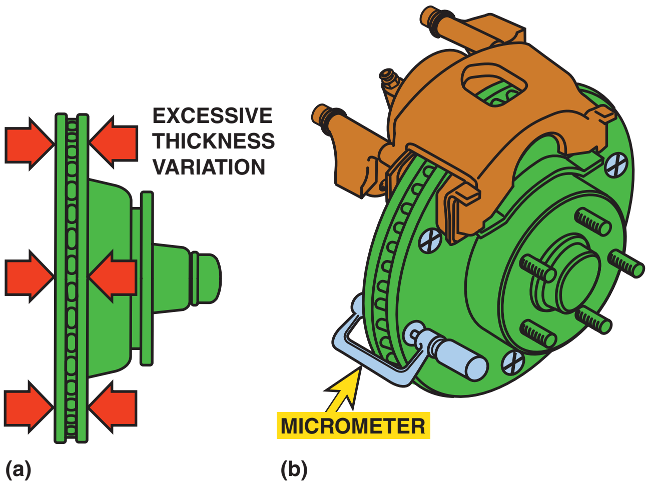


FIGURE 103–30 (a) Disc brake rotor thickness variation (parallelism). (b) The rotor should be measured with a micrometer at four or more equally spaced locations around the rotor.

TECH TIP

Braking Vibration Could Be Due to the Tires

A vibrating condition (roughness) during braking is usually caused by disc brake rotor thickness variation or an out-of-round brake drum. Both conditions should be investigated. However, the tires and/or road conditions can also cause the same vibrations.

Tests performed by vehicle and tire-manufacturing engineers have shown that tires, and tires alone, could be the cause. If no other problem can be isolated, install a different brand of tire on the vehicle and retest. The cause of the tire vibration seems to be due to distortion or movement of the tire tread. A different brand of tires would have a different tread rubber compound, carcass body ply angles, or other factor that can contribute to a vibration during braking.

TECH TIP

Think of a Human Hair

Measurements and specifications do not seem to mean much unless you can visualize the size compared to something with which you are familiar. The diameter of a human hair is from 0.002 to 0.004 inch (2 to 4 thousandths of an inch).

The maximum lateral runout of a rotor is usually within this same dimension. The reason a dial indicator has to be used to measure runout, and a micrometer to measure parallelism, is that the dimensions involved are less than the diameter of a human hair.

rest of the rotor, and because the rusted areas wear faster, this results in a thickness variation when the vehicle is driven again.

Because parallelism variation is much more likely to cause a problem than lateral runout, the maximum amount allowed is much smaller than for runout. Most manufacturers specify that the two friction surfaces of a rotor must be parallel within half a thousandth of an inch, 0.0005 inch (0.013 mm), or less.

CARBON-CERAMIC ROTORS

DESCRIPTION Carbon-ceramic brake (CCB) rotors are used on some high-performance vehicles and are very expensive. Carbon-ceramic rotors are used as standard or optional equipment on vehicles such as Aston Martin, Audi, Bentley, Bugatti, Ferrari, Lamborghini, Mercedes-Benz, and Porsche as well as on the 2009+ Corvette ZR1.

CONSTRUCTION Carbon-ceramic brake rotors are made of a carbon-fiber-reinforced ceramic silicon carbide material. The main ingredient is silicon carbide, which provides the hardness, and the other major ingredient, carbon fiber, provides the strength to the rotors. When the rotors are made, carbon fibers are blended with a resin that has carbon and silicon. The mixture is pressed into a mold to form the rotor and then heated to about 3,000°F (1,650°C) which converts the resin to silicon carbide, which is the "ceramic" in the carbon-ceramic rotor.

ADVANTAGES The advantages of carbon-ceramic brake rotors include the following:

- **Low weight**—This improves vehicle performance and handling.
- **Corrosion and wear resistant**—This means that the rotors should not need to be replaced during the life of the vehicle.

SERVICE PROCEDURES Carbon-ceramic brake rotors cannot be machined or serviced. The brake pads used with carbon-ceramic rotors are special and any other pads other than the specified brake pad should be used.

During service, if needed, the rotor is weighed and if under the minimum specified weight, must be replaced. ● **SEE FIGURE 103–31**.

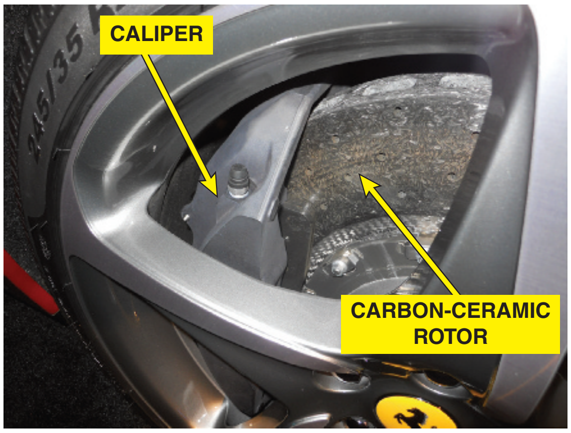


FIGURE 103–31 A carbon-ceramic brake (CCB) rotor on a Ferrari.

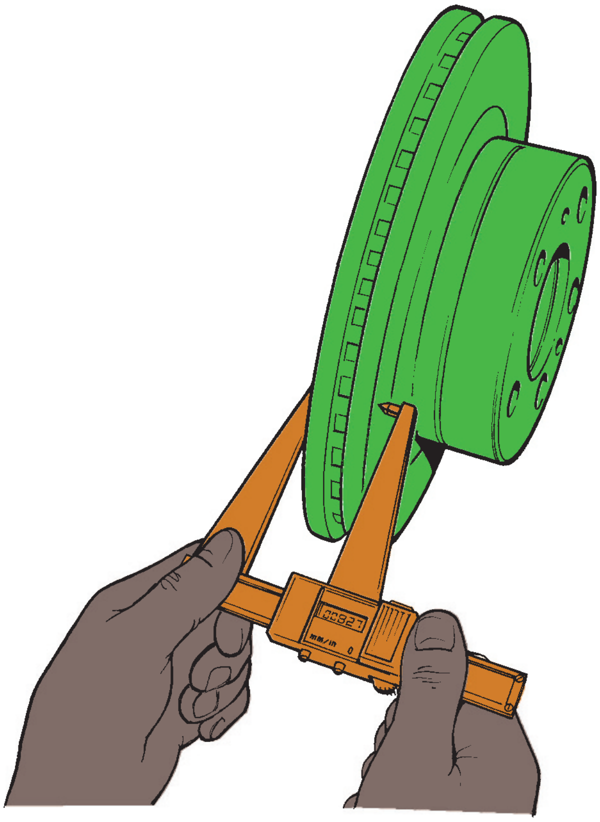


FIGURE 103–32 A digital readout rotor micrometer is an accurate tool to use when measuring a rotor. Both fractional inches and metric millimeters are generally available.

Check service information for the specified procedure to follow for removing the disc brake rotor. Inspect and clean the rotor mounting surface (hub) to make sure that it is clean and flat.

DISC BRAKE ROTOR THICKNESS

Most rotors have a minimum thickness cast or stamped into the rotor. This thickness is minimum wear thickness. At least 0.015 inch (0.4 mm) must remain after machining to allow for wear. Some vehicle manufacturers, such as General Motors, specify that 0.030 inch (0.8 mm) be left for wear. ● **SEE FIGURE 103–32**.

Whenever machining (resurfacing) a rotor, an equal amount of material must be removed from each side.

WHEN THE ROTORS SHOULD BE MACHINED

According to brake design engineers, a worn rotor has a very smooth friction surface that is ideal for replacement (new) disc brake pads. Often when the rotors are machined, the surface finish is not as smooth as specified. Therefore, a rotor should be machined only if one of the following conditions exists:

1. Grooves deeper than 0.060 inch (1.5 mm). This is the approximate thickness of a nickel. ● **SEE FIGURE 103–33**.

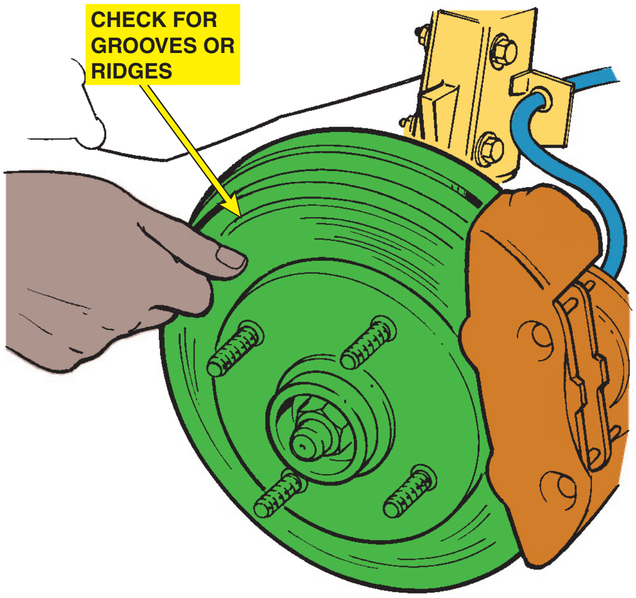

CHECK FOR GROOVES OR RIDGES

FIGURE 103–33 If a fingernail catches on a groove in the rotor, the rotor should be machined.

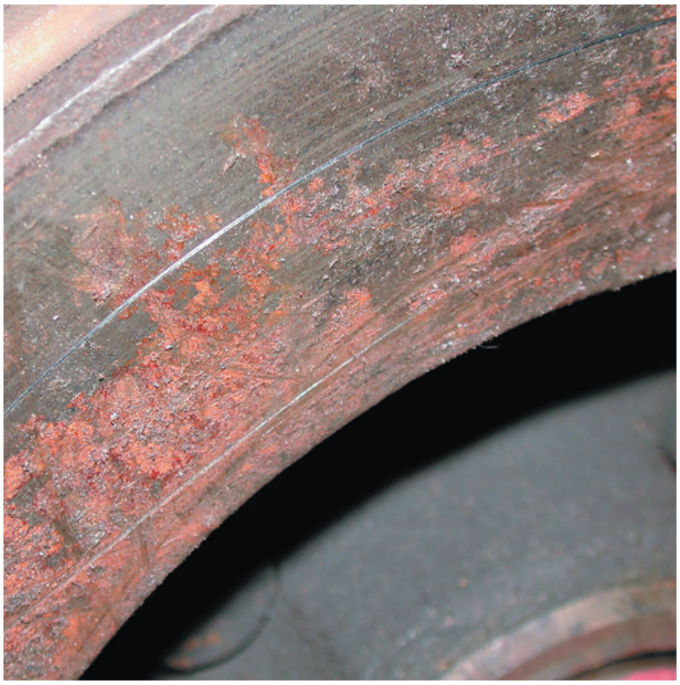


FIGURE 103–34 This rusted rotor should be machined.

2. Thickness variation exceeding specifications and a brake pedal pulsation complaint.
3. Heavy rust that has corroded the friction surface of the rotor. ● **SEE FIGURES 103–34 AND 103–35**.

Therefore, if there is no complaint of a pulsating brake pedal during braking and the rotor is not deeply grooved or rusted, it should not be machined. New disc brake pads perform best against a smooth surface, and a used disc brake rotor is often smoother than a new rotor.

ROTOR FINISH

The smoothness of the rotor is called rotor finish or surface finish. Surface finish is measured in units called **microinches**, abbreviated **μin.**, where the symbol in front of "in."

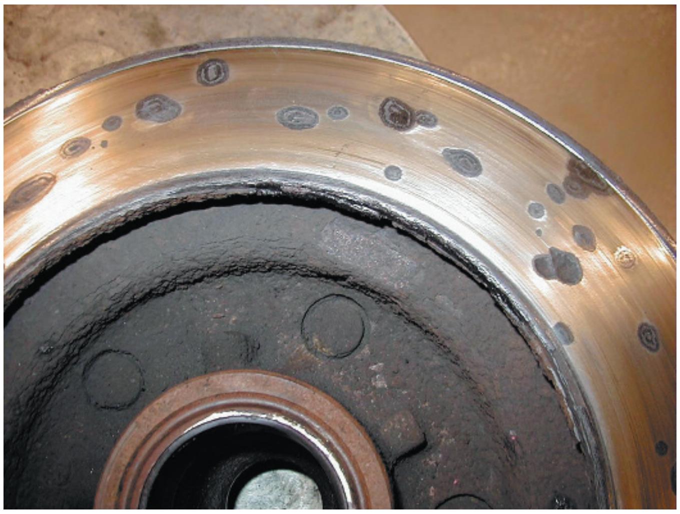


FIGURE 103–35 Rotors that have deep rust pockets usually cannot be machined.

is the Greek lowercase letter μ (mu). One microinch equals 0.000001 inch (0.025 micrometer [μm]). The finish classification of microinch means the distance between the highest peaks and the deepest valley. The usual method of expressing surface finish is the arithmetic average roughness height (AARH), **Ra**, which is the average of all peaks and valleys from the mean (average) line. This surface finish is measured using a machine with a diamond stylus, as shown in ● **FIGURE 103–36**.

Another classification of surface finish that is becoming obsolete is the *root mean square* (RMS). The RMS method gives a slightly higher number and can be obtained by multiplying Ra × 1.11 = RMS.

Often, a machined rotor will not be as smooth as a new rotor, resulting in a hard-stopping complaint after new brakes have been installed. A rough rotor has less surface area touching the new brake pads, resulting in a hard brake pedal and reduced braking effectiveness. Most new rotors have a surface finish of 45 to 60 μin. Ra.

- The higher the Ra of a rotor, the rougher the surface finish.
- The lower the Ra number, the smoother the surface finish.

TECH TIP

The Ballpoint Pen Test

A smooth friction surface on a drum or rotor is necessary for proper brake operation. To quickly determine if the friction surface of a brake drum or rotor is not smooth enough, draw a ballpoint pen across the surface. If the surface is smooth enough, a solid ink line will be observed. If the line drawn by the pen is not solid, then the surface is not smooth enough.

QUALIFYING A BRAKE LATHE

PURPOSE OF QUALIFYING A BRAKE LATHE All brake lathes should be checked regularly to make sure that they are in good condition and are capable of machining brake drums and rotors accurately.

QUALIFYING PROCEDURE To qualify a brake lathe, use the following generic checklist.

STEP 1 Check for proper operation of all motors, switches, and feed controls. Check that the engage and disengage levers function properly.

STEP 2 Make sure radius cones, bell clamps, and taper cones are free of all nicks, burrs, rust, and foreign debris. To restore flatness, use an 80-grit silicon carbide hone and WD-40 lubricant. Apply light pressure using short figure-eight movements to prevent rounding of the edges.

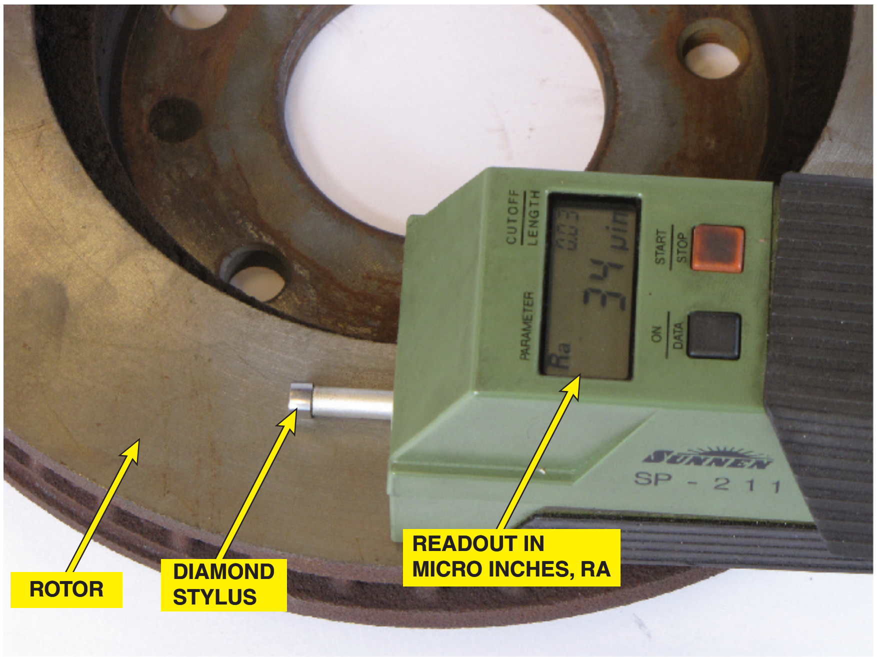


FIGURE 103–36 Electronic surface finish machine. The reading shows about 34 μin. This is a very smooth rotor and is suitable for use with any brake pad.

STEP 3 Check the tapered surfaces on the arbor and spindle to ensure these surfaces are totally free of any contamination. The arbor run out should not be over two thousandths of an inch (0.002") total indicator runout (TIR). ● **SEE FIGURE 103–37**.

STEP 4 The shoulder of the arbor must also be free of nicks or debris. Spray the shoulder of the arbor with WD-40 and use the arbor shaft for a guide to hold the hone perpendicular to the shoulder. Turn the lathe on and hone the shoulder. Apply pressure on the hone with a finger on the arbor.

STEP 5 Check fit of the rotor truer and the top of the dovetail way. A one thousandths feeler gauge should not be able to fit between the top dovetail surface and the bottom of the rotor. Remove the rotor truer and hone the top dovetail surface and the bottom of the rotor truer until the feeler gauge stock cannot be inserted.

STEP 6 The tool bit holder slots on the rotor truer should be clean. Make sure the bottom of the tool bit holder is also clean. The tool bit holder bottom can be cleaned by rubbing it on a hone or a single cut file. The carbide bit seat on the tool bit holder should be clean and flat. If the surface is not flat, replace the tool bit holder.

STEP 7 All end bell clamps can be remachined to reduce runout. Mount the bell clamp with the machined hub mating with the shoulder of the arbor. Use the two small radius adapters next on the arbor and space out to the threads with available radius adapters or one inch spacer.

Tighten the arbor nut. Put a reference mark on the bell clamp that lines up with the two marks on the spindle and arbor. Machine the face of the bell clamp with the rotor truer. True all four bell clamps.

STEP 8 Always align the inside bell clamp with the reference mark put on the hub after machining the bell clamp. Keep all mounting surfaces clean and occasionally check accuracy of setup by holding the inside bell clamp and rotating the rotor 180 degrees. Reclamp and check with the dial indicator. If runout is excessive, hone the adapter. If runout persists, remachine the adapter.

STEP 9 The inside of the hat section of the rotor must be cleaned of all rust, burrs, and any foreign matter. If any debris is present on this surface, the rotor will not reference properly while machining.

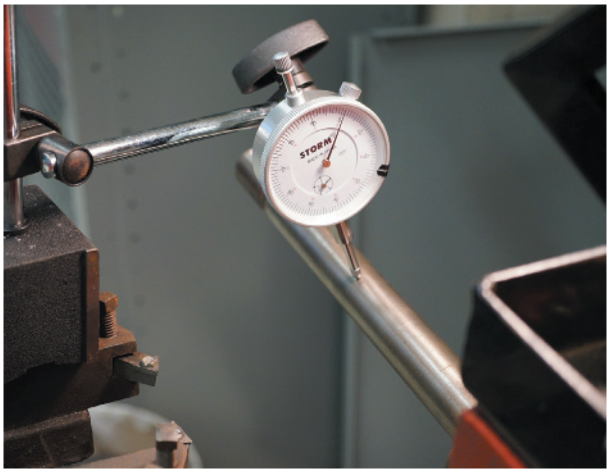


FIGURE 103–37 A dial indicator being used to check the arbor for total indicator runout (TIR) in a brake lathe.

STEP 10 All surfaces of the lathe, arbor, and all of the adapter surfaces must be free of nicks, burrs, and foreign debris.

NOTE: Always follow the lathe manufacturer's specific operating and maintenance instructions.

MACHINING A DISC BRAKE ROTOR

Before machining a rotor, be sure that it can be machined by comparing the minimum thickness specification and the measured thickness of the rotor. Many lathes are capable of removing a large amount of material in one pass, thereby reducing the time necessary to refinish a rotor. These lathes usually use a positive rake tool bit angle. ● **SEE FIGURE 103–38**.

Other lathes that use six-sided reversible tool bits usually use a negative rake tool bit angle. Ammco is an example of a negative rake lathe, whereas Perfect-Hofmann and Accu-turn are examples of positive rake lathes.

CAUTION: Some original equipment and replacement disc brake rotors are close to the minimum allowable thickness when new. Often, these rotors cannot be safely machined at all.

Following is an example of the steps necessary to machine a disc brake rotor. Always follow the instructions for the equipment you are using.

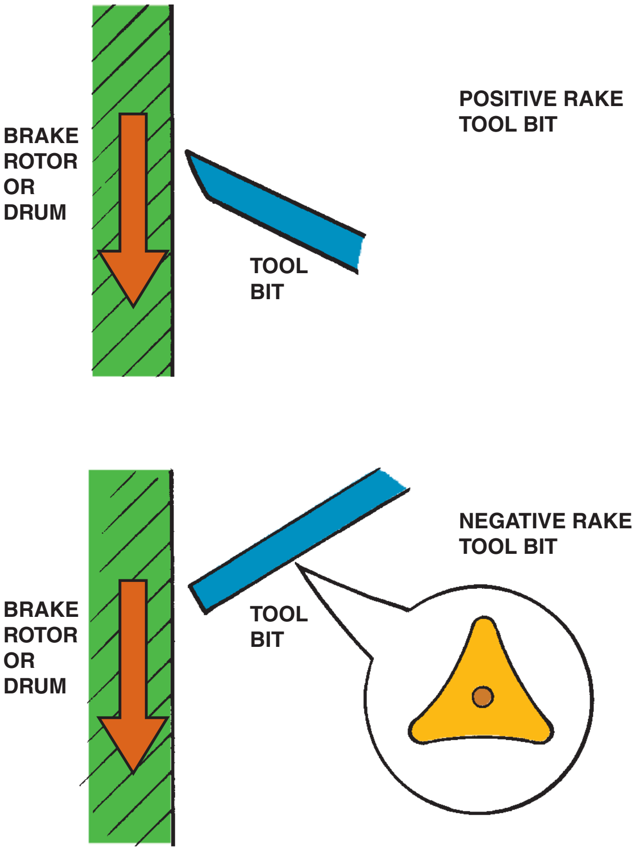
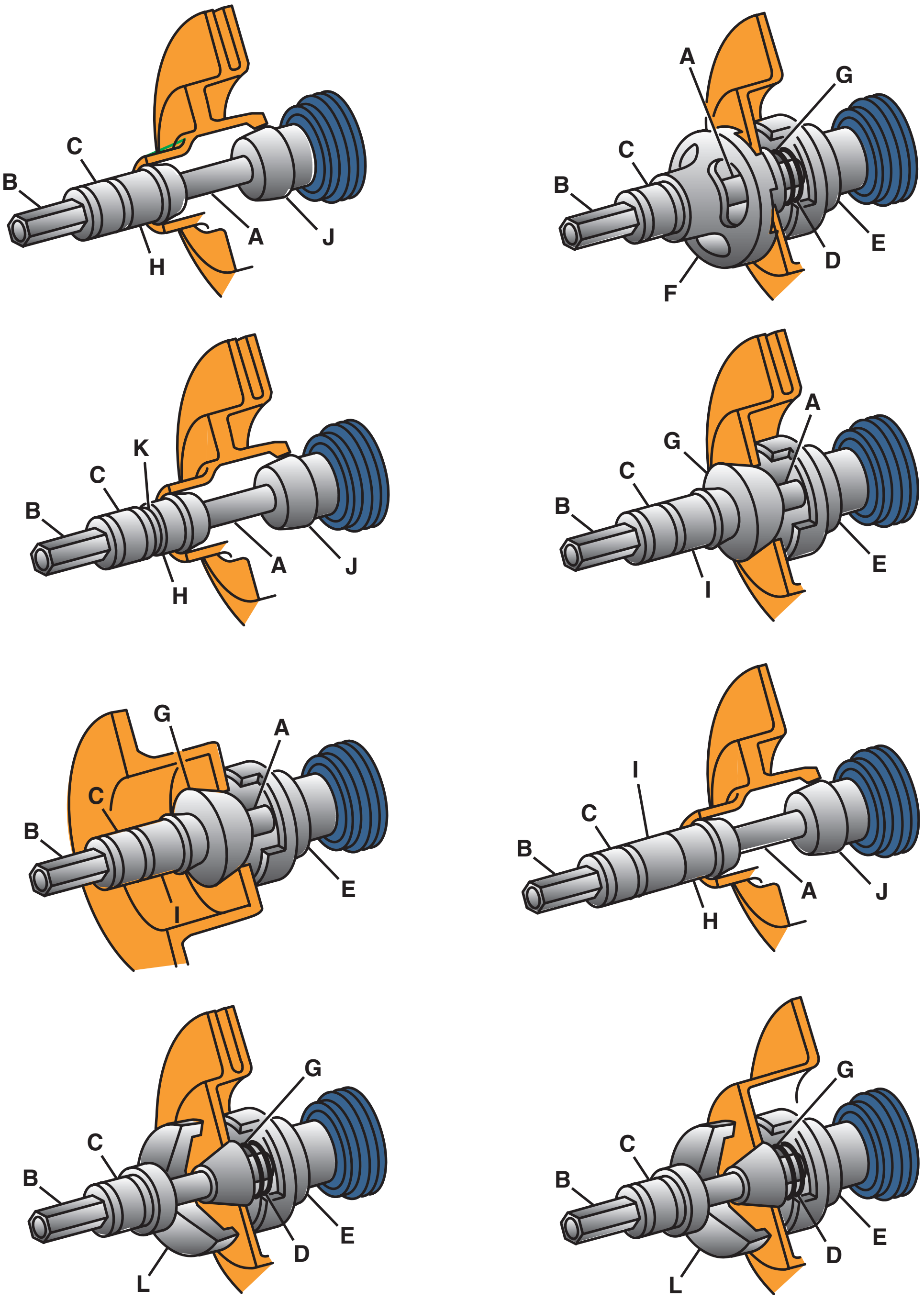


FIGURE 103–38 Most positive rake brake lathes can cut any depth in one pass, thereby saving time. A typical negative rake lathe uses a three-sided turning tool that can be flipped over, thereby giving six cutting edges.

1. Mount the disc brake rotor to the spindle of the lathe using the cones and adapters recommended. ● **SEE FIGURES 103–39 AND 103–40**.
2. Install a rotor damper and position the cutting tools close to the rotor surface, as shown in ● **FIGURE 103–41**.

NOTE: Failure to install the damper causes vibrations to occur during machining that creates a rough surface finish.

3. Make a scratch cut on the rotor face, as shown in ● **FIGURE 103–42**.
4. To check that the rotor is mounted correctly, loosen the retaining nut, turn the rotor one-half turn (180 degrees), and retighten the nut. Make another scratch cut.
   a. The second scratch cut should be side-by-side with the first scratch cut if the rotor is properly installed, as shown in ● **FIGURE 103–43**.



A	1″ ARBOR	G	CENTERING CONE
B	ARBOR NUT	H	TAPERED CONE ADAPTER
C	SELF-ALIGNING SPACER	I	ADAPTER BEING USED AS A SPACER
D	SPRING	J	TAPERED CONE ADAPTER
E	LARGE DIAMETER HUBLESS ADAPTER	K	SPACER
F	ALIGNING CU	L	SMALL DIAMETER HUBLESS ADAPTER

FIGURE 103–39 Recommended adapters and location for machining hubbed and hubless rotors.

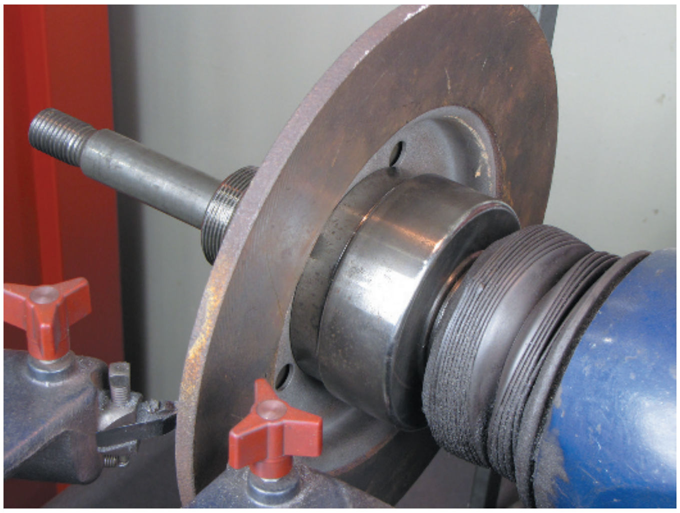


FIGURE 103–40 A composite rotor properly mounted on a brake lathe.

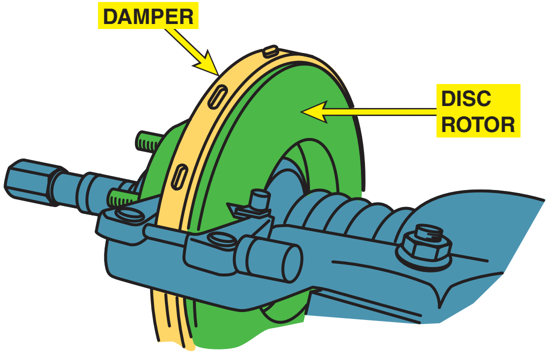


FIGURE 103–41 A damper is necessary to reduce cutting-tool vibrations that can cause a rough surface finish.

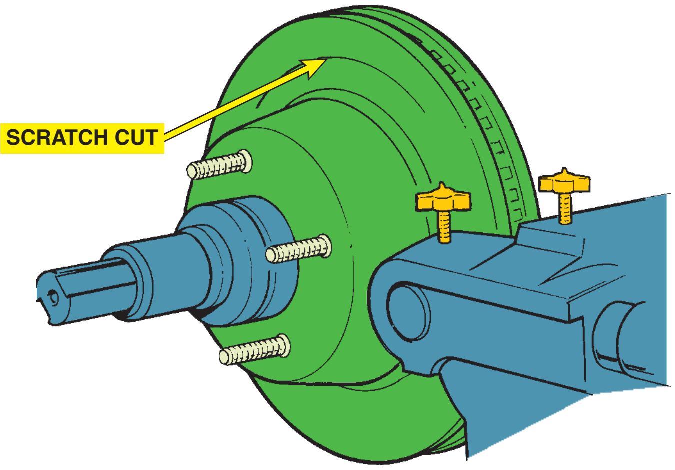


FIGURE 103–42 After installing the rotor on the brake lathe, turn the cutting tool in just enough to make a scratch cut.

b. If the second scratch cut is on the opposite side (180 degrees) from the first scratch cut, the rotor may not be installed on the lathe correctly.

NOTE: The runout as measured with a dial indicator on the brake lathe should be the same as the runout measured on the vehicle. If the runout is not the same, the rotor is not installed on the brake lathe correctly.

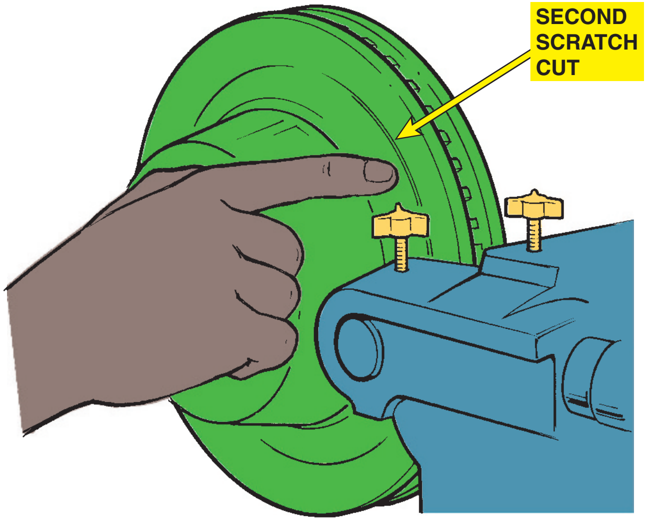


FIGURE 103–43 After making a scratch cut, loosen the retaining nut and rotate the rotor on the spindle of the lathe one-half turn. Tighten the nut and make a second scratch cut. The second scratch cut should be side-by-side with the first scratch if the rotor is installed correctly on the brake lathe.

After proper installation of the disc brake rotor on the brake lathe, proceed with machining the rotors. For best results, do not machine any more material from the rotor than is absolutely necessary. Always follow the recommendations and guidelines as specified by the vehicle manufacturer.

ROUGH CUT A rough cut on a lathe involves cutting 0.005 inch per side with a feed of 0.008 inch per revolution and 150 RPM spindle speed. This usually results in a very coarse surface finish of about 150 μin. Ra.

FINISH CUT A finish cut means removing 0.002 inch per side with a feed of 0.002 inch per revolution and 150 RPM spindle speed. Although this cut usually looks smooth, the surface finish is about 90 to 100 μin. Ra. Even a typical finish cut is still not nearly as smooth as a new rotor.

NOTE: Measure the thickness of the rotor after the finish cut and compare with manufacturer's specifications. Be sure to allow for wear. ● SEE CHART 103–1 for a metric/fractional measurement chart.

NONDIRECTIONAL FINISH Most vehicle and brake component manufacturers recommend a nondirectional finish to help prevent the grooves machined into the rotor from acting like record grooves that can force the pads to move outward while the rotor rotates.

CAUTION: Some nondirectional finish tools such as those that use Scotch Brite (a registered trademark) plastic pads often do not make the rotor as smooth as new, even though the finish has been swirled. ● SEE FIGURE 103–44.

SURFACE FINISHING THE ROTOR The goal of any brake repair or service should be to restore the braking effectiveness to match new vehicle brakes. This means that the rotor finish should be as smooth or smoother than a new rotor for

INCH	DECIMAL INCH	MILLIMETER
1/64	0.015625	0.396785
1/32	0.03125	0.79375
3/64	0.046875	1.190625
1/16	0.0625	1.5875
5/64	0.078125	1.984375
3/32	0.09375	2.38125
7/64	0.109375	2.778125
1/8	0.125	3.175
9/64	0.140625	3.571875
5/32	0.15625	3.96875
11/64	0.171875	4.365625
3/16	0.1875	4.7625
13/64	0.203125	5.159375
7/32	0.21875	5.55625
15/64	0.234375	5.953125
1/4	0.25	6.35001
17/64	0.265625	6.746875
9/32	0.28125	7.14375
19/64	0.296875	7.540625
5/16	0.3125	7.9375
21/64	0.328125	8.334375
11/32	0.34375	8.73125
23/64	0.359375	9.128125
3/8	0.375	9.525
25/64	0.390625	9.921875
13/32	0.40625	10.31875
27/64	0.421875	10.715625
7/16	0.4375	11.1125
29/64	0.453125	11.509375
15/32	0.46875	11.90625
31/64	0.484375	12.303125
1/2	0.50	12.7
33/64	0.515625	13.096875
17/32	0.53125	13.49375
35/64	0.546875	13.890625
9/16	0.5625	14.2875
37/64	0.578125	14.684375
19/32	0.59375	15.08125
39/64	0.609375	15.478125
5/8	0.625	15.875
41/64	0.640625	16.271875
21/32	0.65625	16.66875
43/64	0.671875	17.065625
11/16	0.6875	17.4625
45/64	0.703125	17.859375
23/32	0.71875	18.25625
47/64	0.734375	18.653125
3/4	0.75	19.05
49/64	0.765625	19.446875
25/32	0.78125	19.84375
51/64	0.796875	20.240625
13/16	0.8125	20.6375
53/64	0.828125	21.034375
27/32	0.84375	21.43125
55/64	0.859375	21.828125
7/8	0.875	22.225
57/64	0.890625	22.621875
29/32	0.90625	23.01875
59/64	0.921875	23.415625
15/16	0.9375	23.8125
61/64	0.953125	24.209375
31/32	0.96875	24.60625
63/64	0.984375	25.003125
1	1.00000	25.4

CHART 103–1

Metric/fractional chart.

maximum brake pad contact. Research conducted at Delphi has shown that like-new rotor finish can easily be accomplished by using a block and sandpaper. After completing the finish cut, place 150-grit aluminum-oxide sandpaper on a block and apply steady pressure against the rotor surface for 60 seconds on each side of the rotor. ● **SEE FIGURE 103–45**.

The aluminum oxide is hard enough to remove the highest ridges left by the lathe cutting tool. This results in a surface finish ranging from 20 to 80 μin. and usually less than 40 μin., which is smoother than a new rotor. ● **SEE FIGURE 103–46**.

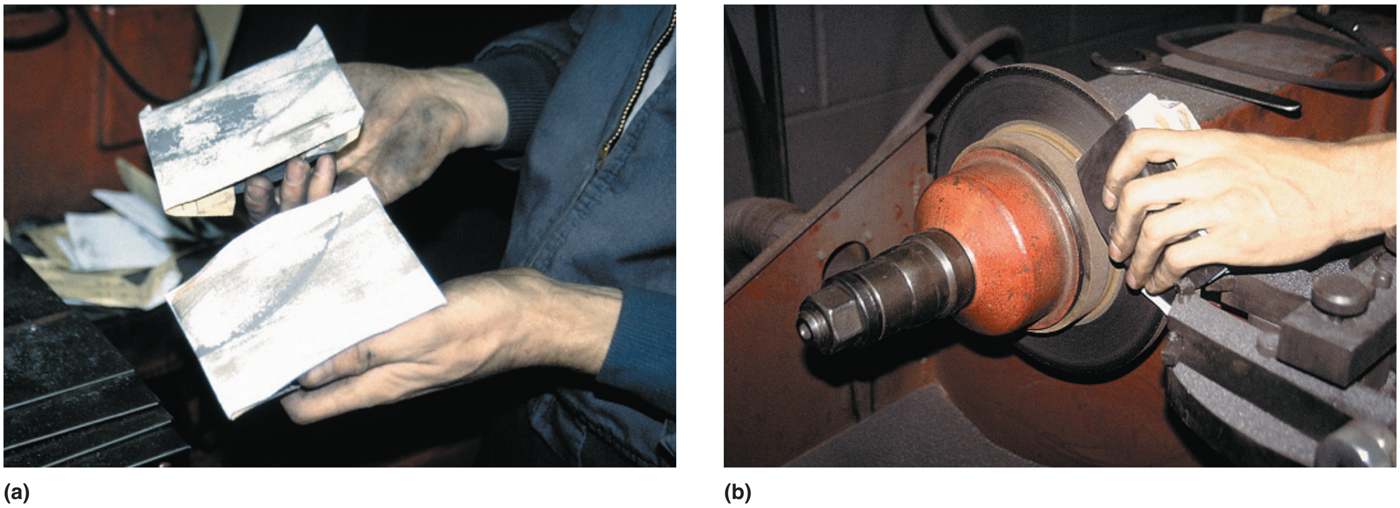
NOTE: Many commercial rotor-finish products may also give as smooth a surface finish. ● SEE FIGURES 103–47 AND 103–48.

Always compare rotor finish to the rotor finish of a new rotor. Microinch finish is often hard to distinguish unless you have a new rotor with which to compare.

ON-THE-VEHICLE ROTOR MACHINING

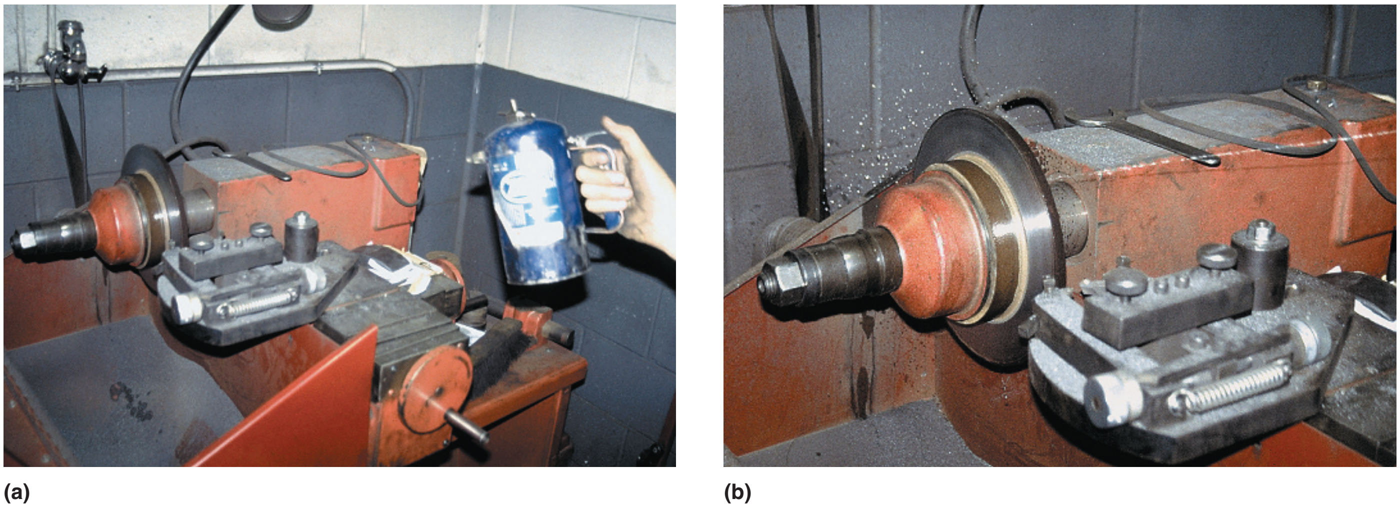
Many vehicle manufacturers recommend on-the-vehicle machining for rotors if the disc brake rotor must be machined due to deep scoring or pulsating brake pedal complaint. This is especially true of composite rotors or for vehicles, such as many Honda vehicles, that require major disassembly to remove the rotors.

Caliper-mount, on-the-vehicle lathes require that the disc brake caliper be removed. The cutter attaches to the steering knuckle or caliper support in the same location as the caliper. ● **SEE FIGURE 103–49**. Hub-mount, on-the-vehicle lathes attach to the hub using the lug nuts of the vehicle. To achieve a proper cut, the hub mount must be calibrated for any runout caused by the hub bearings and the outside surface face of the rotor.


(a)

(b)

FIGURE 103–44 (a) This technician uses two sanding blocks each equipped with 150-grit aluminum-oxide sandpaper. (b) With the lathe turned on, the technician presses the two sanding blocks against the surface of the rotor after the rotor has been machined to achieve a smooth microinch surface finish. Most experts recommend washing the rotor with soap and water to remove the grit from the sanding operation from the fine grooves in the rotor before they are installed on the vehicle.


(a)

(b)

FIGURE 103–45 (a) After machining and sanding the rotor, it should be cleaned. In this case, brake cleaner from an air pressurized spray can is used. (b) With the lathe turning, the technician stands back away from the rotor and sprays both sides of the rotor to clean it of any remaining grit from the sanding process. This last step ensures a clean, smooth surface for the disc brake pads and a quality brake repair. Sanding each side of the rotor surface for one minute using a sanding block and 150-grit aluminum-oxide sandpaper after a finish cut gives the rotor the proper smoothness and finish.

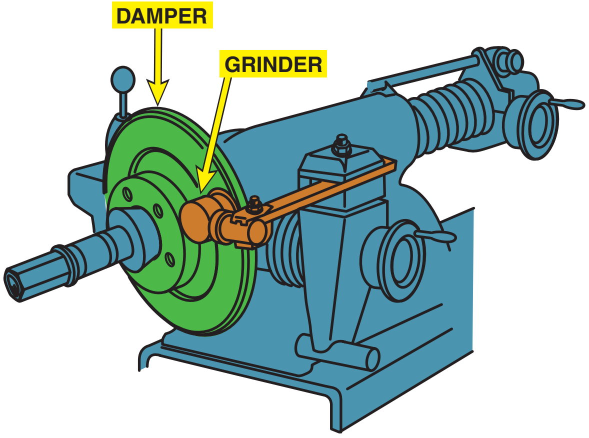


FIGURE 103–46 A grinder with sandpaper can be used to give a smooth nondirectional surface finish to the disc brake rotor.

TECH TIP

Turn or Machine?

When asked about what was done to their vehicle, a common response of customers is "They rotated my rotors." Many customers do not understand the terms that are commonly used in the vehicle service industry. Try to use terms that are technically correct and avoid slang when talking to customers. For example, the expression *machined the rotors* indicates an operation, whereas the expression *turned the rotors* may be misinterpreted by some customers as simply meaning using your hand and moving (rotating) the rotor. *Resurfacing*, *refinishing*, and *reconditioning* are other terms that could be used to describe a drum or rotor machining operation.

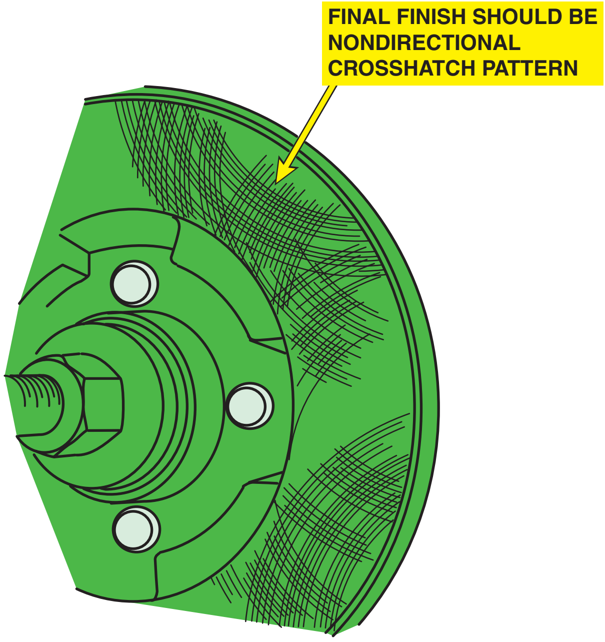


FIGURE 103–47 The correct final surface finish should be smooth and nondirectional.

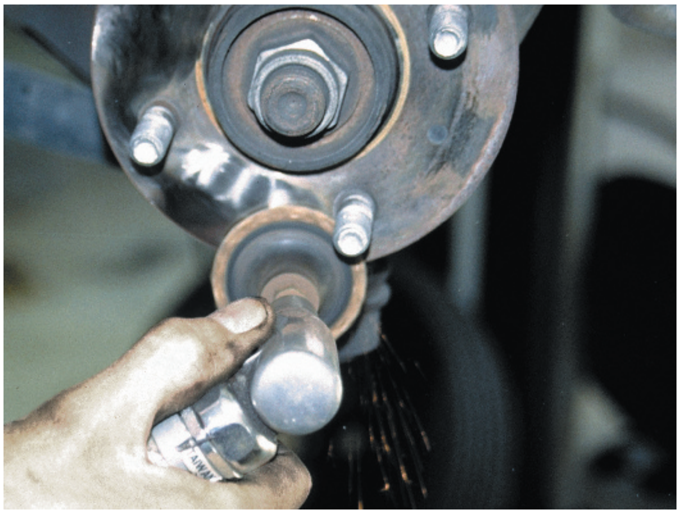


FIGURE 103–48 Rust should always be cleaned from both the rotor and the hub whenever the rotors are machined or replaced. An air-powered die grinder with a sanding disc makes quick work of cleaning this hub.

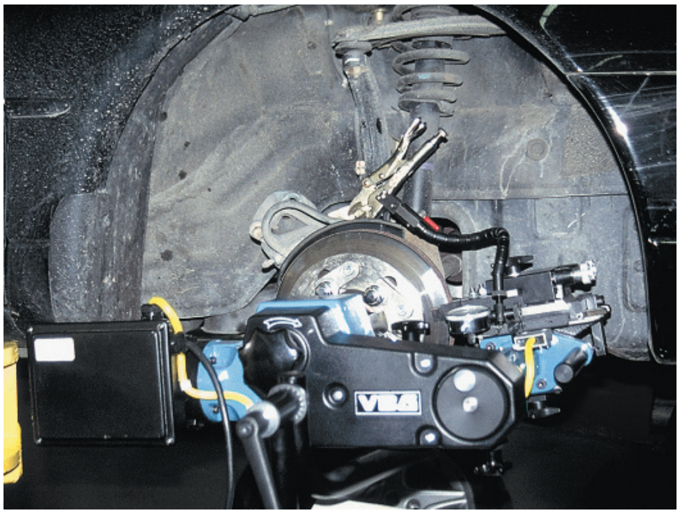


FIGURE 103–49 A typical hub-mount on-the-vehicle lathe. This particular lathe oscillates while machining the rotor, thereby providing a smooth and nondirectional finish at the same time.

NOTE: All on-the-vehicle lathes require that the wheel be removed. For best results, always use a torque wrench when tightening lug nuts or lathe adapters. Unequal torque on the bolts causes stress and distortion that can cause warped rotors and a pulsating brake pedal.

TECH TIP

Always Check the Wheel Studs

Before installing the wheel after brake service, check the condition of the wheel studs and lug nuts. Check for stripped threads, rust, or cracks. If necessary, replace the stud. Most studs are replaced by driving them out using a large hammer and then using washers and a lug nut to draw the serrated shoulder of the lug stud into the rotor stud hole. ● **SEE FIGURE 103–50**. Always use a torque wrench when installing lug nuts to ensure proper and even torque on all lug nuts. This helps to prevent rotor distortion, which can lead to vibration in the steering and/or pedal pulsation during braking.

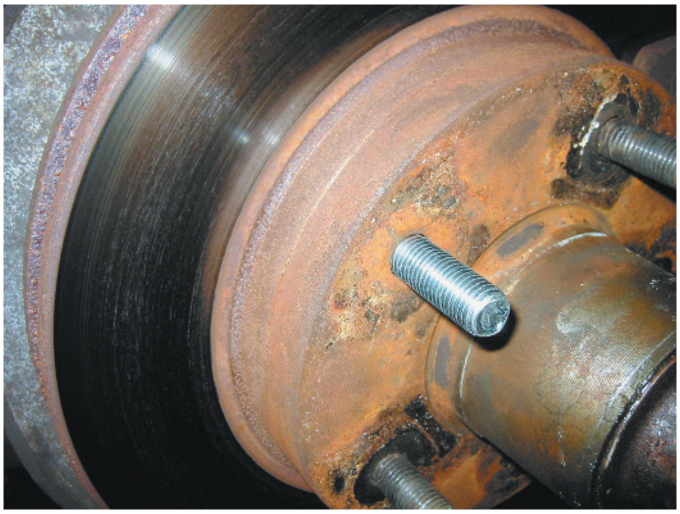


FIGURE 103–50 A wheel stud was replaced on the rotor hub assembly when it was discovered to be stripped.

DRUM MACHINING

STEP BY STEP

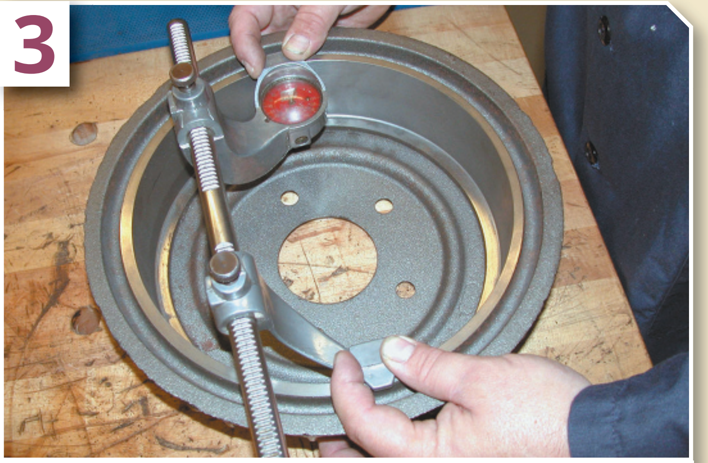
1

Before starting to machine a brake drum, check the drum for any obvious damage such as heat cracks or hard spots.

2

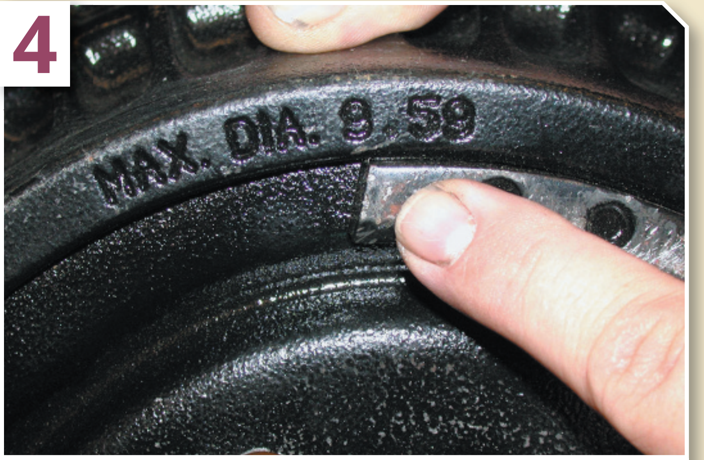
Lightly tap the drum. It should ring like a bell. If a dull thud is heard, the drum may be cracked and should be discarded.

3



Use a drum micrometer to measure the inside diameter of the drum and compare this measurement to specifications to be sure that the drum can be safely machined.

4



Most brake drums have the maximum inside diameter cast into the drum as shown.

5

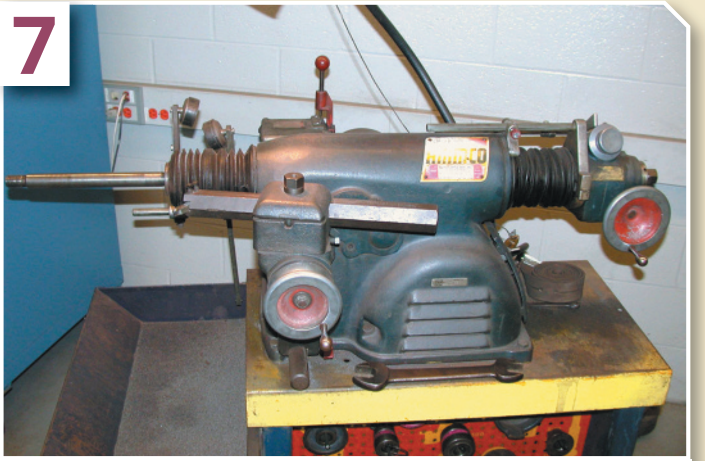
Thoroughly clean the outside and inside of the drum.

6

Be sure the center hole in the drum is clean and free from any burrs that could prevent the drum from being properly centered on the shaft of the brake lathe.

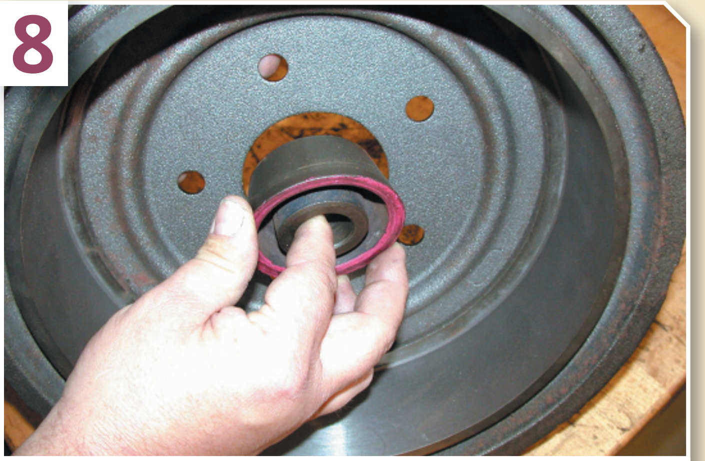
DRUM MACHINING

7



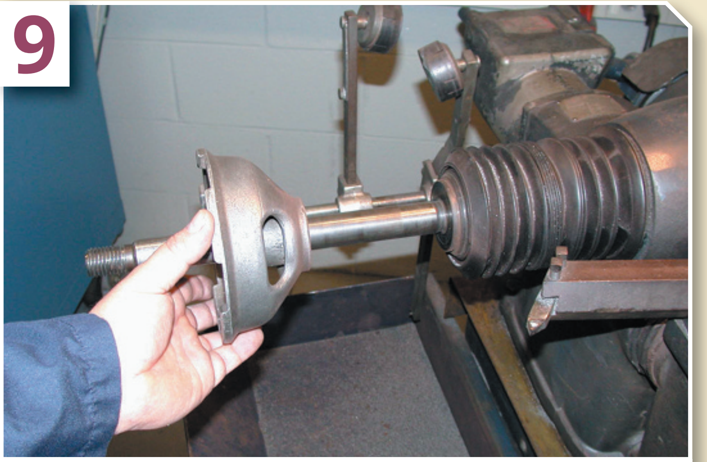
A typical brake lathe used to machine drums.

8



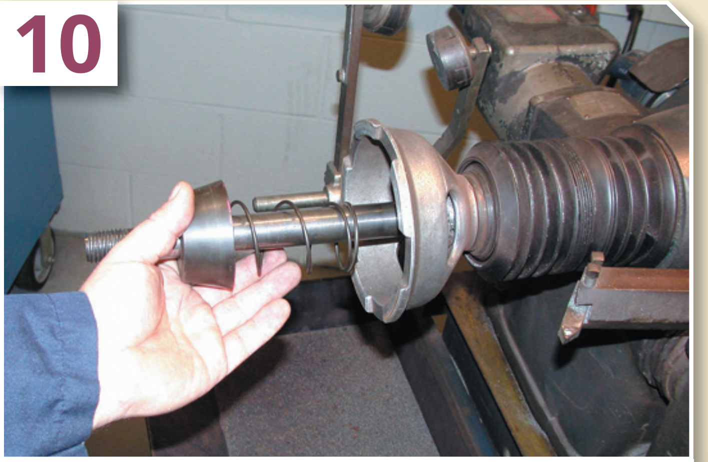
Locate a tapered, centering cone that best fits inside the hole of the brake drum.

9



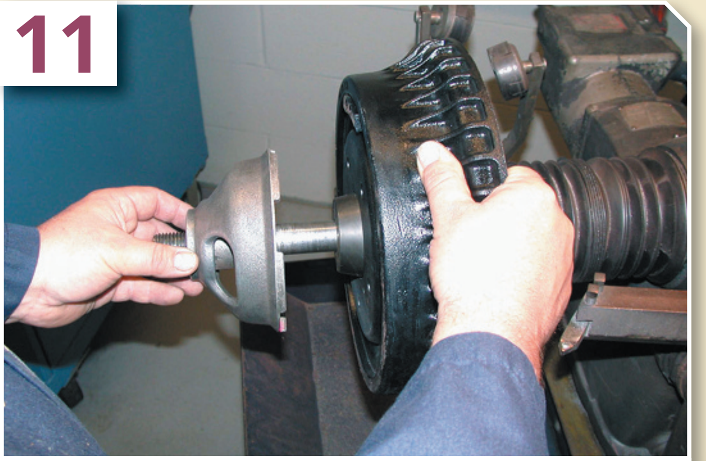
Slide the large face plate over the shaft of the brake lathe.

10



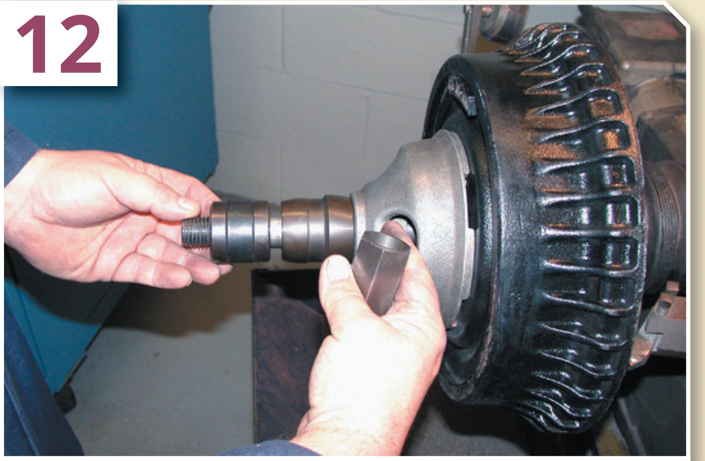
Slide the tapered centering cone onto the shaft with the spring between the face plate and the centering cone.

11



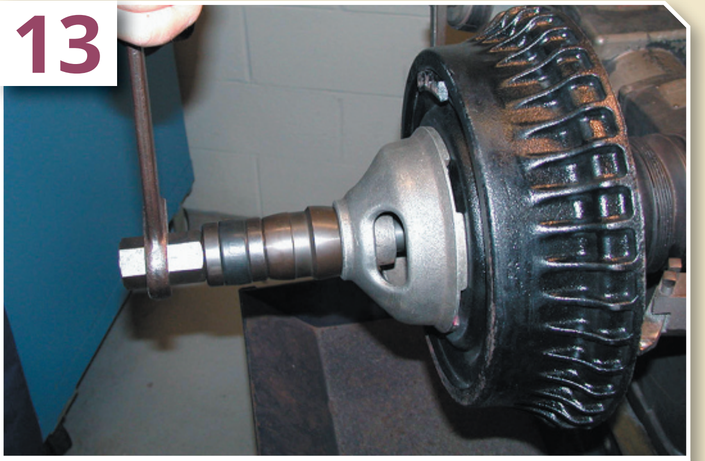
Slide the other face plate onto the shaft.

12



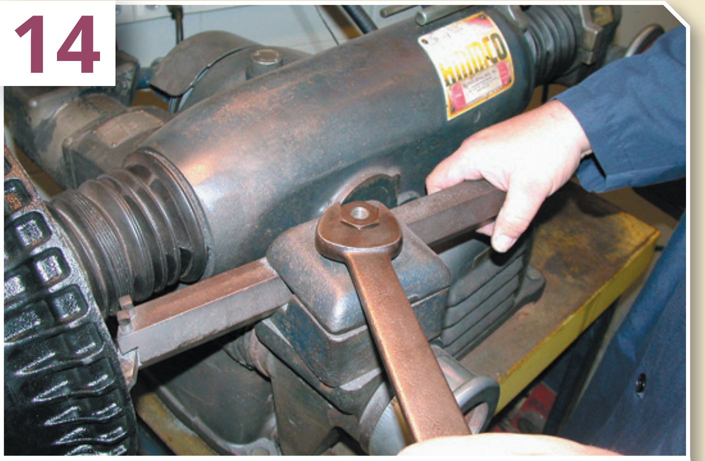
Install the self-aligning spacer (SAS) and left-hand-thread spindle nut.

13



Tighten the spindle nut.

14

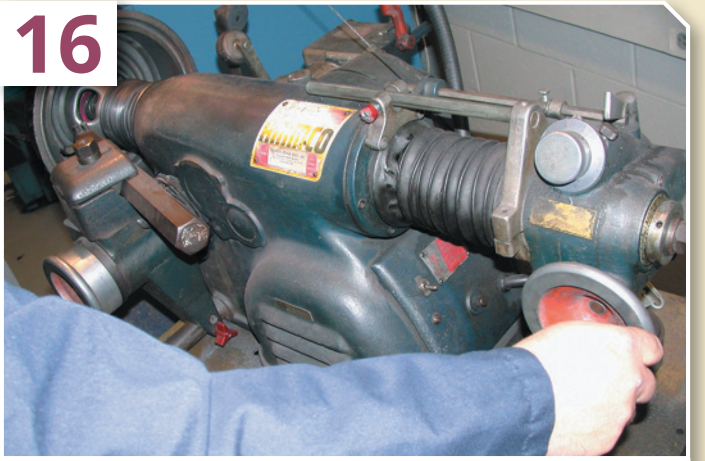


Loosen the turning bar retainer.

15

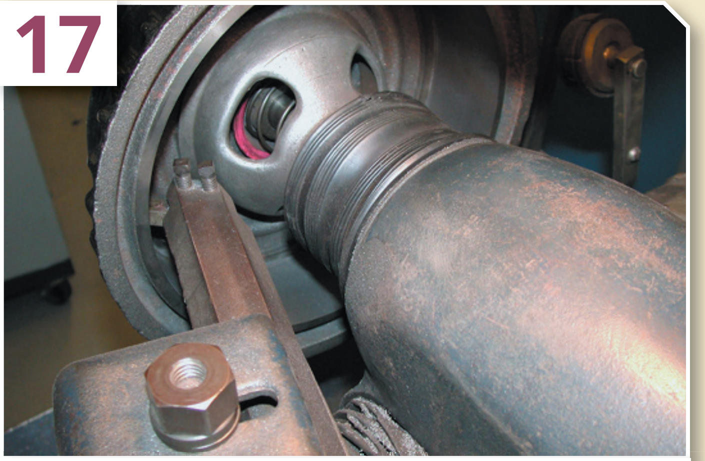
Carefully check the cutting bits and either rotate the bit to a new cutting point or replace it with a new part as necessary.

16



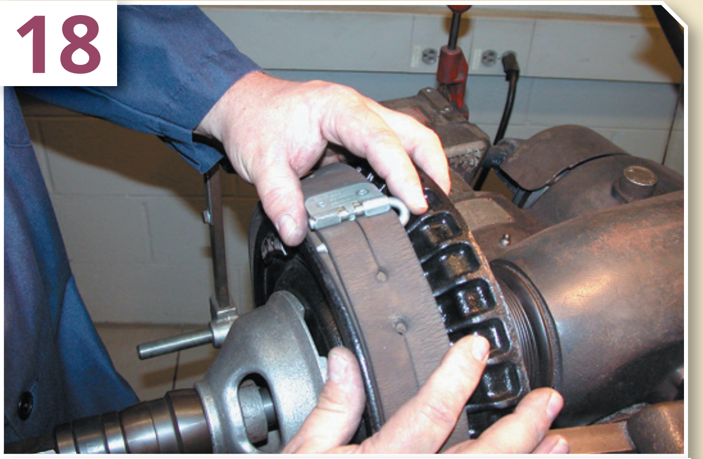
Turn the spindle control knob until the spindle is as short as possible (i.e., the drum as close to the machine as possible) to help reduce vibration as much as possible.

17



Position the cutting bar so that the cutting bit is located at the back surface of the drum.

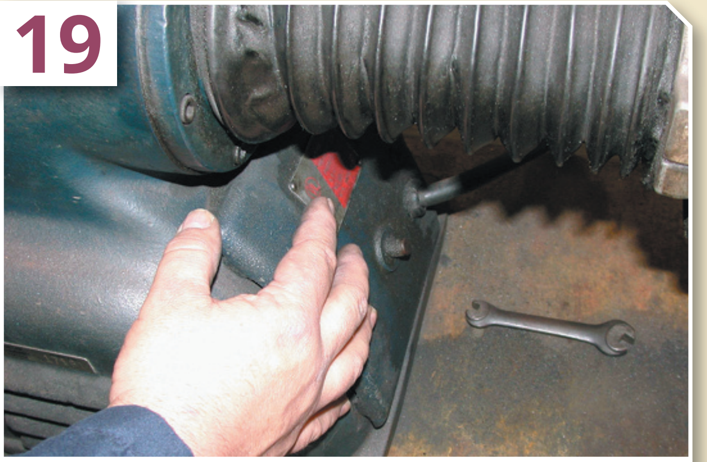
18



Install the silencer band (vibration dampener strap).

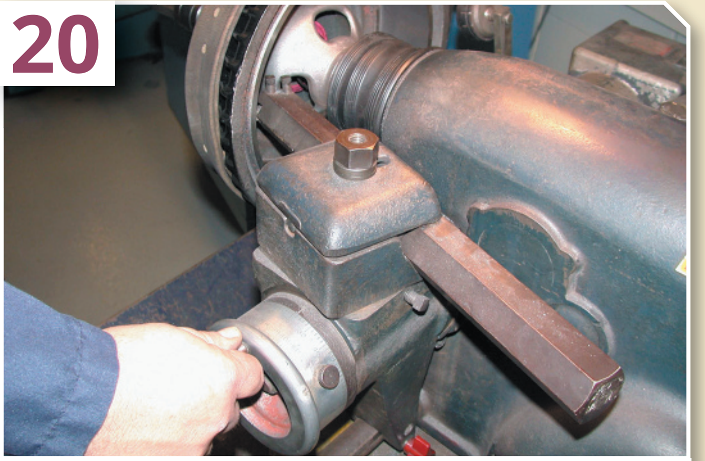
DRUM MACHINING

19



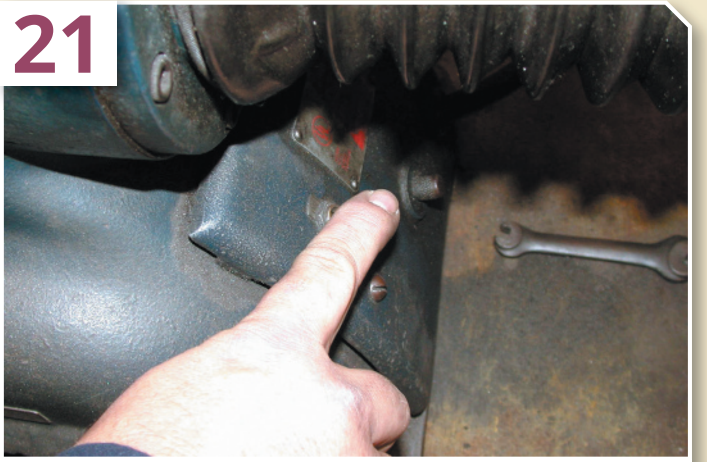
Be sure the tool bit and clothing are away from the drum and turn the brake lathe on.

20



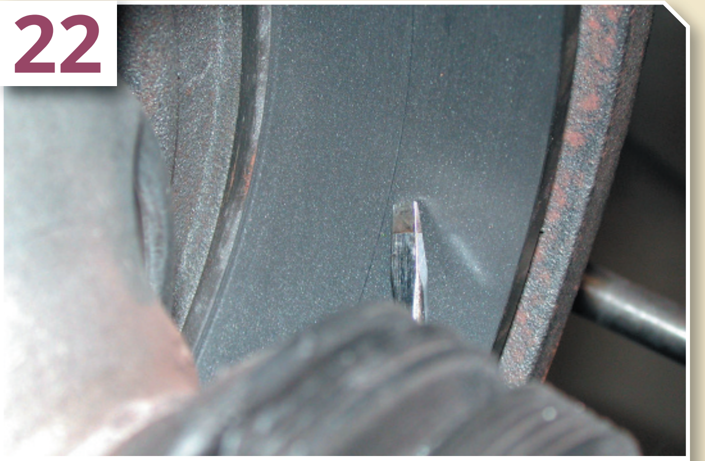
Center the bit in the center of the brake surface of the drum and rotate the control knob that moves the bit into contact with the drum friction surface. This should produce a light scratch cut.

21



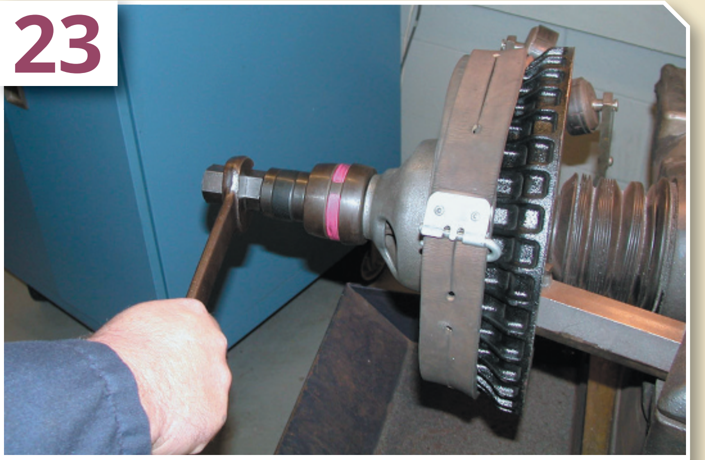
Turn the lathe off.

22



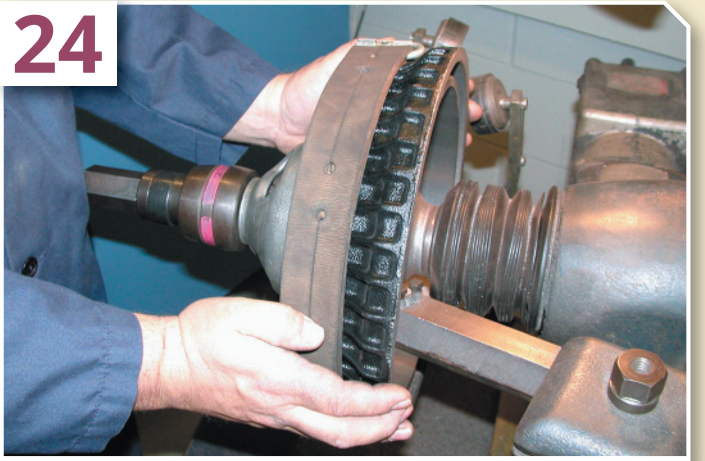
Observe the scratch cut.

23



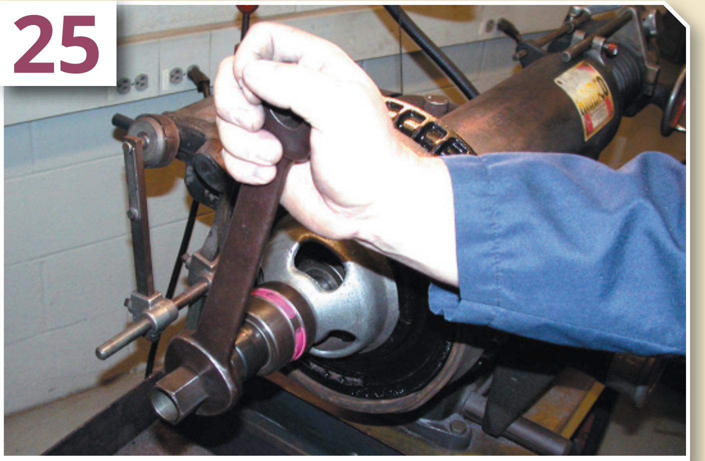
Loosen the spindle nut.

24



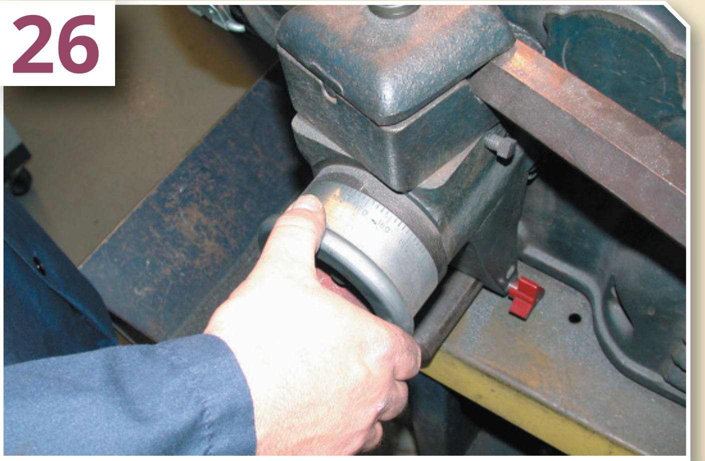
Rotate the drum 180 degrees (one-half turn) on the spindle.

25



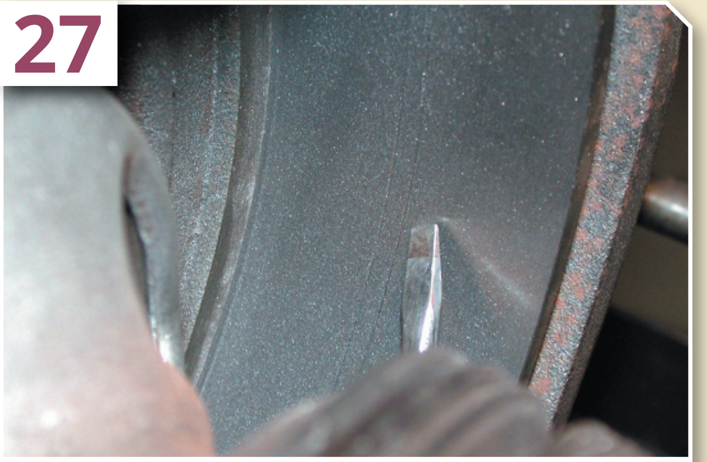
Tighten the spindle nut.

26



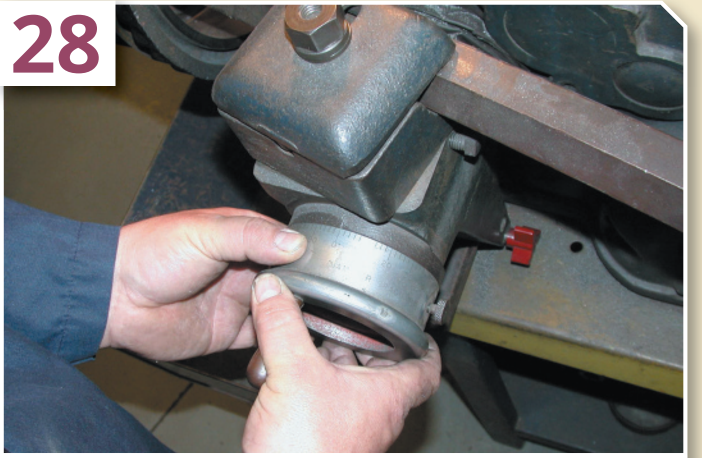
Turn the lathe on, rotate the control knob, and run the cutter into the drum for another scratch cut.

27



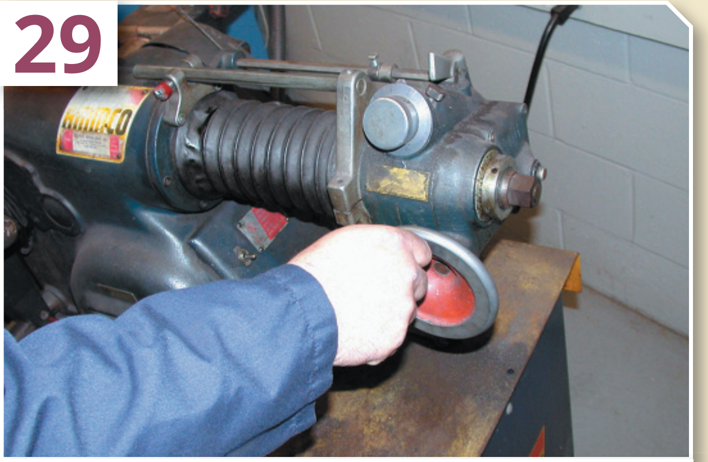
Observe the scratch cut. If the second scratch cut is in the same place as the first scratch cut or extends all the way around the drum, the drum is correctly mounted on the lathe.

28



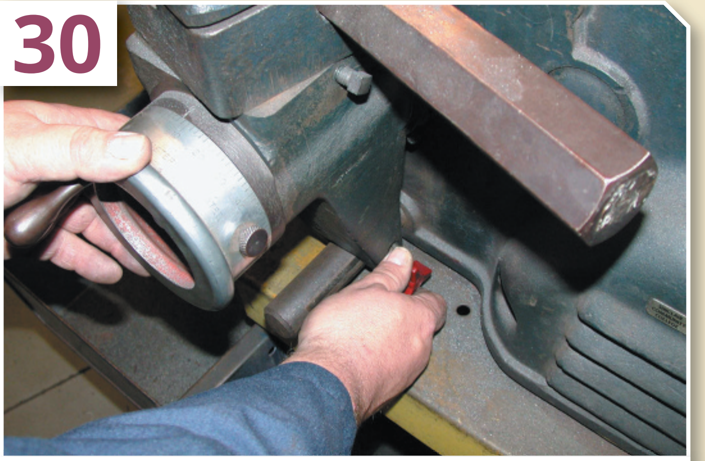
Adjust the depth gauge to zero when the cutter just touches the drum.

29



Run the cutter all the way to the back surface of the drum.

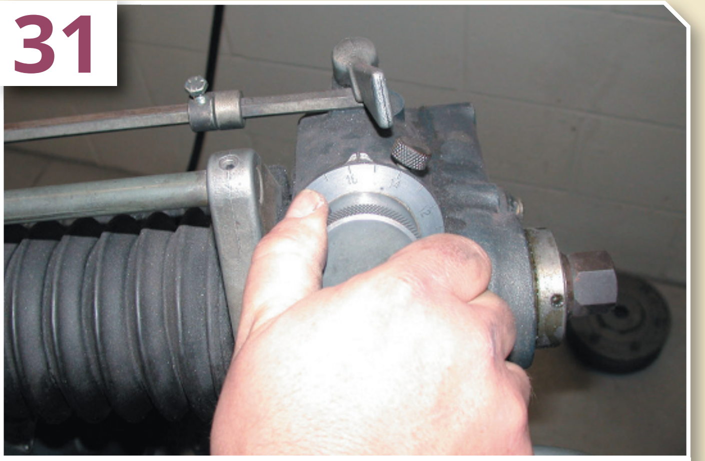
30



Adjust the depth of the cut and lock it in position by turning the lock knob. Most vehicle manufacturers recommend a rough cut depth should be 0.005–0.010 inch and a finish cut of 0.002 inch.

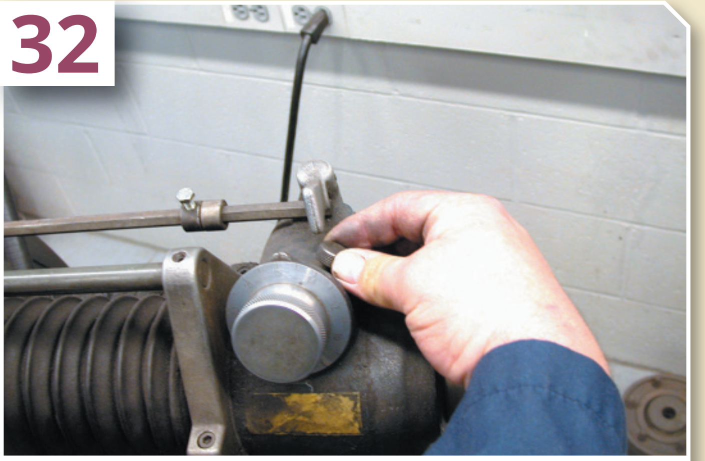
DRUM MACHINING

31



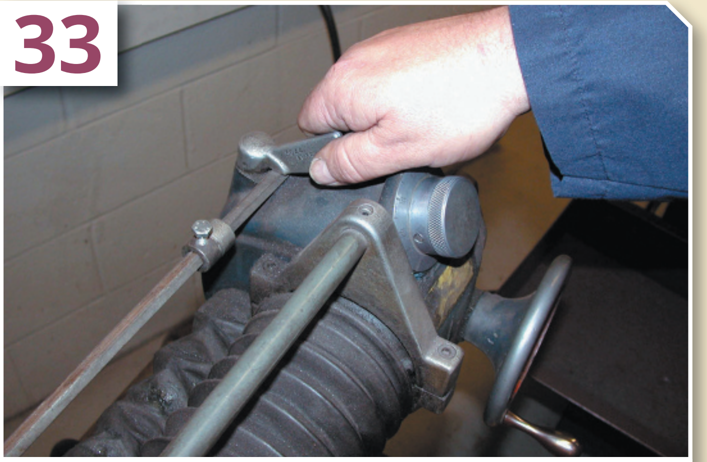
Select a fast-feed rate if performing a rough cut (0.006–0.016 in. per revolution) or 0.002 inch per revolution for a finish cut.

32



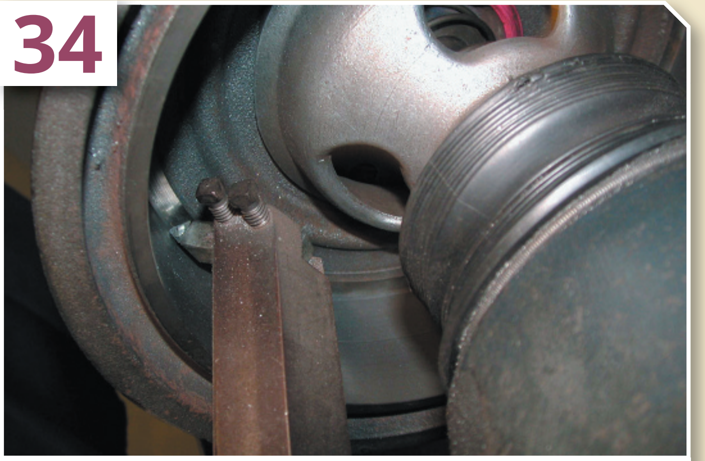
Turn the lock knob to keep the feed adjustment from changing.

33



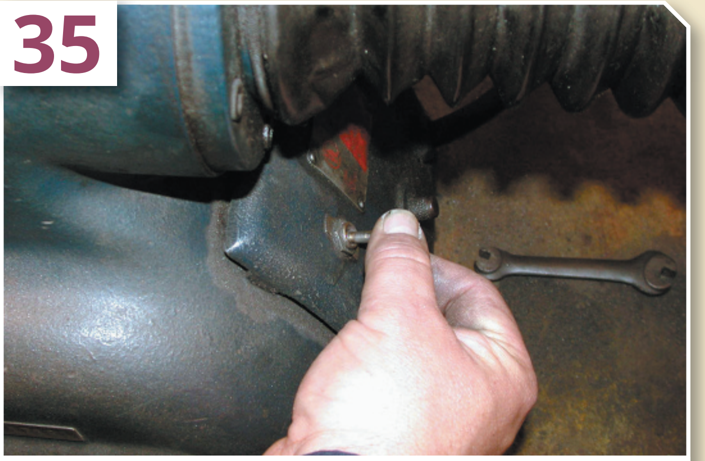
Engage the automatic feed.

34



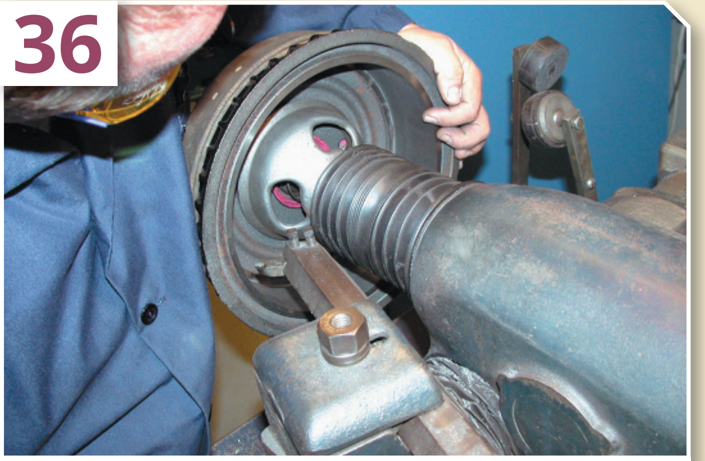
The drum will automatically move as the tool remains stationary to make the cut.

35



Turn the lathe off.

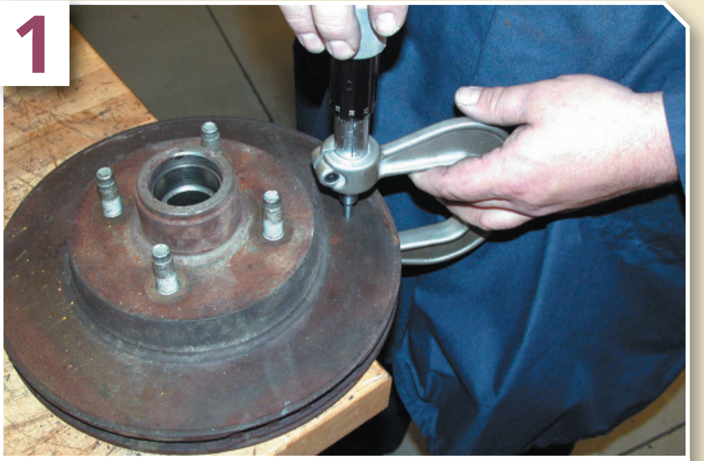
36



If additional material must be removed, proceed with the finish cut. Clean thoroughly before installing on a vehicle.

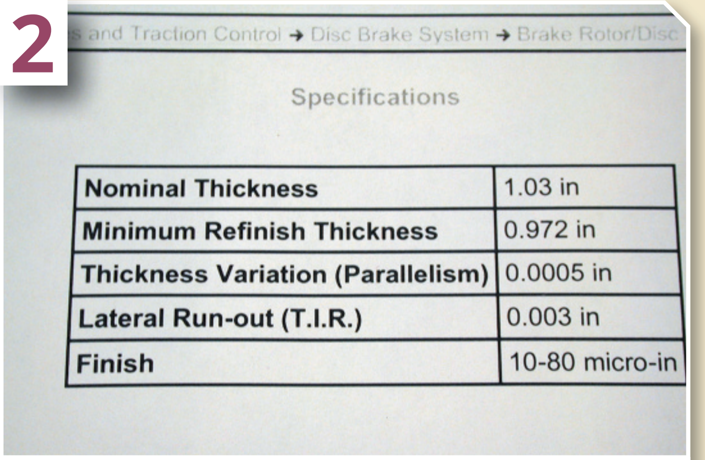
ROTOR MACHINING STEP BY STEP

1



Before machining any rotor, use a micrometer and measure the thickness of the rotor.

2



s and Traction Control → Disc Brake System → Brake Rotor/Disc

Specifications

Nominal Thickness	1.03 in
Minimum Refinish Thickness	0.972 in
Thickness Variation (Parallelism)	0.0005 in
Lateral Run-out (T.I.R.)	0.003 in
Finish	10-80 micro-in

Check the specifications for the minimum allowable thickness.

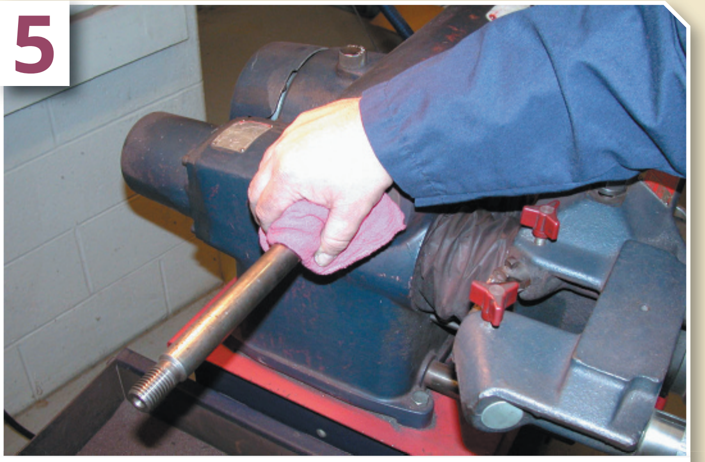
3

Visually check the rotor for evidence of heat cracks or hard spots that would require replacement (rather than machining) of the rotor.

4

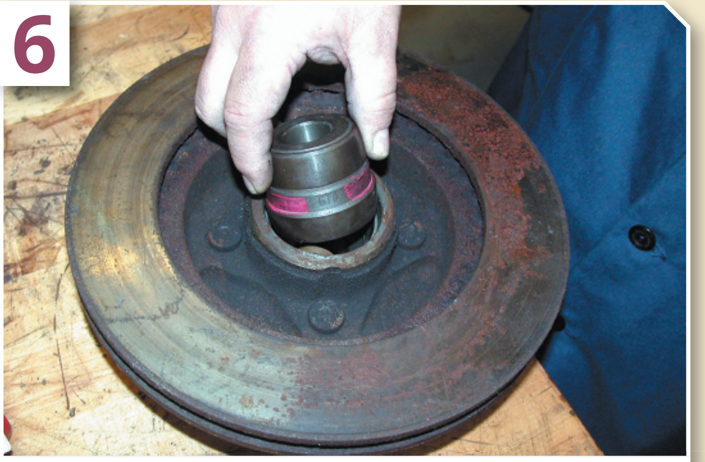
After removing the grease seal and bearings, remove the grease from the bearing races.

5



Clean and inspect the brake lathe spindle for damage or burrs that could affect its accuracy.

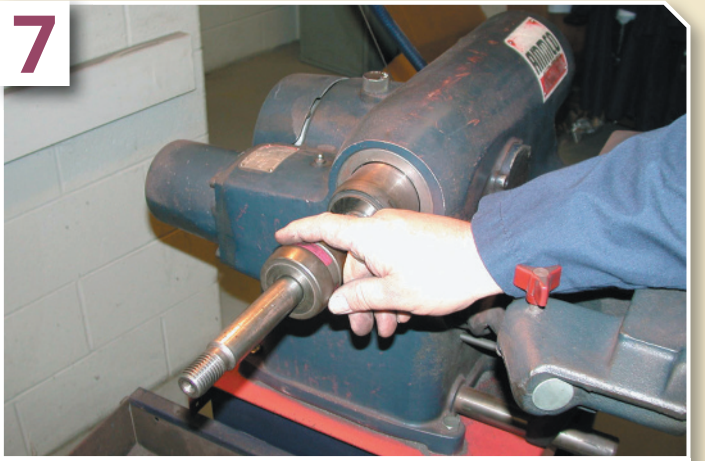
6



Select a tapered cone adapter that fits the inner bearing race.

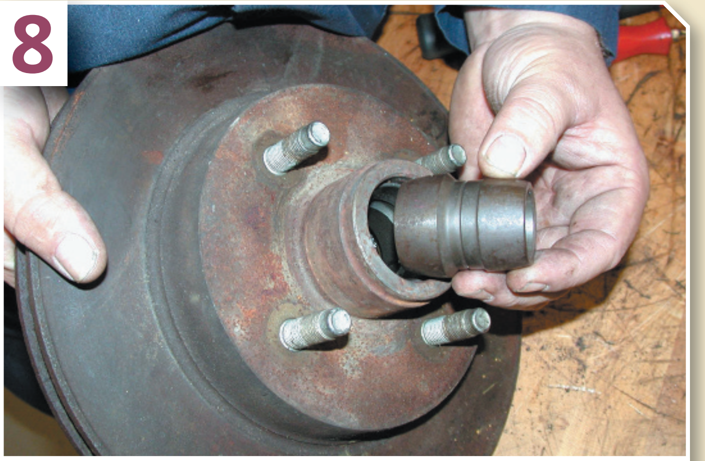
ROTOR MACHINING

7



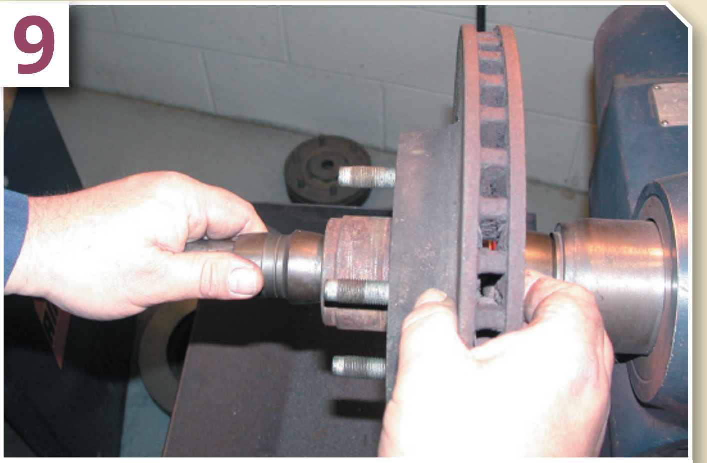
Slide the cone adapter onto the brake lathe spindle.

8



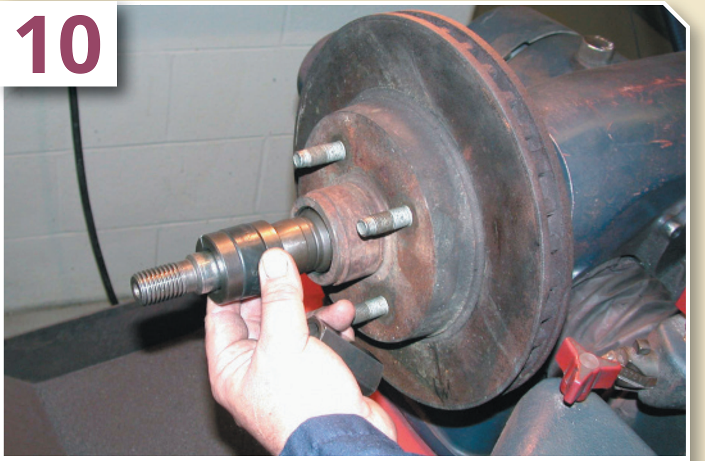
Select the proper size cone adapter for the smaller outer wheel bearing race.

9



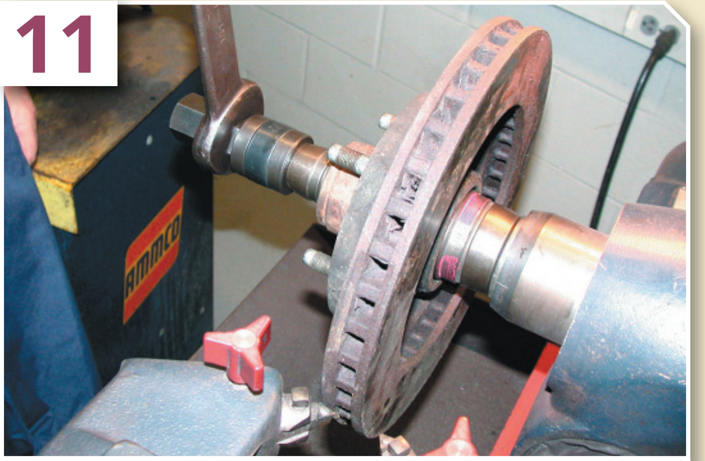
Place the rotor onto the large cone adapter and then slide the small cone adapter into the outer wheel bearing race.

10



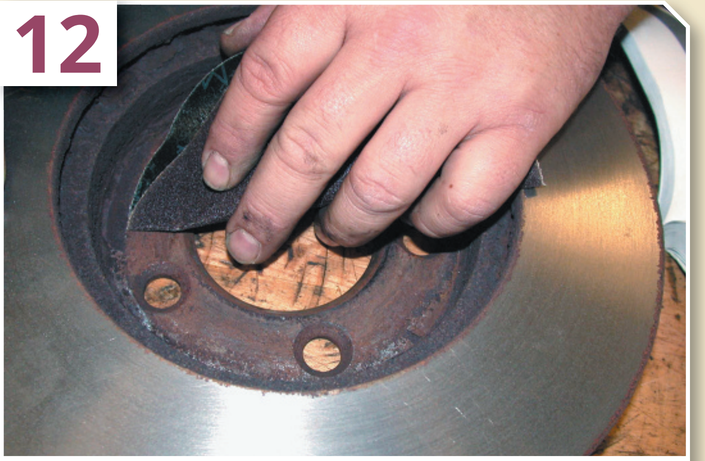
Install the self-aligning spacer (SAS) and spindle nut.

11



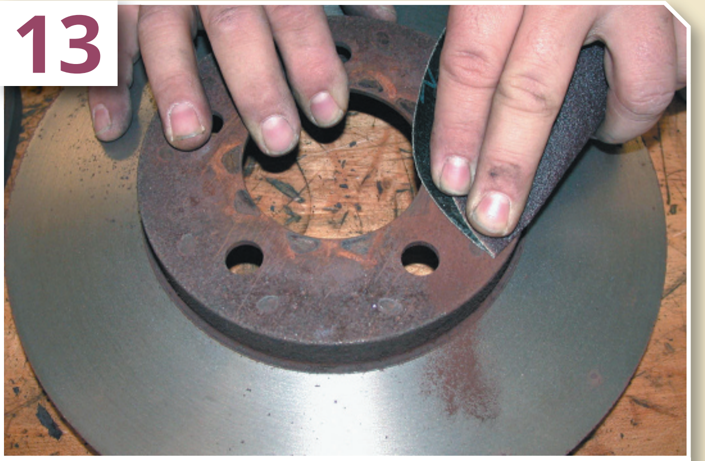
Tighten the spindle nut (usually left-hand threads).

12



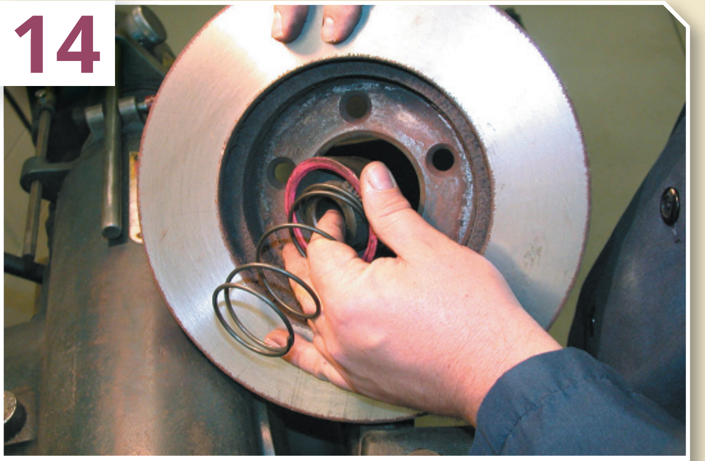
If a hubless rotor is being machined, be sure to thoroughly clean the inside surface.

13



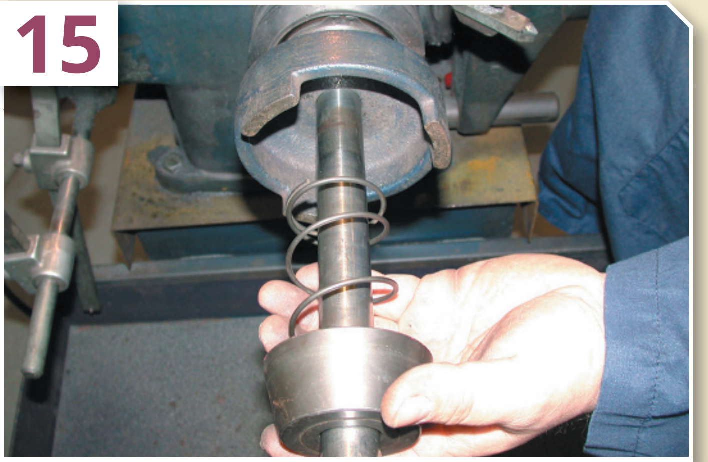
Also remove all rust from the other side of the hubless rotor.

14



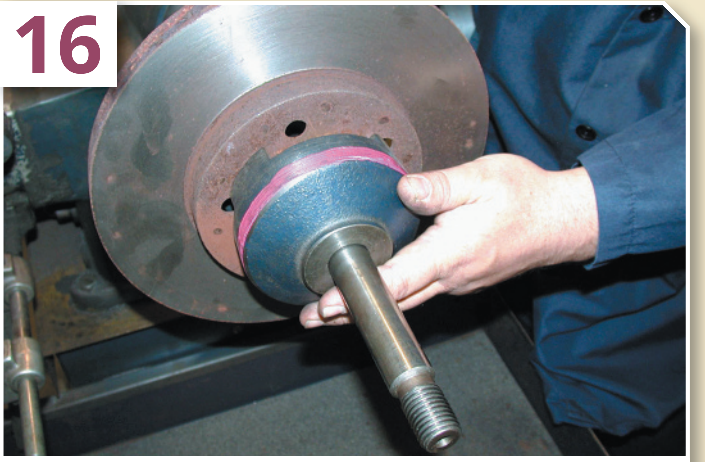
Select the proper centering cone for the hole in the center of the hub.

15



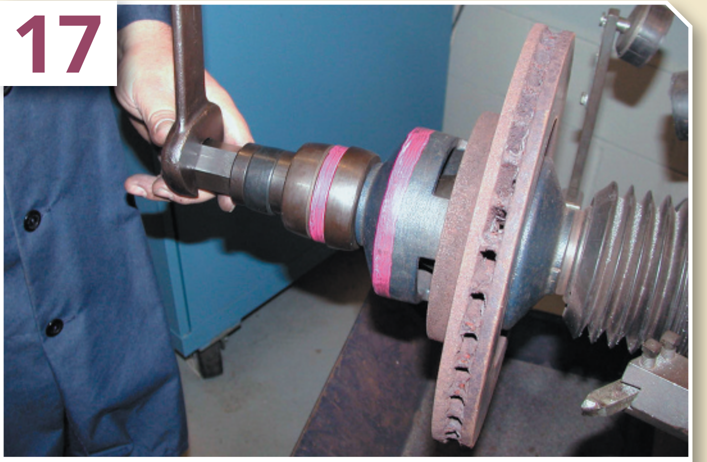
Select the proper size cone-shaped hubless adapter and the tapered centering cone with a spring in between.

16



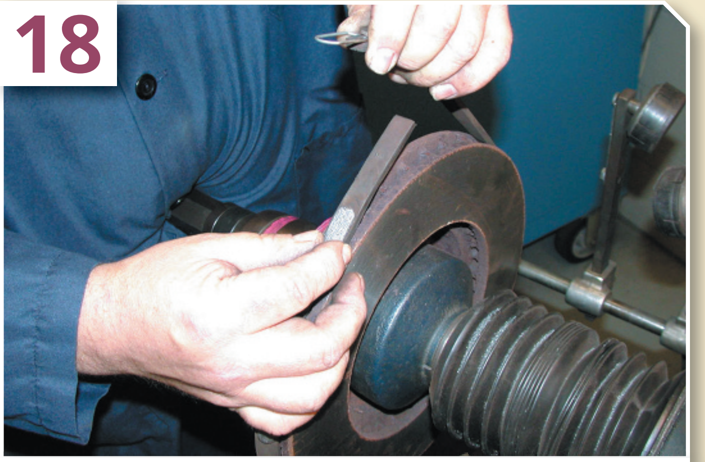
After sliding the rotor over the centering cone, install the matching hubless adapter.

17



Install the self-aligning spacer (SAS) and spindle nut.

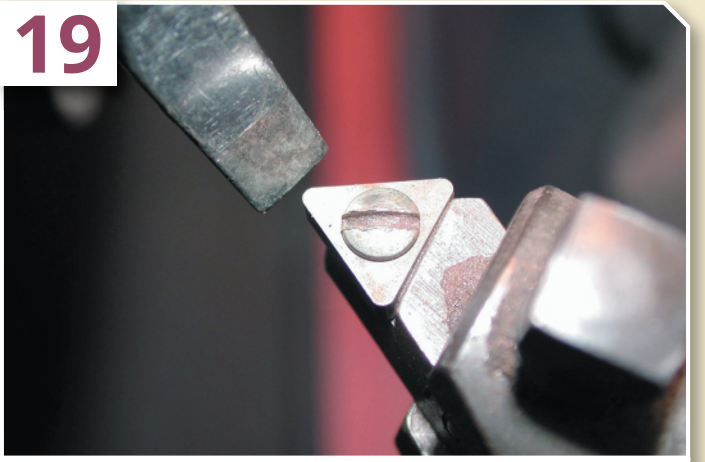
18



After the rotor has been secured to the brake lathe spindle, install the noise silencer band (dampener).

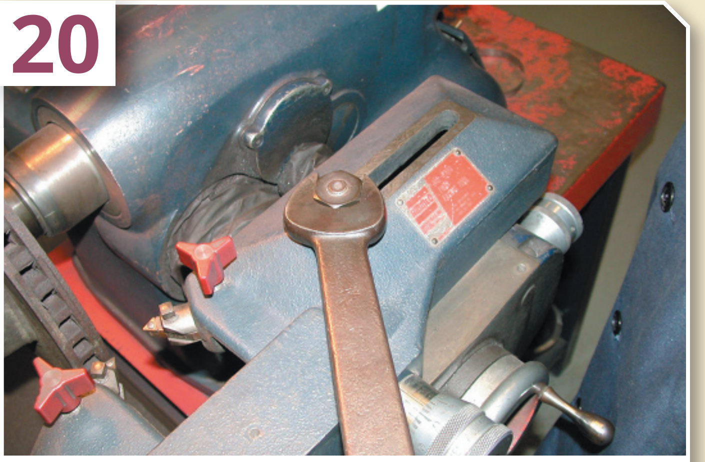
ROTOR MACHINING

19



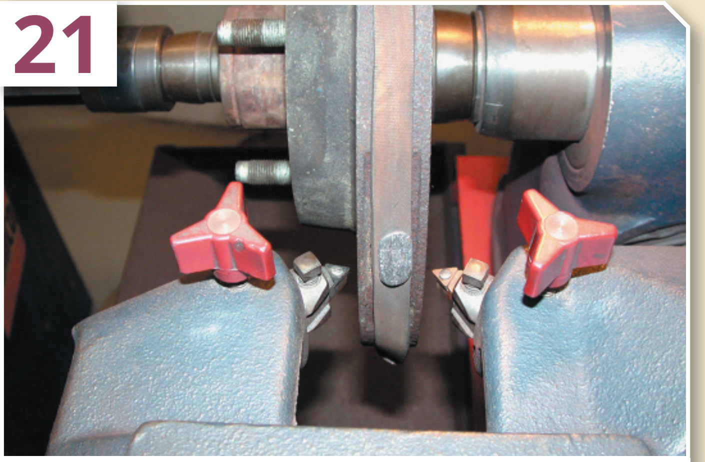
Carefully inspect the cutting bits and replace, if necessary.

20



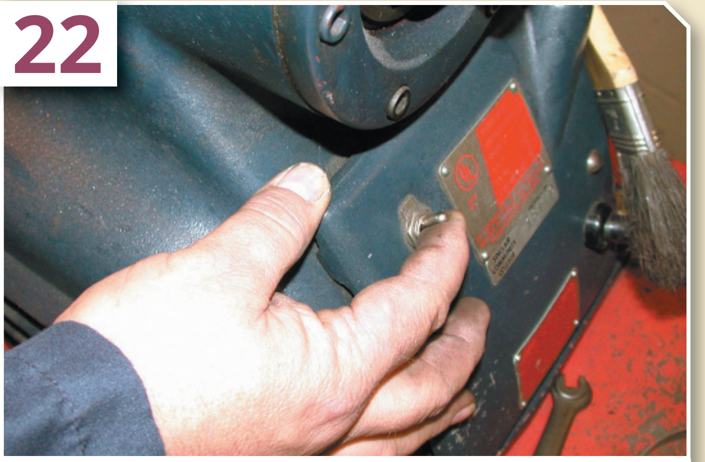
Loosen the tool holder arm.

21



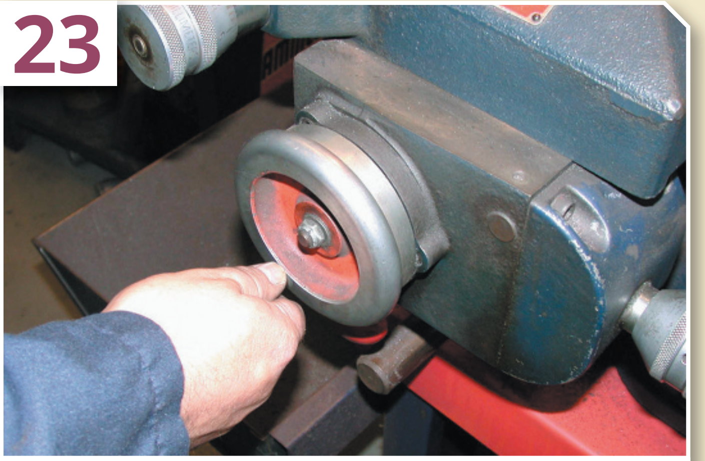
Adjust the twin cutter arm until the rotor is centered between the two cutting bits.

22



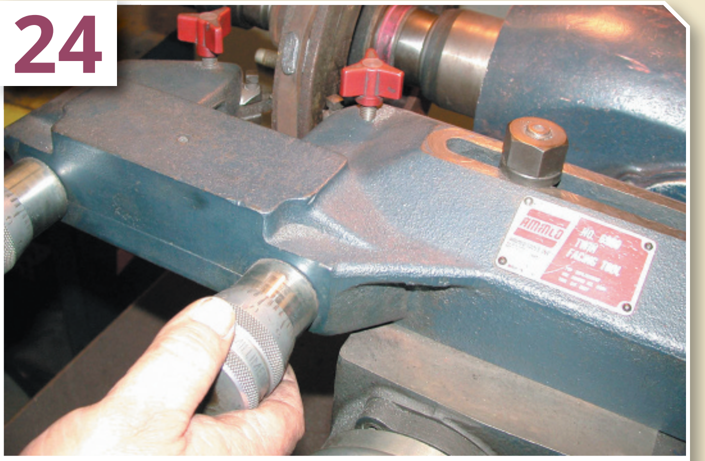
Turn the lathe on.

23



Move the cutter arm toward the center of the rotor, placing the cutting bits in about the center of the friction surface.

24

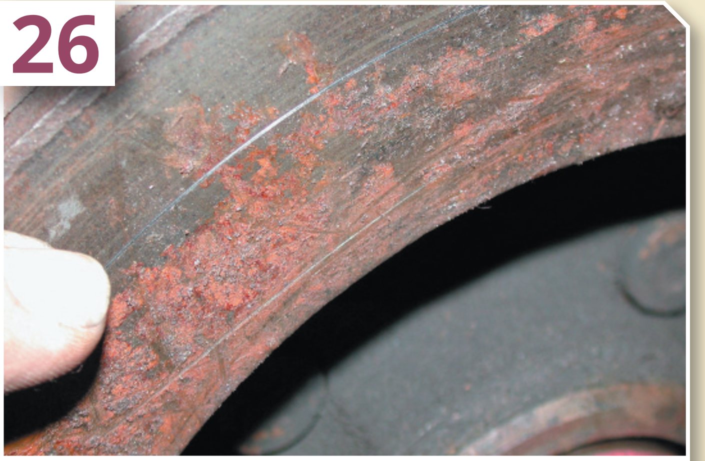


Turn one cutting bit into the surface of the rotor to make a scratch cut. This step checks the lathe setup for accuracy.

25

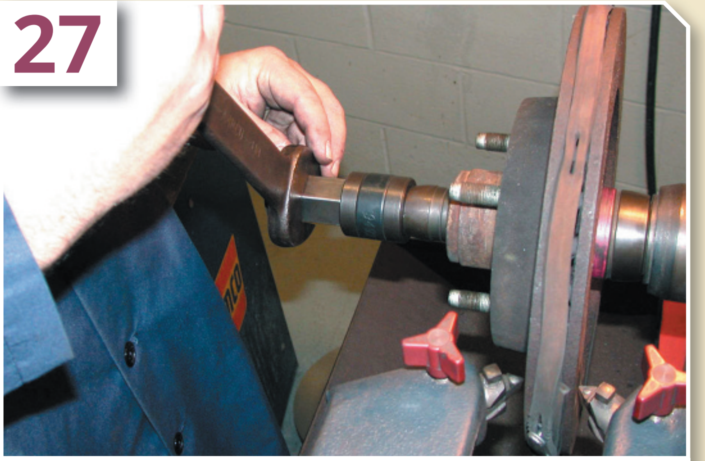
Turn the lathe off.

26



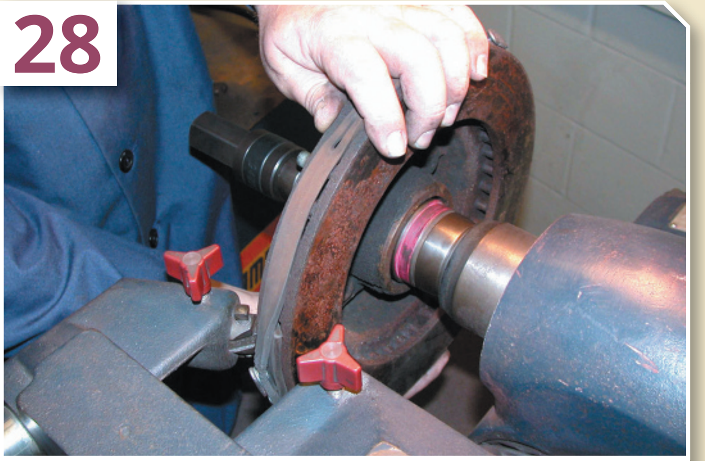
Observe the first scratch cut.

27



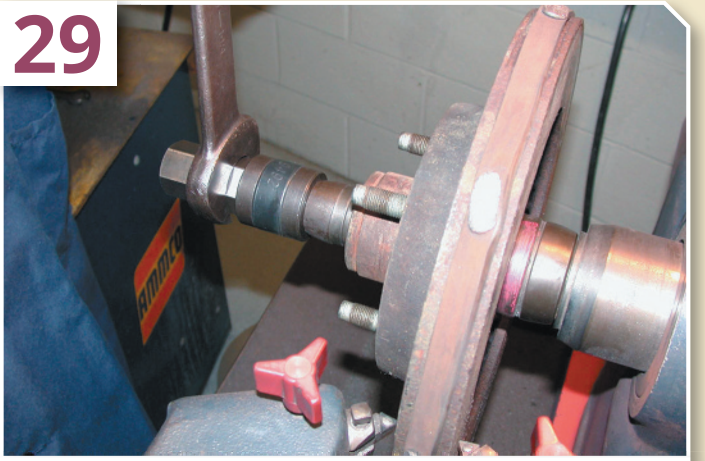
Loosen the spindle retaining nut.

28



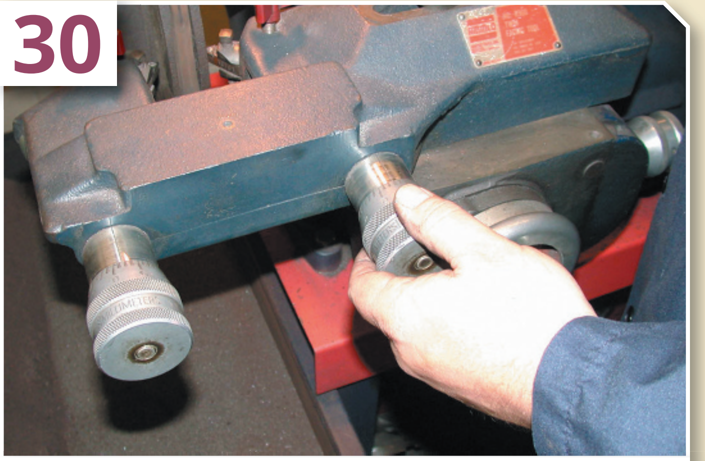
Rotate the rotor 180 degrees (one-half turn) on the spindle of the brake lathe.

29



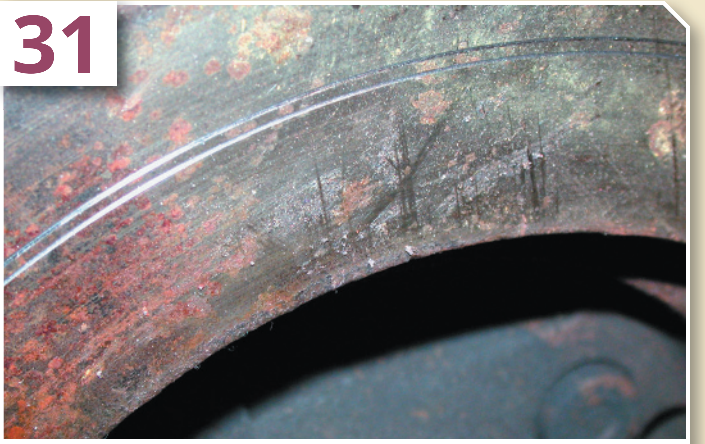
Tighten the spindle nut.

30



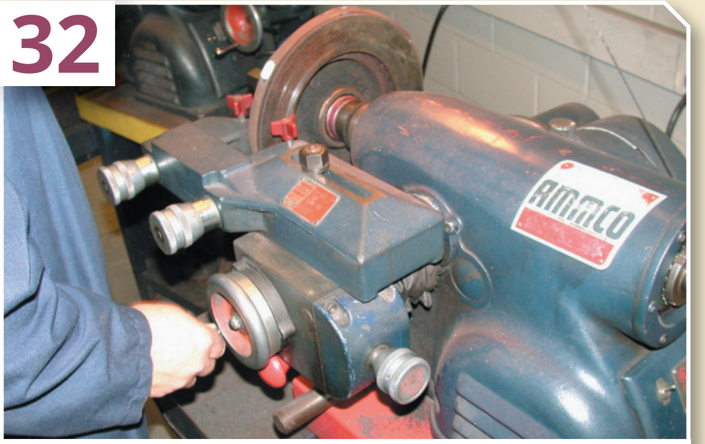
Turn the lathe back on and turn the cutting bit slightly into the rotor until a second scratch cut is made.

ROTOR MACHINING



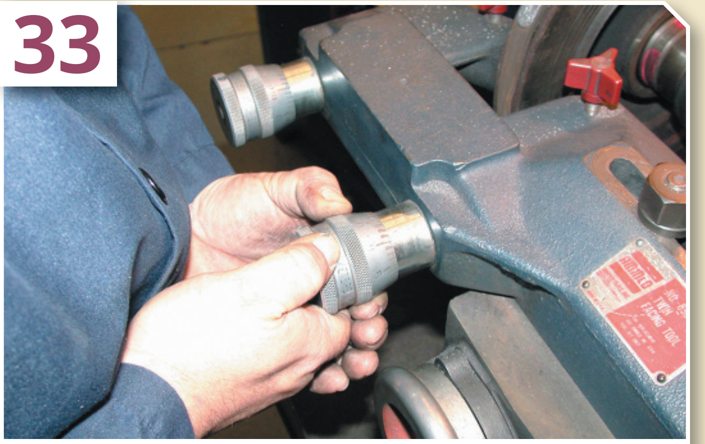
31

If the second scratch cut is in the same location as the first scratch cut or extends all around the surface of the rotor, then the rotor is properly installed on the lathe.



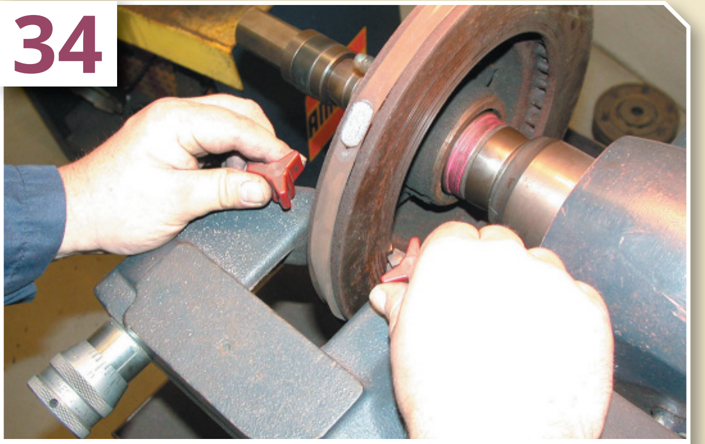
32

Start the machining process by moving the twin cutters to about the center of the rotor friction surface.



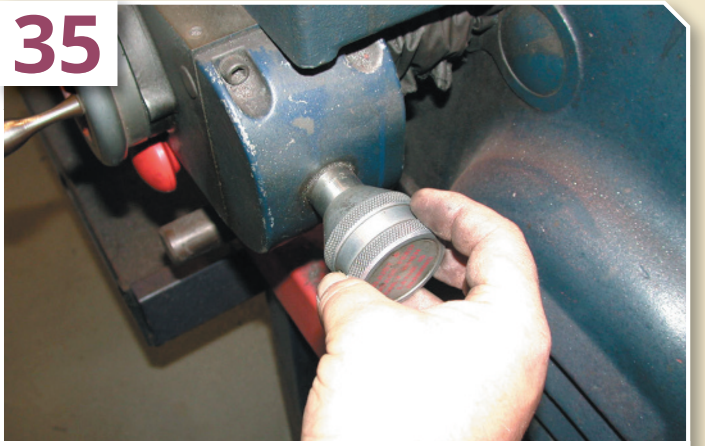
33

Turn the cutting bits inward until they touch the rotor and zero the depth adjustment.



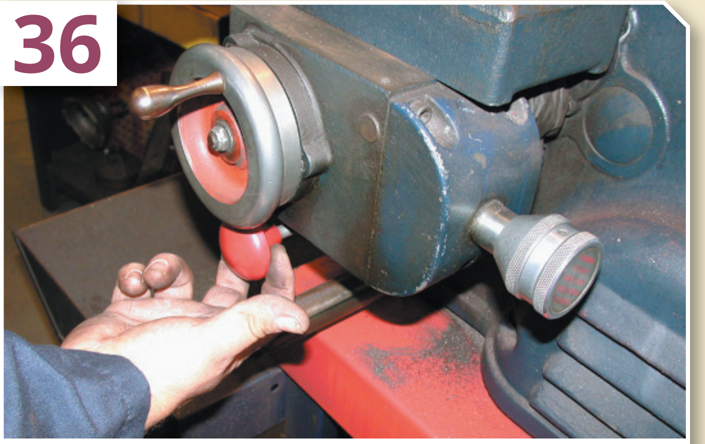
34

Adjust the twin cutters, then dial in the amount of depth (0.005–0.010 in. per side for a rough cut or 0.002 in. for a finish cut) and lock the adjustment so that vibration will not change the setting.



35

Turn the feed control knob until the desired feed rate is achieved for the first or rough cut (0.006–0.010 in. per revolution) or finish cut (0.002 in. per revolution).

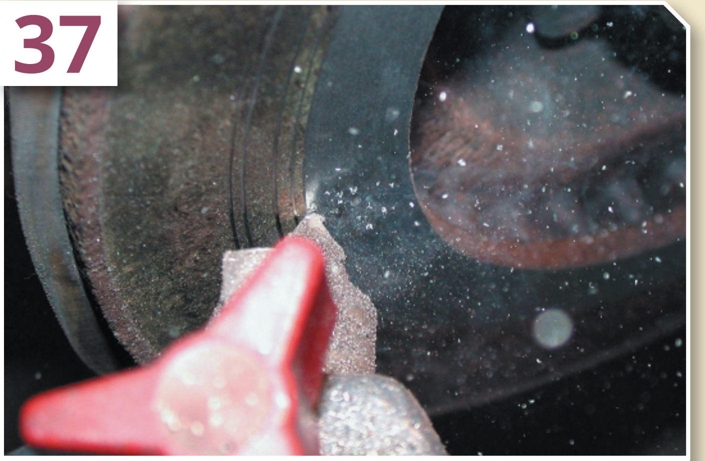


36

Engage the automatic feed.

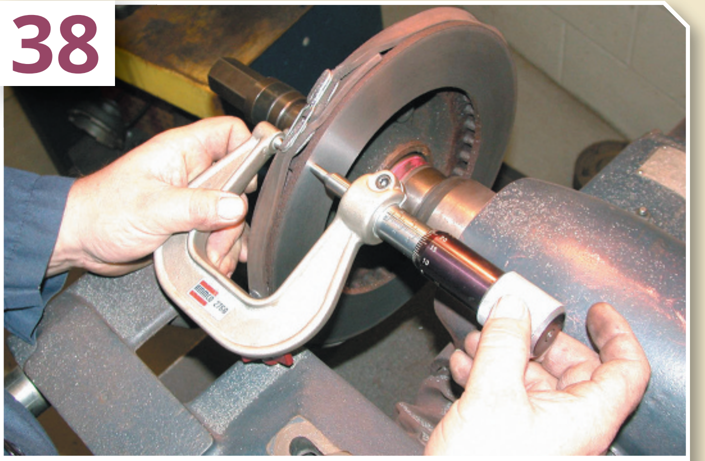
STEP BY STEP

37



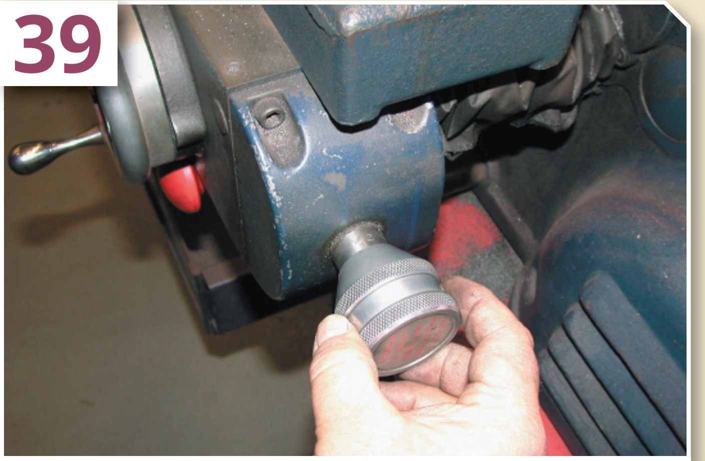
Observe the machining operation.

38



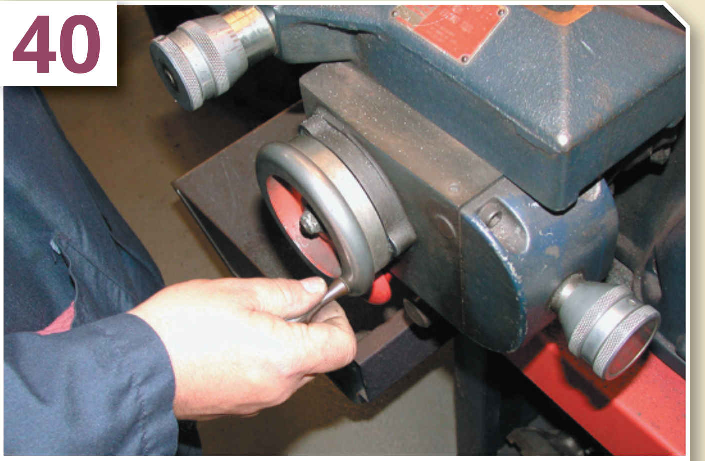
After the cutting bits have cleared the edge of the rotor, turn the lathe off and measure the thickness of the rotor.

39



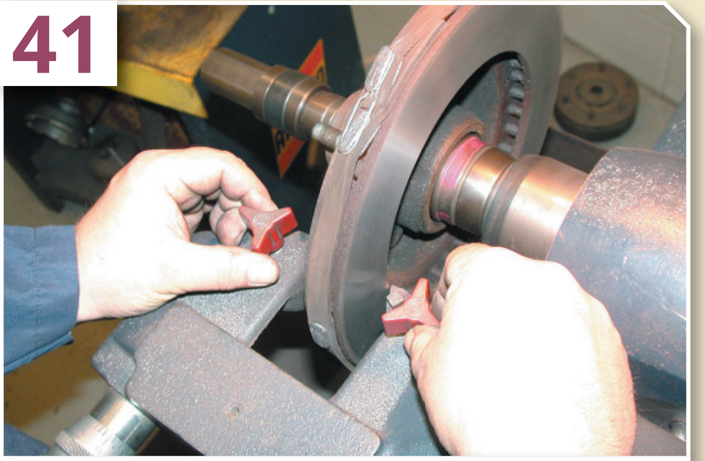
Readjust the feed control to a slow rate (0.002 in. per revolution or less) for the finish cut.

40



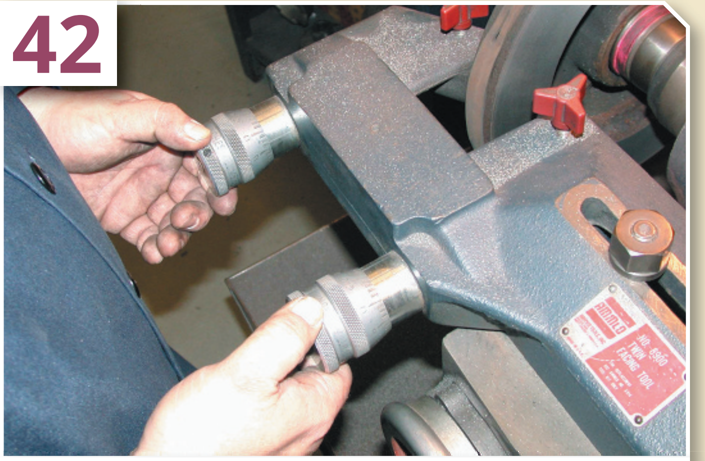
Reposition the cutting bits for the finish cut.

41



Loosen the adjustment locks.

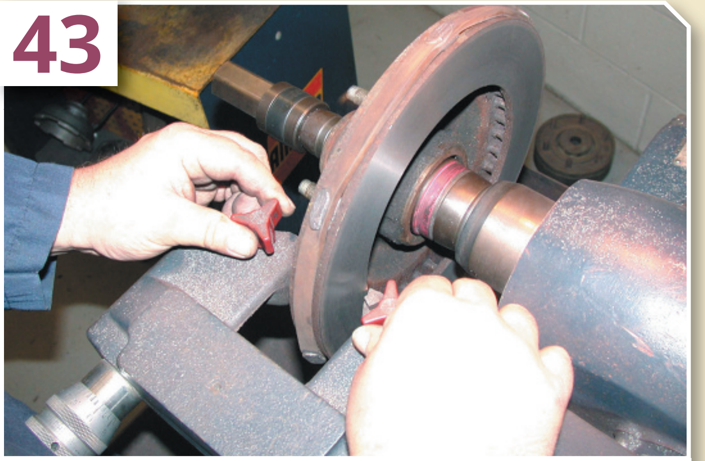
42



Turn the depth of the cut for the finish cut (0.002 in. maximum).

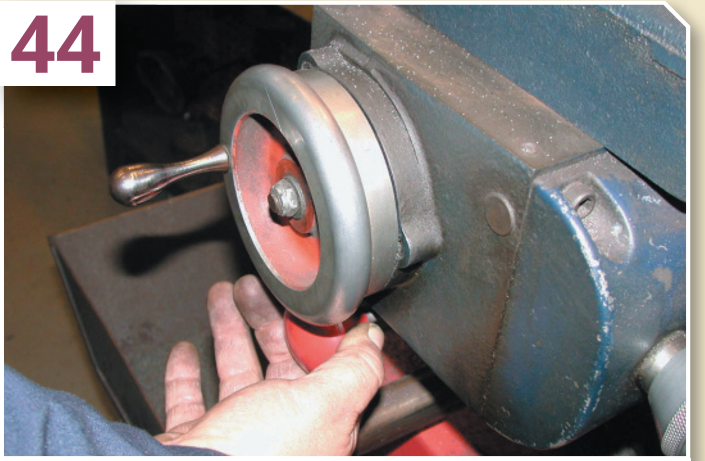
ROTOR MACHINING

43



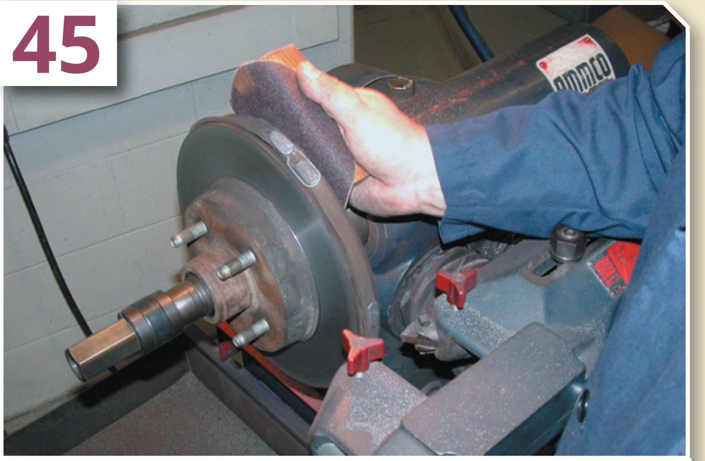
Lock the adjustment.

44



Engage the automatic feed.

45



Use 150-grit aluminum-oxide sandpaper on a block of wood for 60 seconds per side on a grinder to give a nondirectional and smooth surface to both sides of the rotor.

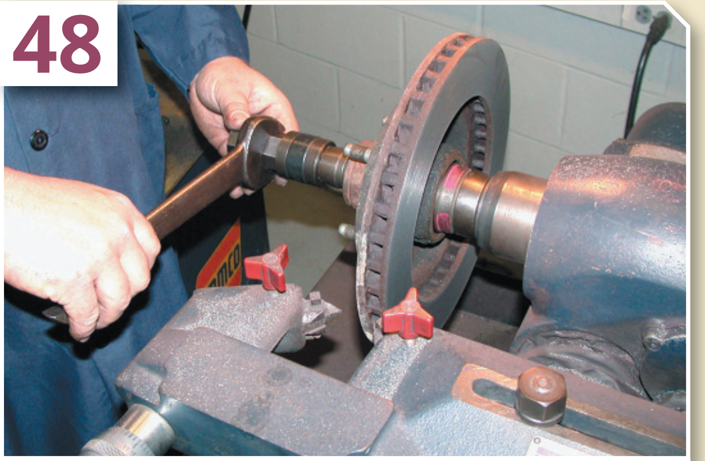
46

After the sanding or grinding operation, thoroughly clean the machined surface of the rotor to remove any and all particles of grit that could affect the operation and life of the disc brake pads.

47

Remove the silencer band.

48



Loosen the spindle retaining nut and remove the rotor.

ON-THE-VEHICLE LATHE

STEP BY STEP

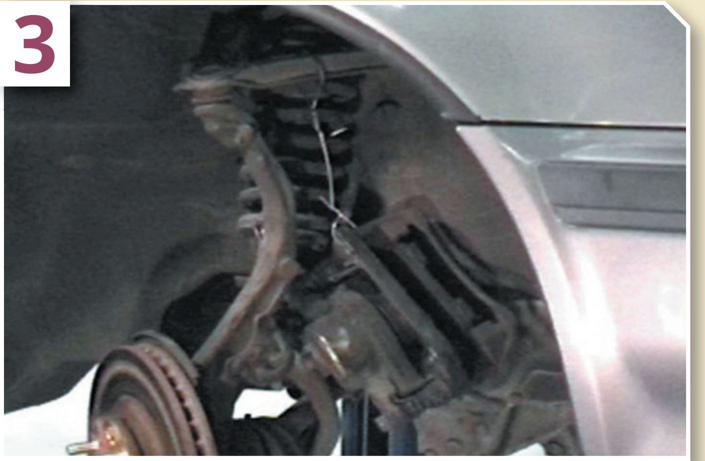
1

Prepare to machine a disc brake rotor using an on-the-vehicle lathe by properly positioning the vehicle in the stall and hoisting the vehicle to a good working height.

2

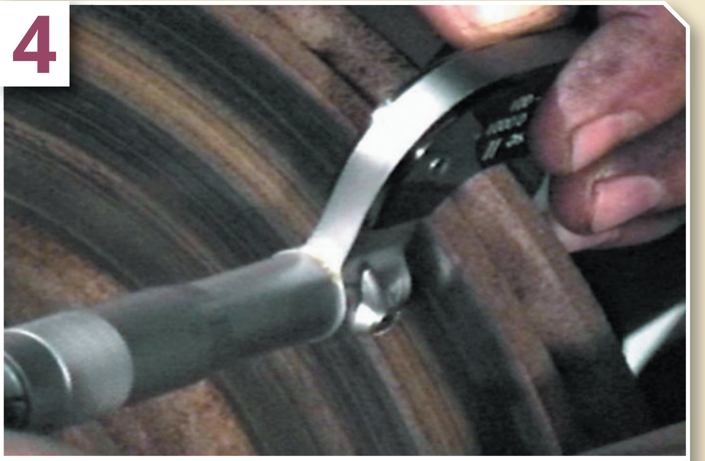
Remove the wheels and place them out of the way.

3



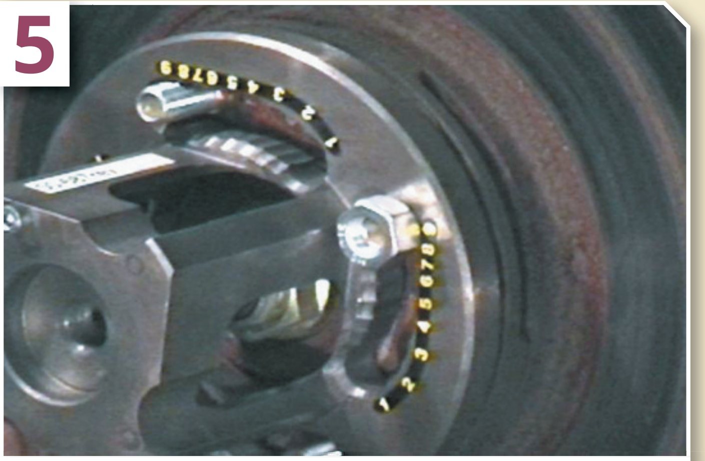
Remove the disc brake caliper and use a wire to support the caliper out of the way of the rotor.

4



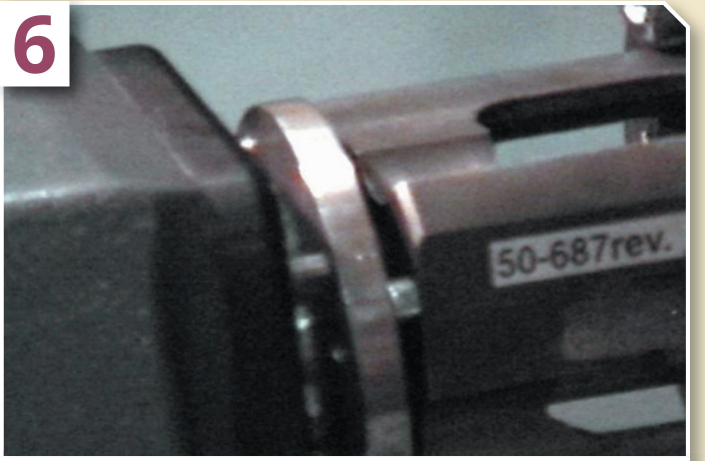
Measure the rotor thickness and compare it with factory specifications before machining. If a discard thickness is specified, be sure to allow an additional 0.015 inch for wear.

5



Install the hub adapter onto the hub and secure it using the wheel lug nuts.

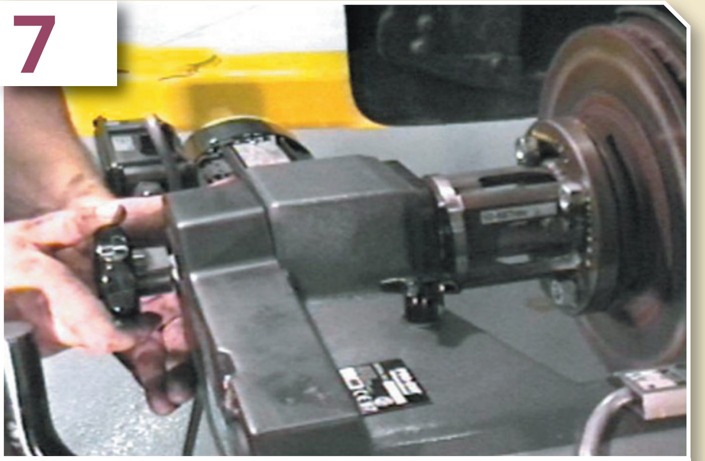
6



Engage the drive unit by aligning the hole in the drive plate with the raised button on the adapter.

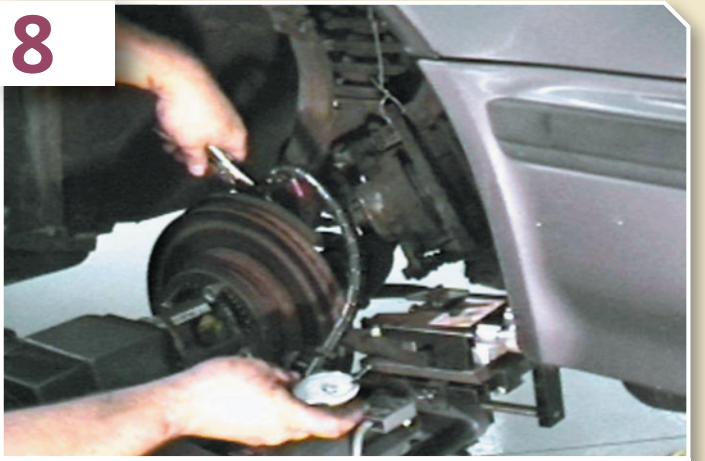
ON-THE-VEHICLE LATHE

7



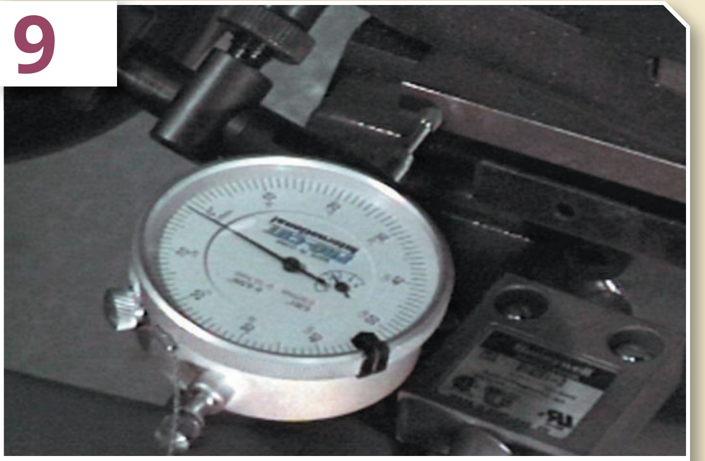
Use the thumb wheel to tighten the drive unit to the adapter.

8



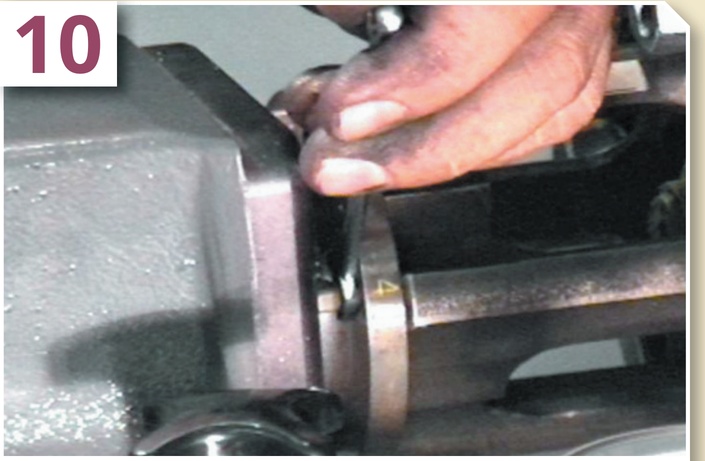
Attach a dial indicator to a secure part on the vehicle and position the dial indicator on a flat portion of the lathe to measure the lathe runout.

9



Rotate the wheel or turn the lathe motor on and measure the amount of runout.

10

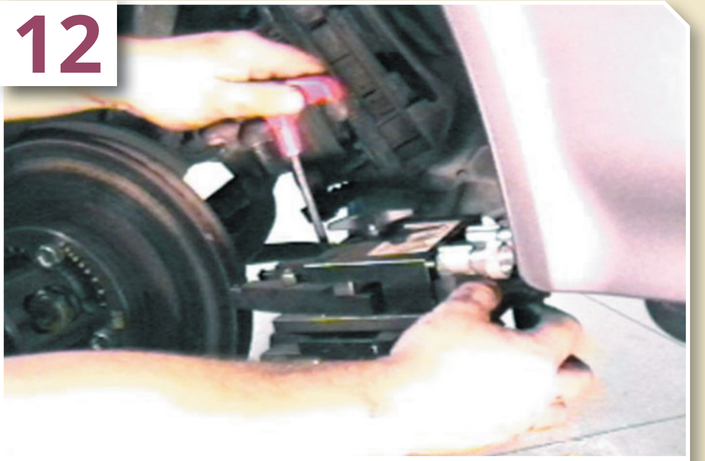


Use a wrench to adjust the runout using the four numbers stamped on the edge of the drive flange as a guide.

11

After the hub runout is adjusted to 0.005 in. or less, remove the dial indicator from the vehicle.

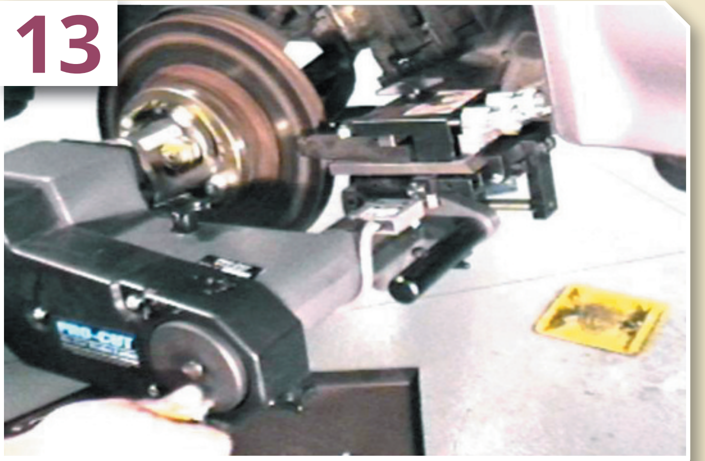
12



Using a T-handle Allen wrench, adjust the cutter arms until they are centered on the disc brake rotor.

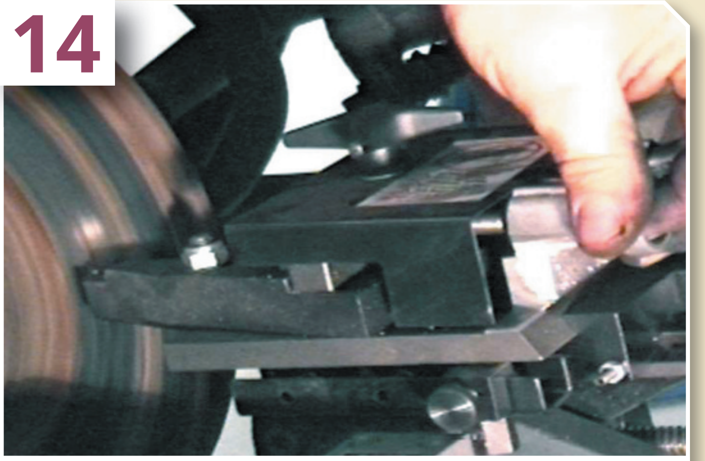
STEP BY STEP

13



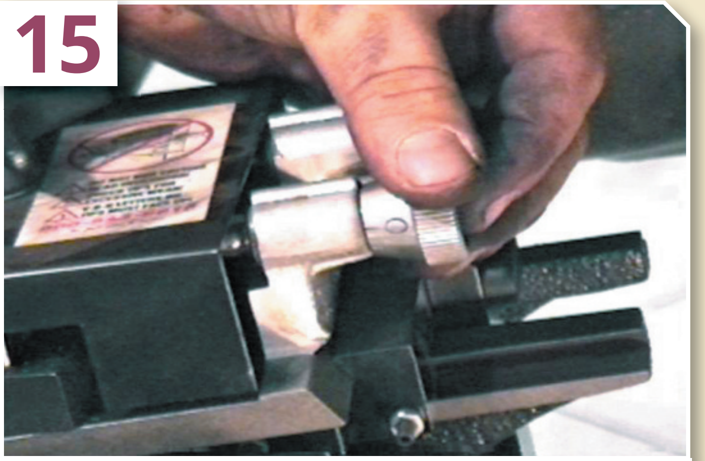
Move the cutters to the center of the rotor.

14



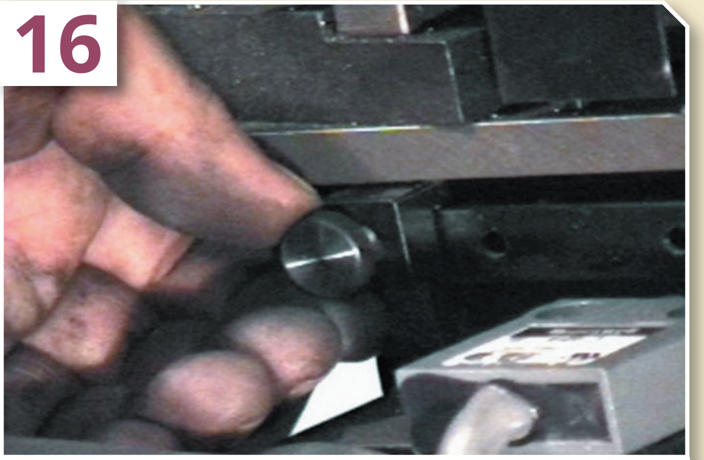
Adjust the cutter depth until each cutter barely touches the rotor.

15



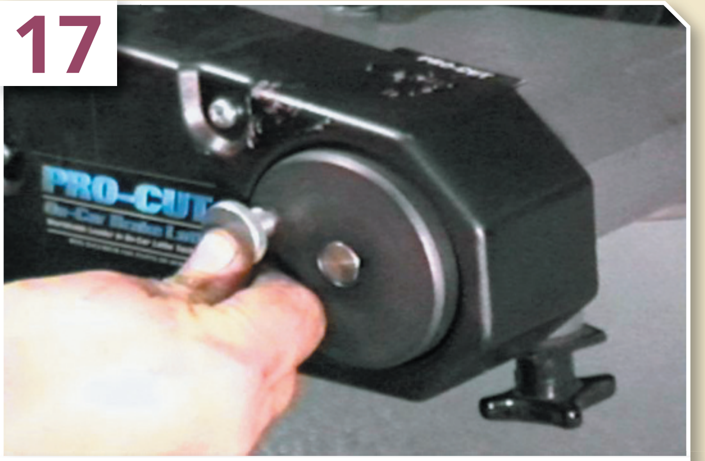
Position the cutters to the inside edge of the rotor surface and adjust the cutters to the desired depth of cut.

16



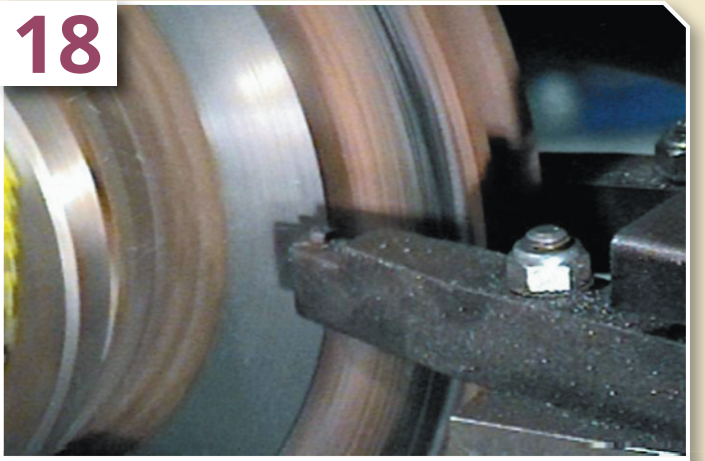
Adjust the automatic shut-off so the lathe will turn itself off at the end of the cut.

17



Turn the lathe on by depressing the start button.

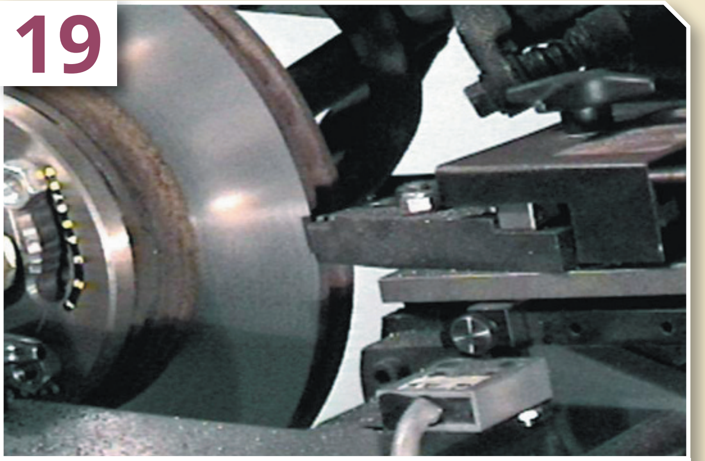
18



Monitor the machining operations as the lathe automatically moves the cutters from the center toward the outside edge of the rotor.

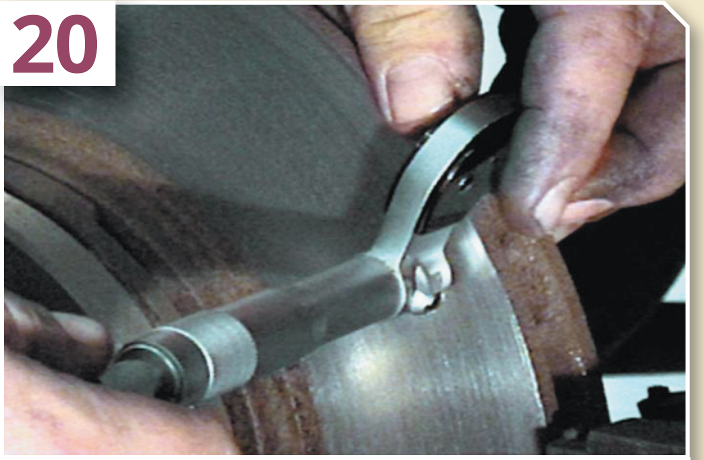
ON-THE-VEHICLE LATHE

19



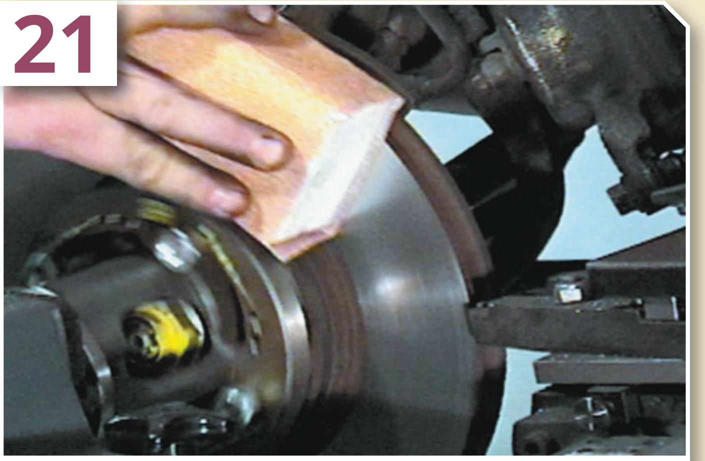
After the lathe reaches the outside edge of the rotor, the drive motor should stop.

20



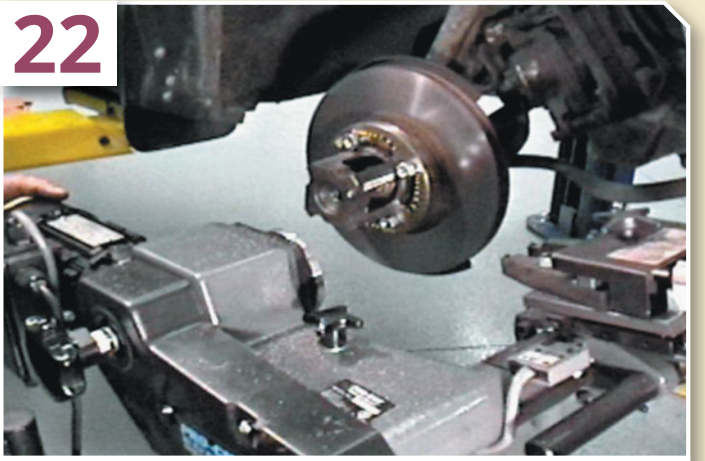
Measure the thickness of the rotor after machining to be certain that the rotor thickness is within service limits.

21



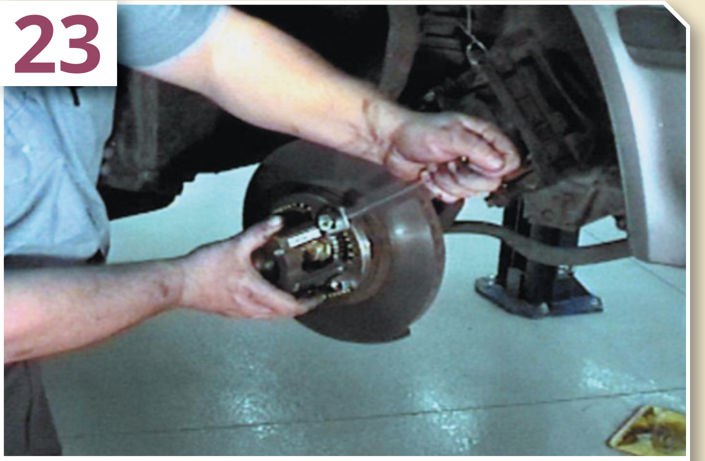
The technician is using 150-grit aluminum-oxide sandpaper and a wood block for 60 seconds on each side of the rotor to provide a smooth surface finish.

22



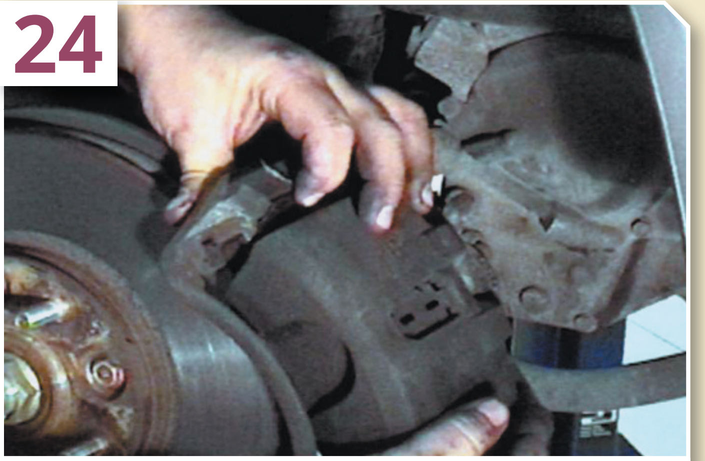
After completing the machining and resurfacing of the rotor, unclamp the drive unit from the hub adapter and clean the rotor.

23



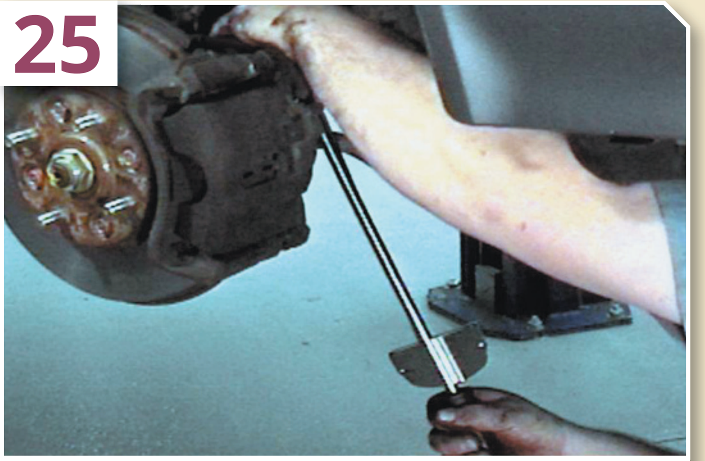
After the drive unit has been removed, remove the lug nuts holding the adapter to the rotor hub.

24



After removing the hub adapter, the caliper can be reinstalled.

25

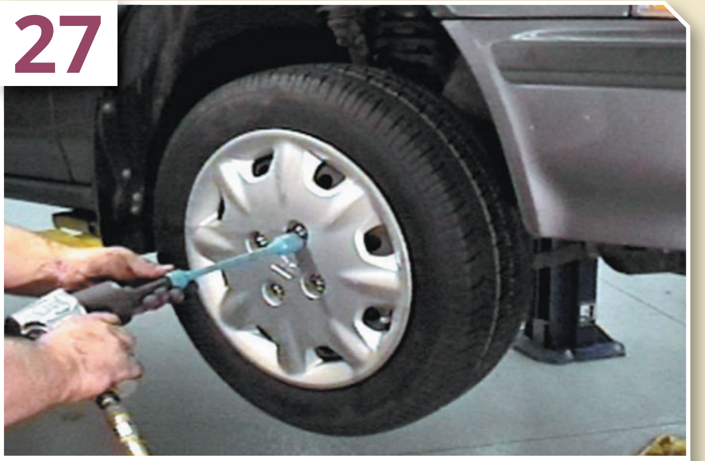


Be sure to torque the caliper retaining bolts to factory specifications.

26

Install the wheel and wheel cover. On this vehicle, the wheel cover must be installed before the lug nuts because the lug nuts hold the wheel cover on the wheel.

27



Always use a torque wrench or a torque-limiting adapter with an air impact wrench as shown here when tightening lug nuts.

28

Pump the brake pedal several times to restore proper brake pedal height. Check and add brake fluid as necessary before moving the vehicle.

REVIEW QUESTIONS

1. Explain the difference between "machine to" specifications and "discard."
2. List the steps for machining a brake drum.
3. Describe how to measure a disc brake rotor for lateral runout and thickness variation.
4. List the steps for machining a disc brake rotor.
5. Describe what is necessary to achieve "like-new" disc brake rotor finish.

CHAPTER QUIZ

1. Brake drums use ___________ for the friction surface area.
   a. cast iron
   b. aluminum
   c. steel
   d. carbon
2. Technician A says that hard spots in a brake drum should be removed using a carbide-tip machining tool. Technician B says that the drum should be replaced if hard spots are discovered. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. The major reason for brake pedal pulsation during braking is due to ___________.
   a. grooved rotors
   b. excessive rotor thickness variation
   c. thin rotors
   d. poor surface finish on the rotors
4. After machining a rotor, what should be done?
   a. Install on the vehicle
   b. Clean the rotor with soap and water
   c. Rub the machined surface with a brake pad to burnish the surface
   d. Use new lug nuts when installing on the vehicle
5. Typical maximum rotor thickness variation (parallelism) specifications is ___________.
   a. 0.0005 inch (0.013 mm)
   b. 0.003 to 0.005 inch (0.08 to 0.13 mm)
   c. 0.030 to 0.050 inch (0.8 to 1.3 mm)
   d. 0.300 to 0.500 inch (8.0 to 13 mm)
6. What should be removed before removing a brake drum?
   a. Tinnerman nuts
   b. Lug nuts
   c. Wheel
   d. All of the above
7. What do the "machine to" and "discard" specifications mean?
   a. "Machine to" means that the brake drum should be machined to that measurement when machining.
   b. The discard measurement is the measurement that requires replacement of the brake drum.
   c. Both a and b
   d. Neither a nor b
8. What is true about rotor finish?
   a. The higher the Ra number, the smoother
   b. Does not pertain to carbon-ceramic rotors
   c. Both a and b
   d. Neither a nor b
9. The brake lathe arbor should be checked using a ___________.
   a. feeler gauge
   b. vacuum gauge
   c. thread pitch gauge
   d. dial indicator
10. Technician A says that bellmouth is a type of drum distortion. Technician B says that out-of-round is a type of drum distortion. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

Chapter

104

POWER BRAKE UNIT OPERATION, DIAGNOSIS, AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the need for power brake assist.
- State the principles of vacuum.
- Discuss vacuum booster theory.
- Discuss the operation of a vacuum check valve.
- Discuss the operation of a vacuum brake booster.
- Describe dual-diaphragm vacuum boosters.
- Discuss the brake assist system.
- Discuss the vacuum booster operation test.
- Describe the vacuum booster leak test.
- Describe the hydraulic system leak test.
- Describe how to adjust the pushrod length.
- Explain the operation and diagnosis of Hydro-Boost hydraulic brake booster.
- List Hydro-Boost symptoms and possible causes.

KEY TERMS:

Atmospheric pressure 1247 • Brake assist system (BAS) 1253 • Dual-diaphragm vacuum booster 1252 • in. Hg (inches of mercury) 1248 • mm Hg (millimeters of mercury) 1248 • Power chamber 1249 • Pressure differential 1247 • Supplemental brake assist (SBA) 1254 • Tandem-diaphragm vacuum booster 1252 • Vacuum 1247

THE NEED FOR POWER BRAKE ASSIST

To double the stopping power of a disc brake, the driver must double the force on the brake pedal. This is the reason that most vehicles equipped with disc brakes are power assisted, even on small, lightweight vehicles. The use of semimetallic brake pads also requires greater force. The most commonly used power-assisted units are vacuum operated.

When a power booster is fitted, the brake pedal ratio is decreased and the master cylinder bore size is increased. The combined effect of these changes is to reduce pedal effort, while greatly increasing pedal reserve. ● **SEE FIGURE 104–1**.

Power boosters do not alter the hydraulic system and they still allow braking even if the booster fails or its power supply is cut off. All boosters have a power reserve that provides assist for at least one hard stop and sometimes several light brake applications, even after power is lost. However, because power brake systems are designed with the added force of the booster taken into account, the amount of brake pedal pressure required to slow or stop a vehicle is much higher than in a non-boosted system once the reserve is used up. For this reason, some vehicles with power brakes have a brake pedal that is wide enough to allow two-foot braking should the booster fail. ● **SEE FIGURE 104–2**.

PRINCIPLES OF VACUUM

Most vacuum-powered brake boosters get their vacuum supply from the engine intake manifold. An engine is essentially a big air pump because the pistons move up and down in the cylinders to pump in air and fuel, and pump out exhaust. They do this by creating differences in air pressure.

As a piston moves downward on an intake stroke with the intake valve open, it creates a larger area inside the cylinder for air to fill. This lowers the air pressure within the cylinder, and the higher pressure air outside the engine flows in through the intake manifold in an attempt to fill the low-pressure area. Although it may seem as though the low pressure is pulling air into the engine, it is really the higher pressure outside that forces air in. The difference in pressure between two areas is called a **pressure differential**.

Because throttle valves and manifold shape restrict intake airflow, high-pressure air from outside the engine is almost never able to move into the cylinders fast enough to fill the space created. As a result, gasoline-powered internal-combustion engines normally operate with a low-pressure area, or partial vacuum, in the intake manifold. The term **vacuum** is used to refer to any pressure lower than **atmospheric pressure**. Atmospheric pressure varies with altitude, but is approximately 14.7 pounds per square inch (PSI) at sea level. ● **SEE FIGURE 104–3**.

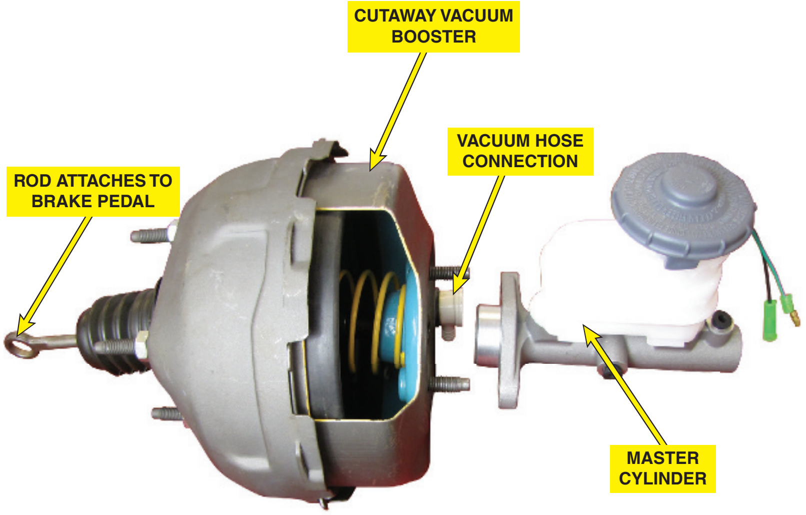


FIGURE 104–1 Typical vacuum brake booster assembly. The vacuum hose attaches to the intake manifold of the engine.

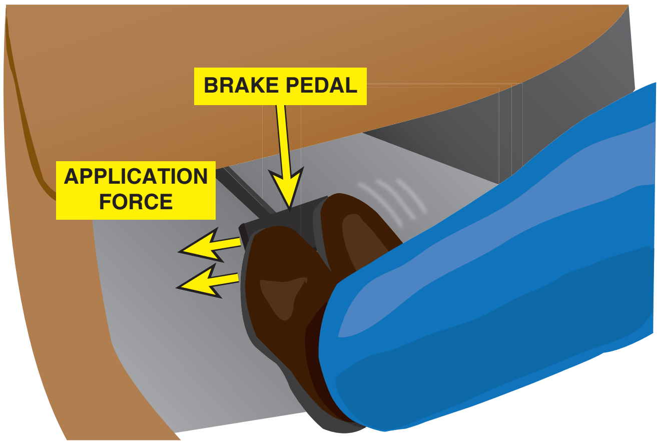


FIGURE 104–2 A wide brake pedal allows two-foot braking if power assist is lost.

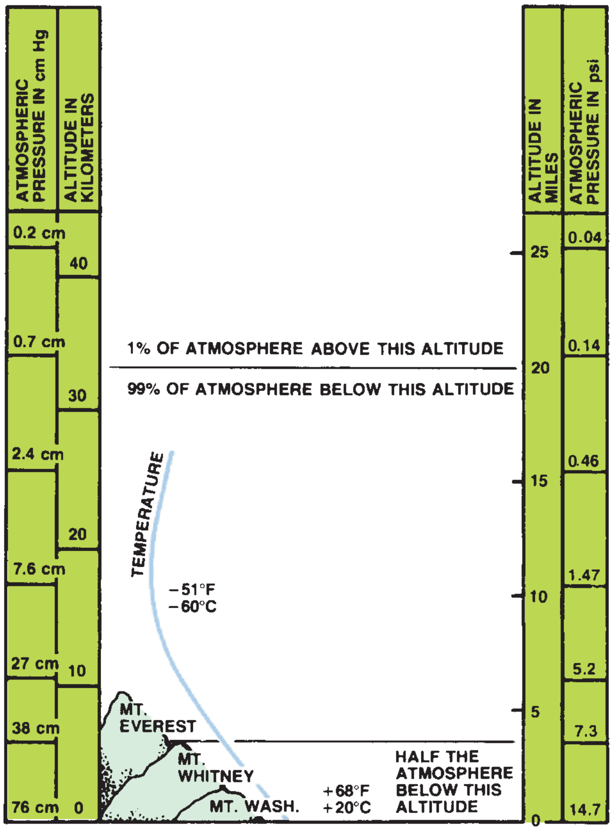


FIGURE 104–3 Atmospheric pressure varies with altitude.

MEASURING VACUUM Vacuum is measured in **inches of mercury (in. Hg)** or in **millimeters of mercury (mm Hg)**, a figure that indicates how far a column of mercury in a tube will rise when a vacuum is applied at one end and atmospheric pressure at the other. Vacuum is a measurement of the pressure differential between the lower pressure inside the tube and the higher pressure outside it.

A perfect vacuum is about 30 in. Hg (762 mm Hg). However, a perfect vacuum occurs only in space and is never achieved in an engine's intake manifold. Manifold vacuum varies with throttle position. The lowest manifold vacuum (highest pressure) occurs when the throttle is wide open with the engine under load. The highest manifold vacuum (lowest pressure) may be as much as 24 in. Hg (610 mm Hg) when the vehicle is rolling rapidly downhill in gear with the throttle closed. Manifold vacuum at idle typically falls between 15 and 20 in. Hg (381 and 508 mm Hg), and most vacuum brake boosters are designed to operate with vacuum levels in this range.

BOOSTER VACUUM SUPPLY Vacuum boosters get their vacuum supply from the engine intake manifold. Diesel engines, however, run unthrottled (engine speed is controlled strictly by the amount of fuel injected) and have little or no intake manifold vacuum. If a vehicle with a diesel engine is equipped with a vacuum-powered brake booster, it must also be fitted with an auxiliary vacuum pump.

Some small gasoline-powered and diesel engines use a belt-driven add-on pump. ● **SEE FIGURE 104–4**.

An electrically powered vacuum pump is turned on and off by a pressure switch on the booster. This means they operate only when needed and thus reduce power drain on the engine. ● **SEE FIGURE 104–5**.

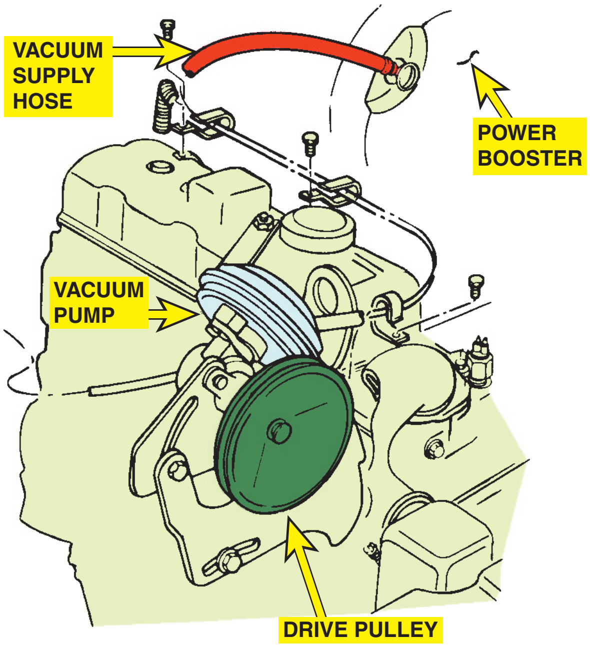


FIGURE 104–4 A belt-driven auxiliary vacuum pump.

VACUUM BOOSTER THEORY

Vacuum boosters use the principle of pressure differential to increase brake application force. The typical vacuum booster has a **power chamber** separated into two smaller chambers by a flexible diaphragm. When air pressure is greater on one side of the diaphragm than the other, a pressure differential is created. In an attempt to equalize pressure in the two chambers, the higher pressure exerts a force that moves the diaphragm toward the lower pressure area. Rods attached to the diaphragm transmit this force, in addition to the force the driver exerts on the brake pedal, to the master cylinder.

The amount of force created in this manner is proportional to the difference in pressure between the two sides. In other words, the greater the pressure differential, the greater the force. To calculate the force, the pressure differential is multiplied by the diaphragm surface area. For example, if a power booster diaphragm has atmospheric pressure (14.7 PSI) on one side, and a typical intake manifold vacuum of 20 in. Hg (10 PSI of absolute pressure), the pressure differential acting on the diaphragm would be as follows:

14.7 PSI − 10 PSI = 4.7 PSI

TECH TIP

Check the Vacuum, Then the Brakes

A customer complained of a very rough idle and an occasional pulsating brake pedal. The customer was certain that the engine required serious work since there were over 100,000 miles on the vehicle. During the troubleshooting procedure, a spray cleaner was used to find any vacuum (air) leaks. A large hole was found melted through a large vacuum hose next to the vacuum hose feeding the vacuum-operated power brake booster.

After repairing the vacuum leak, the vehicle was test driven again to help diagnose the cause of the pulsating brake pedal. The engine idled very smoothly after the vacuum leak was repaired and the brake pulsation was also cured. The vacuum leak resulted in lower-than-normal vacuum being applied to the vacuum booster. During braking, when engine vacuum is normally higher (deceleration), the vacuum booster would assist, then not assist when the vacuum was lost. This on-and-off supply of vacuum to the vacuum booster was noticed by the driver as a brake pulsation. Always check the vacuum at the booster whenever diagnosing any brake problems. Most vehicle manufacturers specify a minimum of 15 in. Hg of vacuum at the booster. The booster should be able to provide at least two or three stops even with no vacuum. The booster should also be checked to see if it can hold a vacuum after several hours. A good vacuum booster, for example, should be able to provide a power assist after sitting all night without starting the engine.

If we once again multiply this times the area of the diaphragm, the result is as follows:

4.7 PSI × 50 sq. in = 235 pounds of force

Vacuum booster diaphragms are sized to fit specific applications and provide the necessary application force. Most vacuum boosters are capable of providing hundreds of pounds of application force. ● **SEE FIGURE 104–6**.

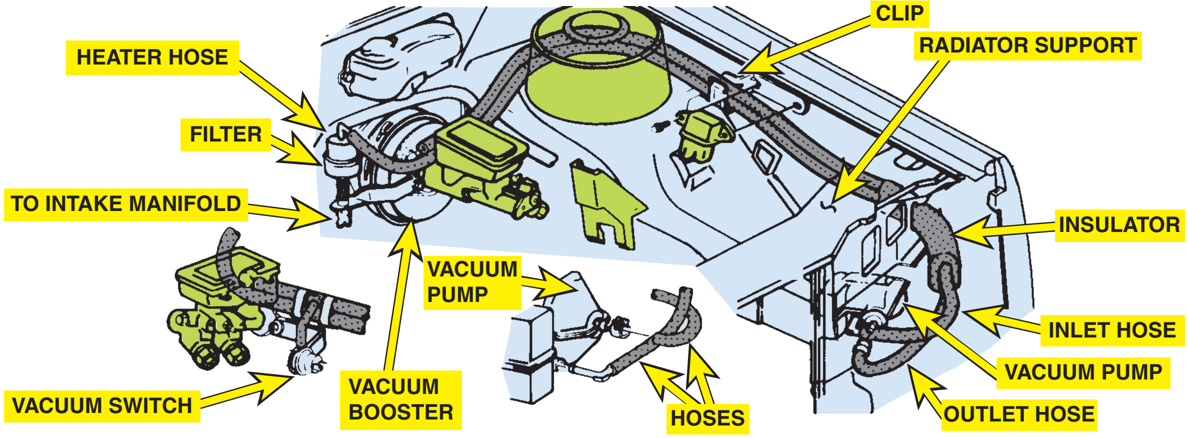


FIGURE 104–5 An electrically powered vacuum pump.

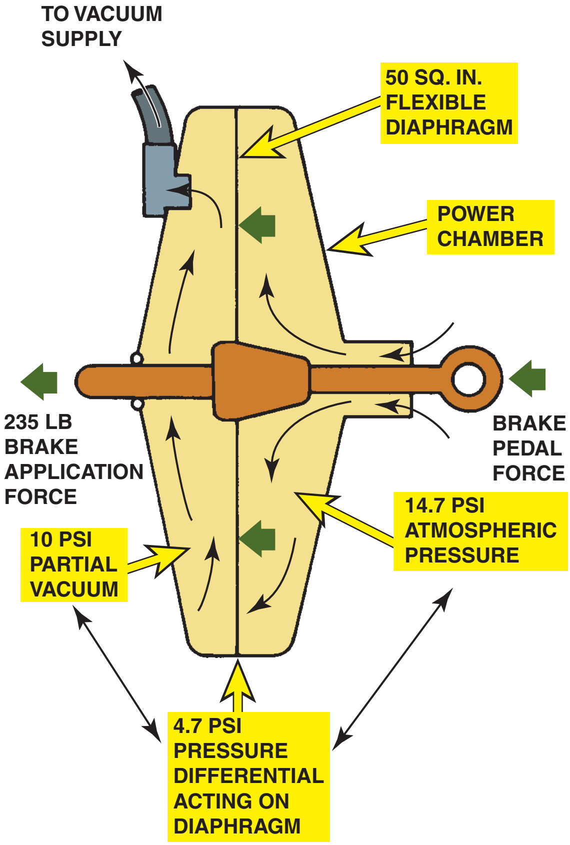
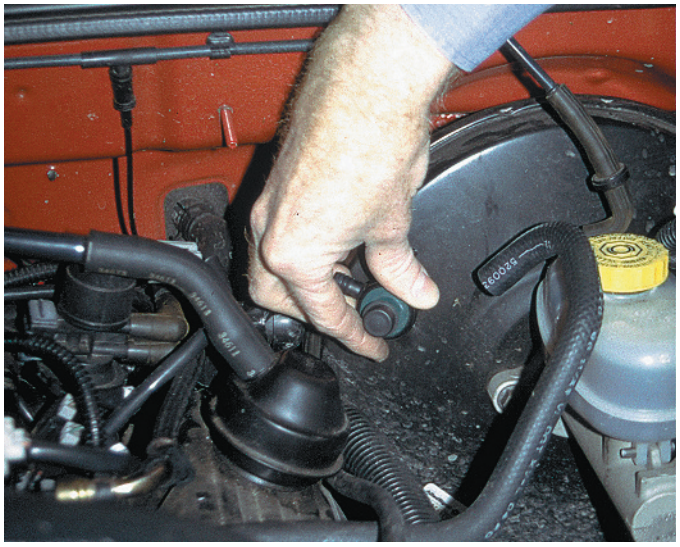

TO VACUUM SUPPLY
50 SQ. IN. FLEXIBLE DIAPHRAGM
POWER CHAMBER
235 LB BRAKE APPLICATION FORCE
BRAKE PEDAL FORCE
14.7 PSI ATMOSPHERIC PRESSURE
10 PSI PARTIAL VACUUM
4.7 PSI PRESSURE DIFFERENTIAL ACTING ON DIAPHRAGM

FIGURE 104–6 Vacuum brake boosters operate on the principle of pressure differential.

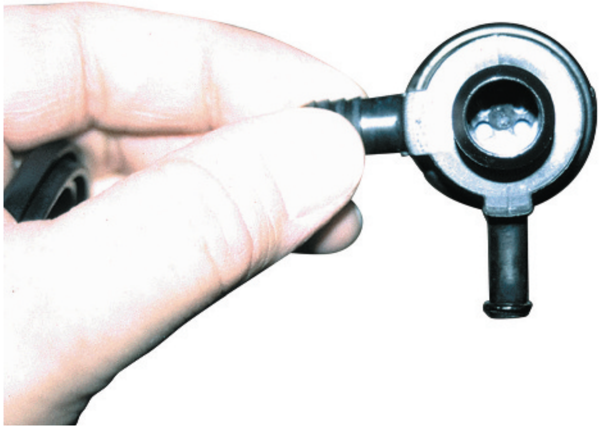
VACUUM CHECK VALVE

All vacuum boosters use a one-way vacuum check valve. This valve allows air to flow in only one direction—from the booster toward the engine. This valve prevents loss of vacuum when the engine stops. Without this check valve, the vacuum stored in the vacuum booster would simply be lost through the hose and intake manifold of the engine. ● **SEE FIGURE 104–7**.

CAUTION: Sometimes an engine backfire can destroy or blow the vacuum check valve out of the booster housing. If this occurs, all power assist will be lost and a much greater-than-normal force must be exerted on the brake pedal to stop the vehicle. Be sure to repair the cause of the backfire before replacing the damaged or missing check valve. Normal causes of backfire include an excessively lean air–fuel ratio or incorrect firing order or ignition timing.



(a)



(b)

FIGURE 104–7 (a) Many vacuum brake booster check valves are located where the vacuum hose from the engine (vacuum source) attaches to the vacuum booster. (b) This one-way valve prevents the loss of vacuum when the engine is off. The diaphragm inside allows air to flow in one direction only.

VACUUM BRAKE BOOSTER OPERATION

A vacuum power-brake booster contains a rubber diaphragm(s) connected to the brake pedal at one end and to the master cylinder at the other end. When the brakes are off or released, there is equal vacuum on both sides of the diaphragm.

The vacuum power unit contains the power-piston assembly, which houses the control valve and reaction mechanism and the power-piston return spring. The control valve is composed of the air valve (valve plunger), the floating control-valve assembly, and the pushrod. The reaction mechanism consists of a hydraulic piston reaction plate and a series of reaction levers. An air filter, air silencer, and filter retainer are assembled around the valve operating rod, filling the cavity inside the hub of the power piston. The pushrod that operates the air valve projects out of the end. ● **SEE FIGURE 104–8**.

RELEASED-POSITION OPERATION At the released position (brake pedal up), the air valve is seated on the floating control valve, which shuts off the air. The floating control valve is held away from the valve seat in the power-piston insert. Vacuum from the engine is present in the space on both sides of the power piston. Any air in the system is drawn through a small passage in the power piston, over the seat in the power-piston insert, and through a passage in the power-piston insert. There is a vacuum on both sides of the power piston, and it is held against the rear of the housing by the power-piston return spring. At rest, the hydraulic reaction plate is held against the reaction retainer.

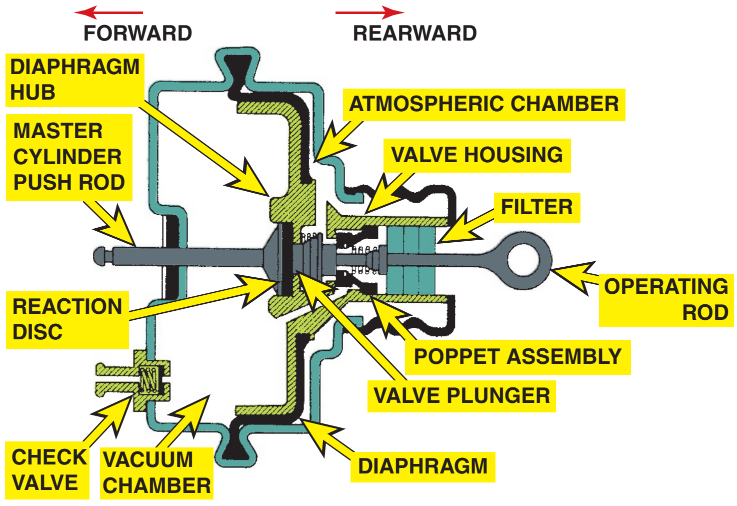


FIGURE 104–8 Cross-sectional view of a typical vacuum brake booster assembly.

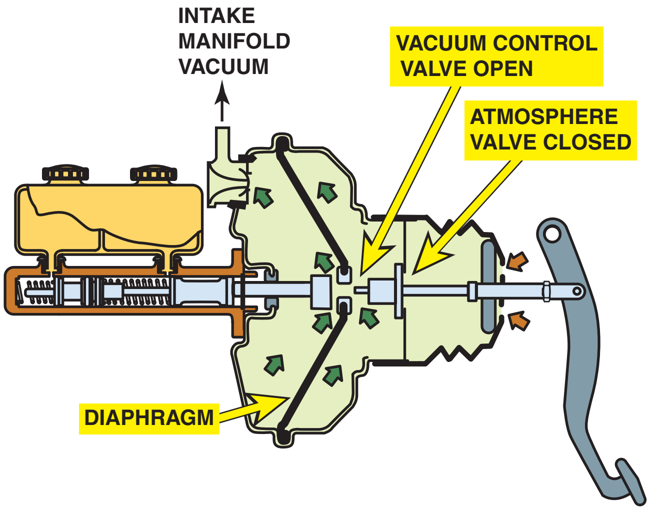


FIGURE 104–9 In the release position (brake pedal up), the vacuum is directed to both sides of the diaphragm.

The air-valve spring holds the reaction lever against the hydraulic reaction plate and holds the air valve against its stop in the tube of the power piston. The floating control-valve assembly is held against the air-valve seat by the floating control-valve spring. ● **SEE FIGURE 104–9**.

APPLIED-POSITION OPERATION

As the brake pedal is depressed, the floating control valve is moved toward its seat in the power piston, away from the rear of the booster. The smaller air valve spring causes the air valve to stretch out toward the retreating floating control valve until it bottoms out on the lip of the power piston's vacuum passage. This closes off the vacuum supply to the rear section of the housing. Since the floating control valve travels farther than the sealing end of the air valve, atmospheric air is allowed to enter between the air valve and the floating control valve pressurizing the rear section of the housing. At this point, the rear section of the housing is pressurized and the front section is under vacuum. Atmospheric pressure can then force the power piston forward.

NOTE: This movement of air into the rear chamber of the brake booster may be heard inside the vehicle as a hissing noise. The loudness of this airflow varies from vehicle to vehicle and should be considered normal.

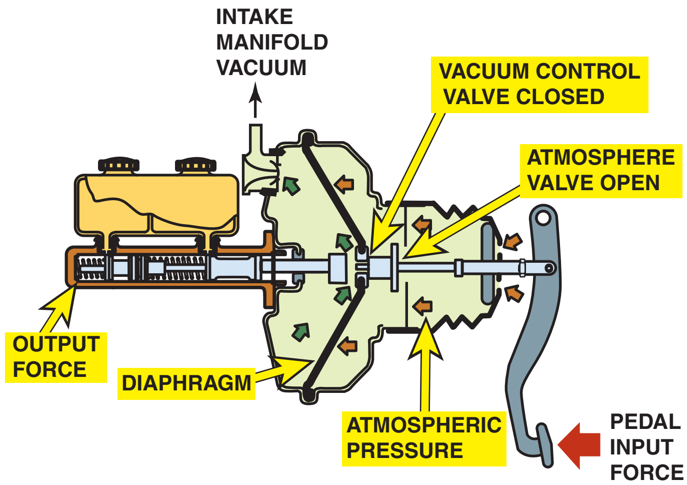


FIGURE 104–10 Simplified diagram of a vacuum brake booster in the apply position. Notice that the atmospheric valve is open and air pressure is being applied to the diaphragm.

As the power piston travels forward, the pushrod pushes against the hydraulic reaction plate in the master cylinder, pushing the master cylinder primary and secondary pistons forward. As back-pressure builds up on the end of the master cylinder piston, the floating control valve is pushed back off of its seat in the power piston, applying back-pressure to the brake pedal. The power-piston return spring also generates some brake pedal force. All in all, approximately 30% of the brake load is applied back to the brake pedal. This gives the driver a feel that is proportional to the degree of brake application. ● **SEE FIGURE 104–10**.

HOLD-POSITION OPERATION

When the desired brake pedal force is reached and there is balance between the opposing forces of the brake pedal and the master cylinder, the power piston moves forward "around" the floating control valve and reaction disc until the air valve sealing end "catches up" with the floating control valve. At this point, the air valve is once again sealed against the floating control valve and is no longer blocking the vacuum passage in the power piston. The floating control valve is again held away from its seat. Vacuum once again is present on both sides of the diaphragm and power piston. The status of the booster is almost exactly as it was in the released state except that the positions of the power piston and subsequently the master cylinder pistons are farther forward. Brake pedal force is keeping the power piston in its position. If additional braking is required (brake pedal pushed farther), the floating control valve moves away from the air valve permitting the power of atmospheric pressure to push the power piston and master cylinder pistons forward. If the pedal is released, since vacuum is then present on both sides of the diaphragm, the power-piston return spring moves the power piston to its released state. ● **SEE FIGURE 104–11**.

VACUUM-FAILURE MODE

In case of vacuum source interruption, the brake operates as a standard brake as follows: As the pedal is pushed down, the operating rod forces the floating control valve against the power piston and reaction disc. This force is then applied to the pushrod and subsequently the hydraulic reaction plate fastened to the master cylinder piston rod, which applies pressure in the master cylinder. For safety in the event of a stalled engine and a loss of vacuum, a power brake booster should have adequate storage of vacuum for several power-assisted stops.

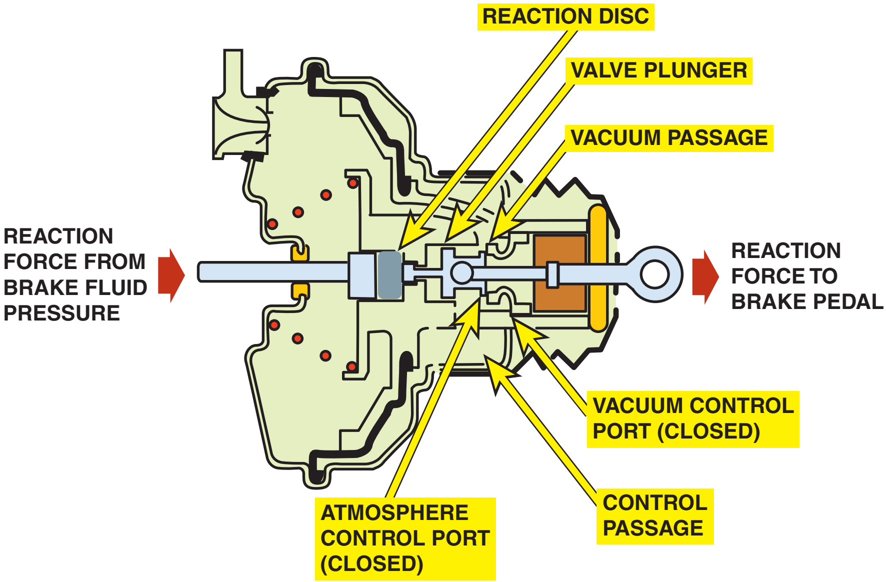

REACTION DISC
VALVE PLUNGER
VACUUM PASSAGE
REACTION FORCE FROM BRAKE FLUID PRESSURE
REACTION FORCE TO BRAKE PEDAL
VACUUM CONTROL PORT (CLOSED)
CONTROL PASSAGE
ATMOSPHERE CONTROL PORT (CLOSED)

FIGURE 104–11 Cross section of a vacuum brake booster in the hold position with both vacuum and atmospheric valves closed. Note that the reaction force from the brake fluid pressure is transferred back to the driver as a reaction force to the brake pedal.

TECH TIP

A Low, Soft Brake Pedal Is Not a Power Booster Problem

Some service technicians tend to blame the power brake booster if the vehicle has a low, soft brake pedal. A defective power brake booster causes a hard brake pedal, not a soft brake pedal. A soft or spongy brake pedal is usually caused by air being trapped somewhere in the hydraulic system.

Many times, the technician has bled the system and, therefore, thinks that the system is free of any trapped air. According to remanufacturers of master cylinders and power brake boosters, most of the returned parts under warranty are not defective. Incorrect or improper bleeding procedures account for much of the problem.

DUAL- (TANDEM-) DIAPHRAGM VACUUM BOOSTERS

To provide power assist, air pressure must work against a rubber diaphragm. The larger the area of the diaphragm, the more force can be exerted. The usual method of increasing the area of the vacuum diaphragm was to increase the diameter of the vacuum booster. However, a larger vacuum booster took up too much room under the hood of many vehicles. Instead of increasing the diameter, vacuum booster manufacturers used two smaller-diameter diaphragms and placed one in front of the other. These designs increased the total area without increasing the physical diameter of the booster. This style is called a **dual-diaphragm** or **tandem-diaphragm vacuum booster**. ● **SEE FIGURE 104–12**.

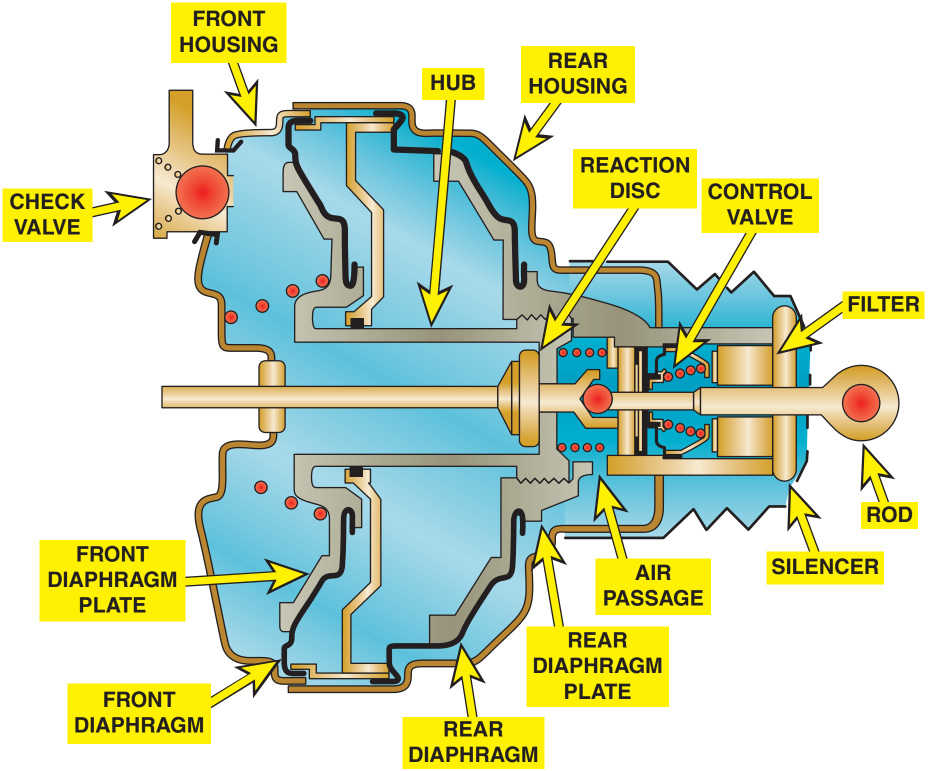

FRONT HOUSING
HUB
REAR HOUSING
CHECK VALVE
REACTION DISC
CONTROL VALVE
FILTER
ROD
SILENCER
AIR PASSAGE
FRONT DIAPHRAGM PLATE
REAR DIAPHRAGM PLATE
FRONT DIAPHRAGM
REAR DIAPHRAGM

FIGURE 104–12 Cutaway showing a dual-diaphragm (tandem) vacuum brake booster.

BRAKE ASSIST SYSTEM

PURPOSE AND FUNCTION Some vehicles are equipped with a **brake assist system (BAS)** that applies the brakes with maximum force if the system detects that the driver is making a panic stop. Tests performed by brake engineers have indicated that it is normal for a person to first apply the brakes rapidly during a panic situation. However, it was also found that the driver would tend to reduce the force applied to the brake pedal. As a result, the vehicle did not brake with the maximum effort.

OPERATION The brake assist system opens an air valve on the rear part of the vacuum booster assembly. As a result, more air at atmospheric pressure can flow into the rear chamber of the vacuum booster, thereby increasing the force applied to the master cylinder. The BAS function works with the electronic stability control (ESC) system to ensure maximum braking efficiency during evasive or emergency situations.

If the speed of the brake pedal application exceeds a predetermined limit as determined by the brake pedal travel sensor, the ABS controller energizes the BAS solenoid valve. When the solenoid valve opens, additional air at atmospheric pressure enters the driver's side of the booster. The additional pressure applies the brakes faster and with more force. The BAS solenoid is deenergized when the brake pedal is released and normal braking returns. ● **SEE FIGURES 104–13 AND 104–14**.

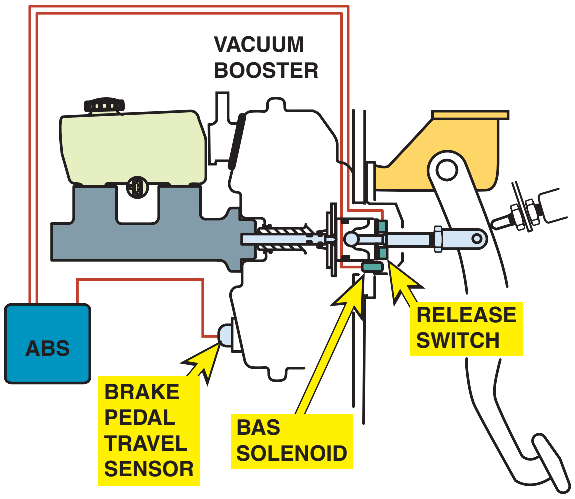


FIGURE 104–13 A typical brake assist system uses a brake pedal travel sensor and a BAS solenoid to apply the brakes during a panic condition.

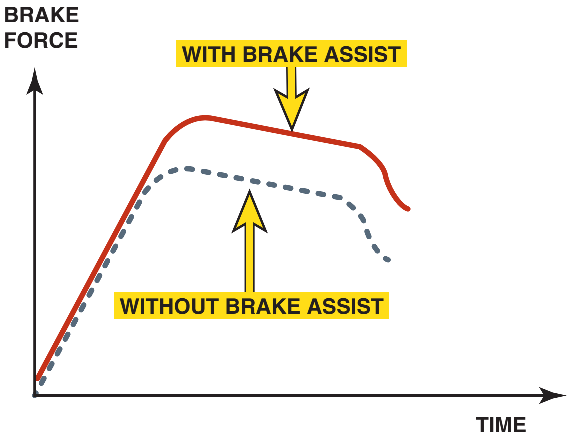


FIGURE 104–14 When the brake assist function operates, the brake force is much higher than normal.

VACUUM BOOSTER OPERATION TEST

With the engine "off," apply the brakes several times to deplete the vacuum. With your foot on the brake pedal, start the engine. The brake pedal *should* drop. If the brake pedal does *not* drop, check for proper vacuum source to the booster. There should be at least 15 in. Hg of vacuum at the booster for proper operation. If there is proper vacuum, repair or replacement of the power booster is required.

VACUUM BOOSTER LEAK TEST

To test if the vacuum booster can hold a vacuum, perform the following steps:

STEP 1 Operate the engine to build up a vacuum in the booster, then turn the engine off.

STEP 2 Wait for one minute.

STEP 3 Depress the brake pedal several times. There should be two or more power-assisted brake applications.

If applications are not power assisted, either the vacuum check valve or the booster is leaking. To test the check valve, remove the valve from the booster and blow through the check valve. If air passes through, the valve is defective and must be replaced. If the check valve is okay, the vacuum booster is leaking and should be repaired or replaced based on the manufacturer's recommendations.

HYDRAULIC SYSTEM LEAK TEST

An internal or external hydraulic leak can also cause a brake system problem. To test if the hydraulic system (and not the booster) is leaking, depress and release the brake pedal (service brakes) several times. This should deplete any residual power assist. On some ABS units, this may require depressing the brake pedal 20 or more times.

After depleting the power-assist unit, depress and then hold the brake pedal depressed with medium force (20 to 35 lb or 88 to 154 N). The brake pedal should *not* fall away. If the pedal falls, the hydraulic brake system is leaking. Check for external leakage at wheel cylinders, calipers, hydraulic lines, and hoses. If there is no external leak, there may be an internal leak inside the master cylinder. Repair or replace components as needed to correct the leakage.

PUSHROD CLEARANCE ADJUSTMENT

Whenever the vacuum brake booster or the master cylinder is replaced, the pushrod length should be checked. The length of the pushrod must match correctly with the master cylinder. ● **SEE FIGURE 104–15**.

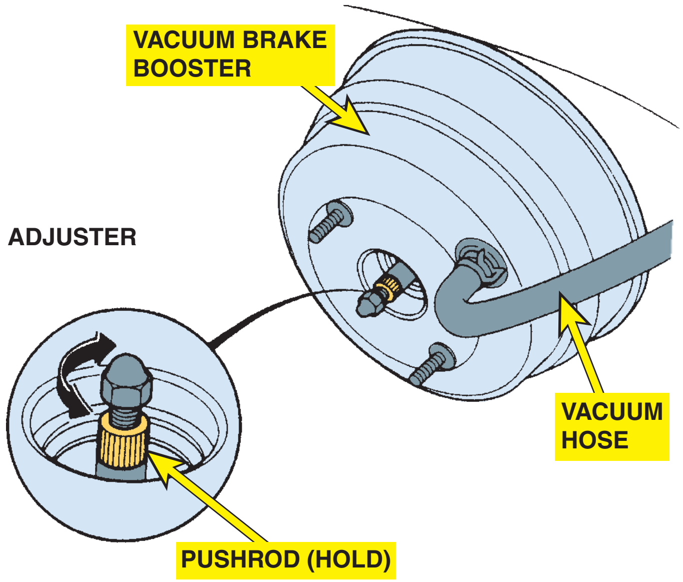


FIGURE 104–15 Typical adjustable pushrod. This adjustment is critical for the proper operation of the braking system. If the pushrod is too long, the brakes may be partially applied during driving. If the rod is too short, the brake pedal may have to be depressed farther down before the brakes start to work.

If the pushrod is too long and the master cylinder is installed, the rod may be applying a force on the primary piston of the master cylinder even though the brake pedal is not applied. This can cause the brakes to overheat, causing the brake fluid to boil. If the brake fluid boils, a total loss of braking force can occur. Obviously, this pushrod clearance check and adjustment is very important. A gauge is often used to measure the position of the master cylinder piston, and then the other end of the gauge is used to determine the proper pushrod clearance. ● **SEE FIGURE 104–16**.

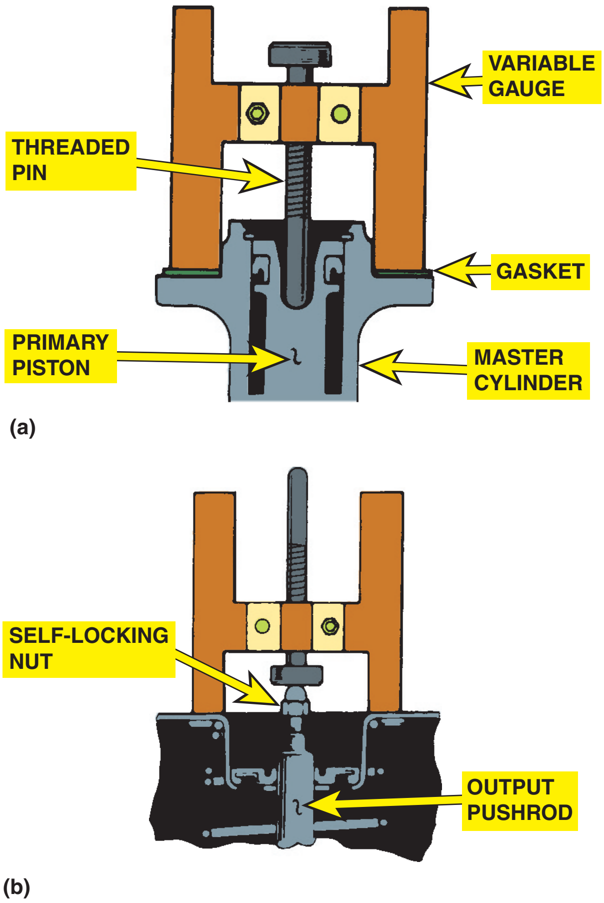


FIGURE 104–16 Typical vacuum brake booster pushrod gauging tool. (a) The tool is first placed against the mounting flange of the master cylinder and the depth of the piston determined. (b) The gauge is then turned upside down and used to gauge the pushrod length. Some vacuum brake boosters do not use adjustable pushrods. If found to be the incorrect length, a replacement pushrod of the correct length should be installed.

FREQUENTLY ASKED QUESTION

What Is Supplemental Brake Assist?

Supplemental brake assist (SBA) is a motor-driven vacuum pump that can supplement engine vacuum to the vacuum brake booster. This unit is used on some General Motors vehicles. When a vehicle is driven under a heavy load, engine vacuum is low. To meet the brake standards, some vehicles are equipped with the brake assist system that consists of the following components:

- A pressure sensor that is used to measure the vacuum in the vacuum booster.
- An intake manifold check valve that is used to prevent vacuum from escaping the vacuum boost.
- A motor-driven vacuum pump.

The vacuum pump motor will start and run if the pressure sensor detects the vacuum in the booster is below 7 in. Hg and will shut off after the vacuum level increases to 9 in. Hg. ● **SEE FIGURE 104–17**.

HYDRO-BOOST HYDRAULIC BRAKE BOOSTER

PURPOSE Hydro-Boost is a hydraulically operated power-assist unit built by Bendix. The Hydro-Boost system uses the pressurized hydraulic fluid from the vehicle's power steering pump as a power source rather than using engine vacuum as is used with vacuum boosters. ● **SEE FIGURE 104–18**.

The Hydro-Boost unit is used on vehicles that lack enough engine vacuum, such as turbocharged or diesel engine vehicles. During operation, diesel engines do not produce vacuum in the intake manifold. As a result, diesel engines must use accessory engine-driven vacuum pumps to operate vacuum accessories. Turbocharged and supercharged engines do not create engine vacuum during periods of acceleration. Even though vacuum is available when the engine is decelerating, some vehicle manufacturers elect to install a Hydro-Boost system rather than equip the vehicle with an accessory engine-driven vacuum pump.

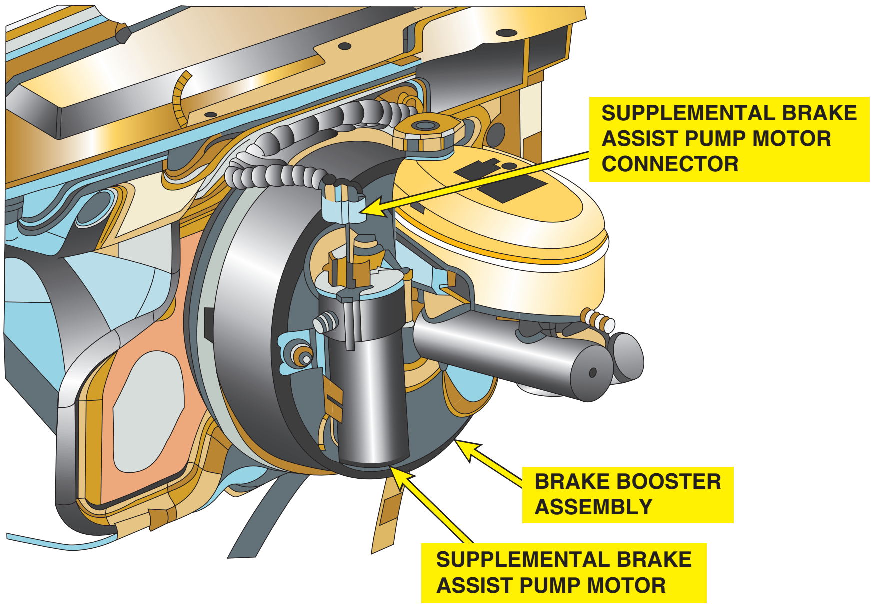

SUPPLEMENTAL BRAKE ASSIST PUMP MOTOR CONNECTOR
BRAKE BOOSTER ASSEMBLY
SUPPLEMENTAL BRAKE ASSIST PUMP MOTOR

FIGURE 104–17 The supplemental brake assist (BAS) pump mounts on the brake booster housing.

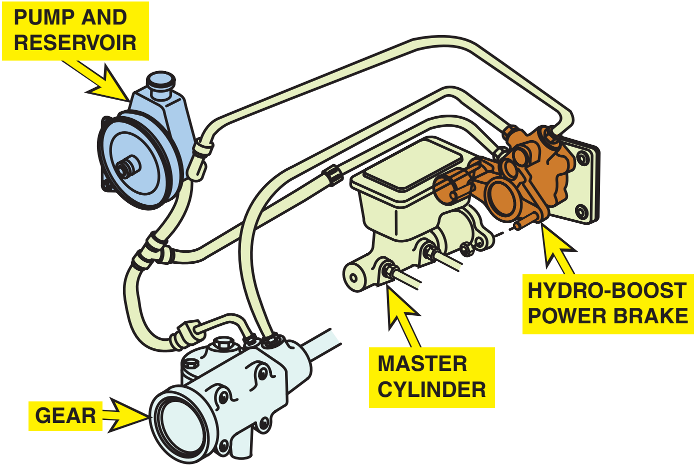


FIGURE 104–18 Hydro-Boost unit attaches between the bulkhead and the master cylinder and is powered by the power steering pump.

OPERATION Fluid pressure from the power steering pump enters the unit and is directed by a spool valve. ● **SEE FIGURE 104–19**. When the brake pedal is depressed, the lever and primary valve are moved. The valve closes off the return port, causing pressure to build in the boost pressure chamber. The hydraulic pressure pushes on the power piston, which then applies force to the output rod that connects to the master cylinder piston. In the event of a power steering pump failure, power assist is still available for several brake applications.

DIAGNOSIS The power source for Hydro-Boost units comes from the power steering pump. The first step of troubleshooting is to perform a thorough visual inspection, including the following:

1. Checking for proper power steering fluid level
2. Checking for leaks from the unit or power steering pump
3. Checking the condition and tightness of the power steering drive belt
4. Checking for proper operation of the base brake system

After checking all of the visual components, check for proper pressure and volume from the power steering pump using a power steering pump tester, as shown in ● **FIGURES 104–20 AND 104–21**.

The pump should be capable of producing a minimum of 2 gallons (7.5 L) with a maximum pressure of 150 PSI (1,000 kPa) with the steering in the straight-ahead position. With the engine "off," the accumulator should be able to supply a minimum of two power-assisted brake applications.

HYDRO-BOOST FUNCTION TEST With the engine off, apply the brake pedal several times until the accumulator is depleted completely. Depress the service brake pedal and start the engine. The pedal should fall and then push back against the driver's foot.

TECH TIP

The Hydro-Boost Accumulator Test

The accumulator stores hydraulic fluid under pressure to provide a reserve in the event of a failure of the power steering system. The accumulator is designed to provide three or more power-assisted stops with the engine off. ● **SEE FIGURE 104–22**.

If the accumulator fails, it does not hold pressure. To easily check whether the accumulator has lost its charge, simply grasp the accumulator with your hand and try to twist or move it. The accumulator should have so much pressure on it that it should not move or wiggle. If the accumulator moves, it has lost its ability to hold pressure and the Hydro-Boost unit should be replaced.

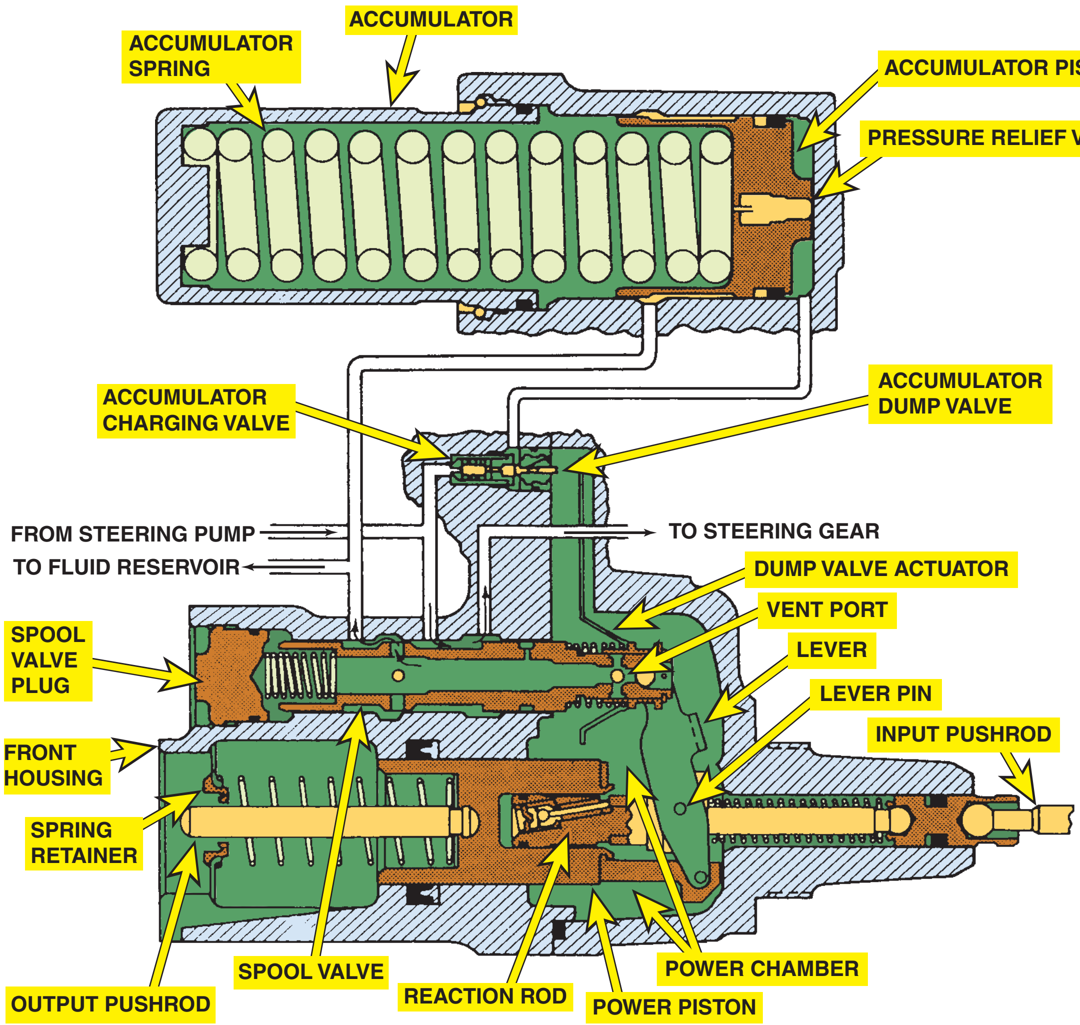

ACCUMULATOR
ACCUMULATOR SPRING
ACCUMULATOR PISTON
PRESSURE RELIEF VALVE
ACCUMULATOR CHARGING VALVE
ACCUMULATOR DUMP VALVE
FROM STEERING PUMP
TO FLUID RESERVOIR
TO STEERING GEAR
DUMP VALVE ACTUATOR
VENT PORT
SPOOL VALVE PLUG
LEVER
LEVER PIN
INPUT PUSHROD
FRONT HOUSING
SPRING RETAINER
OUTPUT PUSHROD
SPOOL VALVE
REACTION ROD
POWER CHAMBER
POWER PISTON

FIGURE 104–19 A Hydro-Boost hydraulic booster in the unapplied position.

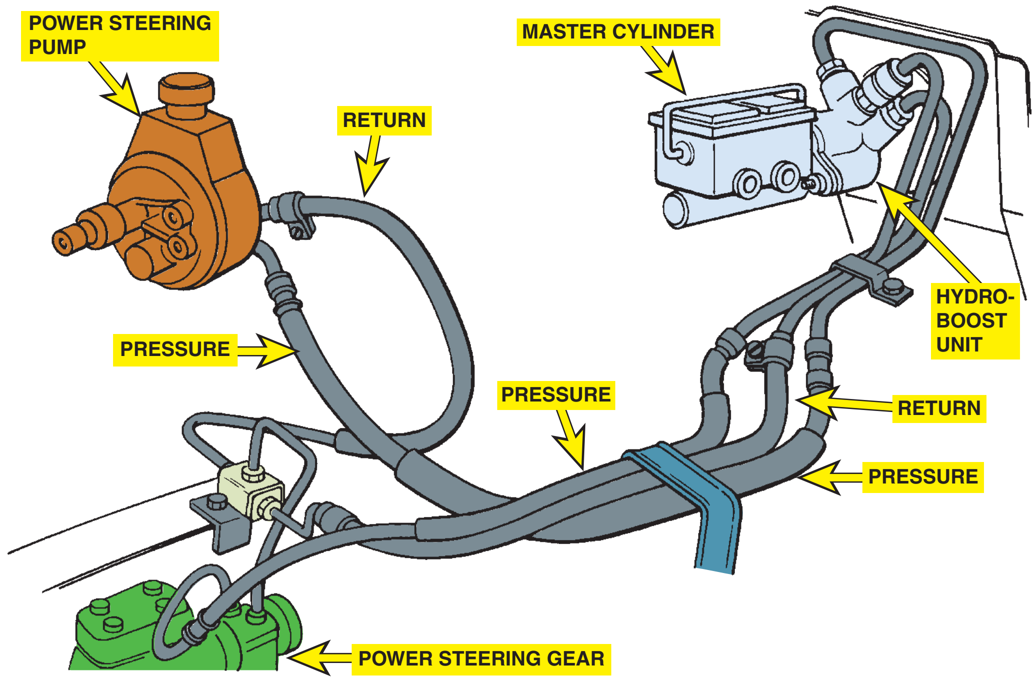

POWER STEERING PUMP
MASTER CYLINDER
RETURN
HYDRO-BOOST UNIT
PRESSURE
PRESSURE
RETURN
PRESSURE
POWER STEERING GEAR

FIGURE 104–20 A typical Hydro-Boost hydraulic line arrangement showing the pump, steering gear, and brake booster assembly.

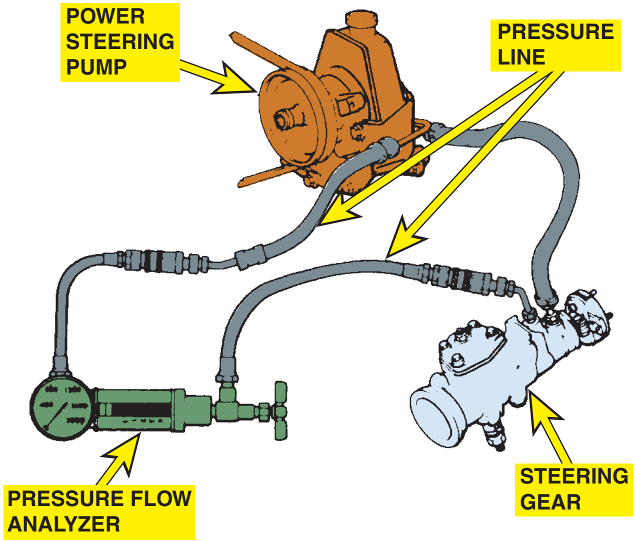


FIGURE 104–21 Pressure and flow analyzer installation to check the power steering pump output.

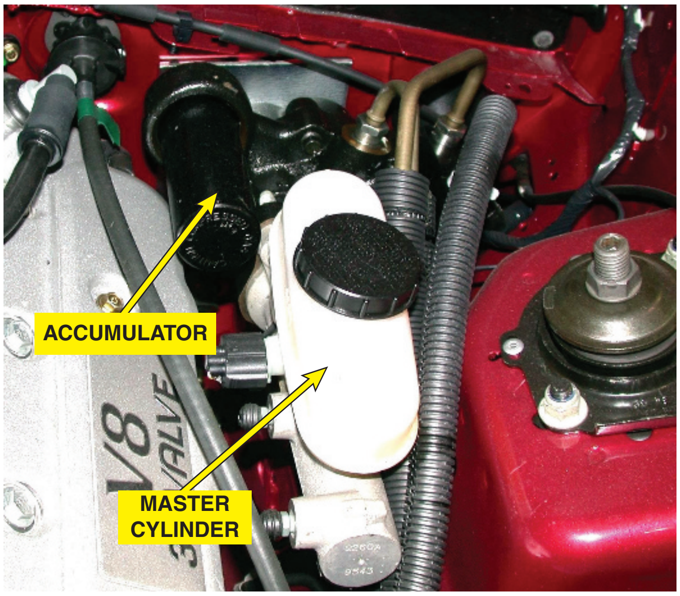


FIGURE 104–22 The accumulator should be able to hold pressure and feel tight when hand force is used to try to move it.

HYDRO-BOOST SYMPTOM-BASED GUIDE

EXCESSIVE BRAKE PEDAL EFFORT Possible causes for this include the following:

1. Loose or broken power steering pump belt
2. No fluid in the power steering reservoir
3. Leaks in the power steering, booster, or accumulator hoses
4. Leaks at tube fittings, power steering, booster, or accumulator connections
5. External leakage at the accumulator
6. Faulty booster piston seal, causing leakage at the booster flange vent
7. Faulty booster cover seal with leakage between the housing and cover
8. Faulty booster spool plug seal

SLOW BRAKE PEDAL RETURN Possible causes for this include the following:

1. Excessive seal friction in the booster
2. Faulty spool action
3. Broken piston return spring
4. Restriction in the return line from the booster to the pump reservoir
5. Broken spool return spring

GRABBY BRAKES Possible causes for this include the following:

1. Broken spool return spring
2. Faulty spool action caused by contamination in the system

BOOSTER CHATTERS—PEDAL VIBRATES Possible causes for this include the following:

1. Power steering pump belt slipping
2. Low fluid level in the power steering pump reservoir
3. Faulty spool operation caused by contamination in the system

FREQUENTLY ASKED QUESTION

How Does an Electric Power Brake Assembly Work?

The base brakes used on electric vehicle use an electric motor actuator to increase the force applied by the driver to the hydraulic system. An electric vehicle does not have an internal combustion engine and therefore does not have engine vacuum, which is used by most power brake systems used on most vehicles

REVIEW QUESTIONS

1. Describe the purpose and function of the one-way check valve used on vacuum brake booster units.
2. Explain how vacuum is used to assist in applying the brakes.
3. Describe how to perform a vacuum booster leak test and hydraulic system leak test.
4. Explain how a Hydro-Boost system functions.
5. What is the difference between vacuum and pressure?

CHAPTER QUIZ

1. A power brake booster provides which of the following design features?
   - **a.** Reduced stopping distance
   - **b.** Reduced brake pedal effort
   - **c.** High brake pedal effort
   - **d.** A lower brake pedal position
2. The proper operation of a vacuum brake booster requires that the engine be capable of supplying at least ___________.
   - **a.** 15 in. Hg vacuum
   - **b.** 17 in. Hg vacuum
   - **c.** 19 in. Hg vacuum
   - **d.** 21 in. Hg vacuum
3. A defective vacuum brake booster will cause a ___________.
   - **a.** hard brake pedal
   - **b.** soft (spongy) brake pedal
   - **c.** low brake pedal
   - **d.** slight hiss noise when the brake pedal is depressed
4. A brake pedal feels spongy when depressed. Technician A says that a defective hydraulic brake booster could be the cause. Technician B says that a defective vacuum brake booster could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Two technicians are discussing vacuum brake boosters. Technician A says that a low, soft brake pedal is an indication of a defective booster. Technician B says that there should be at least two power-assisted brake applications after the engine stops running. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Technician A says that to check the operation of a vacuum brake booster, the brake pedal should be depressed until the assist is depleted and then start the engine. Technician B says that the brake pedal should drop when the engine starts, if the booster is okay. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Which of these could be caused by an improperly adjusted booster pushrod?
   - **a.** Brakes to overheat
   - **b.** A soft pedal
   - **c.** A low pedal
   - **d.** None of these
8. An accumulator such as that used on hydraulic brake boosters ___________.
   - **a.** reduces brake pedal noise
   - **b.** provides higher force being fed back to the driver's foot
   - **c.** provides a reserve in the event of a failure
   - **d.** works against engine vacuum
9. The typical vacuum booster has a power chamber separated into two smaller chambers by a ___________.
   - **a.** gasket
   - **b.** check valve
   - **c.** wire mesh
   - **d.** flexible diaphragm
10. When the brakes are released, the booster has ___________ on both sides of the power piston.
    - **a.** brake fluid
    - **b.** vacuum
    - **c.** atmospheric pressure
    - **d.** None of the above

Chapter

105

ABS COMPONENTS AND OPERATION

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and theory of the antilock brake system (ABS).
- Describe the components of ABS.
- Discuss ABS channels.
- Discuss ABS controller inputs and outputs.
- Discuss wheel speed sensors.
- Discuss hydraulic modulator assembly.
- Discuss advanced ABS functions.
- Discuss automatic emergency braking.

KEY TERMS:

Accumulator 1267 • Active wheel speed sensors 1264 • Antilock brake system (ABS) 1259 • Automatic emergency braking (AEB) 1269 • Control module 1261 • Passive wheel speed sensor 1264 • Pressure decay stage 1266 • Pressure dump stage 1266 • Pressure holding stage 1266 • Pressure increase stage 1266 • Pressure reduction stage 1266 • Pressure release stage 1266 • Select low principle 1262 • Tire-pressure monitoring system (TPMS) 1268 • Tire slip 1259 • Variable reluctance (VR) 1264 • Wheel speed sensors (WSS) 1264

ANTILOCK BRAKE SYSTEM

PURPOSE AND FUNCTION **Antilock brake systems (ABS)** help prevent the wheels from locking during sudden braking, especially on slippery surfaces.

- This helps the driver maintain control.
- Antilock brakes increase safety because they eliminate wheel/tire lockup and minimize the danger of skidding, allowing the vehicle to stop in a straight line.
- ABS also allows the driver to maintain steering control during heavy braking so the vehicle can be steered to avoid an obstacle or another vehicle.
- ABS can improve braking when road conditions are less than ideal, as when making a sudden panic stop or when braking on a wet or slick road. ABS does this by monitoring the relative speed of the wheels to one another. It uses this information to modulate brake pressure as needed to control slippage and maintain traction when the brakes are applied.

ABS AND TIRE TRACTION Preventing brake lockup is important because of the adverse effect a locked wheel has on tire traction. The brakes slow the rotation of the wheels, but it is the friction between the tire and road that stops the vehicle and allows it to be steered. If tire traction is reduced, stopping distances increase and the directional stability of the vehicle suffers. Traction is defined in terms of **tire slip**, which is the difference between the actual speed and the rate at which the tire tread moves across the road.

- A free-rolling wheel has nearly zero tire slip
- A locked wheel has 100% tire slip. ● **SEE FIGURE 105–1**.

When the brakes are applied, the rotational speed of the wheel drops, and tire slip increases because the tread moves across the road slower than the actual vehicle speed. This slip creates friction that converts kinetic energy into braking and cornering force.

TIRE SLIP AND BRAKING DISTANCE On dry or wet pavement, maximum braking traction occurs when tire slip is held between approximately 15% and 25%. ● **SEE FIGURE 105–2**.

On snow- or ice-covered pavement, the optimum slip range is 20% to 50%. In each case, if tire slip increases beyond these levels, the amount of traction decreases. A skidding tire with 100% slip provides 20% to 30% less braking traction on dry pavement, and this is generally true on slippery roads as well. In nearly all cases, the shortest stopping distances are obtained when the brakes are applied with just enough force to keep the tire slip in the range where traction is greatest.

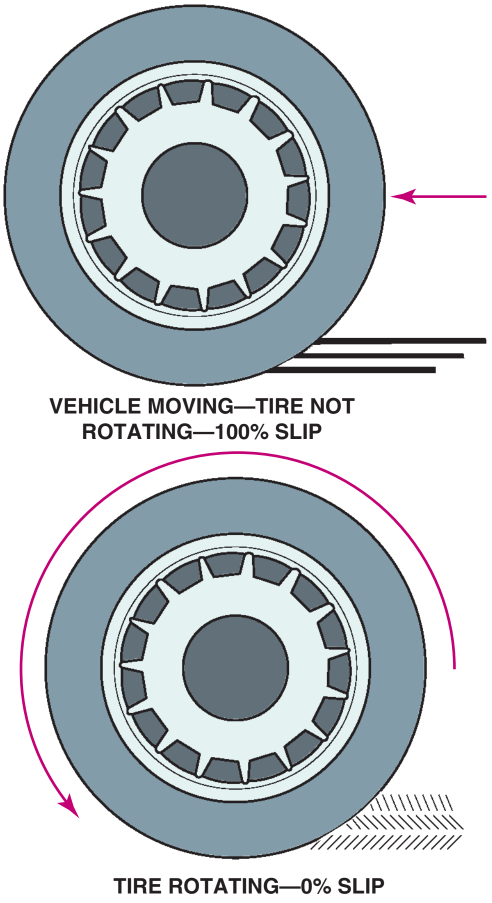


FIGURE 105–1 Maximum braking traction occurs when tire slip is between 10% and 20%. A rotating tire has 0% slip and a locked-up wheel has 100% slip.

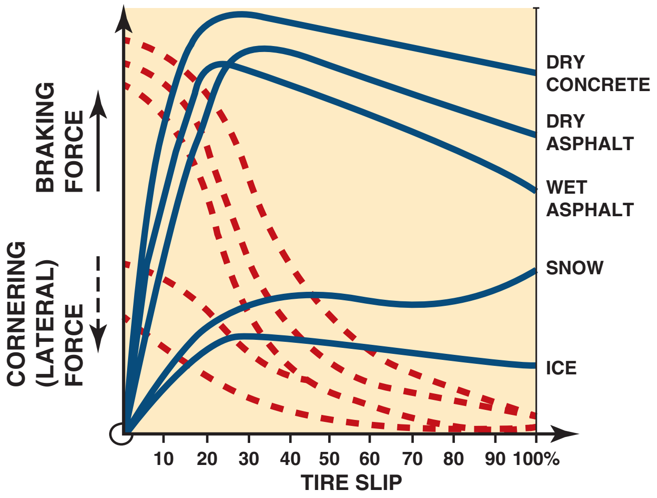


FIGURE 105–2 Traction is determined by pavement conditions and tire slip.

TIRE SLIP AND VEHICLE STABILITY A tire's contact patch with the road can provide only a certain amount of traction. When a vehicle is stopped in a straight line, nearly all of the available traction can be used to provide braking force. Only a small amount of traction is required to generate lateral force that keeps the vehicle traveling in a straight line. However, if a vehicle has to stop and turn at the same time, the available traction must be *divided* to provide both cornering (lateral) and braking force.

No tire can provide full cornering power and full braking power at the same time. When a brake is locked and the tire has 100% slip, all of the available traction is used for braking, and none is left for steering. As a result, a skidding tire follows the path of least resistance. This means that if the rear brakes lock, the back end of the vehicle will tend to swing around toward the front causing a spin. If the front brakes lock, steering control will be lost and the vehicle will slide forward in a straight line until the brakes are released to again make traction available for steering.

TECH TIP

Tire "Chirp" Noise during Hard Braking Is Normal

Sometimes customers state that they do not think that their antilock brake system (ABS) is working correctly because they heard the tires making noise (chirping sound) during hard braking. This is normal as the tires slip about 20% during an ABS stop.

ABS LIMITATIONS There are two situations in which an antilock brake system will *not* provide the shortest stopping distances.

1. The first involves straight stops made on smooth, dry pavement by an *expert* driver. Under these conditions, a skilled driver can hold the tires consistently closer to the ideal slip rate than the ABS can. ● **SEE FIGURE 105–3**.

   This is possible because current antilock brake systems may allow the amount of tire slip to drop as low as 5%, which is somewhat below the point where maximum tire traction is achieved. However, for the average driver, or under less-than-ideal conditions, antilock brakes will almost always stop the vehicle in a shorter distance.
2. The other situation in which antilock brakes will not provide the shortest stops is when braking on loose gravel or dirt, or in deep, fluffy snow. Under these conditions, a locked wheel will stop the vehicle faster because loose debris builds up and forms a wedge in front of the tire that helps stop the vehicle. ● **SEE FIGURE 105–4**.

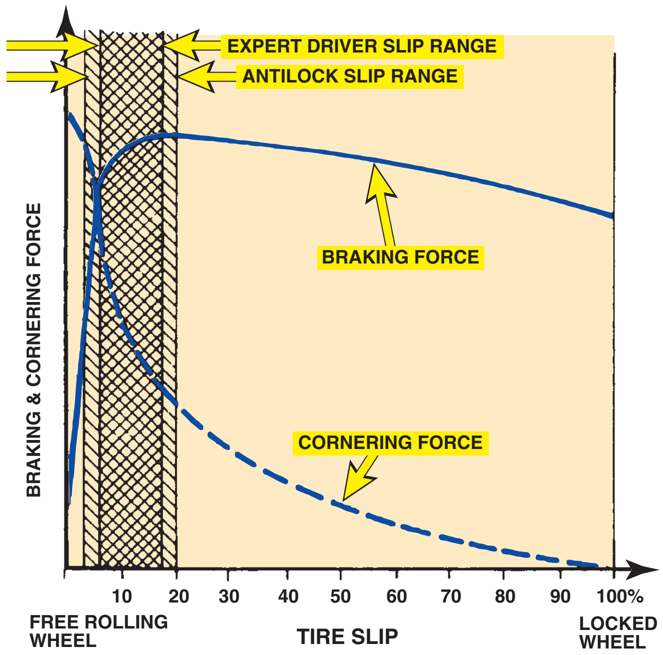


FIGURE 105–3 A good driver can control tire slip more accurately than an ABS if the vehicle is traveling on a smooth, dry road surface.

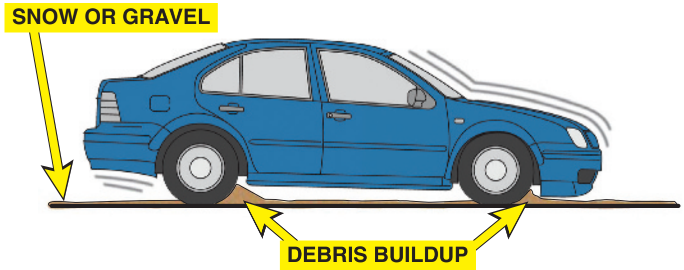


FIGURE 105–4 A wedge of gravel or snow in the front of a locked wheel can help stop a vehicle faster than would occur if the wheel brakes were pulsed on and off by an antilock brake system.

An antilock brake system will prevent this wedge from forming, so some vehicles with antilock brakes have a switch on the instrument panel that allows the system to be deactivated when driving on these kinds of road surfaces.

ABS AND THE LAWS OF PHYSICS No ABS can overcome the laws of physics. The weight and speed of a moving vehicle give it a great deal of kinetic energy and only so much of that energy can be converted into braking or cornering force at any given time.

- The limiting factor in this conversion is the traction between the tires and road. Although a vehicle with four-wheel antilock brakes will stop in very nearly the shortest possible distance, this will still not prevent an accident if the brakes are applied too late to bring the vehicle to a complete stop before impact. However, because steering control is retained with four-wheel antilock brakes, it may be possible to drive the vehicle around a potential accident while in the process of braking.
- Another situation where antilock brakes cannot defy the laws of physics occurs when a vehicle enters a corner traveling faster than it is physically possible to negotiate the turn. In this situation, antilock brakes will not prevent the vehicle from leaving the road. However, they will allow the vehicle to be slowed and steered in the process, thus lessening the severity of the eventual impact. ● **SEE FIGURE 105–5**.

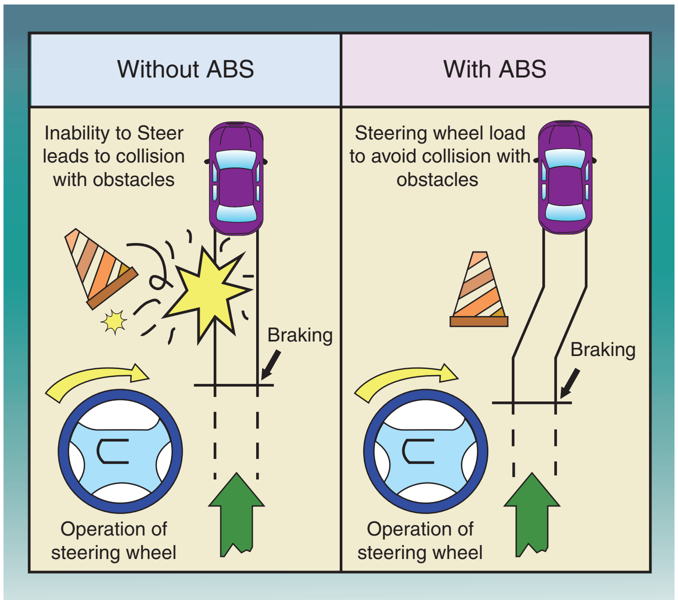

Without ABS
With ABS
Inability to Steer leads to collision with obstacles
Braking
Operation of steering wheel
Steering wheel load to avoid collision with obstacles
Braking
Operation of steering wheel

FIGURE 105–5 Being able to steer and control the vehicle during rapid braking is one major advantage of an antilock brake system.

ABS PARTS INVOLVED

WHEEL SPEED SENSOR INPUT All ABS control tire slip by monitoring the relative deceleration rates of the wheels during braking. Wheel speed is monitored by wheel speed sensors.

- If one wheel starts to slow at a faster rate than the others, or at a faster rate than that which is programmed in the antilock control module, it indicates a wheel is starting to slip and is in danger of losing traction and locking.
- The ABS responds by momentarily reducing hydraulic pressure to the brake on the affected wheel or wheels. This allows the wheel to speed up momentarily so it can regain traction. As traction is regained, brake pressure is reapplied to again slow the wheel.
- The cycle is repeated over and over until the vehicle stops or until the driver eases pressure on the brake pedal.

CONTROL MODULE The control module receives wheel speed information from the wheel speed sensors (WSS) and then sends a voltage signal to the control solenoids which then controls brake fluid pressure at the wheel brakes. The ABS electronic control module is a digital microprocessor that uses inputs from its various sensors to regulate hydraulic pressure during braking to prevent wheel lockup. The ABS controller may be referred to as:

- Electronic brake control module (EBCM)
- Electronic brake module (EBM)
- Controller antilock brakes (CAB)

The module may be located on the hydraulic modulator assembly (as it is on many of the newer compact ABS), or it may be located elsewhere in the vehicle, such as the trunk, passenger compartment, or under the hood.

VALVES Electrically operated solenoid valves are used to hold, release, and reapply hydraulic pressure to the brakes. This produces a pulsating effect, which can be felt in the brake pedal during hard braking. The rapid modulation of brake pressure in a given brake circuit reduces the braking load on the affected wheel and allows it to regain traction to prevent lockup. The effect is much the same as pumping the brakes, except that the ABS does it automatically for each brake circuit, and at speeds that would be humanly impossible—up to 20 times per second depending on the system (some cycle faster than others). ● **SEE FIGURE 105–6**.

FREQUENTLY ASKED QUESTION

When Was ABS First Used?

Antilock brake systems were first used in the 1950s on aircraft and then first used on a 1970 Lincoln Continental using a rear-wheel braking system called "Sure Track" as an option. Also in 1970, General Motors Corporation offered a rear-wheel antilock brake system on selected rear-wheel-drive vehicles, which was called "Track Master" made by AC Electronics Division of GM. In 1971, Chrysler Imperial offered a three-channel system that used four wheel speed sensors built by Bendix Corporation, called "Sure Brake" by Chrysler.

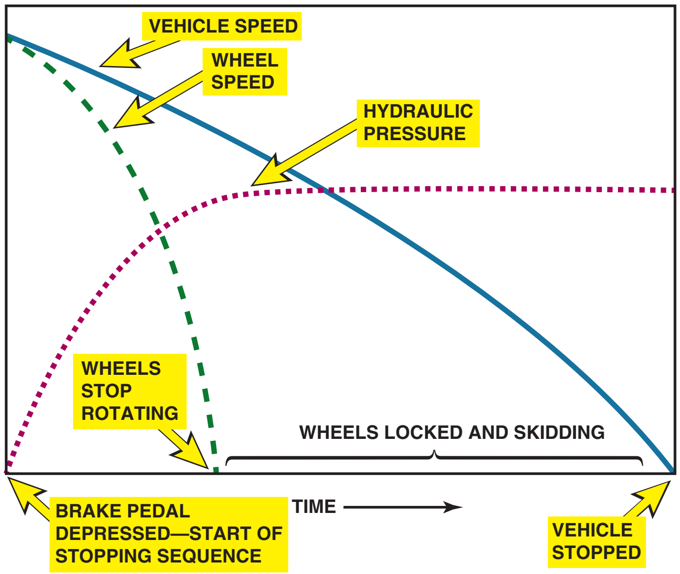


FIGURE 105–6 A typical stop on a slippery road surface without antilock brakes. Notice that the wheels stopped rotating and skidded until the vehicle finally came to a stop.

Once the rate of deceleration for the affected wheel catches up with the others, normal braking function and pressure resume, and antilock reverts to a passive mode.

PUMP A pump is used in most antilock systems to restore brake fluid pressure after the valves have released the pressure in an effort to control wheel slippage.

ABS CHANNELS

All ABS keep track of wheel deceleration rates with wheel speed sensors. The various ABS use a different number of sensors, depending on how the system is configured. These include

- single-channel systems
- three-channel systems
- four-channel systems

● **SEE FIGURE 105–7**.

SINGLE-CHANNEL SYSTEMS Most of the early antilock brake systems were used to control the rear brakes only. This type of system was called single-channel ABS. The single-channel rear-wheel only ABS is used on older rear-wheel-drive pickups and vans.

- Ford version is called Rear Antilock Brake System (RABS)
- General Motors and Chrysler version is called Rear Wheel Antilock (RWAL)—pronounced "R wall."

The front wheels have no speed sensors, and only a single speed sensor mounted in the differential or transmission is used for both rear wheels. Rear-wheel antilock systems are typically used on applications where vehicle loading can affect rear-wheel traction, which is why it is used on pickup trucks and vans. Because the rear-wheel antilock systems have only a single channel, they are much less complex and costly than their multichannel, four-wheel counterparts.

THREE-CHANNEL ABS SYSTEMS Some four-wheel ABS have a separate wheel speed sensor for each front wheel but use a common speed sensor for both rear wheels. These are called "three-channel" systems. The rear wheel speed sensor is mounted in either the differential or the transmission. The sensor reads the combined or average speed of both rear wheels. This type of setup saves the cost for an additional sensor and reduces the complexity of the system by allowing both rear wheels to be controlled at the same time which is called the **select low principle**. Three-channel systems were the most common type of ABS setup used on early rear-wheel-drive applications.

FOUR-CHANNEL ABS On some applications, each wheel is equipped with its own speed sensor. This type of arrangement is called a "four-wheel, four-channel" system since each wheel speed sensor provides input for a separate hydraulic control circuit or "channel." The term *channel* always refers to the number of separate or individually controlled ABS hydraulic circuits in an ABS, not the number of wheel speed sensor electrical circuits.

NOTE: For vehicle stability systems to function, there has to be four wheel speed sensors and four channels so the hydraulic control unit can pulse individual wheel brakes to help achieve vehicle stability.

ABS OPERATION ABS have a conventional brake master cylinder and vacuum power booster with a separate hydraulic modulator unit. Some also have an electric pump for ABS braking (to reapply pressure during the ABS hold–release–reapply cycle), but do not use the pumps for normal power assist. Nonintegral ABS are the most common type of ABS because of their lower cost and simplicity. ● **SEE FIGURE 105–8**.

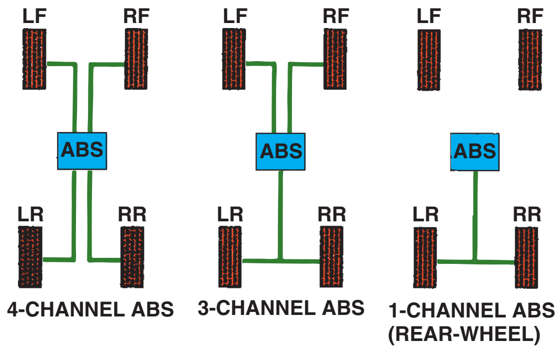


FIGURE 105–7 ABS configuration includes four-channel, three-channel, and single-channel systems.

ABS CONTROLLER INPUTS AND OUTPUTS

INPUTS The key inputs for the ABS control module come from the wheel speed sensors and the brake pedal switch. The brake pedal switch signals the control module when the brakes are being applied, which causes it to go from a "standby" mode to an active mode. At the same time, the wheel speed sensors provide

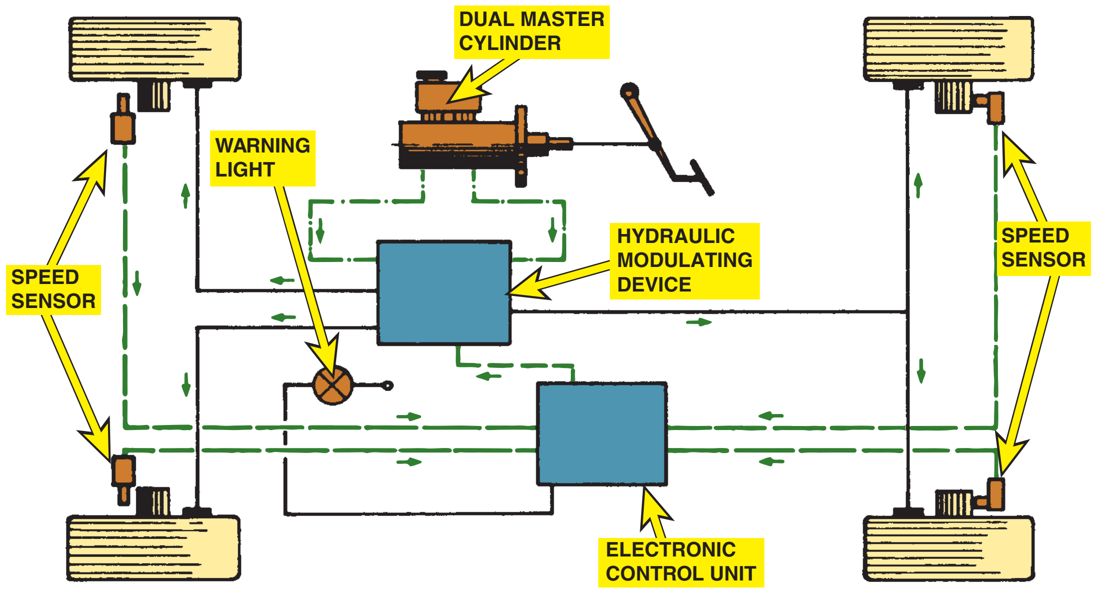

DUAL MASTER CYLINDER
WARNING LIGHT
SPEED SENSOR
HYDRAULIC MODULATING DEVICE
SPEED SENSOR
ELECTRONIC CONTROL UNIT

FIGURE 105–8 A schematic drawing of a typical antilock brake system.

information about what is happening to the wheels while the brakes are being applied.

NOTE: A fault with the brake switch will not prevent ABS operation.

The brake switch allows the controller to react faster to an ABS event. The signals being sent to the ABS controller (module) include the following:

- Wheel speed—from wheel speed sensors
- Brake on/off—from the brake pedal switch
- Steering wheel position—used for electronic stability control
- Yaw and accelerometer sensors—used for electronic stability control system

OUTPUTS The ABS controller (module) controls the following components:

- System relay
- Inlet valves
- Outlet valve
- Pump motor
- ABS warning lamp (amber ABS dash light)

● **SEE FIGURE 105–9**.

MODULE OPERATION If the control module detects a difference in the deceleration rate between one or more wheels when braking, or if the overall rate of deceleration is too fast and exceeds the limits programmed into the control module, it triggers the ABS control module to momentarily take over. The control module cycles the solenoid valves in the modulator assembly to pulsate hydraulic pressure in the affected brake circuit (or circuits) until wheel speed sensor information indicates that the deceleration rates have returned to normal and braking is under control. Normal braking resumes. When the brake pedal is released or when the vehicle comes to a stop, the control module returns to a standby mode until it is again needed.

ABS WARNING LAMP Every ABS has an amber indicator lamp on the instrument panel that warns the driver when a problem occurs within the ABS.

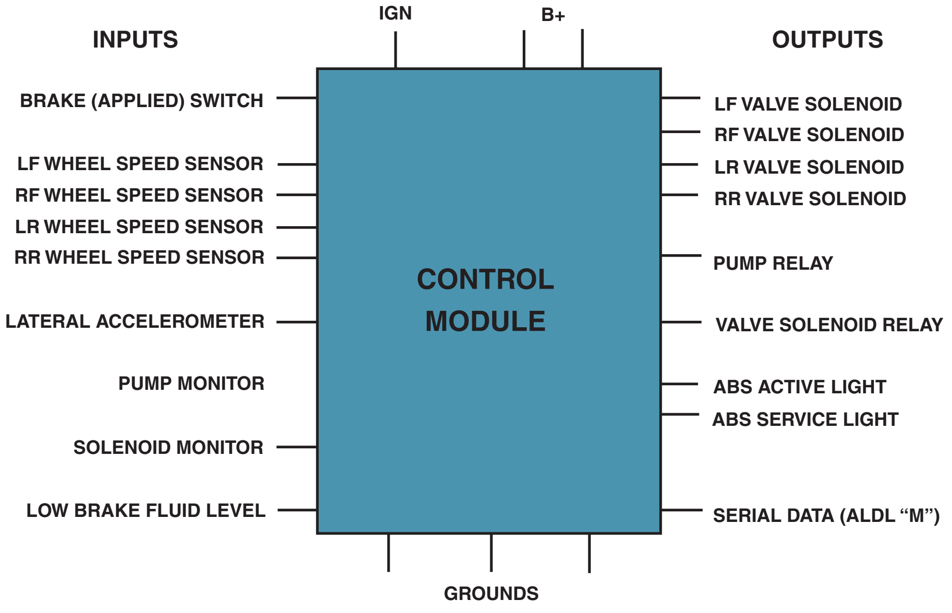

INPUTS
IGN
B+
OUTPUTS
BRAKE (APPLIED) SWITCH
LF WHEEL SPEED SENSOR
RF WHEEL SPEED SENSOR
LR WHEEL SPEED SENSOR
RR WHEEL SPEED SENSOR
LATERAL ACCELEROMETER
PUMP MONITOR
SOLENOID MONITOR
LOW BRAKE FLUID LEVEL
CONTROL MODULE
LF VALVE SOLENOID
RF VALVE SOLENOID
LR VALVE SOLENOID
RR VALVE SOLENOID
PUMP RELAY
VALVE SOLENOID RELAY
ABS ACTIVE LIGHT
ABS SERVICE LIGHT
SERIAL DATA (ALDL "M")
GROUNDS

FIGURE 105–9 Typical inputs and outputs for brake control modules.

- The lamp comes on when the ignition is turned on for a bulb check, then goes out after the engine starts.
- If the warning light remains on or comes on while driving, it usually indicates a fault in the ABS that will require further diagnosis.
- On most applications, the ABS is disabled if the ABS warning light comes on and remains on. This should have no effect on normal braking, unless the red brake warning lamp is also on which could indicate a base brake hydraulic fault.

WHEEL SPEED SENSORS

PURPOSE AND FUNCTION The purpose and function of **wheel speed sensors**, abbreviated WSS, is to monitor the speed of the wheels. The antilock brake controller uses the data from the wheel speed sensors to control the solenoids (valves) in the hydraulic brake control module and controls how fast the wheels are slowing during a stop.

WHEEL SPEED SENSOR LOCATIONS The sensor itself may be mounted on or in

- steering knuckle
- wheel hub
- brake backing plate
- transmission tail shaft housing
- transfer case
- differential housing
- integral part of the wheel bearing and hub assembly.

The sensor (reluctor) ring may be mounted on the

- axle hub behind the brake rotors
- brake rotors or drums
- outside of the outboard constant velocity joints on a front-wheel-drive vehicle
- transmission tail shaft housing
- inside the differential on the ring gear or pinion gear shaft. ● **SEE FIGURE 105–10**.

PASSIVE WHEEL SPEED SENSORS A **passive wheel speed sensor** generates its own output signal and can operate without an outside voltage being applied. Passive wheel speed sensors are often called **variable reluctance (VR)**-type sensor, which uses a magnetic core surrounded by coil windings. The sensor is mounted at a specific gap from a notch-and-tooth reluctor ring. ● **SEE FIGURE 105–11**.

- As the wheel turns, teeth on the reluctor (sensor) ring move through the pickup's magnetic field.
- As the gap between the notch and the ring changes with the rotation of the reluctor, the sensor induces an alternating current (AC) voltage in the sensor windings.
- The voltage signal will increase in amplitude with an increase with the speed of the reluctor ring, also called a *tone ring*. A typical passive WSS starts to produce a usable speed signal above 2 MPH (3 km/h).
- The variable-reluctance sensor is a two-wire sensor mounted in the steering knuckle and rear suspension or axle. This reverses the polarity of the magnetic field and induces an alternating current voltage in the sensor windings.
- The number of voltage pulses per second induced in the pickup changes frequency. ● **SEE FIGURE 105–12**.
- The frequency of the signal is therefore proportional to wheel speed. The higher the frequency, the faster the wheel is turning.

The control module then monitors wheel speed by counting the pulses from each of the wheel speed sensors. If the frequency signal from one wheel starts to change abruptly with respect to the others, it tells the module that wheel is starting to lose traction. The module then applies antilock braking if needed to maintain traction.

The major problem with this type of sensor is that the voltage output and frequency are very low at slow speeds and therefore cannot produce accurate wheel speed for ABS and traction control. ● **SEE FIGURE 105–13**.

NOTE: Many vehicles that use a passive type of wheel speed sensor apply a small voltage, usually 2.5 volts, to the wires of the sensor to check for circuit continuity. This bias voltage does not affect the operation of the sensor because the sensor creates an AC voltage output which rides on top of the applied DC voltage and is used only for circuit diagnosis.

ACTIVE WHEEL SPEED SENSORS **Active wheel speed sensors** are called active because they require outside electrical

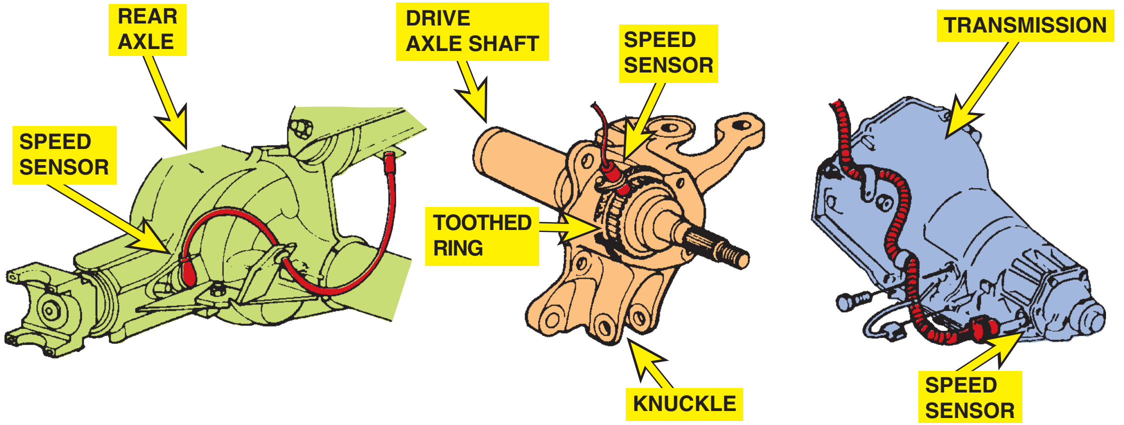


FIGURE 105–10 Wheel speed sensors for the rear wheels may be located on the rear axle, on the transmission, or on the individual wheel knuckle.

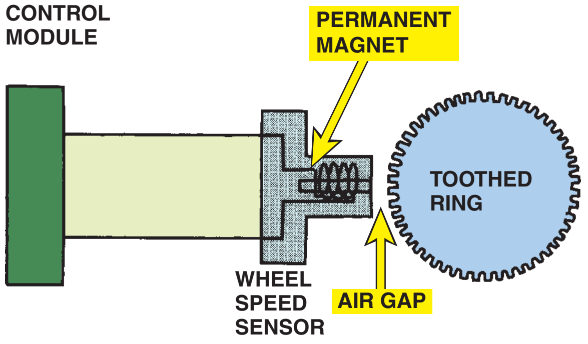


FIGURE 105–11 A schematic of a typical wheel speed sensor.

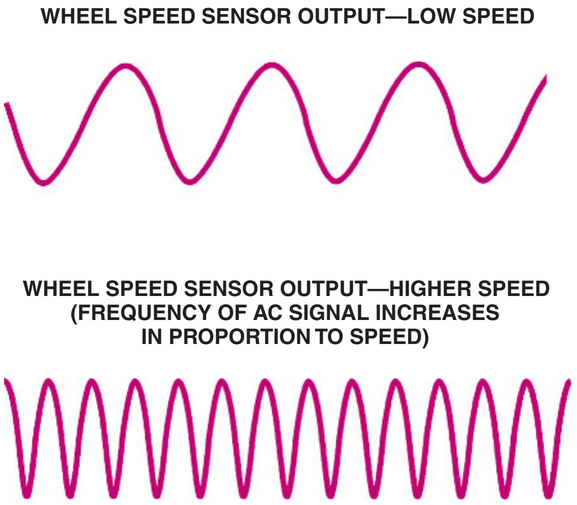


FIGURE 105–12 Wheel speed sensors produce an alternating current (AC) signal with a frequency that varies in proportion to wheel speed.

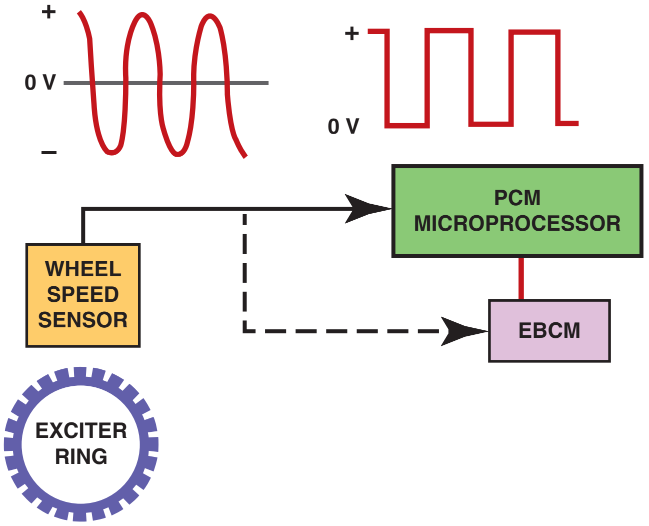


FIGURE 105–13 A typical passive variable-reluctance sensor produces a sine wave (continuously variable) output signal which is then converted to a square wave inside the PCM and/or the electronic brake control module (EBCM).

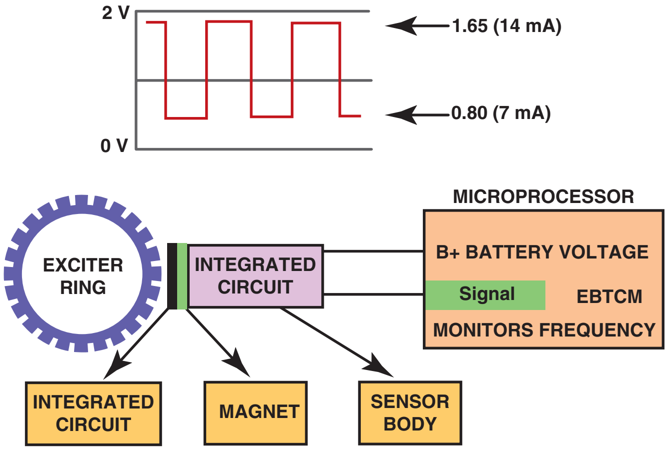


FIGURE 105–14 A digital wheel speed sensor produces a square wave output signal.

power to operate. An active WSS is also called a *digital wheel speed sensor* because it generates a digital on and off output signal and is capable of detecting wheel speed as low as 0 MPH (0 km/h). There are two types of active wheel speed sensors:

1. **Hall-effect**—A Hall-effect sensor uses a permanent magnet behind an integrated circuit (IC) chip. The magnetic field penetrates the IC and the toothed wheel. If the toothed wheel is turning, the magnetic field is changing. The IC is measuring the change in the field and is addressing the changes in a rectangle signal. The signal is not dependent on the speed.
2. **Magneto-resistive (MR)**—The most common type of active sensor is the magneto-resistive type, which uses a magneto-resistive circuit to produce a square waveform where the frequency is proportional to the wheel speed.

   A digital wheel speed sensor can also detect direction and can therefore be used by the controller for advanced features such as hill holding. The accuracy of these digital sensors also makes correlation to global positioning used in navigational systems more accurate, especially when the vehicle is being driven at slow speeds.

The typical active wheel speed sensor uses two wires with the ground supplied by the sensor mount:

- A 12-volt supply
- A DC signal from the sensor

The sensor voltage toggles between about 0.8 volt and 1.9 volt.

● **SEE FIGURE 105–14.**

HYDRAULIC MODULATOR ASSEMBLY

PURPOSE AND FUNCTION The modulator valve body is part of the master cylinder assembly in integral antilock systems but separate in nonintegral systems. It contains solenoid valves for each brake unit (in Delphi ABS-VI applications, however, motor-driven valves are used instead of solenoids). The exact number of valves per circuit depends on the ABS and the application. Some use a pair of on–off solenoid valves for each brake circuit, while others use a single valve that can operate in more than one position.

ABS SOLENOID A solenoid consists of a wire coil with a movable core and a return spring. When current from the ABS control module energizes the coil, it pulls on the movable core. Depending on how the solenoid is constructed, this may open or close a valve that is attached to the movable core. When the control current is shut off, the solenoid snaps back to its normal or rest position.

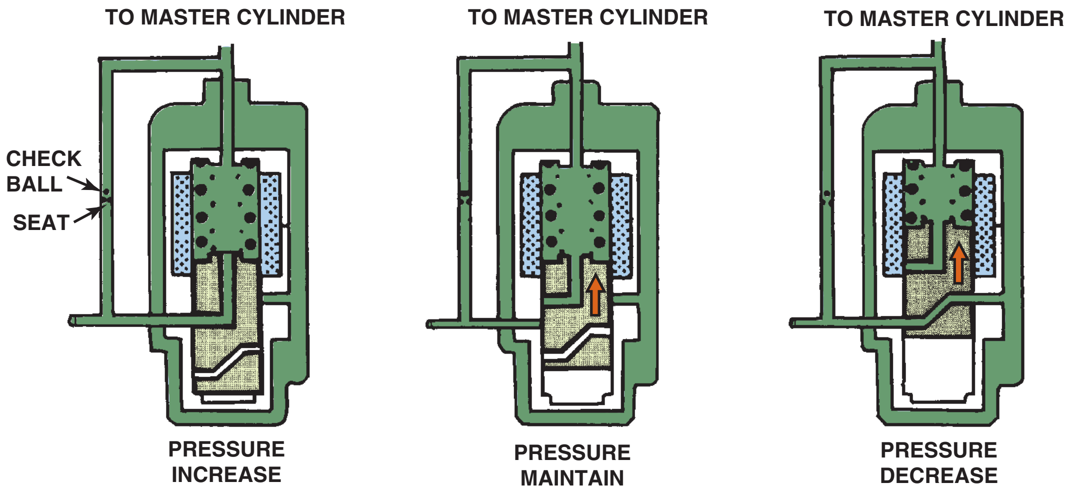

TO MASTER CYLINDER
TO MASTER CYLINDER
TO MASTER CYLINDER
CHECK BALL
SEAT
PRESSURE INCREASE
PRESSURE MAINTAIN
PRESSURE DECREASE

FIGURE 105–15 An ABS three-way solenoid can increase, maintain, or decrease brake pressure to a given brake circuit.

Some solenoids are designed to do more than just switch on or off to open or close a valve. Some pull a valve to an intermediate position when a certain level of current is applied to the coil, then pull the valve to a third position when additional current is provided. ● **SEE FIGURE 105–15.**

This design allows a single solenoid to perform the same functions as two or even three single-position solenoids. The solenoids in the hydraulic modulator assembly are used to open and close passageways between the master cylinder and the individual brake circuits. By opening or closing the modulator valves to which they're attached, brake pressure within any given circuit can be held, released, and reapplied to prevent lockup during hard braking.

ABS CONTROL PRESSURE STAGES The standard ABS control strategy that is used is a three-step cycle:

1. The first step is to hold or isolate the pressure in a given brake circuit by closing an *isolation solenoid* in the modulator assembly. This solenoid is normally electrically and hydraulically opened. When the solenoid is electrically closed, it becomes hydraulically closed, which blocks off the line and prevents any further pressure from the master cylinder reaching the brake. This is called the **pressure holding stage**. ● **SEE FIGURE 105–16.**
2. If the wheel speed sensor continues to indicate the wheel is slowing too quickly and is starting to lock, the same solenoid or a second release solenoid is energized to open a vent port that releases pressure from the brake circuit. ● **SEE FIGURE 105–17.**
3. The fluid is usually routed into a spring-loaded or pressurized storage reservoir (called an accumulator) so it can be reused as needed. Releasing pressure in the brake circuit allows the brake to loosen its grip so the wheel can speed up and regain traction. This is called
   - **pressure reduction stage**
   - **pressure release stage**
   - **pressure decay stage**
   - **pressure dump stage**

   The *pressure reduction solenoid* is normally hydraulically closed and electrically opened.

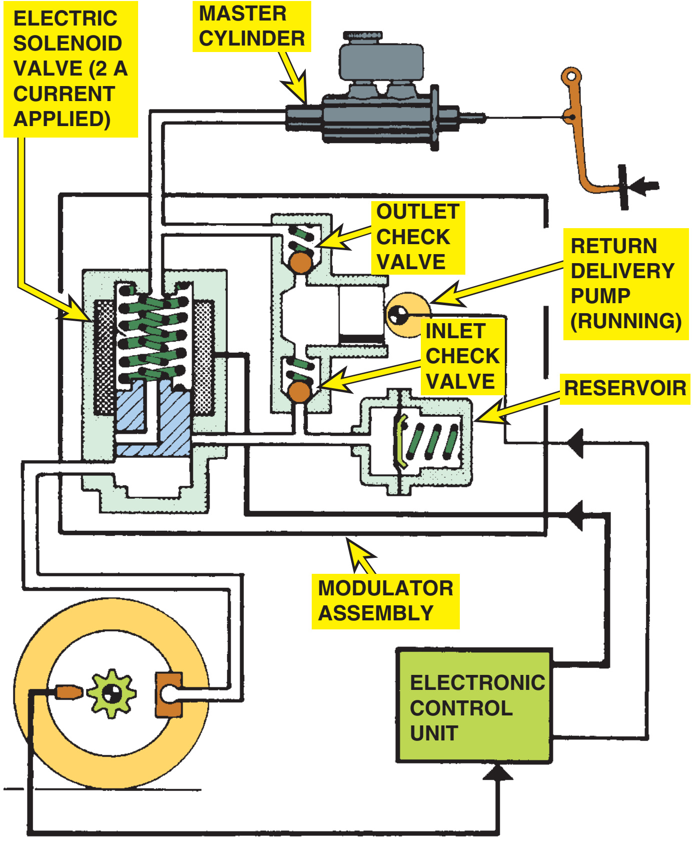

ELECTRIC SOLENOID VALVE (2 A CURRENT APPLIED)
MASTER CYLINDER
OUTLET CHECK VALVE
RETURN DELIVERY PUMP (RUNNING)
INLET CHECK VALVE
RESERVOIR
MODULATOR ASSEMBLY
ELECTRONIC CONTROL UNIT

FIGURE 105–16 The isolation or hold phase of an ABS on a Bosch 2 system.

4. The release and isolation solenoids are then closed and the additional solenoid energized, so pressure can be reapplied to the brake from the master cylinder or accumulator to reapply the brake. This is called the **pressure increase stage**. During this stage, the isolation solenoid is electrically and hydraulically opened. The pressure reduction solenoid is electrically opened and hydraulically closed. ● **SEE FIGURE 105–18.**

The hold–release–reapply cycle repeats as many times as needed until the vehicle either comes to a halt or the driver releases the brake pedal. The speed at which this occurs depends

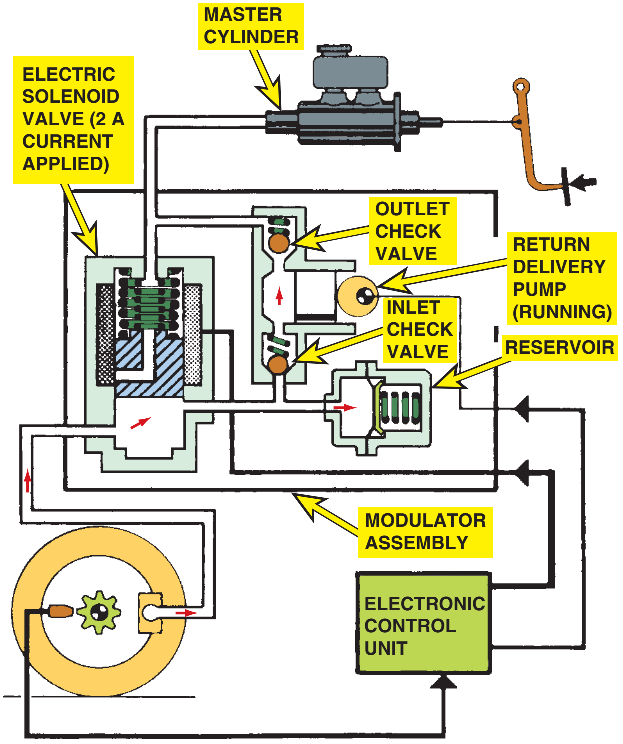

MASTER CYLINDER
ELECTRIC SOLENOID VALVE (2 A CURRENT APPLIED)
OUTLET CHECK VALVE
RETURN DELIVERY PUMP (RUNNING)
INLET CHECK VALVE
RESERVOIR
MODULATOR ASSEMBLY
ELECTRONIC CONTROL UNIT

FIGURE 105–17 During the pressure reduction stage, pressure is vented from the brake circuit so the tire can speed up and regain traction.

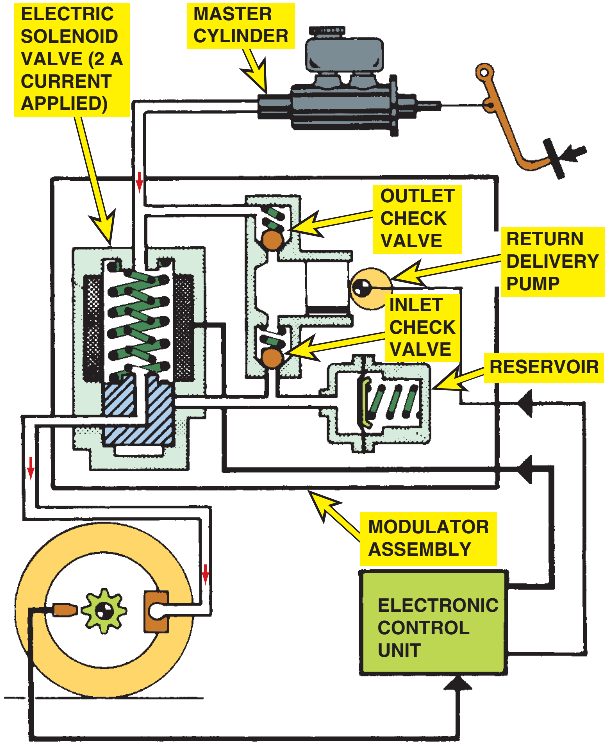

ELECTRIC SOLENOID VALVE (2 A CURRENT APPLIED)
MASTER CYLINDER
OUTLET CHECK VALVE
RETURN DELIVERY PUMP
INLET CHECK VALVE
RESERVOIR
MODULATOR ASSEMBLY
ELECTRONIC CONTROL UNIT

FIGURE 105–18 The control module reapplies pressure to the affected brake circuit once the tire achieves traction so that normal braking can continue.

on the particular ABS that is on the vehicle, but can range from a few times per second up to dozens of times per second.

PUMP MOTOR AND ACCUMULATOR

A high-pressure electric pump is used in some ABS to generate power assist for normal braking, as well as the reapplication of brake pressure during ABS braking. ● **SEE FIGURE 105–19**.

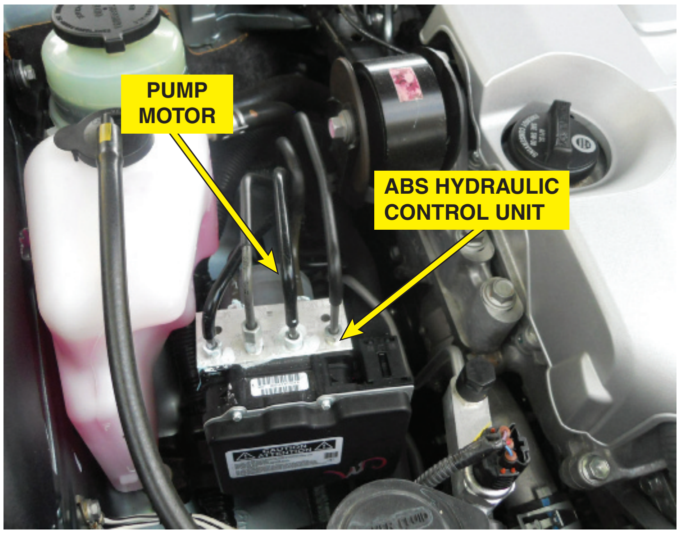

PUMP MOTOR
ABS HYDRAULIC CONTROL UNIT

FIGURE 105–19 A typical ABS hydraulic control assembly.

In some systems, it is used only for the reapplication of pressure during ABS braking. The pump motor is energized by a relay, which is switched on and off by the ABS control module. The fluid pressure generated by the pump is stored in the **accumulator**. Some antilock brake systems have more than one accumulator.

- The accumulator on ABS, where the hydraulic modulator is part of the master cylinder assembly, consists of a pressure storage chamber filled with nitrogen gas. A thick rubber diaphragm forms a barrier between the nitrogen gas and brake fluid. As fluid is pumped into the accumulator, it compresses the gas and stores pressure. When the brake pedal is depressed, pressure from the accumulator flows to the master cylinder to provide power assist.
- A pair of pressure switches mounted in the accumulator circuit signals the ABS control module to energize the pump when pressure falls below a preset minimum, then to shut the pump off once pressure is built back up. Should the pump fail (a warning lamp comes on when reserve pressure drops too low), there is usually enough reserve pressure in the accumulator for 10 to 20 power-assisted stops. After that, there is no power assist. The brakes still work, but with greatly increased effort.
- On ABS that have a conventional master cylinder and vacuum booster for power assist, a small accumulator or pair of accumulators may be used as temporary storage reservoirs for brake fluid during the hold–release–reapply cycle. This type of accumulator typically uses a spring-loaded diaphragm rather than a nitrogen-charged chamber to store pressure.

⚠ WARNING

A fully charged accumulator in an old integral ABS system can store up to 2,700 PSI (19,000 kPa) of pressure for power-assist braking and for reapplying the brakes during the hold–release–reapply cycle for antilock braking. This stored pressure represents a potential hazard for a brake technician who is servicing the brakes, so the accumulator should be depressurized prior to doing any type of brake service work by pumping the brake pedal 25 to 40 times with the ignition key off.

TECH TIP

Best to Keep Stock Tire Diameter

Vehicles equipped with antilock brakes are "programmed" to pulse the brakes at just the right rate for maximum braking effectiveness. A larger tire rotates at a slower speed and a smaller-than-normal tire rotates at a faster speed. Therefore, tire size affects the speed and rate of change in speed of the wheels as measured by the wheel speed sensors. While changing tire size will not prevent ABS operation, it will cause less effective braking during hard braking with the ABS activated. Using the smaller spare tire can create such a difference in wheel speed compared with the other wheels that a false wheel speed sensor code may be set and an amber ABS warning lamp on the dash may light. However, most ABS will still function with the spare tire installed, but the braking performance will not be as effective. For best overall performance, always replace tires with the same size and type as specified by the vehicle manufacturer.

NOTE: In nonintegral ABS where an accumulator is used to temporarily hold fluid during the release phase of the hold–release–reapply ABS cycle, the accumulator consists of a spring-loaded diaphragm. This type of accumulator does *not* have to be depressurized prior to performing brake service.

ADVANCED ABS FUNCTIONS

OVERVIEW Much of the same equipment that allows an ABS system to control wheel lockup during braking can be adapted to control other vehicle dynamics. Some of these advanced ABS functions are

- Traction Control
- Stability Control, also called Vehicle Stability Enhancement System (VSES)
- Electronic front/rear proportioning
- Hill start assist
- Tire-pressure monitoring system (TPMS)

TRACTION CONTROL These systems may be called Traction Control (TC), Traction Control System (TCS), or Acceleration Slip Regulation (ASR). Much of the same equipment that allows an ABS system to control wheel lockup during deceleration can be adopted to control wheel spin during acceleration.

STABILITY CONTROL Some vehicles may be equipped with stability control systems (Stabilitrak®), also called Vehicle Stability Enhancement System (VSES), which is a software extension of the ABS control module that senses (using the WSS input) when a vehicle is braking in a turn. The software balances brake forces at wheels (side-to-side) to counteract a yaw movement and improve the vehicle stability while braking in cornering maneuvers. The system is active during all braking—not just during ABS events.

FREQUENTLY ASKED QUESTION

How Much Positive Slip Is Allowed during Rapid Acceleration?

Many electric vehicles are able to accelerate at a rapid rate without wheel spin. According to electric vehicle manufacturer engineers, the electric motor controller is responsible for the torque delivery and it monitors the wheel speed sensor to maintain about a 3% positive slip. This means that there is some slippage but the 3% rate allows the vehicle to accelerate at the fastest possible rate without a loss of traction.

ELECTRONIC PROPORTIONING Electronic front-to-rear proportioning control makes it possible to eliminate the mechanical proportioning valve on the vehicle. This is also called Dynamic Rear Proportioning (DRP) or Electronic Brake Distribution (EBD), depending on the manufacturer. By using EBCM control software and the hydraulic modulator assembly, best front-to-rear brake balance can be maintained at all times.

- As the vehicle decelerates under braking, the ABS/TCS module monitors the wheel speed sensors.
- If rear-wheel speeds show a slightly greater deceleration rate than the front wheels, the electronic brake control module will reduce the rear-wheel brake pressure by commanding the appropriate solenoid valves on and off.

HILL START ASSIST The hill start assist feature allows the driver to launch the vehicle without a rollback while moving the foot from the brake pedal to the accelerator pedal. The electronic brake control module calculates the brake pressure that is needed to hold the vehicle on an incline and locks that pressure for a certain time by commanding the appropriate solenoid valves on and off when the brake pedal is released. Hill start assist is activated when the electronic brake control module determines that the driver wishes to move the vehicle uphill, either backwards or forwards.

The following inputs are used for the hill start assist feature:

- Brake switch
- Brake pressure sensors
- Longitudinal acceleration sensor
- Engine torque
- Reverse gear information
- Clutch switch
- Accelerator pedal position
- Vehicle speed

TPMS **Tire-pressure monitoring systems (TPMS)** are required on all new vehicles. The type often used before the 2008 model year was an *indirect* system that used the wheel speed sensors. Some vehicles such as 2010 and newer VW/Audi and many 2013 and newer Hondas use digital (active) wheel speed senor information to detect an individual low tire and is therefore able to meet the standards for tire-pressure monitoring systems.

A tire that is underinflated will have a slightly smaller rolling radius than one that is properly inflated. This will create a difference in the wheel speed sensor reading if the difference in inflation pressure is 12 PSI or more. The ABS controller will then turn on the *low tire pressure* warning lamp to warn the driver that tires need attention. To help compensate for speed variation during cornering, an indirect tire-pressure monitoring system checks the rotating speeds of diagonally opposed wheels.

- The system adds the speeds of the right front and left rear and then subtracts that value from the sum of the left front and right rear tires.
- If the total is less than or equal to a threshold value, no warning is given. However, if the total is greater than a predetermined value, the TPMS warning light is illuminated.

The warning lamp will stay on until air is added to the tire and the ignition is cycled off and on.

CASE STUDY

Weird Chevrolet Truck Brakes

The owner of a newer Chevrolet pickup truck complained that sometimes after stopping on a hill, the brakes felt as if the brakes were slow to release when the driver removed their foot from the brake pedal and started to accelerate when the traffic light turned green. The technician was able to duplicate the concern if stopped on a hill either upward or downward. The technician discovered when searching service information that the vehicle was equipped with a hill assist program. This part of the antilock brake system holds the brake applied if the longitudinal acceleration sensor senses that the vehicle was on a hill and the driver exerted a force to the brake pedal to keep the vehicle stopped. Under these conditions, the ABS controller maintained brake fluid pressure in the system to keep the brakes applied until the driver released the brake pedal. What the driver was feeling was the slight delay in the releasing of the brakes when the brake pedal was released.

Summary:

Complaint—Brakes are slow to release at times.
Cause—Normal condition when the vehicle is stopped on a hill when equipped with hill assist.
Correction—Informed driver that this is normal operation due to hill assist function.

AUTOMATIC EMERGENCY BRAKING

OPERATION **Automatic emergency braking (AEB)** is often part of a safety package that includes radar cruise control and will apply the brakes in the event of a possible collision. Sensors such as radar, sonar, and/or cameras are used depending on the system to detect the distance to another object. The controller, usually an ABS controller, then issues a warning if a collision is possible. This warning can include one or more of the following:

1. A buzzer
2. A warning light flashing on the dash
3. A vibration of the driver's seat

If the warnings are ignored, the automatic braking system will intervene and either provide brake assist or apply the brakes autonomously (by itself) to achieve maximum braking in an effort to avoid a collision. ● **SEE FIGURE 105–20**.

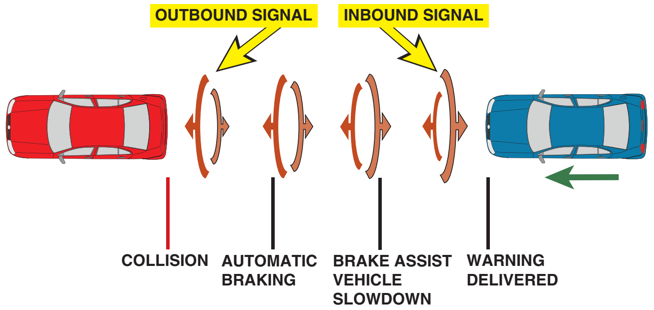
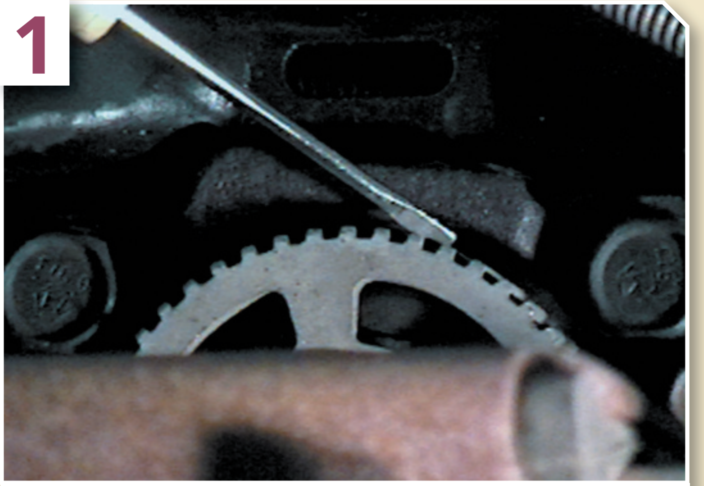


FIGURE 105–20 Sensors are used to detect when the distance is closing fast enough that a collision may be possible and the system intervenes and automatically applies the brakes if needed.

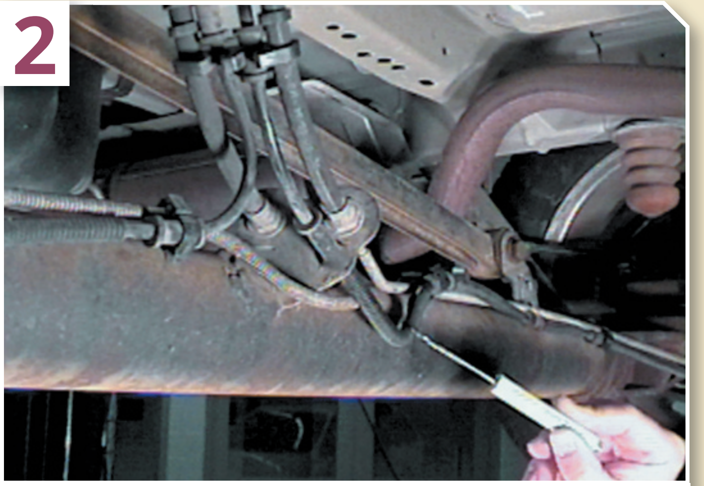
WHEEL SPEED SENSOR

1



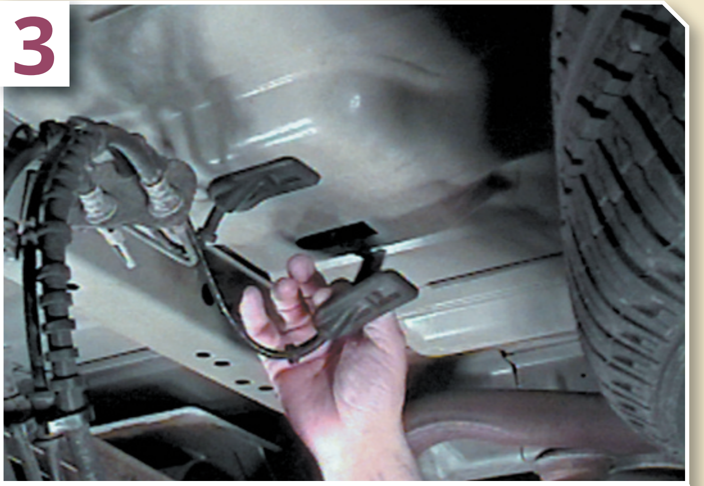
A tone ring and a wheel speed sensor on the rear of a Dodge Caravan.

2



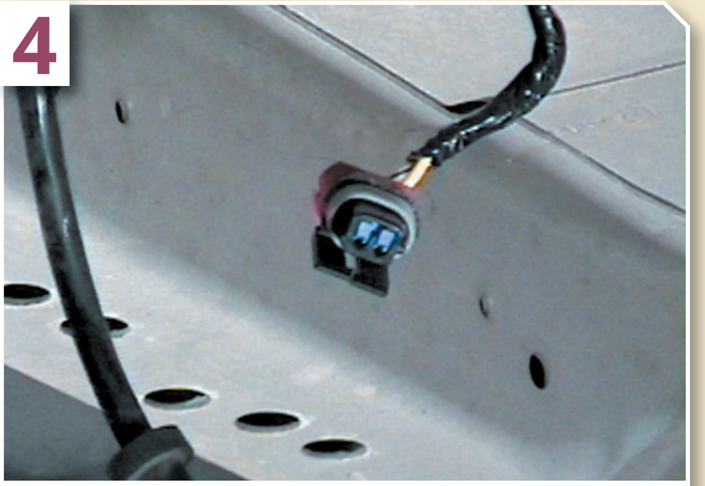
The wiring from the wheel speed sensor should be inspected for damage.

3



To test a wheel speed sensor, disconnect the sensor connector to gain access to the terminals.

4



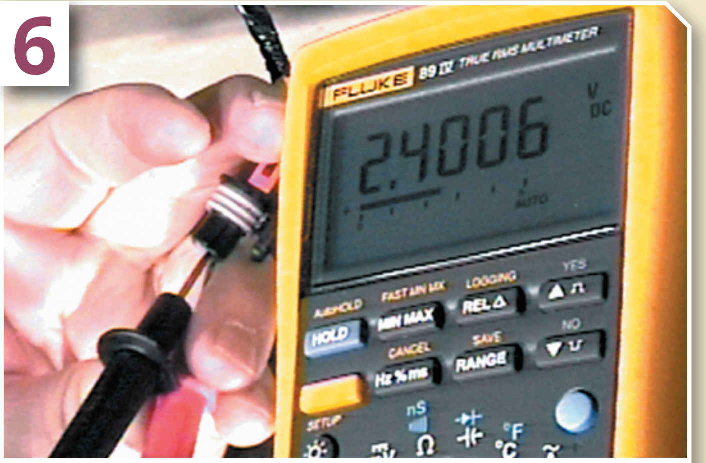
Pulling down the rubber seal reveals the connector.

5

CANCEL
Hz % ms
RANGE
SETUP
mV
Ω
°F
°C
V
OFF
VIEW MEM
CLEAR MEM
mA
μA

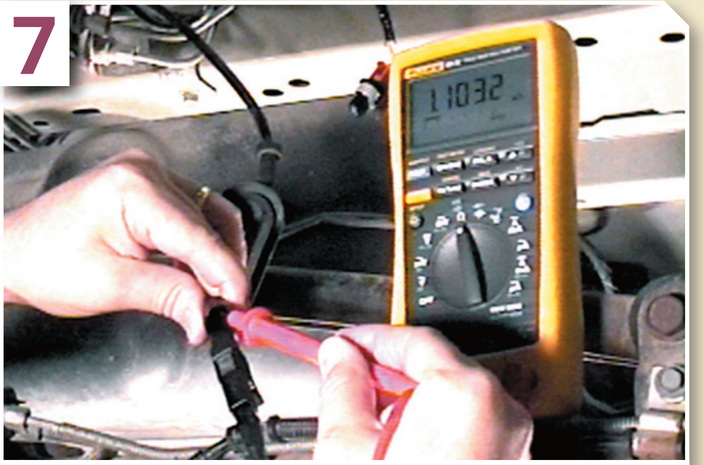
The ABS controller (computer) on this vehicle supplies a 2.5 volt reference signal to the wheel speed sensors.

6


FLUKE 89 IV TRUE RMS MULTIMETER
2.4006
V DC
HOLD
MIN MAX
REL Δ
RANGE
Hz % ms
SETUP

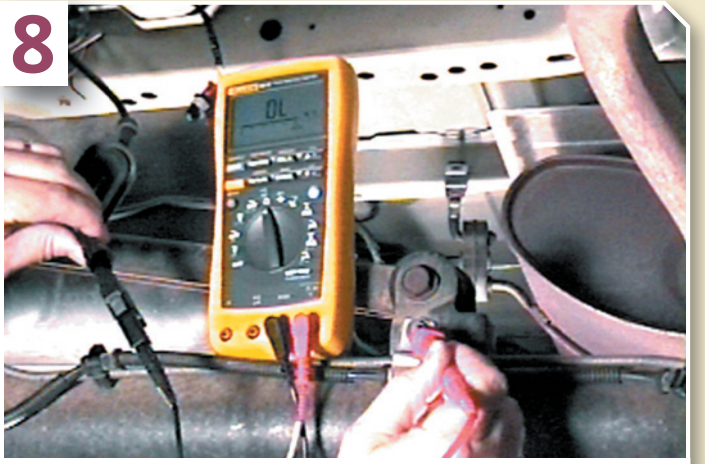
The meter reads about 2.4 volts, indicating that the ABS controller is supplying the voltage to the wheel speed sensor.

7



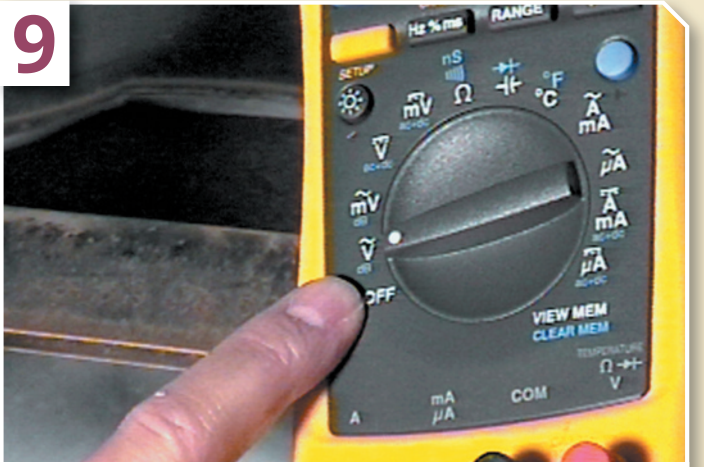
The test probes are touched to the terminals leading to the wheel speed sensor and the resistance is 1.1032 k ohms or 1,103.2 ohms.

8



The meter should (and does) read "OL," indicating that the wheel speed sensor and pigtail wiring is not shorted to ground.

9

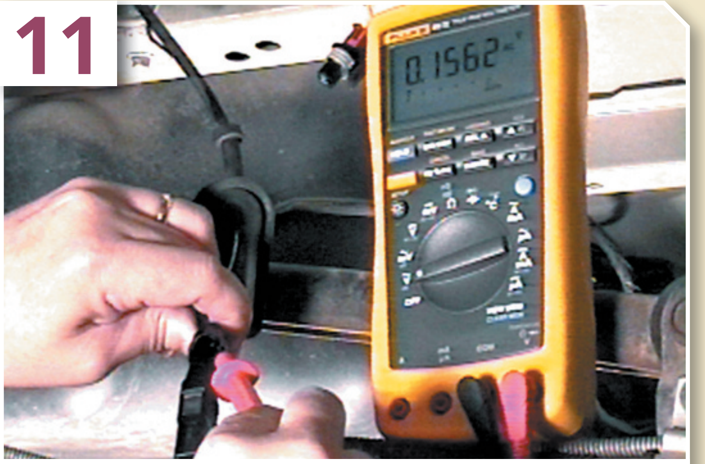

Hz % ms
RANGE
SETUP
nS
mV
Ω
°F
°C
mA
µA
V
mV
V
OFF
mA
µA
VIEW MEM
CLEAR MEM
TEMPERATURE
A
mA
µA
COM
V

To measure the output of the wheel speed sensor, select AC volts on the digital multimeter.

10

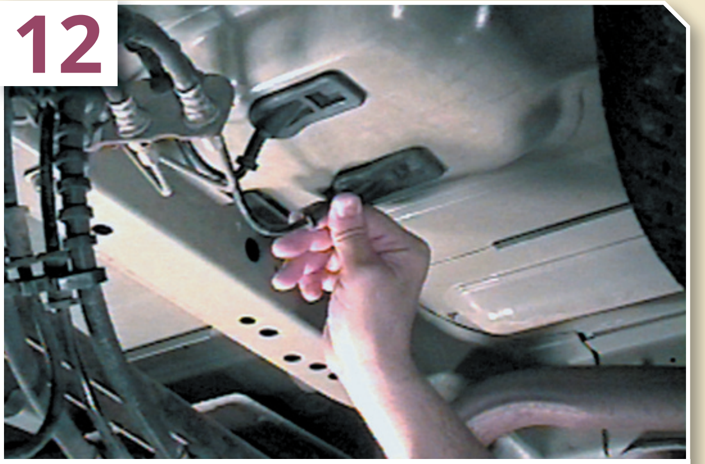
Rotate the wheel and tire assembly by hand while observing the AC voltage output on the digital multimeter.

11



A good wheel speed sensor should be able to produce at least 100 mV (0.1 V) when the wheel is spun by hand.

12



After testing, carefully reinstall the wiring connector into the body and under the rubber grommet.

REVIEW QUESTIONS

1. How does an antilock brake system (ABS) work?
2. What are the three stages of ABS operation?
3. How does an active wheel speed sensor work?
4. What is the difference between a three- and a four-channel system?
5. When is it possible for a vehicle to stop in a shorter distance without ABS than with ABS?

CHAPTER QUIZ

1. The maximum traction between a tire and the road occurs when the tire is ______________.
   - **a.** locked and skidding
   - **b.** rotating freely
   - **c.** slipping 15% to 25%
   - **d.** slipping 80% to 90%
2. Antilock brakes cannot defy the laws of physics under what conditions?
   - **a.** When a vehicle enters a corner traveling faster than it is physically possible to negotiate the turn
   - **b.** If the brakes are applied too late to bring the vehicle to a complete stop before impact
   - **c.** Being able to stop the vehicle in a short distance under all conditions
   - **d.** All of the above
3. Technician A says that the antilock brake system (ABS) may not result in shorter stopping distance compared to brakes without ABS. Technician B says that a pulsating brake pedal during normal braking is a characteristic feature of most ABS-equipped vehicles. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Which type of ABS requires the use of four wheel speed sensors?
   - **a.** One channel
   - **b.** Two channel
   - **c.** Three channel
   - **d.** Four channel
5. Two technicians are discussing ABS wheel speed sensors. Technician A says that some ABS use a sensor located in the rear-axle pinion gear area. Technician B says that all ABS use a wheel speed sensor at each wheel. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. Technician A says that some ABS wheel speed sensors are used as part of the tire pressure monitoring system (TPMS). Technician B says that the ABS is used as part of the hill assist system. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Technician A says that the ABS controller can perform automatic emergency braking. Technician B says that the ABS system can apply the wheel brakes individually if needed for electronic stability control. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. A passive wheel speed sensor is also referred to as a ______________ sensor.
   - **a.** variable reluctance (VR)
   - **b.** magnetic
   - **c.** magneto-resistive (MR)
   - **d.** Either a or b
9. An active wheel speed sensor is also referred to as a ______________ sensor.
   - **a.** variable reluctance (VR)
   - **b.** Hall-effect
   - **c.** magneto-resistive (MR)
   - **d.** Either b or c
10. Which part of an antilock brake system is used for tire pressure monitoring?
    - **a.** Hydraulic control module
    - **b.** Wheel speed sensors
    - **c.** Yaw sensor
    - **d.** Brake pedal position (BPP) sensor

Chapter

106

ABS DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the ABS diagnostic procedure.
- Explain how to diagnose the OBD-II ABS system.
- Explain how to diagnose wheel speed sensors.
- List the steps in the hydraulic ABS service procedure.

KEY TERMS:

Amber ABS warning lamp 1274 • Red brake warning lamp (RBWL) 1274

ABS FAULT DIAGNOSIS

ABS DIAGNOSTIC STEPS Customer concerns about a fault with the antilock brake system can be best handled by performing the following:

STEP 1 **Verify the customer concern.** This step is very important because often a problem with the base brakes is thought by the customer to be a fault with the antilock brake system. It is helpful for the owner to drive the vehicle with a service technician if the problem is not readily apparent.

STEP 2 **Perform a visual inspection.** If the red brake warning lamp is on, then look for a fault such as leaks in the base brake hydraulic system, including

- Master cylinder
- Electrohydraulic control unit
- Flexible brake hoses
- Brake lines and fittings
- Calipers and/or wheel cylinders

STEP 3 **Check for stored diagnostic trouble codes (DTCs).** Use a scan tool or other necessary methods to retrieve diagnostic trouble codes. If found, follow the specified factory procedures to isolate and determine the cause.

STEP 4 **Check for technical service bulletins (TSBs).** TSBs are often helpful when trying to find the cause of a problem that cannot be easily found. Many TSBs include what DTCs are stored, so this step needs to be performed alter the diagnostic trouble codes have been retrieved.

STEP 5 **Determine the root cause.** Using all of the resources and tests as specified in service information, determine the root cause of the problem.

STEP 6 **Complete the repair.** This step may involve replacing wheel speed sensor or a hydraulic component. If a hydraulic part was replaced, then the system should be bled using the factory-specified procedure.

STEP 7 **Verify the repair.** Always test-drive the vehicle under the same conditions that were needed to verify the problem to be sure that the cause has been corrected. Clear all diagnostic trouble codes.

BRAKE WARNING LAMP OPERATION The first step in the visual diagnosis of an antilock brake system problem is to check the status of the red and/or amber brake warning lamps. ● **SEE FIGURE 106–1**.

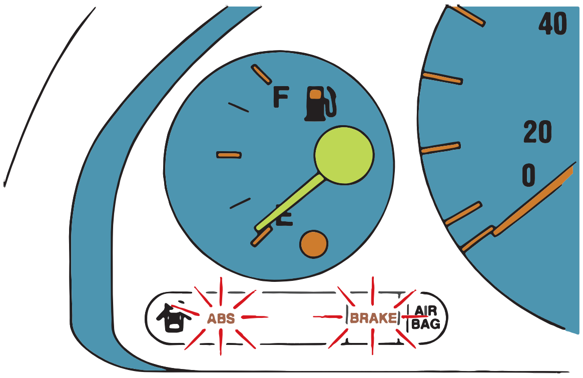


FIGURE 106–1 On most vehicles equipped with ABS, the ABS and the BRAKE warning lamp should come on as a bulb check when the ignition is first switched on.

RED BRAKE WARNING LAMP A **red brake warning lamp (RBWL)** warns of a possible dangerous failure in the base brakes, such as:

- Low brake fluid level
- Low pressure in half of the hydraulic system
- The parking brake is applied
- May light due to an ABS failure, such as low brake pressure on an integral system

AMBER ABS WARNING LAMP The **amber ABS warning lamp** usually comes on after a vehicle start during the initialization or start-up self-test sequence. The exact time the amber lamp remains on after the ignition is turned on varies with the vehicle and the ABS design. If the amber warning lamp stays on after the vehicle is started, this means that a fault in the ABS system has been detected. ● **SEE FIGURE 106–2**.

THOROUGH VISUAL INSPECTION

Many ABS-related problems can be diagnosed quickly if all the basics are carefully inspected.

A thorough visual inspection should include the following items in ● **CHART 106–1**.

TEST-DRIVE AND VERIFY THE FAULT

A test-drive is a very important diagnostic procedure. Many ABS and diagnostic trouble codes will not set unless the vehicle is moving. Often, the driver has noticed something like the self-test while driving and believed it to be a fault in the system.

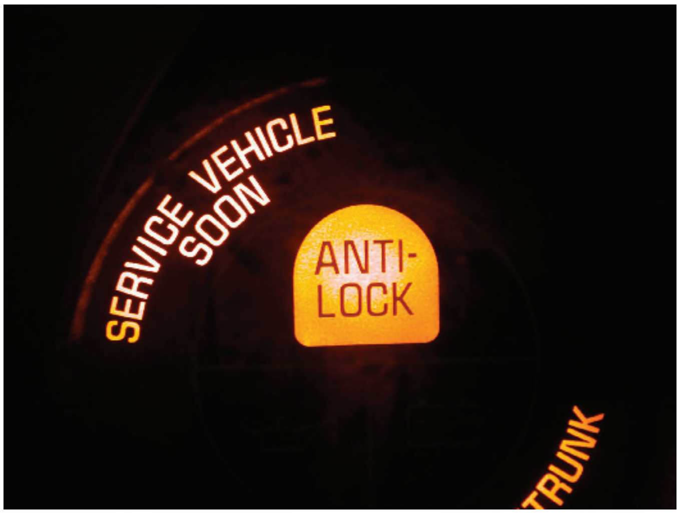


FIGURE 106–2 An amber ABS.

NOTE: Some ABS units will cause the brake pedal to move up and down slightly during cycling of the valves during the self-test. Each system has unique features. The service technician will have to learn to avoid attempting to repair a problem that is not a fault of the system.

ITEM TO CHECK	WHAT TO LOOK FOR
Brake fluid level	Check the condition and level in the reservoir.
Brake fluid leaks	Check for rusty and leaking brake lines and cracks in flexible lines or other physical damage.
Fuses and fusible links	Check all ABS-related fuses and electrical power distribution.
Wiring and connections	Check all wiring, especially wheel speed sensor leads, for damage.
Wheel speed sensors	Check that the sensor ring teeth are not damaged. Clean debris from the sensor if possible. ● **SEE FIGURE 106–3.**
NOTE: Most wheel speed sensors are magnetic and therefore can attract and hold metallic particles. Be sure to remove any metallic debris from around the magnetic wheel speed sensor.	
Parking brake	Check that the parking brake is correctly adjusted and fully released.
Wheel bearings	All wheel bearings must be free of defects and adjusted properly.
Wheels and tires	Check for correct size, proper inflation, and legal tread depth.

CHART 106–1

Items that should be checked when diagnosing a concern about the antilock brake system (ABS).

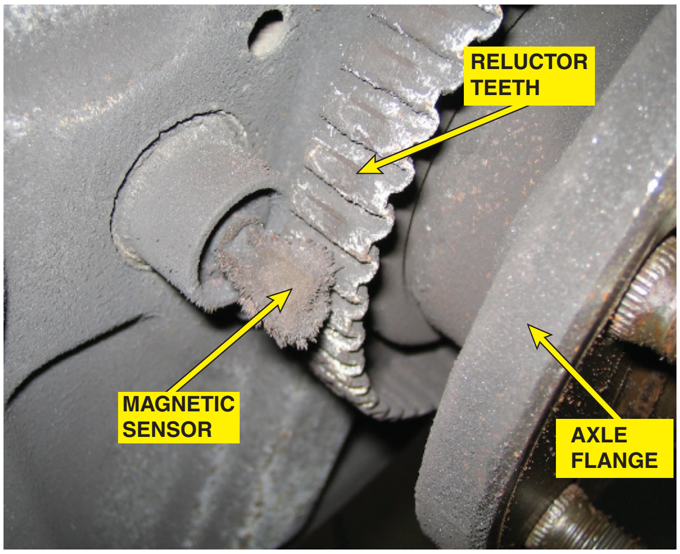


FIGURE 106–3 A visual inspection of the wheel speed sensor on this older vehicle showed metal "fuzz" had been attracted to the magnetic sensor.

TECH TIP

Check for Flood Damage

There are often strange electrical problems that can occur including false DTCs or intermittent operation of electrical sensors, ABS, accessories, or gauges. Sometimes the root of these problems is due to rust and corrosion after a vehicle is involved in a flood.

Here are some telltale signs that a vehicle may have due to flooding:

- Mud, silt, or caked dust under the dash and inside the doors
- Corroded electrical connectors at the computer, fuse box, or ABS controller (computer)
- Visible waterline in the doors or behind panels
- Rust in abnormal places such as seat springs or brackets behind the dash
- Moisture in lenses
- Musty smell and/or strong air freshener smell
- Powdery corrosion on aluminum parts such as intake manifold and inside the throttle bore
- Rust or moisture inside electrical switches or relays
- Areas that are normally dusty, such as an ashtray or glove box, are very clean

FREQUENTLY ASKED QUESTION

What's That Noise and Vibration?

Many vehicle owners and service technicians have been disturbed to hear and feel an occasional groaning noise. It is usually heard and felt through the vehicle after first being started and driven. Because it occurs when first being driven in forward or reverse, many technicians have blamed the transmission or related driveline components. This is commonly heard on many ABS vehicles as part of a system check. As soon as the ABS controller senses speed from the wheel speed sensors after an ignition cycles on, the controller will run the pump either every time or whenever the accumulator pressure is below a certain level. This can occur while the vehicle is being backed out of a driveway or being driven forward because wheel sensors can only detect speed—not direction. Before serious and major repairs are attempted to "cure" a noise, make sure that it is not the normal ABS self-test activation sequence of events.

Before driving, start the engine and observe the red and/or amber brake warning lamps.

- If the red brake warning lamp is on, the base brakes may not be functioning correctly. Do not drive the vehicle until the base brakes are restored to proper operation.
- If the amber warning lamp is on, then the vehicle can be carefully driven because the antilock brake system will not likely be functioning when the warning lamp is on.

AUTEL
MaxiSys

FIGURE 106–4 A factory or factory-level scan tool like the one shown here is the best to use when diagnosing an ABS problem.

ABS DIAGNOSIS

SCAN TOOL DIAGNOSIS Most vehicles built since 1996 use the OBD-II diagnostic connector to transmit ABS diagnostic trouble code information to a scan tool. A factory scan tool or an enhanced factory-level scan tool will be needed to retrieve ABS diagnostic trouble codes (DTCs) and scan tool data such as wheel speed sensor information. Scan tools can be divided into three basic groups:

1. **Factory scan tools.** These are the scan tools required by all dealers that sell and service the brand of vehicle. Examples of factory scan tools include
   - **General Motors**—Tech 2 or GM MDI and GDS II (Global Diagnostic System II). ● **SEE FIGURE 106–4**.
   - **Ford**—New Generation Star (NGS) and IDS (Integrated Diagnostic Software), VCM, VCM2, or VCM3
   - **Chrysler**—DRB-III or Star Scan, wiTECH
   - **Honda**—HDS or Master Tech
   - **Toyota**—Master Tech or Techstream ADVi

   All factory scan tools are designed to provide bidirectional capability, which allows the service technician the opportunity to operate components using the scan tool, thereby confirming that the component is able to work when commanded. Also, all factory scan tools are capable of displaying all factory parameters.
2. **Aftermarket scan tools.** These scan tools are designed to function on more than one brand of vehicle. Examples of aftermarket scan tools include
   - **Snap-on**—Various models available including the Solus, Ethos, Verus, and Modis
   - **OTC**—Various models available including Encore, Pegasus, Genisys, and Task Master
   - **Launch**—Various models available
   - **Autel**—Various models available
   - **AutoEnginuity** and other programs that use a laptop or handheld computer for the display

   While many aftermarket scan tools can display most if not all of the parameters of the factory scan tool, there can be a difference when trying to troubleshoot some faults.

3. **Code readers.** Many lower cost scan tools offer limited diagnostic information and many will not be able to retrieve or display ABS-related diagnostic trouble codes. Many global (generic) scan tools are only capable of reading emission-related DTCs. If purchasing a low-cost code reader, select one that has the ability to read ABS-related codes. However, these tools are often *not* able to display data such as vehicle speed from each wheel speed sensor.

OBD-II CONNECTOR The data link connector (DLC) is a standardized 16 cavity connector where a scan tool can be connected to retrieve diagnostic information from the vehicle's computers. The normal location is under the dash on the driver's side usually located within 12 inches (30 cm) of the center of the vehicle. It can be covered but if it is, then the cover has to be able to be removed without the use of a tool, such as when it is located underneath the ash tray.

CASE STUDY

The Mystery ABS Amber Warning Light

The owner complained to a service technician that the ABS warning light would come on but only while driving down from a parking garage. When the driver turned off the ignition and restarted the engine, the ABS amber light was not on and did not come on again until the vehicle was again driven down the spiral parking garage ramp. The service technician used a scan tool and found that no DTCs had been stored.

NOTE: Some ABS systems will not retain a DTC unless the problem is currently present and the ABS amber warning light is on.

All of the brakes were in excellent condition, but the brake fluid level was down a little. After topping off the master cylinder with clean DOT 3 brake fluid, the vehicle was returned to the customer with the following information:

- The ABS amber warning light may have been triggered by the brake fluid level switch. While driving down the steep parking garage ramp, the brake fluid moved away from the fluid level sensor.

NOTE: While the brake fluid level sensor normally would turn on the red brake warning light, in some systems it turns on the amber ABS light if the brake fluid falls below a certain level in the ABS reservoir.

- The difference in wheel speed between the outboard and the inboard wheels could have triggered a fault code for a wheel speed sensor during the drive down the spiral parking garage ramp.

Summary:

Complaint—Driver stated that the amber ABS warning lamp would come on but only when descending in a parking garage.
Cause—Possible low brake fluid level or normal operation due to change in wheel speed while turning sharply.
Correction—Added a slight amount of brake fluid to return the level to the "MAX" level and returned to owner.

CASE STUDY

The Nervous Honda Civic

A customer complained that sometimes during normal braking, the ABS would be activated (brake pedal pulsated) just before coming to a stop. However, the ABS light would not come on. The service technician was able to duplicate the condition and there were no DTCs stored. Using a scan tool to monitor the wheel speed sensors, the technician discovered that the left front wheel speed was slightly different than the others. A thorough visual inspection revealed that the tone wheel (reluctor ring) was cracked. This crack created a different wheel speed signal to the ABS controller than the other wheels and the controller activated the ABS as it would normally—that was why there were no DTCs. Other things that could have caused this problem, which is often called "false modulation," include a bent wheel, mismatched tire sizes, or metal debris around the sensor.

Summary:

Complaint—Driver complained that the ABS caused the brake pedal to pulsated but only when the vehicle was slowing to a stop.
Cause—A cracked tone (reluctor) ring was discovered on the right front.
Correction—The customer authorized the replacement of a new wheel bearing assembly which included the tone ring and the problem was corrected.

"C" (CHASSIS) DTCS The antilock brake system (ABS) may trigger different faults to indicate ABS performance concerns. They may be related to performance concerns in the system, components, internal control performance, programming, and communication.

The ABS control module, commonly called the electronic brake control module (EBCM), is used to control ABS operation. The EBCM/BCM uses the signals provided by the wheel speed sensors to monitor the rotational speed of each wheel. A wheel that is about to lock up or slip will begin to rotate much slower than the other wheels when the brake pedal is applied. If the EBCM detects an impending wheel lockup, it will operate the appropriate valves in the brake pressure modulator valve along with the hydraulic pump in order to keep the wheel rotating while still maintaining a high level of deceleration.

The EBCM is capable of recognizing a fault with the ABS. The EBCM constantly monitors ABS inputs and outputs for erroneous signals that could indicate a component is not operating properly or that a circuit or component is damaged. If the EBCM recognizes a fault, it records a diagnostic trouble code, illuminates the ABS warning lamp in the instrument panel cluster, and may also disable certain ABS functions. ● **SEE CHART 106–2** for a list of global (generic) ABS-related "C" codes.

DIAGNOSTIC TROUBLE CODE (DTC)	DESCRIPTION
C0000	Vehicle Speed Information Circuit Malfunction
C0035	Left Front Wheel Speed Circuit Malfunction
C0040	Right Front Wheel Speed Circuit Malfunction
C0041	Right Front Wheel Speed Sensor Circuit Range/Performance (EBCM)
C0045	Left Rear Wheel Speed Circuit Malfunction
C0046	Left Rear Wheel Speed Sensor Circuit Range/Performance (EBCM)
C0050	Right Rear Wheel Speed Circuit Malfunction
C0051	LF Wheel Speed Sensor Circuit Range/Performance (EBCM)
C0060	Left Front ABS Solenoid #1 Circuit Malfunction
C0065	Left Front ABS Solenoid #2 Circuit Malfunction
C0070	Right Front ABS Solenoid #1 Circuit Malfunction
C0075	Right Front ABS Solenoid #2 Circuit Malfunction
C0080	Left Rear ABS Solenoid #1 Circuit Malfunction
C0085	Left Rear ABS Solenoid #2 Circuit Malfunction
C0110	Pump Motor Circuit Malfunction
C0121	Valve Relay Circuit Malfunction
C0128	Low Brake Fluid Circuit Low
C0221	Right Front Wheel Speed Sensor Circuit Open
C0222	Right Front Wheel Speed Signal Missing
C0223	Right Front Wheel Speed Signal Erratic
C0225	Left Front Wheel Speed Sensor Circuit Open
C0226	Left Front Wheel Speed Signal Missing
C0235	Rear Wheel Speed Signal Circuit Open
C0236	Rear Wheel Speed Signal Circuit Missing
C0238	Wheel Speed Mismatch
C0241	EBCM Control Valve Circuit
C0245	Wheel Speed Sensor Frequency Error
C0267	Pump Motor Circuit Open/Shorted
C0271, C0272, C0273, C0284	EBCM Malfunction
C0281	Brake Switch Circuit

CHART 106–2

Selected ABS-related "C" codes.

TECH TIP

Space Saver Spare Tire May Trigger Wheel Speed Fault Code

If a vehicle has been using a small space saver-type spare tire, then the difference in outside diameter may trigger a wheel speed sensor diagnostic trouble code (DTC) and turn on the amber ABS warning lamp. Try to find out from the customer if they had driven on a spare tire before replacing a wheel speed sensor based on a stored DTC.

TECH TIP

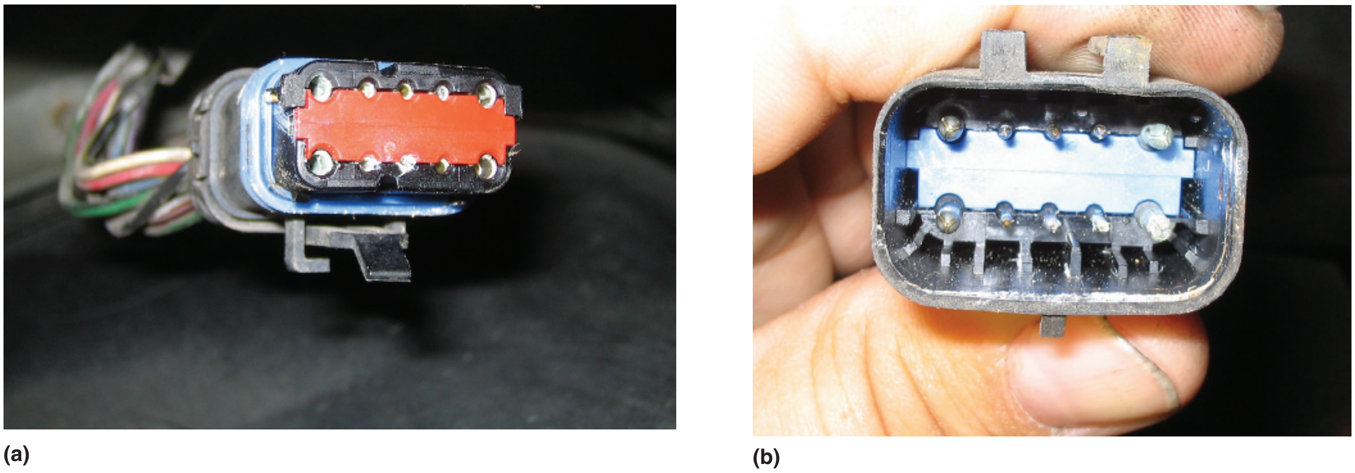
Check Power and Ground First

Before replacing an expensive EBCM, make sure to verify power and ground circuits at the EBCM connector. Also check power and ground at the other end of the harness, such as at the fuse box and fuses and the bolted ground connection on the vehicle chassis. ● **SEE FIGURE 106–5**.

CONTROL MODULE INTERNAL PERFORMANCE FAULT A control module internal performance fault indicates that there is a malfunction internal to the EBCM that cannot be repaired at the dealership. Typically, if an EBCM reports an internal performance fault, the EBCM must be replaced.

COMMUNICATION FAULT If the EBCM is unable to communicate with another module on its network, the EBCM may set a communication fault. This type of fault likely does not indicate that there is a problem within the ABS, but rather sets as a result of another module failing to communicate with the EBCM.

COMPONENT-RELATED FAULT A component-related fault specifically identifies an ABS component that is not functioning properly. While an ABS component–related fault will name an ABS component in its description, do not assume that the component has failed. This fault sets to indicate that a fault has affected the operation of the component named in the description. Further diagnosis is required to identify the cause of the fault.


(a)

(b)

FIGURE 106–5 (a) This corroded electrical connector to the ABS hydraulic control module helped explain why there were many stored diagnostic trouble codes (DTCs). (b) The male terminals also showed signs of corrosion inside this connector.

WHEEL SPEED SENSOR DIAGNOSIS

COMMON CAUSES OF FAULTS Wheel speed sensor (WSS) circuits are often the cause of many ABS problems. These components may suffer from physical damage, buildup of metallic debris on the sensor tip, corrosion, poor electrical connections, and damaged wiring.

PASSIVE WHEEL SPEED SENSOR DIAGNOSIS The passive wheel speed sensor generates an alternating current (AC) voltage as the teeth of a tone wheel pass by. The sensor contains a permanent magnet and a coil of wire. The reluctor notches disturb the magnetic field, causing the sensor to output a small AC voltage signal. After performing a good visual check of the wiring and connectors, use a DVOM and/or oscilloscope to check the wheel speed sensors. ● **SEE FIGURE 106–6.**

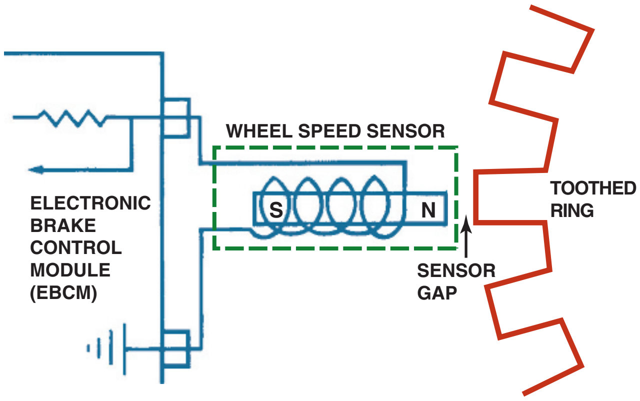


FIGURE 106–6 Typical wheel speed sensor. When a tooth on the sensor ring is close to the sensor, the strength of the magnetic field is stronger because the metal of the tooth conducts magnetic lines of force better than air. When the tooth moves away, the magnetic field strength is reduced. It is this changing magnetic field strength that produces the changing voltage. Frequency of the signal is determined by the speed of the rotating sensor.

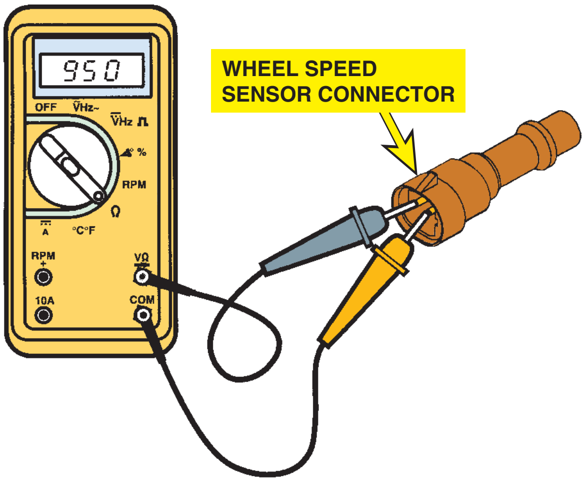


FIGURE 106–7 Measuring the resistance of a wheel speed sensor.

RESISTANCE MEASUREMENT The resistance of most WSS ranges from 800 to 2,500 ohms (Ω). Therefore, a reading of about 1,000 ohms (1 kΩ) would indicate proper sensor coil resistance.

Always check service information for the specified resistance for the wheel speed sensor on the vehicle being tested. ● **SEE FIGURE 106–7.**

CHECKING FOR SHORT-TO-GROUND To check for a short-to-ground, connect either lead of the ohmmeter to one of the WSS wires and the other to a good, clean chassis ground. The resistance should be infinity (OL). If a low resistance reading is obtained, the sensor or sensor wiring is shorted-to-ground and must be replaced.

AC VOLTAGE CHECK To check for the proper AC voltage output from a wheel speed sensor, connect a digital meter to the WSS terminals or input to the controller in the breakout box and set the meter to read AC volts. Rotate the wheel by hand at a rate of one revolution per second. A good WSS should produce voltage of at least 0.1 volt (100 mV). A sensor voltage of lower than 0.1 volt (100 mV) may be caused by three things.

1. Excessive clearance between the sensor and the tone ring
2. Buildup of debris on the end of the sensor. Most wheel speed sensors are magnetic and can attract metallic particles, which can affect the operation of the sensor.

TECH TIP

Perform a "Wiggle Test"

Whenever testing a wheel speed sensor, it is a good idea to move or wiggle the sensor wiring and connector when taking a resistance or voltage measurement in case of a broken wire or corroded connector. If the reading on the meter changes when the wiring is being moved, then this confirms that there is a possible problem with the wiring or the connections so further diagnosis will be needed.

3. Excessive resistance in the sensor or sensor wiring, which can also cause a weak signal to be produced by the WSS.

SCOPE TESTING To test a wheel speed sensor using a scope, attach the scope leads to the sensor terminals or to the input connector on the breakout box. Rotate the wheel by hand or by using engine power with the vehicle safely hoisted with all four wheels off the ground.

- A good WSS should produce an alternating current sine wave signal that increases in frequency and amplitude with increasing wheel speed. ● **SEE FIGURE 106–8**.
- Damaged or missing teeth on the tone ring will cause flat spots or gaps in the sine wave pattern. ● **SEE FIGURE 106–9**.

A bent axle or hub will produce a wavelike pattern that fluctuates as the strength of the sensor signal changes with each revolution.

SCAN TOOL TESTING A scan tool can be used to check for the proper operation of the WSS. As an assistant drives the vehicle, connect the scan tool and monitor the speed of all of the sensors. All of the sensors should indicate the same speed. If a sensor shows a slower or faster speed than the others, carefully check the tone ring for damage such as a crack.

TECH TIP

Quick and Easy Wheel Speed Sensor Diagnosis

A fault in a wheel speed sensor (WSS) is a common ABS problem. A quick and easy test that works on most Bosch ABS (and perhaps others) involves the following steps:

STEP 1 Hoist the vehicle safely.

STEP 2 Key on, engine off (KOEO).

STEP 3 Spin a tire by hand as fast as possible.

STEP 4 The ABS amber warning light should come on, indicating that a speed was detected but not by all the wheel speed sensors.

STEP 5 Turn the ignition off to reset the ABS warning light.

STEP 6 Repeat the test on each of the remaining wheels.

If any wheel fails to turn on the ABS light, carefully inspect the wheel speed sensor for proper resistance and the tone ring and wiring. If the ABS light is on all the time and does not reset when the ignition is turned off, the problem is not caused by a wheel speed sensor.

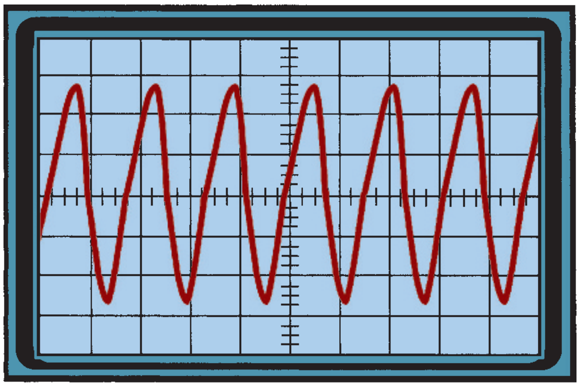


FIGURE 106–8 A scope can be used to check for proper operation of a wheel speed sensor.

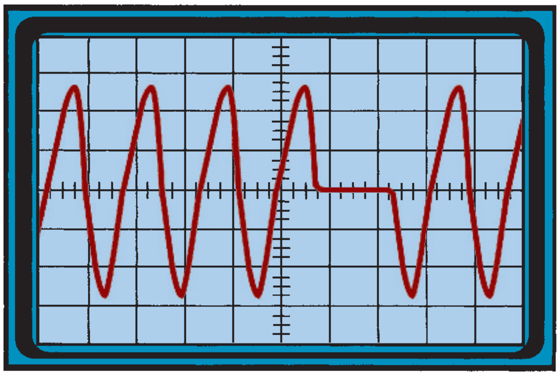


FIGURE 106–9 A broken tooth on a wheel speed sensor tone ring shows on the scope trace as a missing wave.

FREQUENTLY ASKED QUESTION

Why Does My Scan Tool Show Speed When Stopped?

Some vehicles, especially older General Motors vehicles (Chevrolet, Buick, Pontiac, Cadillac, and GMC), will show 2 or 3 MPH on the scan tool with the vehicle in the shop and not moving. This is perfectly normal and there is no fault so no service or repair is needed to be performed. The reading seems to be a default reading because many passive wheel speed sensors are not capable of supplying a usable wheel speed until over 3 MPH.

ACTIVE WHEEL SPEED SENSOR DIAGNOSIS Many 2005 and newer vehicles use active wheel speed sensors. To test an active (digital) wheel speed sensor, perform the following steps:

STEP 1 These sensors are most easily checked using a scan tool. With the scan tool attached, drive the vehicle straight while an assistant observes the speed of each wheel. All four wheel speed sensors should read the same speed when driving straight ahead.

STEP 2 Check that battery voltage is available at the sensor with the key on, engine off (KOEO). If the sensor does not have 12 volts, then the problem is most likely in the ABS controller or the wiring between the controller and the sensor.

FREQUENTLY ASKED QUESTION

Is a Wheel Speed Sensor Adjustable?

Some older ABS applications use adjustable wheel speed sensors. Most sensors adjust by first loosening a set screw, then inserting a nonmagnetic brass or plastic feeler gauge between the tip of the sensor and a high point on the tone ring.

When installing a new wheel speed sensor, look for a piece of paper or plastic on the tip. The paper or plastic is the precise thickness to guarantee a correct air gap between the tip of the sensor and the tone ring. Adjust the sensor so the tip just touches the tone ring and you can slip the paper or plastic out without ripping it. Tighten the setscrew and the air gap is properly set. ● **SEE FIGURE 106–10**.

STEP 3 Check the low reference (signal ground) circuit. With the ignition off and the wheel speed sensor disconnected, measure the resistance between the wheel speed sensor's low reference circuit and ground. The resistance should be no greater than 5 ohms.

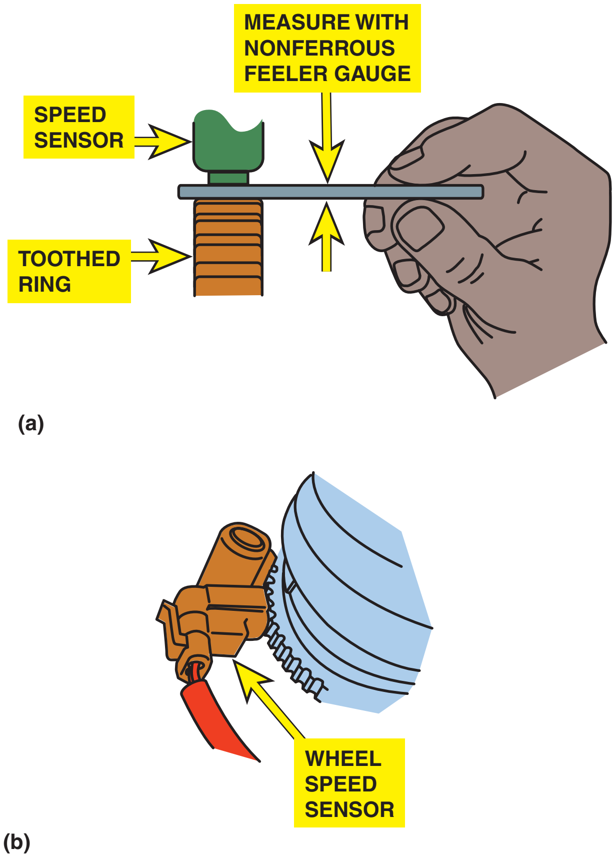


FIGURE 106–10 (a) Always use a nonferrous (brass or plastic) feeler (thickness) gauge when measuring the gap between the toothed ring and the wheel speed sensor. (b) Sometimes a sensor is equipped with a paper spacer that is the exact thickness of the spacing required between the toothed ring and the sensor. If equipped, the sensor is simply installed with the paper touching the toothed wheel. A typical gap ranges from 0.020 to 0.050 inch (0.5 to 1.3 mm).

STEP 4 Measure the signal voltage provided by the EBCM along the wheel speed sensor signal circuit KOEO. The voltage should be greater than 11 volts.

HYDRAULIC ABS SERVICE

CHECK SERVICE INFORMATION Before doing any brake work on a vehicle equipped with antilock brakes, always check the service information for the exact vehicle being serviced. For example, some manufacturers recommend discharging the hydraulic accumulator by depressing the brake pedal many times before opening bleeder valves. Many service checks require that a pressure gauge be installed in the system.

BLEEDING THE ELECTRONIC-HYDRAULIC ASSEMBLY Air can easily get trapped in the ABS electronic-hydraulic (E-H) assembly whenever the hydraulic system is opened. Even though the master cylinder and all four wheel cylinders/calipers have been bled, sometimes the brake pedal will still feel spongy. Some E-H units can be bled through the use of a scan tool where the valves are pulsed in sequence by the electronic brake controller (computer). Some units are equipped with bleeder valves while others must be bled by loosening the brake lines. Bleeding the E-H unit also purges out the older brake fluid, which can cause rust and corrosion damage. Always check the label on the brake fluid reservoir and/or service information or owner's manual for the specified brake fluid to use.

CAUTION: When checking brake fluid level, some integral ABS and hybrid brake systems using an accumulator unit requires that the brake pedal be depressed as many as 40 times to discharge brake fluid fully from the accumulator. Failure to discharge the accumulator fully can falsely show that the brake fluid level is too low. If additional brake fluid is added, the fluid could overflow the reservoir during an ABS stop when the accumulator discharges brake fluid back into the reservoir.

MANUALLY BLEEDING ABS WHEEL BRAKES During routine brake service, attempt to keep the air from entering the hydraulic system by doing the following:

1. Do not allow the brake system to run dry. Use a brake pedal depressor or plug any open brake line to keep brake fluid from flowing out of the brake master cylinder reservoir.
2. Do not allow the master cylinder to run dry during the bleeding operation. Check the master cylinder reservoir often and keep it filled with fresh brake fluid from a sealed container.
3. Always bench bleed a replacement master cylinder to help prevent against introducing air into the hydraulic system. After depressing the unit as per manufacturer's recommended procedures, the brakes can be bled using the same procedure as for a vehicle without ABS. Air trapped in the ABS hydraulic unit may require that a scan tool be used to cycle the valves. ● **SEE FIGURES 106–11 AND 106–12**.

The bleeding procedure for vehicles equipped with antilock brakes is often different than vehicles without ABS. Check service information for the specified bleeding procedure and sequence.

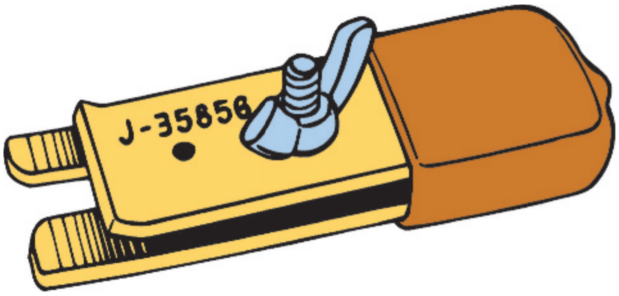


FIGURE 106–11 Special bleed valve tools are often required when bleeding some ABS units such as the Kelsey-Hayes 4WAL system.

SCAN TOOL BLEEDING To bleed the system using a scan tool, use the following steps:

STEP 1 Check service information and determine the specified procedure to follow. This usually involves manually bleeding the wheel brakes before using a scan tool.

STEP 2 Use a factory scan tool or one that is capable of performing an automated bleed procedure.

STEP 3 Connect the scan tool to the data link connector (DLC).

STEP 4 Enter vehicle information as shown on the display of the scan tool and locate the antilock brake system function area.

STEP 5 Select ABS-automated bleed from the ABS menu. The instructions on the scan tool could include several steps including manually bleeding the system, then allowing the scan tool to cycle the hydraulic ABS solenoid valves and then bleeding again.

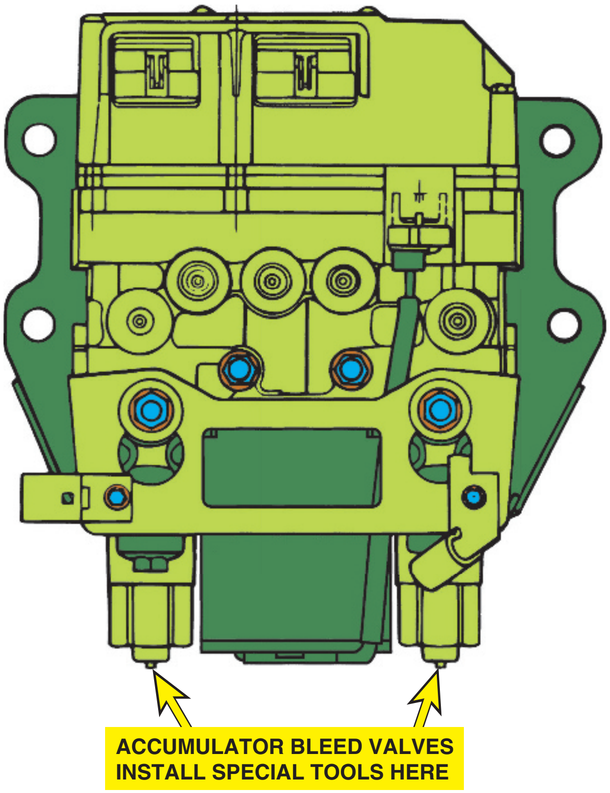


FIGURE 106–12 Two bleed valve tools are needed to bleed the Kelsey-Hayes 4WAL system, which attaches to the bleeder valves on the accumulator.

REVIEW QUESTIONS

1. Why should the operation of the red and amber brake warning lamps be included in the diagnostic procedure?
2. What are the steps of the diagnostic procedure?
3. Why are many stored diagnostic trouble codes (DTCs) found under the chassis area?
4. How is a multimeter used to check for proper wheel speed sensor operation?
5. What are the symptoms of a vehicle being under water?

CHAPTER QUIZ

1. The red brake warning lamp is on and the amber ABS lamp is off. Technician A says that a fault is possible in the base brake system. Technician B says that the red brake warning lamp can be turned on by a low brake fluid level in the master cylinder. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that a DTC in the EBCM will turn on the ABS warning lamp. Technician B says that ABS trouble codes (DTCs) are type "C" codes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that using the space-saving small spare tire may trigger an ABS amber warning lamp. Technician B says that if the red brake warning light is on, the vehicle should not be test driven. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. What type of scan tool is needed to retrieve data from the antilock brake system (ABS)?
   a. Factory scan tool
   b. Enhanced factory-level scan tool
   c. Code reader
   d. Either a or b

5. A cracked tone (reluctor) ring will often cause what type of problem?
    - **a.** The antilock brake system will be disabled and the amber ABS warning lamp will be on
    - **b.** False ABS actuation at low speed
    - **c.** A brake failure that will turn on the red brake warning light
    - **d.** The affected wheel brake will be applied all of the time
6. Two technicians are discussing passive-type wheel speed sensors. Technician A says that wheel speed sensors are magnetic. Technician B says that the toothed sensor ring is magnetic. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B
7. A passive-type wheel speed sensor (WSS) is being checked for the proper resistance, which should be 800 – 2,500 ohms. The meter reads 1.1 kΩ. This means _______________.
    - **a.** the sensor has a normal resistance reading
    - **b.** the sensor is electrically shorted
    - **c.** the sensor is electrically open
    - **d.** the sensor is grounded
8. A DTC C0040 has been found on a vehicle with the ABS warning light ON. What could cause this code to set?
    - **a.** A solenoid malfunction
    - **b.** Speed circuit fault
    - **c.** Pump motor fault
    - **d.** A wiring open circuit
9. Technician A says that the ABS electrohydraulic unit can be bled using bleeder screws and the manual method. Technician B says that a scan tool is often required to bleed the ABS electrohydraulic unit. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B
10. The ABS controller uses what signal characteristic from a wheel speed sensor?
    - **a.** Voltage
    - **b.** Frequency
    - **c.** Resistance
    - **d.** Electromagnetic

Chapter 107

ELECTRONIC STABILITY CONTROL SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the need for electronic stability control (ESC).
- Describe the FMVSS requirements.
- Describe the sine with dwell (SWD) test.
- List the sensors needed for the ESC system.
- Describe how a traction control (TC) system works.
- Explain how to diagnose ESC/TC system faults.

KEY TERMS:

Electronic brake control module (EBCM) 1285 • Electronic stability control (ESC) 1283 • Hand-wheel position sensor 1285 • Lateral acceleration sensor 1285 • Oversteering 1283 • Positive slip 1287 • Sine with dwell (SWD) test 1284 • Steering wheel position sensor 1285 • Telltale light 1284 • Traction control (TC) 1287 • Understeering 1283 • Vehicle speed (VS) sensor 1285 • Yaw rate sensor 1286

THE NEED FOR ELECTRONIC STABILITY CONTROL

PURPOSE AND FUNCTION **Electronic stability control (ESC)** is a system designed to help drivers to maintain control of their vehicles in situations where the vehicle is beginning to lose control. Keeping the vehicle on the road prevents run-off-road crashes, which are the conditions that lead to most single-vehicle accidents and rollovers.

SYSTEM REQUIREMENTS The ESC is defined as a system that has all of the following features:

1. Helps vehicle directional stability by applying and adjusting individual wheel brakes to help bring the vehicle back to the intended direction.
2. Uses sensors to determine when the vehicle is not under control.
3. Uses a steering wheel position sensor to determine the intended direction of the driver.
4. Operates at all vehicle speeds, except at low speeds where loss of control is unlikely.

The electronic stability control system applies individual wheel brakes to bring the vehicle under control if either of the following conditions occur:

- **Oversteering**—In this condition, the rear of the vehicle tends to move outward or breaks loose, resulting in the vehicle spinning out of control. This condition is also called *loose*. If the condition is detected during a left turn, the ESC system would apply the right front brake to bring the vehicle back under control.
- **Understeering**—In this condition, the front of the vehicle tends to continue straight ahead when turning, a condition that is also called *plowing* or *tight*. If this condition is detected during a right turn, the ESC system would apply the right rear wheel brake to bring the vehicle back under control. ● **SEE FIGURE 107–1**.

NOTE: When the brakes are applied during these corrections, a thumping sound and vibration may be sensed.

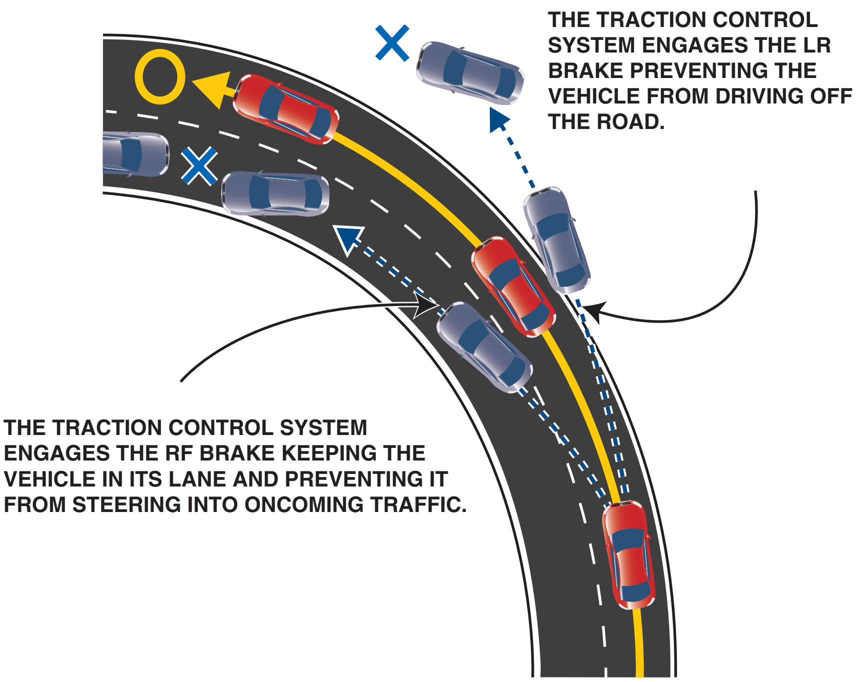

THE TRACTION CONTROL SYSTEM ENGAGES THE LR BRAKE PREVENTING THE VEHICLE FROM DRIVING OFF THE ROAD.
THE TRACTION CONTROL SYSTEM ENGAGES THE RF BRAKE KEEPING THE VEHICLE IN ITS LANE AND PREVENTING IT FROM STEERING INTO ONCOMING TRAFFIC.

FIGURE 107–1 The electronic stability control (ESC) system applies individual wheel brakes to keep the vehicle under control of the driver.

TELLTALE LAMP The ESC lamp, called a **telltale light**, is required to remain on for as long as the malfunction exists, whenever the ignition is in "On" ("Run") position. The ESC malfunction telltale will flash to indicate when the ESC system is operating to help restore vehicle stability.

ESC SWITCH Some, but not all, vehicle manufacturers install a switch to temporarily disable or limit the ESC functions. This allows the driver to disengage ESC or limit the operation when the full ESC might not be needed such as:

- When a vehicle is stuck in sand/gravel
- When the vehicle is being operated on a racetrack for maximum performance

The electronic stability control system is turned back on when the ignition is turned off and then back on and is in the default position.

FEDERAL MOTOR VEHICLE SAFETY STANDARD (FMVSS) NO. 126

Federal Motor Vehicle Safety Standard (FMVSS) No. 126 (June 26, 2008), Electronic Stability Control Systems, requires that all passenger cars, multipurpose passenger vehicles, trucks, and buses that have a gross vehicle weight rating (GVWR) of 10,000 pounds (4,536 kg) or less to be equipped with an electronic stability control system by September 1, 2011 (2012 model-year vehicles).

The ESC system must meet the following requirements:

1. The ESC system must be able to apply all four brakes individually. This means that the vehicle must be equipped with a four-channel antilock brake system (ABS) which uses a wheel speed sensor at each wheel.
2. The ESC must be programmed to work during all phases of driving including acceleration, coasting, and deceleration (including braking).
3. The ESC system must work when the antilock brake system or traction control is activated.

SINE WITH DWELL TEST

The standardized test used to determine if an electronic stability control system functions okay is called the **sine with dwell (SWD) test**. A vehicle is driven at 50 mph (80 km/h) and driven on a curved course that looks like a sine wave or the letter "S" on its side. Then the vehicle is held in a straight-ahead position for 0.5 second (500 ms) and before being steered back onto the curved section of the test. ● **SEE FIGURE 107–2**.

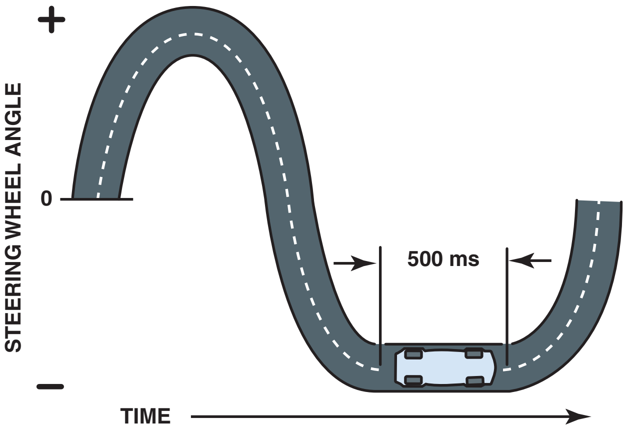

+
0
−
STEERING WHEEL ANGLE
500 ms
TIME

FIGURE 107–2 The sine with dwell test is designed to test the electronic stability control (ESC) system to determine if the system can keep the vehicle under control.

The quick changes involved in this test are designed to upset the chassis of the vehicle and cause the electronic stability control system to act to keep the vehicle under control during the entire test.

Stability control systems are offered under the following names:

- **Acura:** Vehicle Stability Assist (VSA)
- **Audi:** Electronic Stabilization Program (ESP)
- **BMW:** Dynamic Stability Control (DSC), including Dynamic Traction Control
- **Chrysler:** Electronic Stability Program (ESP)
- **Dodge:** Electronic Stability Program (ESP)
- **Ferrari:** Controllo Stabilita (CST)
- **Ford:** AdvanceTrac and Interactive Vehicle Dynamics (IVD)
- **General Motors:** StabiliTrak (except Corvette—Active Handling)
- **Hyundai:** Electronic Stability Program (ESP)
- **Honda:** Electronic Stability Control (ESC), Vehicle Stability Assist (VSA), and Electronic Stability Program (ESP)
- **Infiniti:** Vehicle Dynamic Control (VDC)
- **Jaguar:** Dynamic Stability Control (DSC)
- **Jeep:** Electronic Stability Program (ESP)
- **Kia:** Electronic Stability Program (ESP)
- **Land Rover:** Dynamic Stability Control (DSC)
- **Lexus:** Vehicle Dynamics Integrated Management (VDIM) with Vehicle Stability Control (VSC) and Traction Control (TRAC) Systems
- **Lincoln:** Advance Trak
- **Maserati:** Maserati Stability Program (MSP)
- **Mazda:** Dynamic Stability Control (DSC)
- **Mercedes:** Electronic Stability Program (ESP)
- **Mercury:** AdvanceTrak
- **Mini Cooper:** Dynamic Stability Control (DSC)
- **Mitsubishi:** Active Skid and Traction Control MULTIMODE
- **Nissan:** Vehicle Dynamic Control (VDC)
- **Porsche:** Porsche Stability Management (PSM)
- **Rover:** Dynamic Stability Control (DSC)
- **Saab:** Electronic Stability Program (ESP)
- **Saturn:** StabiliTrak
- **Subaru:** Vehicle Dynamics Control Systems (VDCS)
- **Suzuki:** Electronic Stability Program (ESP)
- **Toyota:** Vehicle Dynamics Integrated Management (VDIM) with Vehicle Stability Control (VSC)
- **Volvo:** Dynamic Stability and Traction Control (DSTC)
- **VW:** Electronic Stability Program (ESP)

FREQUENTLY ASKED QUESTION

Can a Vehicle with a Modified Suspension Pass the Test?

Yes, if the system is properly engineered. To be sure, check with the company offering a suspension test to verify that the vehicle will still be able to pass the sine with dwell (SWD) test. This ensures that any changes are within the range where the ESC system can control the vehicle during emergency maneuvers. ● **SEE FIGURE 107–3.**

FIGURE 107–3 Using a simulator is the most cost-effective way for vehicle and aftermarket suspension manufacturers to check that the vehicle is able to perform within the FMVSS No. 126 standard for vehicle stability.

ESC SENSORS

STEERING WHEEL POSITION SENSOR Depending on the vehicle, the **steering wheel position sensor** may also be called a **hand-wheel position sensor**. The function of this sensor is to provide the driver's intended direction with signals relating to steering wheel position, speed, and direction. ● **SEE FIGURES 107–4 AND 107–5.**

VEHICLE SPEED SENSOR The **vehicle speed (VS) sensor** is used by the **electronic brake control module (EBCM)** to help control the suspension system. The vehicle speed sensor is a magnetic sensor and generates an analog signal whose frequency increases as the speed increases. ● **SEE FIGURE 107–6.**

LATERAL ACCELERATION SENSOR The function of the **lateral acceleration sensor** is to provide the suspension control

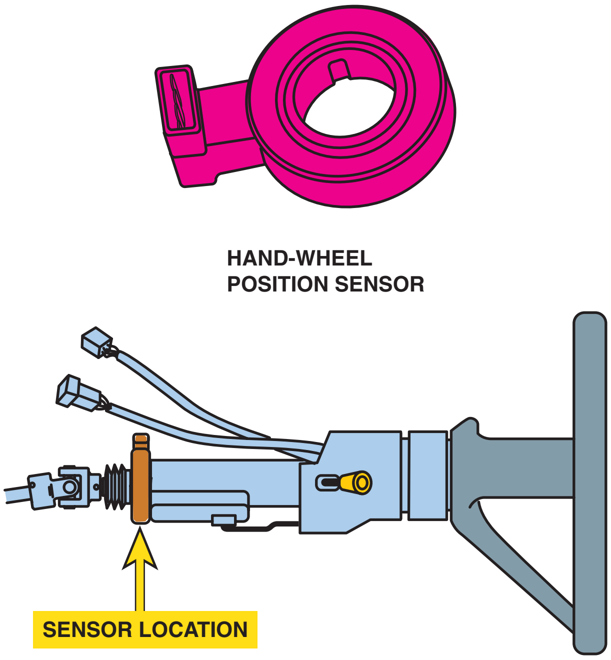


FIGURE 107–4 The hand-wheel position sensor is usually located at the base of the steering column.

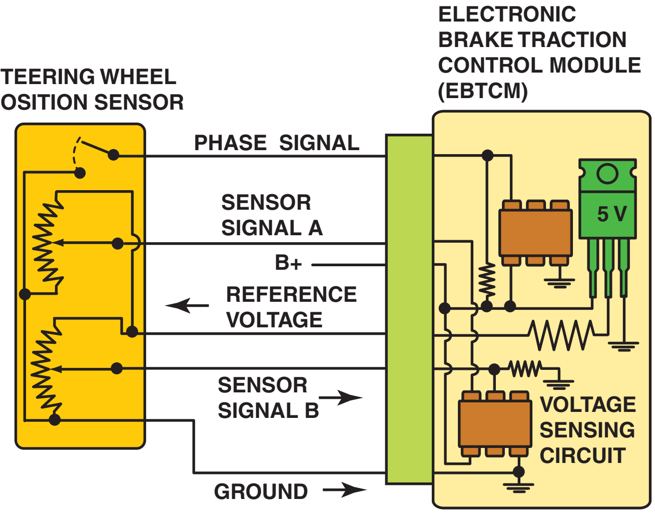

ELECTRONIC
BRAKE TRACTION
CONTROL MODULE
(EBTCM)
STEERING WHEEL
POSITION SENSOR
PHASE SIGNAL
SENSOR
SIGNAL A
B+
REFERENCE
VOLTAGE
SENSOR
SIGNAL B
GROUND
5 V
VOLTAGE
SENSING
CIRCUIT

FIGURE 107–5 Hand-wheel (steering wheel) position sensor schematic.

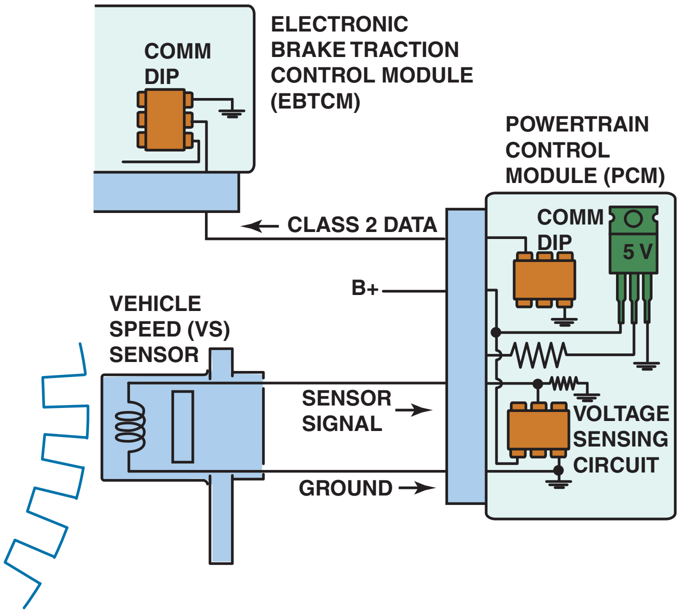

COMM
DIP
ELECTRONIC
BRAKE TRACTION
CONTROL MODULE
(EBTCM)
POWERTRAIN
CONTROL
MODULE (PCM)
CLASS 2 DATA
COMM
DIP
5 V
B+
VEHICLE
SPEED (VS)
SENSOR
SENSOR
SIGNAL
GROUND
VOLTAGE
SENSING
CIRCUIT

FIGURE 107–6 The VS sensor information is transmitted to the EBCM by Class 2 serial data.

module with feedback regarding vehicle cornering forces. This type of sensor is also called a G-sensor, with the letter "G" representing the force of gravity. For example, when a vehicle enters a turn, the sensor provides information as to how hard the vehicle is cornering. This information is processed by the suspension control module to provide appropriate damping on the inboard and outboard dampers during cornering events.

This sensor can be either a stand-alone unit or combined with the yaw rate sensor.

Typically, the sensor is mounted in the passenger compartment:

- under the front seat
- in the center console
- on the package shelf

● **SEE FIGURE 107–7**.

YAW RATE SENSOR The **yaw rate sensor** provides information to the suspension control module and the EBCM. This information is used to determine how far the vehicle has deviated from the driver's intended direction. ● **SEE FIGURE 107–9**.

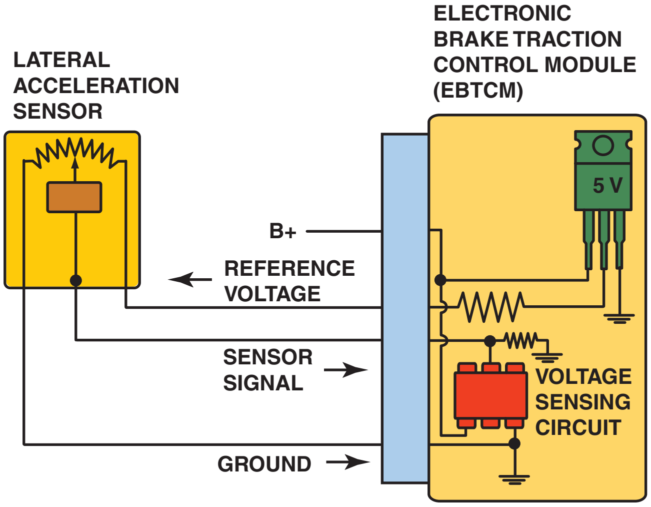

LATERAL
ACCELERATION
SENSOR
ELECTRONIC
BRAKE TRACTION
CONTROL MODULE
(EBTCM)
5 V
B+
REFERENCE
VOLTAGE
SENSOR
SIGNAL
GROUND
VOLTAGE
SENSING
CIRCUIT

FIGURE 107–7 A schematic showing the lateral acceleration sensor and EBCM.

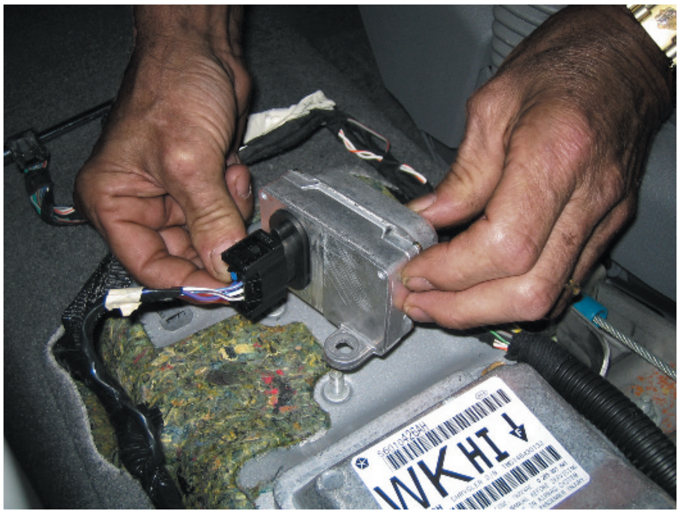


FIGURE 107–8 A lateral acceleration sensor is usually located under the center console and can be easily checked by unbolting it and turning it on its side while monitoring the sensor value using a scan tool. When it is on its side, the sensor value should read 1.0 G.

TECH TIP

Quick and Easy Lateral Acceleration Sensor Test

Most factory scan tools will display the value of sensors, including the lateral acceleration sensor. However, the sensor value will read zero unless the vehicle is cornering. A quick and easy test of the sensor is to simply unbolt the sensor and rotate it 90 degrees with the key on engine off. ● **SEE FIGURE 107–8**. Now the sensor is measuring the force of gravity and should display 1.0 G on the scan tool. If the sensor does not read close to 1.0 G or reads zero all of the time, the sensor or the wiring is defective.

This sensor can be either a stand-alone unit or combined with the lateral acceleration sensor. Typically, the sensor is mounted in the passenger compartment under the front seat, in the center console, or on the rear package shelf.

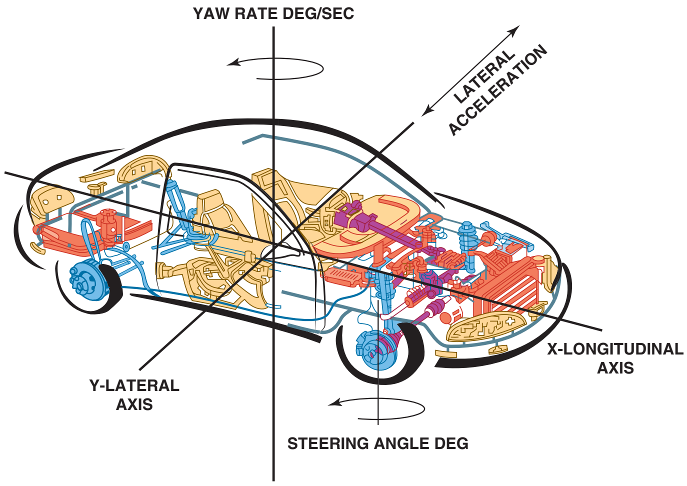


FIGURE 107–9 The yaw sensor is used to determine the rate that the vehicle is rotating around its axis, measured in degrees per second (deg/sec).

This sensor does set DTC codes. These codes can be found in service information. ● **SEE FIGURE 107–10**.

TRACTION CONTROL

PURPOSE AND FUNCTION

Traction control (TC) can be separate or used as part of the electronic stability control system. Traction control allows an ABS to control wheel spin during acceleration. When tires lose traction during acceleration, it is called **positive slip**.

Low-speed traction control uses the braking system to limit positive slip up to a vehicle speed of about 30 mph (48 km/h). Traction control is usually a part of the electronic stability control system. ● **SEE FIGURE 107–11**.

Traction control uses the same wheel speed sensors as ABS, but requires additional programming in the control module so the system monitors wheel speed continuously, not just when braking. Traction control also requires the following:

- Additional solenoids in the hydraulic modulator so the brake circuits to the drive wheels can be isolated from the non-drive wheels when braking is needed to control wheel spin.
- Use of a pump and accumulator to generate and store pressure for traction control braking. If a wheel speed sensor detects wheel spin in one of the drive wheels during acceleration, the control module energizes a solenoid that allows stored fluid pressure from the accumulator to apply the brakes on the wheel that is spinning. This slows the wheel that is spinning and redirects engine torque through the differential to the opposite drive wheel to restore traction.

Traction control works just as well on front-wheel-drive vehicles as it does on rear-wheel-drive vehicles.

SYSTEM COMPONENTS

The main controller for the traction can include one of the following, depending on make, model, and year of vehicle:

1. The body control module (BCM)
2. The powertrain control module (PCM)
3. The antilock brake system controller

The controller uses inputs from several sensors to determine if a loss of traction is occurring. The input signals used for traction control include the following:

- **Throttle position (TP) sensor**—This indicates the position of the throttle, which is the driver command for power.
- **Wheel speed sensor (WSS)**—The controller monitors all four wheel speed sensors. If one wheel is rotating faster than the other, this indicates that the tire is slipping or has lost traction.
- **Engine speed (RPM)**—This information is supplied from the engine controller powertrain control module and indicates the speed of the engine.
- **Transmission range switch**—Determines which gear the driver has selected so that the PCM can take corrective action.

TRACTION CONTROL OPERATION

The outputs of the traction control system can include one or more of the following:

- Retard ignition timing to reduce engine torque.
- Decrease the fuel injector pulse-width to reduce fuel delivery to the cylinder to reduce engine torque.

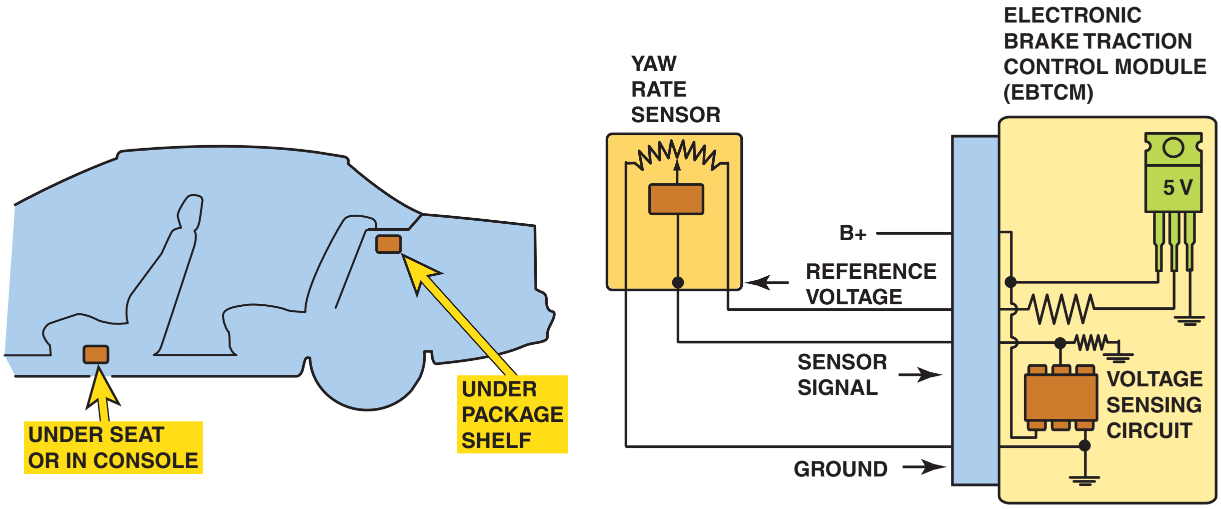


FIGURE 107–10 Yaw rate sensor showing the typical location and schematic.

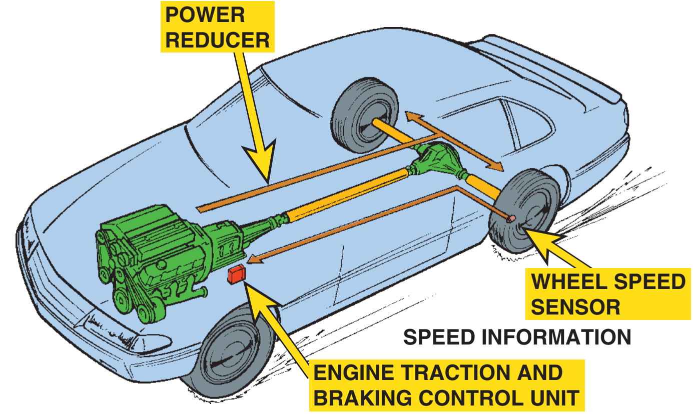


FIGURE 107–11 Typical traction control system that uses wheel speed sensor information and the engine controller (PCM) to apply the brakes at lower speeds and also reduce engine power applied to the drive wheels.

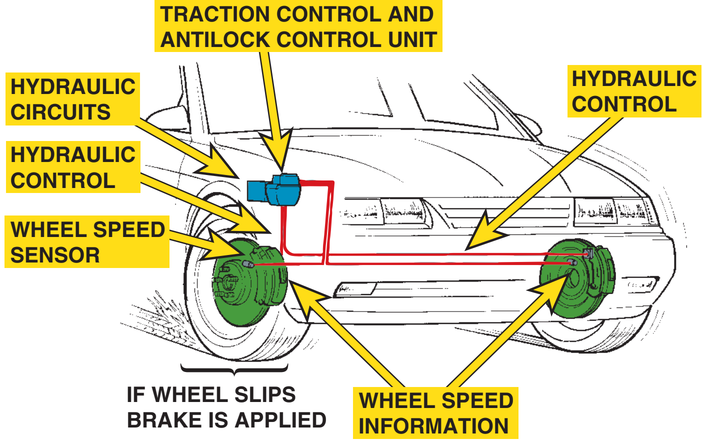


FIGURE 107–12 Wheel speed sensor information is used to monitor if a drive wheel is starting to spin.

- Reduce the amount of intake air if the engine is equipped with an electronic throttle control (ETC). Reduced airflow will reduce engine torque.
- Upshift the automatic transmission/transaxle. If the transmission is shifted into a higher gear, the torque applied to the drive wheels is reduced.

Most traction control systems are capable of reducing positive wheel slip at all vehicle speeds. Most speed traction control systems use accelerator reduction and engine power reduction to limit slip before applying the brakes to the wheel that is spinning. This action helps reduce the possibility of overheating the brakes if the vehicle were being driven on an icy or snow-covered road. ● **SEE FIGURE 107–12**.

Therefore, the controller usually performs actions to restore traction in the following order:

1. Reduces engine torque to the drive wheels. This can include some or all of the following:
   - Retard spark timing
   - Reduce injector on-time (pulse-width)
   - Close or reduce the throttle opening
   - Shift the automatic transmission to a higher gear
2. Applies individual wheel brakes to slow or stop the wheel from spinning. The ABS controller supplies to the wheel brake only the pressure that is required to prevent tire slipping during acceleration. The amount of pressure varies according to the condition of the road surface and the amount of engine power being delivered to the drive wheels. A program inside the controller will disable traction control if brake system overheating is likely to occur.
3. Lights a low traction or traction control warning light on the dash.
   ● **SEE FIGURE 107–13**.

FREQUENTLY ASKED QUESTION

Does Traction Control Engage Additional Drive Wheels?

When the term *traction control* is used, many people think of four-wheel-drive or all-wheel-drive vehicles and power trains. Instead of sending engine torque to other drive wheels, it is the purpose and function of the traction control system to prevent the drive wheel(s) from slipping during acceleration. A slipping tire has less traction than a nonslipping tire—therefore, if the tire can be kept from slipping (spinning), more traction will be available to propel the vehicle. Traction control works with the engine computer to reduce torque delivery from the engine, as well as the controller to apply the brakes to the spinning wheel if necessary to regain traction.

TRACTION ACTIVE LAMP On most applications, a "TRAC CNTL" indicator light or "TRACTION CONTROL ACTIVE" message flashes on the instrumentation when the system is engaging traction control. This helps alert the driver that the wheels are losing traction. In most applications, the message does not mean there is anything wrong with the system—unless the ABS warning lamp also comes on or the traction control light remains on continuously.

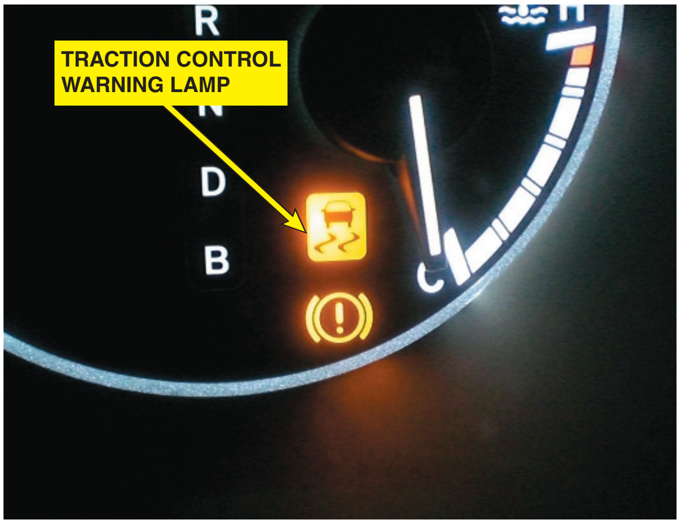


FIGURE 107–13 A traction control or low traction light on the dash is confusing to many drivers. When the lamp is on or flashing, it indicates that a low traction condition has been determined and the traction control system is working to restore traction. A flashing traction dash light does not indicate a fault.

TRACTION DEACTIVATION SWITCH Many vehicles with traction control have a dash-mounted switch that allows the driver to deactivate the system when desired (as when driving in deep snow). An indicator light shows when the system is on or off and may also signal the driver when the traction control system is actively engaged during acceleration.

ESC/TC DIAGNOSIS

STEPS INVOLVED Because the electronic stability control (ESC) and traction control (TC) systems use some of the same sensors and controllers, the diagnosis for them is about the same. To diagnose faults with either system, follow the recommended procedures found in service information. The usual procedure involves the following steps:

STEP 1 **Verify the customer concern (complaint).** This step includes trying to duplicate what the customer or driver is concerned about the system. If the traction control or ESC light is flashing, this indicates that it is trying to bring the vehicle under control. This may be normal operation if the following conditions exist:

- Icy or slippery road conditions
- Worn tires that lack traction

STEP 2 **Perform a thorough visual inspection** including the following:

- Check that all tires are the same size and tread depth.

NOTE: Using a spare tire on the drive wheel could cause the traction control and/or ESC amber warning light to flash because the controller is seeing that the smaller tire is rotating faster than the other side.

STEP 3 **Check service information** for the specified procedure to follow to retrieve diagnostic trouble codes. Most vehicles require the use of a factory-brand scan tool. ● **SEE FIGURE 107–14**.

FIGURE 107–14 The use of a factory scan tool is often needed to diagnose the ESC system.

STEP 4 **Follow the troubleshooting procedure** as specified to fix the root cause of the problem. This means following the instructions displayed on the scan tool or service information. The steps usually include all or many of the following:

- Brake fluid level
- Wheel speed sensor resistance
- Fault with the base brake system, such as air in the lines that could prevent the traction control controller from applying the wheel brakes

STEP 5 **Repair the fault.**

STEP 6 **Road test the vehicle** under the same conditions that were performed to verify the fault to be sure that the fault has been repaired.

REVIEW QUESTIONS

1. What is the difference between oversteering and understeering?
2. What is the "sine with dwell" test?
3. What are some of the other names used to identify an electronic stability control (ESC) system?
4. What sensors are used in the electronic stability control system?
5. What action does the traction control system perform to help the drive wheels maintain traction during acceleration?

CHAPTER QUIZ

1. Which sensor is used by the ESC controller to determine the driver's intended direction?
   a. Yaw sensor
   b. Steering wheel (hand-wheel) position sensor
   c. Vehicle speed (VS) sensor
   d. Lateral acceleration sensor
2. The electronic stability control (ESC) system requires that the vehicle be equipped with what type of brake system?
   a. Four-wheel disc brakes
   b. Four-channel ABS
   c. Three-channel ABS
   d. Front disc with rear drum brakes

3. Which Federal Motor Safety Standard requires electronic stability control to be on all vehicles by 2011?
- **a.** 126
- **b.** 113
- **c.** 109
- **d.** 101

4. What is the name of the standard test that is performed to verify ESC operation?
- **a.** ESC plus
- **b.** Vehicle stability enhancement test
- **c.** Sine with dwell
- **d.** Anti-skid test

5. What other name is used to describe an electronic stability control (ESC) system?
- **a.** Vehicle Stability Assist (VSA)
- **b.** Electronic Stability Program (ESP)
- **c.** Vehicle Dynamic Control (VDC)
- **d.** Any of the above

6. A diagnostic trouble code (DTC) has been set for a fault with lateral acceleration sensor or circuit. What test could be performed to check if the sensor is working?
- **a.** Unplug it and see if the scan tool reads 1.0 G.
- **b.** Disconnect the sensor and hold it sideways to see if a scan tool reads 0.0 G.
- **c.** Disconnect the sensor and hold it sideways to see if a scan tool reads 1.0 G.
- **d.** Drive the vehicle in a circle to see if the scan tool reads 0.0 G.

7. A lateral acceleration sensor is usually located where in the vehicle?
- **a.** Under the front seat
- **b.** In the center console
- **c.** On the package shelf
- **d.** Any of the above locations

8. Traction control uses the antilock brake system and other devices to limit ____________ of the drive wheels during acceleration.
- **a.** positive slip
- **b.** negative slip
- **c.** side slip
- **d.** yaw slip

9. When diagnosing ESC or TC system concerns, ____________ is usually required.
- **a.** a factory scan tool
- **b.** specific service information (SI)
- **c.** performing a visual inspection
- **d.** All of the above

10. A traction control system can often control all *except* ____________.
- **a.** limit engine torque delivered to the drive wheel
- **b.** engage four-wheel drive
- **c.** upshift the automatic transmission
- **d.** apply the wheel brake to the wheel that is losing traction

SECTION XII

STEERING AND SUSPENSION (A4)

CHAPTERS

108 Tires and Wheels
109 Tire-Pressure Monitoring Systems
110 Tire and Wheel Service
111 Suspension System Components and Operation
112 Front Suspension and Service
113 Rear Suspension and Service
114 Electronic Suspension Systems
115 Steering Columns and Gears
116 Steering Linkage and Service
117 Hydraulic Power Steering Systems
118 Electric Power Steering Systems
119 Wheel Alignment Principles
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Chapter 108

TIRES AND WHEELS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and functions of tires.
- Identify the parts of a tire.
- Describe how a tire is constructed.
- Discuss tire service descriptions.
- Discuss the uniform tire quality grading system.
- Discuss the DOT tire code.
- Discuss tire conicity and ply steer.
- Describe spare tires.
- Describe run-flat tires.
- Explain the construction and sizing of steel and alloy wheels.
- Describe tire valves.
- Describe lug nuts.

KEY TERMS:

Back spacing 1303 • Bead 1292 • Belt 1293 • Body ply 1293 • Bolt circle 1303 • Carcass ply 1293 • Center section 1302 • Conicity 1301 • DOT tire code 1300 • Green tire 1294 • High-flotation tires 1295 • Hydroplaning 1292 • Inner liner 1294 • JWL 1304 • Load index 1297 • Lug nuts 1305 • Major splice 1294 • Offset 1303 • Ply steer 1301 • Rim width 1297 • Run-flat tires 1302 • Schrader valve 1305 • Sidewall 1292 • Speed ratings 1297 • Spider 1302 • Tread 1292 • UTQGS 1299 • Wear bars 1292

INTRODUCTION TO TIRES

PURPOSE The friction (traction) between the tire and the road determines the handling characteristics of any vehicle. Think about this statement for a second. The compounding, construction, and condition of tires are some of the most important aspects of the steering, suspension, alignment, and braking systems of any vehicle. A vehicle that handles poorly or that pulls, darts, jumps, or steers “funny” may be suffering from defective or worn tires. Understanding the construction of a tire is important for the technician to be able to identify tire failure or vehicle handling problems.

FUNCTION Tires are mounted on wheels that are bolted to the vehicle to provide:

1. Shock absorber action when driving over rough surfaces
2. Friction (traction) between the wheels and the road

All tires are assembled by hand from many different component parts consisting of various rubber compounds, steel, and various types of fabric material. Tires are also available in many different designs and sizes.

PARTS OF A TIRE

TREAD **Tread** refers to the part of the tire that contacts the ground. *Tread rubber* is chemically different from other rubber parts of a tire and is compounded for a combination of traction and tire wear. *Tread depth* is usually 11/32 inch deep on new tires (this could vary, depending on manufacturer, from 9/32 to 15/32 inch). ● **FIGURE 108–1** shows a tread depth gauge.

NOTE: A tread depth is always expressed in 1/32s of an inch, even if the fraction can be reduced to 1/16s or 1/8s.

Wear indicators are also called **wear bars**. When tread depth is down to the legal limit of 2/32 inch bald strips appear across the tread. ● **SEE FIGURE 108–2**.

Tie bars are molded into the tread of most all-season-rated tires. These rubber reinforcement bars are placed between tread blocks on the outer tread rows to prevent unusual wear and to reduce tread noise. As the tire wears normally, the tie bars will gradually appear. This should not be mistaken for an indication of excess outer edge wear. A tire tread with what appears to be a solid band across the entire width of the tread is what the service technician should consider the wear bar indicator.

Grooves are large, deep recesses molded in the tread and separating the tread blocks. These grooves are called *circumferential grooves* or *kerfs.* Grooves running sideways across the tread of a tire are called *lateral grooves.* ● **SEE FIGURE 108–3**.

Grooves in both directions are necessary for wet traction. The trapped water can actually cause the tires to ride up on a layer of water and lose contact with the ground, as shown in ● **FIGURE 108–4**. This is called **hydroplaning**. With worn tires, hydroplaning can occur at speeds as low as 30 MPH on wet roads. Stopping and cornering is impossible when hydroplaning occurs. *Sipes* are small slits in the tread area to increase wet and dry traction.

SIDEWALL The **sidewall** is that part of the tire between the tread and the wheel. The sidewall contains all the size and construction details of the tire.

Some tires turn brown on the sidewalls after a short time. This is due to ozone (atmosphere) damage that actually causes the rubber to oxidize. Premium-quality tires contain an anti-oxidizing chemical additive blended with the sidewall rubber to prevent this discoloration.

WHITE SIDEWALL/LETTERED When pneumatic tires were first constructed in the early 1900s, only natural rubber was used. The entire tire was white. When it was discovered that carbon black greatly increased the toughness of a tire, it was used. The public did not like the change from white tires to black, so tire manufacturers put the carbon black (lamp black) only in the rubber that was to be used for the tread portion of the tire. This tire lasted a lot longer because the black rubber tread that touched the ground was stronger and tougher; it sold well because the sidewalls were white.

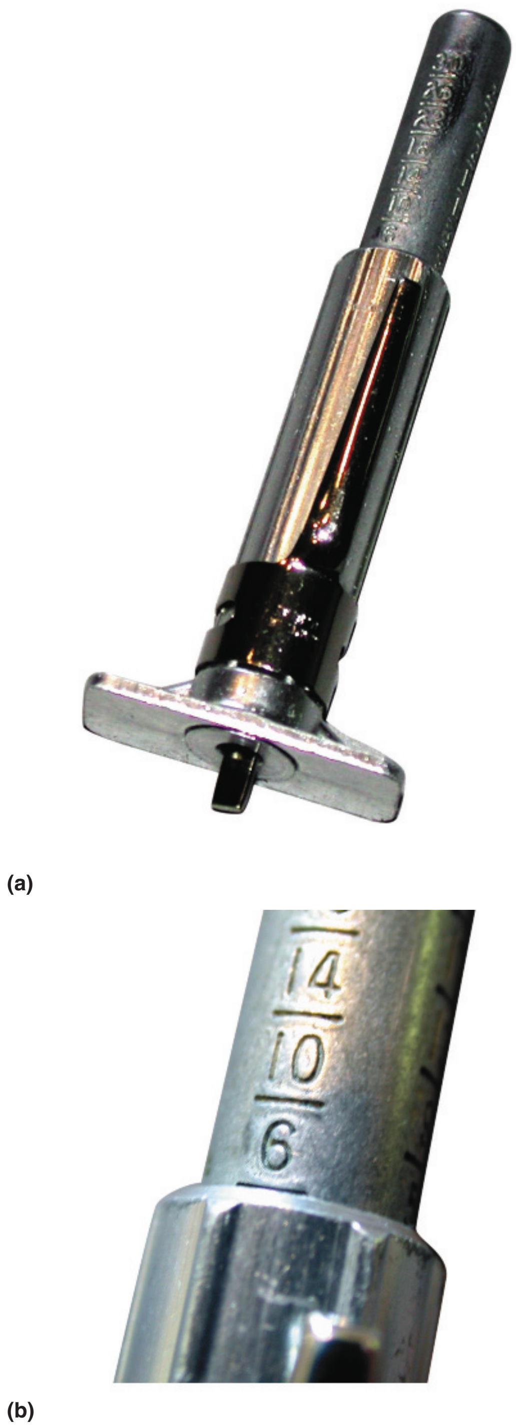


FIGURE 108–1 (a) A typical tire tread depth gauge. The center movable plunger is pushed down into the groove of the tire. (b) The tread depth is read at the top edge of the sleeve. In this example, the tread depth is 6/32 inch.

White sidewall or white lettered tires actually contain a strip of white rubber under the black sidewall. This is ground off at the factory to reveal the white rubber. Only whitewalls or white letter lines contain this expensive white rubber. Various widths of whitewalls are made possible simply by changing the width of the grinding wheel.

BEAD The **bead** is the foundation of the tire and is located where the tire grips the inside of the wheel rim.

1. The bead is constructed of many turns of copper- or bronze-coated steel wire.

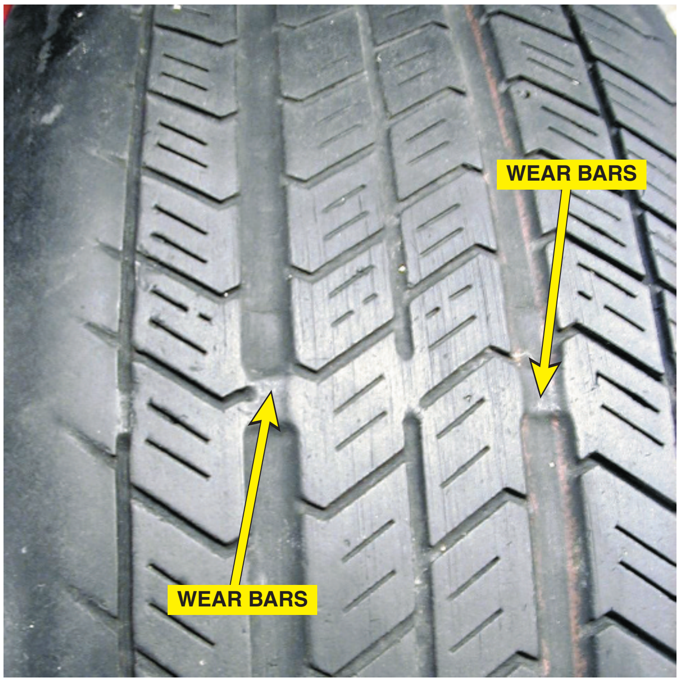


FIGURE 108–2 Wear indicators (wear bars) are strips of bald tread that show when the tread depth is down to 2/32 inch, which is the legal limit in many states.

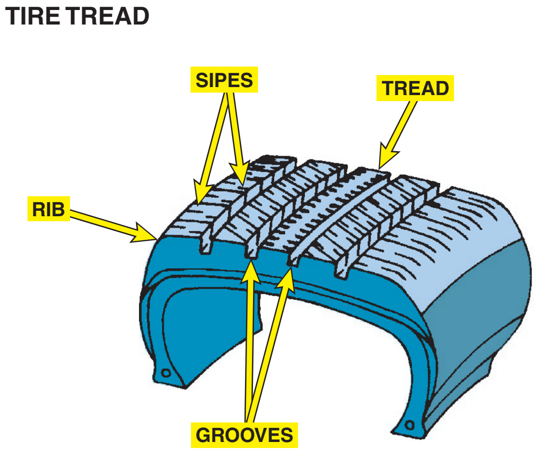


FIGURE 108–3 The tire tread runs around the circumference of the tire, and its pattern helps maintain traction. The ribs provide grip, while the grooves direct any water on the road away from the surface. The sipes help the tire grip the road.

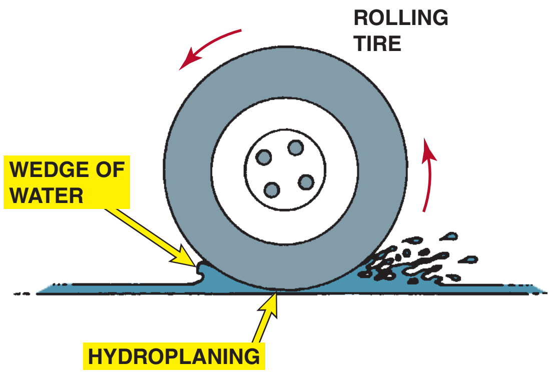


FIGURE 108–4 Hydroplaning can occur at speeds as low as 30 MPH (48 km/h). If the water is deep enough and the tire tread cannot evacuate water through its grooves fast enough, the tire can be lifted off the road surface by a layer of water. Hydroplaning occurs at lower speeds as the tire becomes worn.

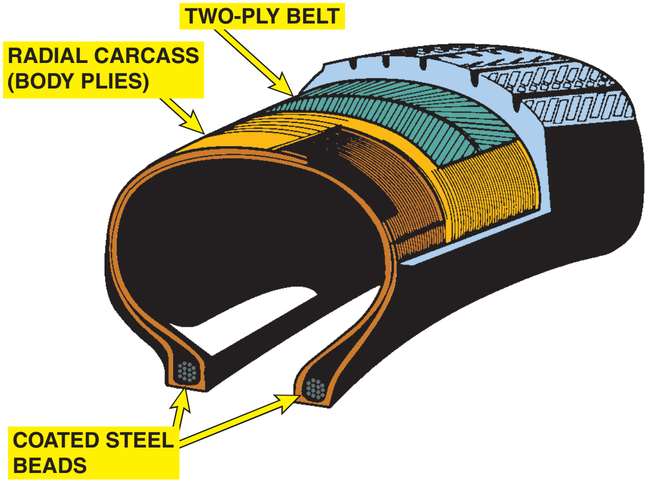


FIGURE 108–5 Typical construction of a radial tire. Some tires have only one body ply, and some tires use more than two belt plies.

2. The main body plies (layers of material) are wrapped around the bead.
3. Most radial-ply tires and all truck tires wrap the bead with additional material to add strength.

CAUTION: If the bead of a tire is cut or damaged, the tire must be replaced!

BODY PLY A tire gets its strength from the layers of material wrapped around both beads under the tread and sidewall rubber. This creates the main framework, or "carcass," of the tire; these **body plies** are often called **carcass plies**. A four-ply tire has four separate layers of material. If the body plies overlap at an angle (bias), the tire is called a *bias-ply* tire. If only one or two body plies are used and they do not cross at an angle, but lie directly from bead to bead, then the tire is called *radial ply*. ● **SEE FIGURE 108–5**.

1. Rayon is a body ply material used in many tires because it provides a very smooth ride. A major disadvantage of rayon is that it rots if exposed to moisture.
2. Nylon is a strong body ply material. Though it is still used in some tires, it tends to "flat-spot" after sitting overnight.
3. Aramid is the generic name for aromatic polyamide fibers developed in 1972. Aramid is several times stronger than steel (pound for pound) and is used in high-performance-tire construction. Kevlar is the DuPont brand name for aramid and a registered trademark of E.I. DuPont de Nemours and Co.
4. Polyester is the most commonly used tire material because it provides the smooth-ride characteristics of rayon with the rot resistance and strength of nylon.

BELT A tire **belt** is two or more layers of material applied over the body plies and under the tread area only to stabilize the tread and increase tread life and handling.

1. Tire belts can consist of the following materials:
   a. Steel mesh
   b. Nylon
   c. Rayon
   d. Fiberglass
   e. Aramid
2. All radial tires are belted.

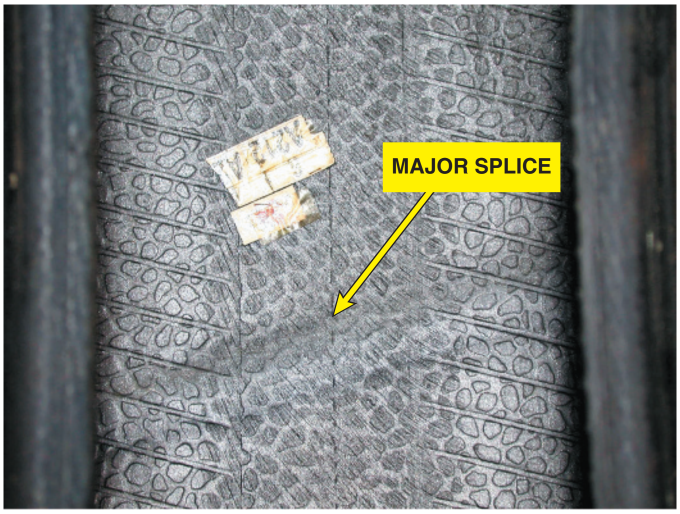


FIGURE 108–6 The major splice of a tire can often be seen and felt on the inside of the tire. The person who assembles (builds) the tire usually places a sticker near the major splice as a means of identification for quality control.

NOTE: Most tires rated for high speed use a nylon "overlay" or "cap belt" between the two-ply belt and the tread of the tire. This overlay helps stabilize the belt package and helps hold the tire together at high speeds, when centrifugal force acts to tear a tire apart.

INNER LINER The **inner liner** is the soft rubber lining (usually a butyl rubber compound) on the inside of the tire that protects the body plies and helps provide for self-sealing of small punctures.

MAJOR SPLICE When the tire is assembled by a craftsperson on a tire-building machine, the body plies, belts, and tread rubber are spliced together. The fabric is overlapped approximately five threads. The point where the majority of these overlaps occur is called the **major splice**, which represents the stiffest part of the tire. This major splice is visible on most tires on the inside, as shown in ● **FIGURE 108–6**.

NOTE: On most new vehicles and/or new tires, the tire manufacturer paints a dot on the sidewall near the bead, indicating the largest diameter of the tire. The largest diameter of the tire usually is near the major splice. The wheel manufacturer either marks the wheel or drills the valve core hole at the smallest diameter of the wheel. Therefore, the dot should be aligned with the valve core or marked for best balance and minimum radial runout.

TIRE MOLDING

After the tire has been assembled by the tire building machine, it is called a **green tire**. ● **SEE FIGURE 108–7**. At this stage in construction, the rubber can be returned and reused because it has not been changed chemically. The completed green tire is then placed in a mold where its shape, tread design, and all sidewall markings are formed. ● **SEE FIGURE 108–8**.

While in the mold, a steam bladder fills the inside of the tire and forces the tire against the outside of the mold. After approximately 30 minutes at 300°F (150°C), the heat changes the chemistry of the rubber. The tire is no longer called a green tire but a *cured tire,* and after inspection and cleaning, it is ready for shipment.

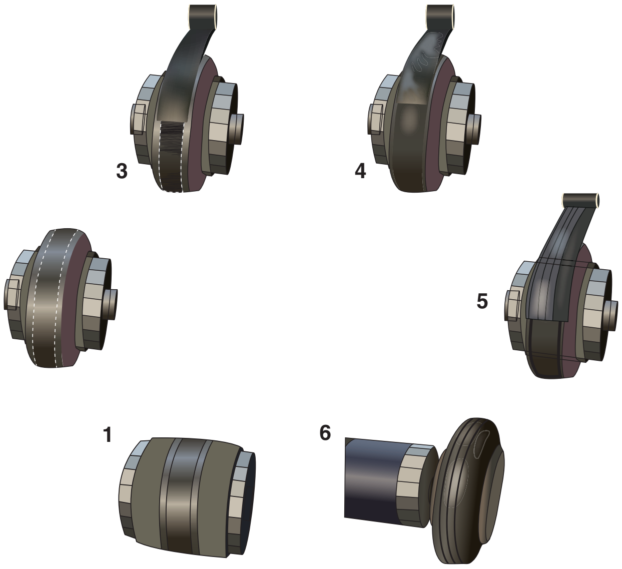


FIGURE 108–7 Complete stage 1 (body plies, sidewall components, and beads). 2. Building drum expands in preparation to receive the belts and tread. 3. Application of belt #1. 4. Application of belt #2. 5. Application of the tread. 6. Drum retracts to release the completed green (uncured) tire.

Some tires use letters at the end of the tire size (suffixes) to indicate special applications, including the following:

LT	light truck
ML	mining and logging
MH	mobile home
ST	special trailer
TR	truck

FREQUENTLY ASKED QUESTION

Why Do I Get Shocked by Static Electricity When I Drive a Certain Vehicle?

Static electricity builds up in insulators due to friction of the tires with the road. Newer tires use silica and contain less carbon black in the rubber, which makes the tires electrically conductive. Because the tires cannot conduct the static electricity to the ground, it builds up inside the vehicle and is discharged through the body of the driver and/or passenger whenever the metal door handle is touched.

NOTE: Toll booth operators report being shocked by many drivers as money is being passed between the driver and the toll booth operator.

Newer tire sidewall designs that use silica usually incorporate carbon sections that are used to discharge the static electricity to ground. To help reduce the static charge buildup, spray the upholstery with an antistatic spray available at discount and grocery stores.

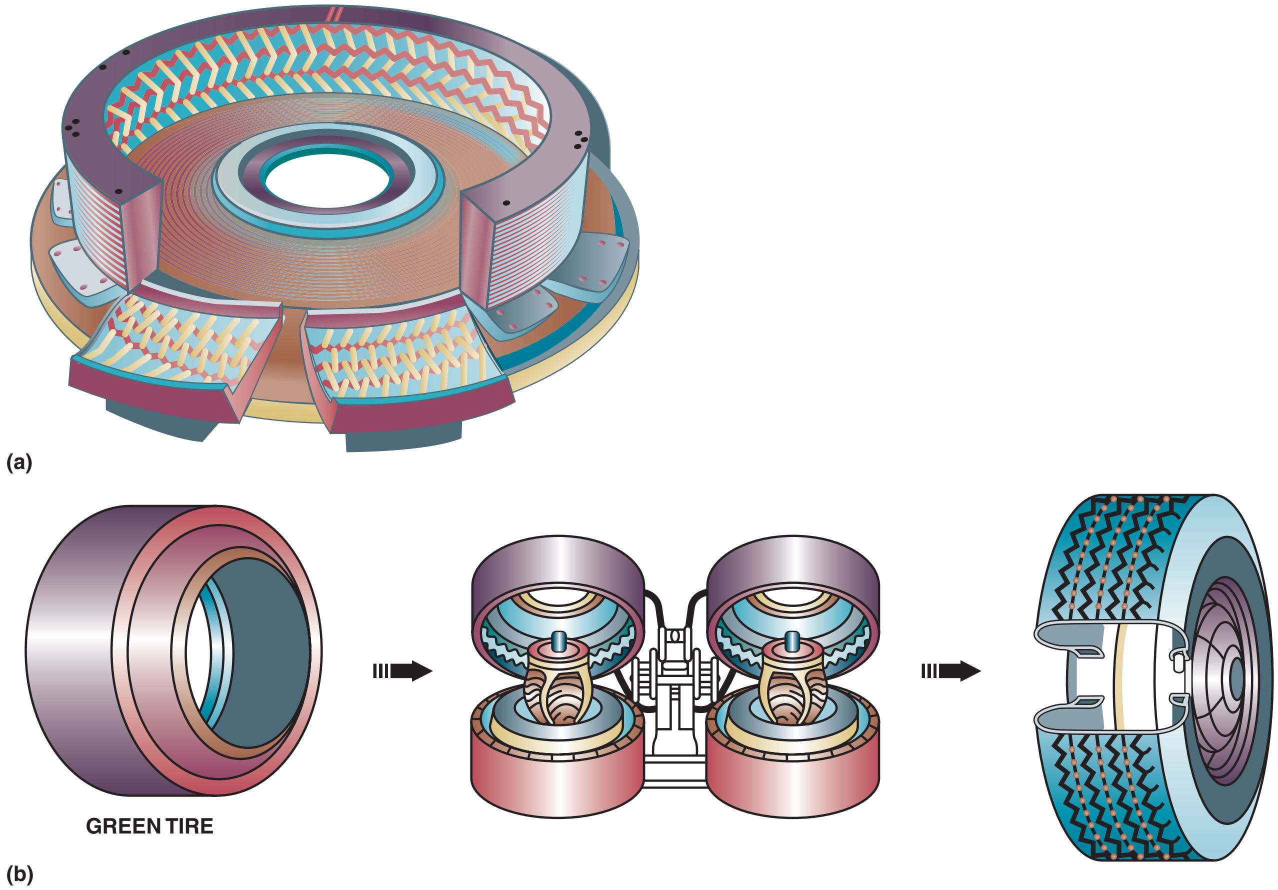


FIGURE 108–8 After the entire tire has been assembled into a completed "green" tire, it is placed into a tire-molding machine where the tire is molded into shape and the rubber is changed chemically by the heat. This nonreversible chemical reaction is called vulcanization. (a) A segmented-type mold (b) A clamshell-type mold showing the steam-filled bladder that inflates which forces the green tire into the mold.

FREQUENTLY ASKED QUESTION

How Much Does Tire Pressure Change with a Change in Temperature?

As the temperature of a tire increases, the pressure inside the tire also increases. The general amount of pressure gain (when temperatures increase) or loss (when temperatures decrease) is as follows:

10°F increase causes 1 PSI increase

10°F decrease causes 1 PSI decrease

For example, if a tire is correctly inflated to 35 PSI when cold and then driven on a highway, the tire pressure may increase 5 PSI or more.

CAUTION: DO NOT LET AIR OUT OF A HOT TIRE! If air is released from a hot tire to bring the pressure down to specifications, the tire will be *underinflated* when the tire has cooled. The tire-pressure specification is for a cold tire.

Always check the tire pressures on a vehicle that has been driven fewer than 2 miles (3.2 km).

Air pressure in the tires also affects fuel economy. If all four tires are underinflated (low on air pressure), fuel economy is reduced about **0.1 mile per gallon (mpg) for each 1 PSI low**. For example, if all four tires were inflated to 25 PSI instead of 35 PSI, not only is tire life affected but fuel economy is reduced by about 1 mile per gallon (10 × 0.1 = 1 mpg).

SERVICE DESCRIPTION

Tires built after 1990 use a "service description" method of sidewall information in accordance with ISO 4000 (International Standards Organization) that includes size, load, and speed rating together in one easy-to-read format. ● **SEE FIGURE 108–9**.

P-Metric Designation	Service Description
P205/75HR × 15	205/75R × 15 92H
P passenger vehicle	205 cross-sectional width in mm
205 cross-sectional width in mm	75 aspect ratio
75 aspect ratio	R radial construction
H speed rating (130 MPH/210 km/h)	15 rim diameter in inches
R radial construction	92 load index
15 rim diameter in inches	H speed rating (130 MPH/210 km/h)

HIGH-FLOTATION TIRE SIZES **High-flotation tires** for light trucks are designed to give improved off-road performance on sand, mud, and soft soil and still provide acceptable hard-road surface performance. These tires are usually larger than conventional tires and require a wider-than-normal

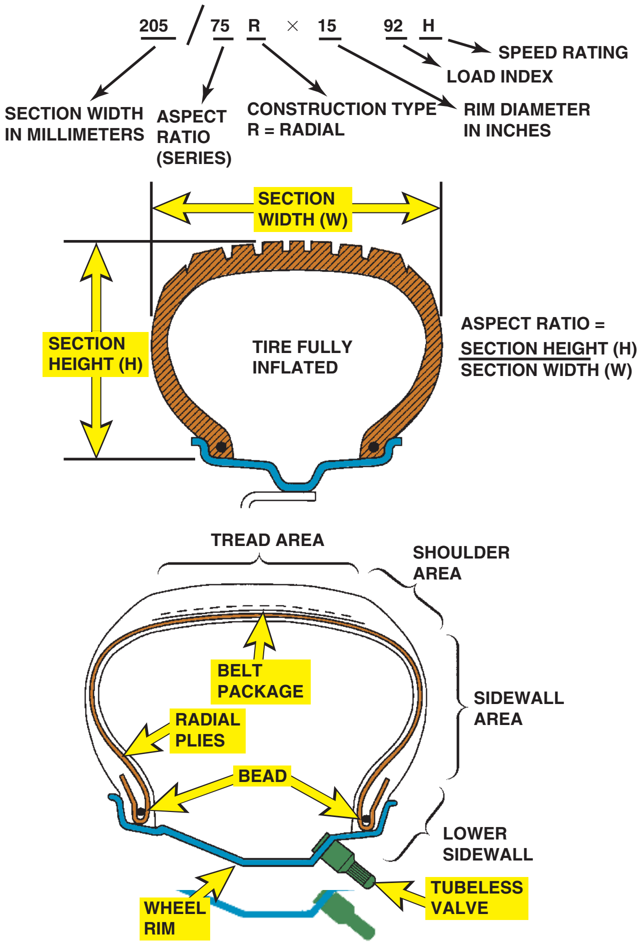


FIGURE 108–9 (a) Tire size designation includes cross-sectional width and aspect ratio. The aspect ratio is the proportional relationship between the width and the height of the tire expressed as a percentage. (b) Cross-sectional view of a typical tire showing the terminology.

FREQUENTLY ASKED QUESTION

What Effect Does Tire Size Have on Overall Gear Ratio?

Customers often ask what effect changing tire size has on fuel economy and speedometer readings. If larger (or smaller) tires are installed on a vehicle, many other factors also will change. These include the following:

1. **Speedometer reading.** If larger-diameter tires are used, the speedometer will read slower than you are actually traveling. This can result in speeding tickets!
2. **Odometer reading.** Even though larger tires are said to give better fuel economy, just the opposite can be calculated! Since a larger-diameter tire travels farther than a smaller-diameter tire, the larger tire will cause the odometer to read a shorter distance than the vehicle actually travels. For example, if the odometer reads 100 miles traveled on tires that are 10% oversized in circumference, the actual distance traveled is 110 miles.
3. **Fuel economy.** If fuel economy is calculated on miles traveled, the result will be *lower* fuel economy than for the same vehicle with the original tires.

$$\text{Calculation: MPH} = \frac{\text{RPM} \times \text{diameter} \times 3.14}{\text{gear ratio}}$$

$$\text{RPM} = \frac{\text{MPH} \times \text{gear ratio}}{\text{diameter} \times 3.14}$$

$$\text{gear ratio} = \frac{\text{RPM} \times \text{diameter} \times 3.14}{\text{MPH}}$$

FREQUENTLY ASKED QUESTION

How Much Bigger Can I Go?

Many owners think they can improve their vehicle by upgrading the tire size over the size that comes from the factory to make their vehicle look sportier and ride and handle better. When changing tire size, there are many factors to consider:

1. The tire should be of the same outside diameter as the original to maintain the proper suspension, steering, and ride height specifications.
2. Tire size affects vehicle speed sensor values, ABS brake wheel sensor values that can change automatic transmission operation, and ABS operation.
3. The tire should not be so wide as to contact the inner wheel well or suspension components.
4. Generally, a tire that is 10 mm wider is acceptable. For example, an original equipment tire size 205/75 × 15 (outside diameter = 27.1 in.) can be changed to 215/75 × 15 (outside diameter = 27.6 in.). This much change is less than 1/2 inch in width and increases the outside diameter by 1/2 inch.

NOTE: Outside diameter is calculated by adding the wheel diameter to the cross-sectional height of the tire, multiplied by 2. ● SEE FIGURE 108–10.

5. Whenever changing tires, make sure that the load capacity is the same or greater than that of the original tires.
6. If wider tires are desired, a lower aspect ratio is required to maintain the same, or close to the same, overall outside diameter of the tire.

Old	New
P205/75 × 15	P215/70 × 15
205 × 0.75 = 154 mm	215 × 0.70 = 151 mm

Notice that the overall sidewall height is generally maintained.

If even larger tires are needed, then 225/60 × 15s may be OK—let's check the math:

$$225 \times 0.60 = 135 \text{ mm}$$

Notice that this is much too short a sidewall height when compared with the original tire.

7. Use the "plus 1" or "plus 2" concept. When specifying wider tires, the sidewall height must be reduced to maintain the same, or close to the same, original equipment specifications. The "plus 1" concept involves replacing the wheels with wheels 1 in. larger in diameter to compensate for the lower aspect of wider tires.

Original	Plus 1
205/75 × 15	225/60 × 16

The overall difference in outside diameter is only 0.5 inch, even though the tire width has increased from 205 to 225 mm and the wheel diameter has increased by 1 inch. If money is no object and all-out performance is the goal, a “plus 2” concept can also be used (use a P245/50 × 17 tire and change to 17 inch diameter wheels).

Here the overall diameter is within 1/20 inch of the original tire/wheel combination, yet the tire width is 1.6 inches (40 mm) wider than the original tire. Refer to the section “Wheels” later in this chapter for proper wheel back spacing and offset when purchasing replacement wheels.

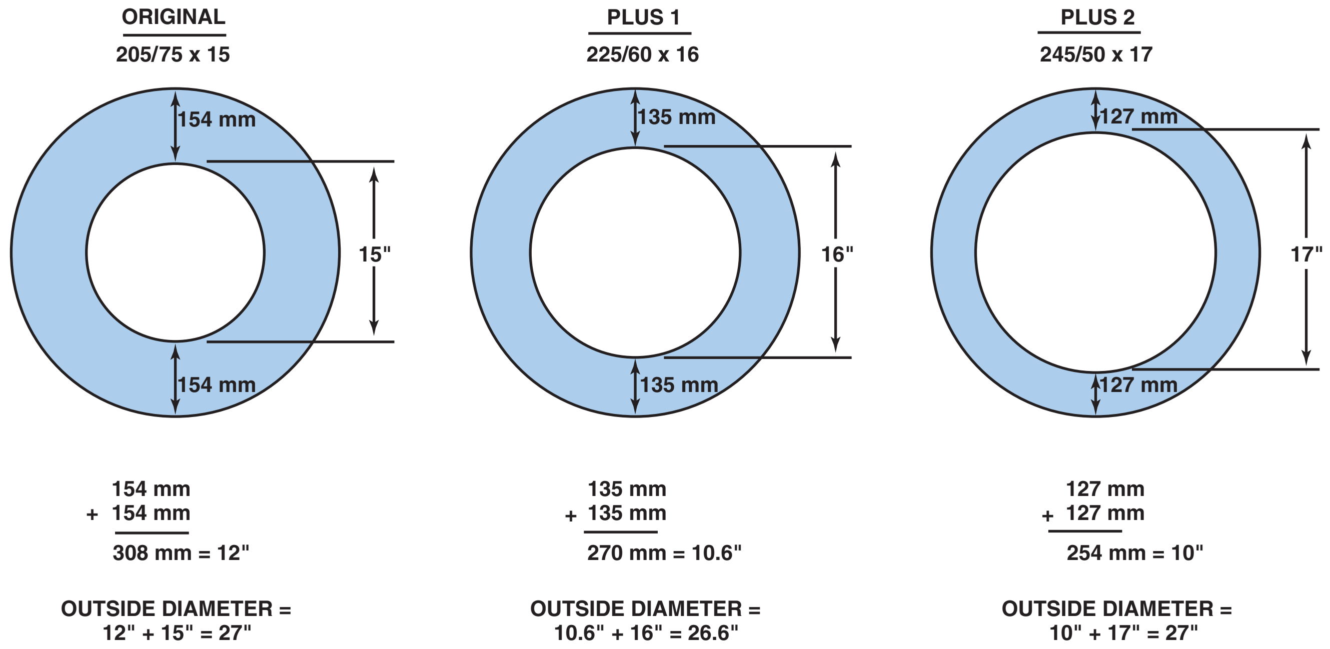


FIGURE 108–10 Notice that the overall outside diameter of the tire remains almost the same and at the same time the aspect ratio is decreased and the rim diameter is increased.

wheel width. High-flotation tires have a size designation such as 33 × 12.50R × 15LT:

33	approximate overall tire diameter in inches
12.50	approximate cross-sectional width in inches
R	radial-type construction
15	rim diameter in inches
LT	light-truck designation

LOAD INDEX AND EQUIVALENT LOADS

The **load index**, as shown in ● **FIGURE 108–11**, is an abbreviated method to indicate the load-carrying capabilities of a tire. The weights listed in the chart represent the weight that *each tire* can safely support. Multiply this amount by 4 to get the maximum that the vehicle should weigh fully loaded with cargo and passengers.

SPEED RATINGS

Tires are rated according to the maximum *sustained* speed. A vehicle should never be driven faster than the **speed rating** of the tires. ● **SEE CHART 108–1**.

CAUTION: A high-speed rating does not guarantee that the tires will not fail, even at speeds much lower than the rating. Tire condition, inflation, and vehicle loading also affect tire performance.

As the speed rating of a tire increases, fewer compromises exist for driver comfort and low noise level. The higher speed rating does not mean a better tire. To survive, a high-speed tire must be built with stiff tread compounds, reinforced body (carcass) construction, and fabric angles that favor high speed and high performance over other considerations. For example, a V-rated tire often has less tread depth than a similar tire with an H-speed rating, and therefore will often not give as long of a service life. Since the speed ratings were first developed in Europe, the letters correspond to metric speed in kilometers per hour, with a conversion to miles per hour as noted.

TIRE PRESSURE AND TRACTION

All tires should be inflated to the specifications given by the vehicle manufacturer. Most vehicles have recommended tire inflation figures written in the owner’s manual or on a placard or sticker on the door post or glove compartment. ● **SEE FIGURE 108–12**.

The pressure number molded into the sidewall of a tire should be considered the maximum pressure when the tire is cold. (Pressures higher than that stated on the sidewall may be measured on a hot tire.)

RIM WIDTH AND TIRE SIZE

The **rim width** is the distance between the tire flanges sometimes called the “flange-to-flange” width. As a general rule, for a given rim width it is best not to change tire width more than 10 mm (either wider or narrower).

Load Index	Load (kg)	Load (lb)
75	387	853
76	400	882
77	412	908
78	425	937
79	437	963
80	450	992
81	462	1,019
82	475	1,047
83	487	1,074
84	500	1,102
85	515	1,135
86	530	1,168
87	545	1,201
88	560	1,235
89	580	1,279
90	600	1,323
91	615	1,356
92	630	1,389
93	650	1,433
94	670	1,477
95	690	1,521
96	710	1,565
97	730	1,609
98	750	1,653
99	775	1,709
100	800	1,764
101	825	1,819
102	850	1,874
103	875	1,929
104	900	1,934
105	925	2,039
106	950	2,094
107	975	2,149
108	1,000	2,205
109	1,030	2,271
110	1,060	2,337
111	1,090	2,403
112	1,120	2,469
22	1,150	2,535
114	1,180	2,601
115	1,215	2,679

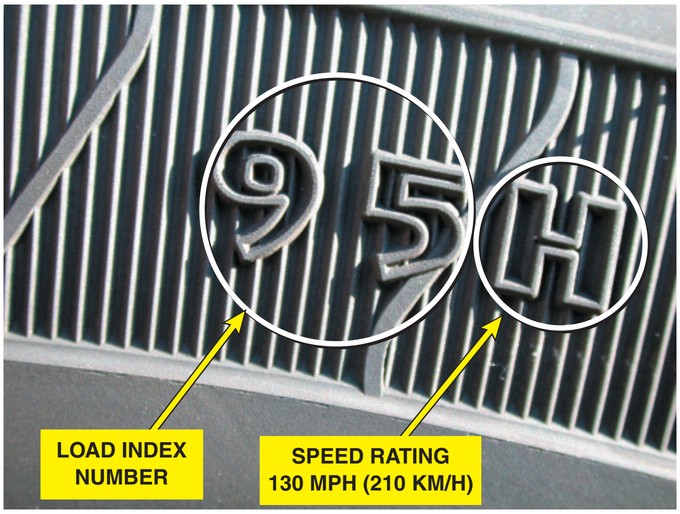


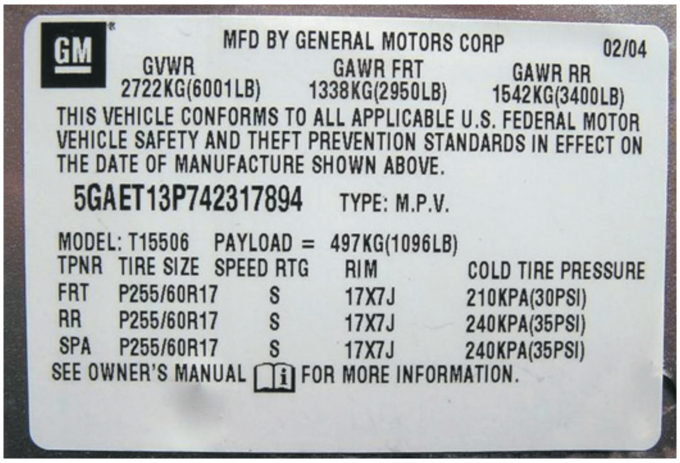
FIGURE 108–11 Typical sidewall markings for load index and speed rating following the tire size.

LETTER	MAXIMUM RATED SPEED
L	120 km/h (75 MPH)
M	130 km/h (81 MPH)
N	140 km/h (87 MPH)
P	150 km/h (93 MPH)
Q	160 km/h (99 MPH)
R	170 km/h (106 MPH)
S	180 km/h (112 MPH)
T	190 km/h (118 MPH)
U	200 km/h (124 MPH)
H	210 km/h (130 MPH)
V	240 km/h (149 MPH)
W	270 km/h (168 MPH)
Y	300 km/h (186 MPH)
Z	open-ended*

CHART 108–1

Speed ratings are based on continuous operation at the speed rated speed.

*The exact speed rating for a particular Z-rated tire is determined by the tire manufacturer and may vary according to size. For example, not all Brand X Z-rated tires are rated at 170 MPH, even though one size may be capable of these speeds.


GM® MFD BY GENERAL MOTORS CORP 02/04
GVWR 2722KG(6001LB) GAWR FRT 1338KG(2950LB) GAWR RR 1542KG(3400LB)
THIS VEHICLE CONFORMS TO ALL APPLICABLE U.S. FEDERAL MOTOR VEHICLE SAFETY AND THEFT PREVENTION STANDARDS IN EFFECT ON THE DATE OF MANUFACTURE SHOWN ABOVE.
5GAET13P742317894 TYPE: M.P.V.
MODEL: T15506 PAYLOAD = 497KG(1096LB)

TPNR	TIRE SIZE	SPEED RTG	RIM	COLD TIRE PRESSURE
FRT	P255/60R17	S	17X7J	210KPA(30PSI)
RR	P255/60R17	S	17X7J	240KPA(35PSI)
SPA	P255/60R17	S	17X7J	240KPA(35PSI)

SEE OWNER'S MANUAL FOR MORE INFORMATION.

FIGURE 108–12 A typical door placard used on a General Motors vehicle indicating the recommended tire inflation. Note that the information also includes the size and speed rating of the tire as well as the recommended wheel size.

For a given tire width, it is best not to vary rim width more than 1/2 inch in either direction. For example, if the original tire size is 195/70 × 14, then either a 185/70 × 14 (−10 mm) or a 205/70 × 14 (+10 mm) *could* be used on the original rim (wheel) without undue harm *if* the replacement tire has proper clearance with the body and suspension components.

Installing a tire on too narrow a wheel will cause the tire to wear excessively in the center of the tread. Installing a tire on too wide a wheel will cause excessive tire wear on both edges.

UNIFORM TIRE QUALITY GRADING SYSTEM

The U.S. Department of Transportation and the National Highway Traffic Safety Administration developed a system of tire grading, the **Uniform Tire Quality Grading System (UTQGS)**, to help customers better judge the relative performance of tires. The three areas of tire performance are tread wear, traction, and temperature resistance, as shown in ● **FIGURE 108–13**.

NOTE: All tires sold in the United States must have UTQGS ratings molded into the sidewall.

TREAD WEAR The tread wear grade is a comparison rating based on the wear rate of a standardized tire, tested under carefully controlled conditions, which is assigned a value of 100. A tire rated 200 should have a useful life twice as long as the standard tire's.

NOTE: The standard tire has a rating for tread wear of 100. This value has generally been accepted to mean a useful life of 20,000 miles of normal driving. Therefore, a tire rated at 200 could be expected to last 40,000 miles.

Tread Wear Rating Number	Approximate Number of mi/km
100	20,000/32,000
150	30,000/48,000
200	40,000/64,000
250	50,000/80,000
300	60,000/96,000
400	80,000/129,000
500	100,000/161,000

The tread wear life of any tire is affected by driving habits (fast stops, starts, and cornering will decrease tread life), tire rotation (or lack of tire rotation), inflation, wheel alignment, road surfaces, and climate conditions.

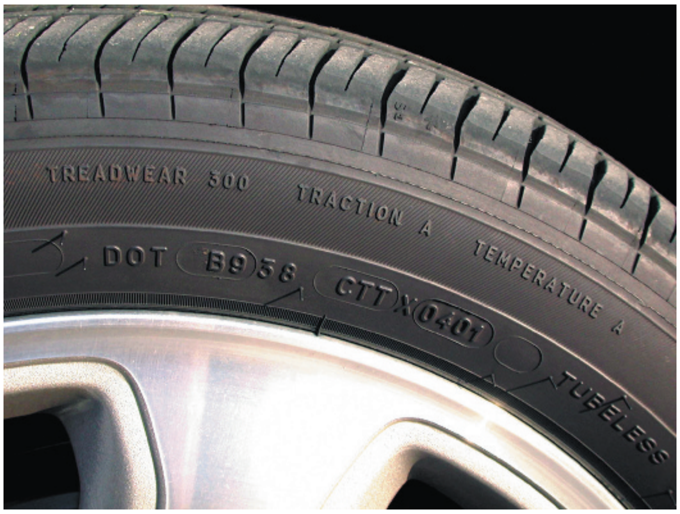


FIGURE 108–13 Typical "Uniform Tire Quality Grading System" (UTQGS) ratings imprinted on the tire sidewall.

TRACTION Traction performance is rated by the letters AA, A, B, and C, with AA being the highest.

NOTE: The traction rating is for wet braking distance only! It does not include cornering traction or dry braking performance.

The traction rating is only one of many other factors that affect wet braking traction, including air inflation, tread depth, vehicle speed, and brake performance.

TEMPERATURE RESISTANCE Temperature resistance is rated by the letters A, B, and C, with A being the highest rating. Tires generate heat while rotating and flexing during normal driving conditions. A certain amount of heat buildup is desirable because tires produce their highest coefficient of traction at normal operating temperatures. For example, race car drivers frequently swerve their cars left and right during the pace laps, causing increased friction between the tire and the road surface, which warms their tires to operating temperature. However, if temperatures rise too much, a tire can start to come apart—the oils and rubber in the tire start to become a liquid! Grade C is the minimum level that all tires must be able to pass under the current Federal Motor Vehicle Safety Standard No. 109.

M&S RATING Most all-season tires are rated and labeled as *M & S*, *MS*, or *M + S*, and therefore must adhere to general

FREQUENTLY ASKED QUESTION

What Type of Tires Should Be Used and When?

Owners of vehicles are often confused when it comes to replacing tires. Unless the rims (wheels) have been replaced with ones of a different size than the vehicle originally came with, the information needed can be found either in the owner's manual or on a sticker on the driver's door jamb. The four things that need to be checked when replacing tires include

1. **The correct size.** A tire size describes the width of the tire, the height of the sidewall, and the rim diameter. This should be the same size that was originally on the vehicle.
2. **Speed rating.** The speed rating is given as a letter (Q, T, S, H, V, W, and Y) and should be the same as the original tires that came with the vehicle.
3. **The load rating.** This is especially important when tires are being purchased for a pickup truck or SUV where a full load may be carried. Check the load rating on the sidewall of the tires to make sure that they match or exceed the load rating of the original tires. The load rating is given as a number in combination with the speed rating (i.e., 93 V) and together is known as the "service description" of the tire.
4. **Summer, Winter, or All-Season-Summer tires.** If the vehicle will be driven in a climate that is above 45°F (7°C), then summer-type tires can be used.
    - **Winter tires.** If the vehicle is going to be driven in winter conditions at temperatures always below 45°F (7°C), then winter tires should be selected.
    - **All-season tires.** If the vehicle will be driven under a variety of conditions and both above and below 45°F (7°C), then all-season type tires should be selected.

design features as specified by the Rubber Manufacturers Association (RMA).

Tires labeled M & S are constructed with an aggressive tread design, as well as tread compounds and internal construction that are designed for mud and snow. One design feature is that the tire has at least 25% void area. This means that the tread blocks have enough open space around them to allow the blocks to grab and clean themselves of snow and mud. Block angles, dimensional requirements, and minimum cross-sectional width are also a requirement for the M & S designation.

The tread rubber used to make all-season tires is also more flexible at low temperatures. This rubber compound is low-bounce (called high-hysteresis) and is more likely to remain in contact with the road surface. The rubber compound is also called *hydrophilic*, meaning that the rubber has an affinity for water (rather than being *hydrophobic* rubber, which repels water).

NOTE: Most vehicle manufacturers recommend that the same *type* of tire be used on all four wheels even though the size of the tire may vary between front and rear on some high-performance vehicles. Therefore, if all-season replacement tires are purchased, a complete set of four should be used to be assured of proper handling and uniform traction characteristics. While *tire* manufacturers have been recommending this for years—since the late 1980s—most *vehicle* manufacturers are also recommending that all four tires be of the same construction and tread type to help ensure proper vehicle handling.

FOUR SEASONS TIRES This is a new category created by tire companies. Four seasons tires are the same as all-season tires except most of these are also three-peak mountain snowflake (3PMSF) rated. They have minimum snow traction ability tested versus an industry standard reference test tire (SRTT)—minimum 110 rating.

The three-mountain snowflake rated tires are required to be installed on vehicles in many states and provinces during the winter months, usually December 15 to March 15. ● **SEE FIGURE 108–14**. For reference, most all-season tires have a traction rating of 70-80, so this means that the four-season tires offer more traction on snow.

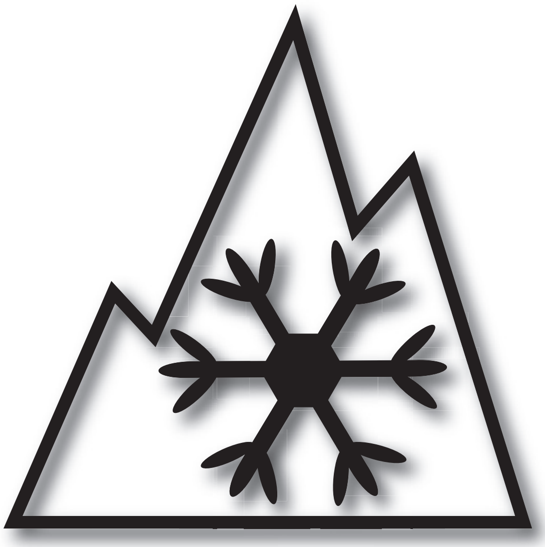


FIGURE 108–14 The three-mountain peak symbol indicates that the tire is rated with the necessary snow traction to be the specified winter tire required in some states and Canadian provinces for use in the winter months.

ALL-TERRAIN AND PERFORMANCE TIRES All -terrain (A/T) designates a performance category for marketing differentiation, not actual performance rating. Other names used by marketing without actual test specifications include

- Touring-Usually an all-season tire and often include an asymmetrical tread pattern.
- All-season High Performance (AS HP).
- Mud-terrain (M/T) tires. The tire is designed to handle both off and on road driving.
- Highway-terrain (H/T) tires. H/T tires allow a driver to use the same tires for everyday highway driving as well occasional off-road driving.

DOT TIRE CODE

All tires sold in the United States must be approved by the U.S. Federal Department of Transportation (DOT). The **DOT tire code** requirements include resistance to tire damage that could be caused by curbs, chuckholes, and other common occurrences for a tire used on public roads.

NOTE: Most race tires are *not* DOT-approved and must never be used on public streets or highways.

Each tire that is DOT-approved has a DOT number molded into the sidewall of the tire. This number is usually imprinted on only one side of the tire and is usually on the side *opposite the whitewall*. The DOT code includes letters and numbers, such as **MJP2CBDX264.**

The first two letters identify the manufacturer and location. For this example, the first two letters (MJ) mean that the tire was made by the Goodyear Tire and Rubber Company in Topeka, Kansas. The last three numbers are the build date code, which is the year (1994),

CASE STUDY

Tire Date Code Information Saved Me Money!

This author was looking at a three-year-old vehicle and noticed that the right rear tire had a build date code newer than the vehicle. I asked the owner, "How badly was this vehicle hit?" The owner stumbled and stuttered a little, then said, "How did you know that an accident occurred?" I told the owner that the right rear tire, while the exact same tire as the others, had a date code indicating that it was only one year old, whereas the original tires were the same age as the vehicle.

The owner immediately admitted that the vehicle slid on ice and hit a curb, damaging the right rear tire and wheel. Both the tire and wheel were replaced and the alignment checked. The owner then dropped the price of the vehicle $500!

Summary:

Complaint—buyer of a used car noticed that one tire was newer than the others.
Cause—The owner admitted that the vehicle had slid off the road and hit a curb causing damage to the wheel and tire.
Correction—Because the perspective buyer knew the date code, and mentioned this to the seller, the purchase price was reduced saving the buyer money.

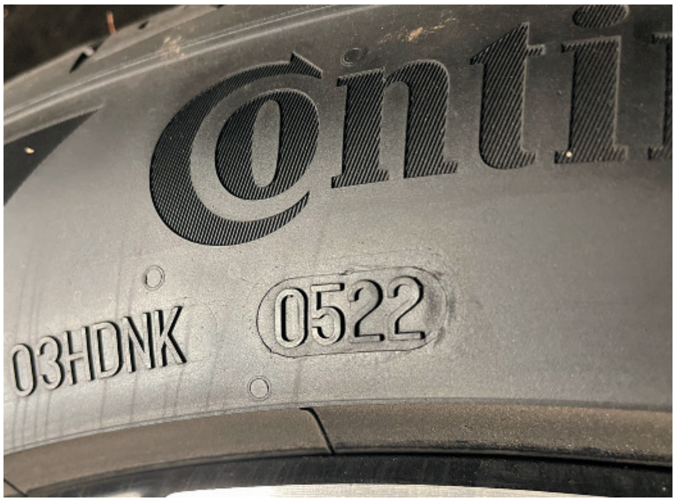


FIGURE 108–15 Typical DOT date code. This tire was built in the 5th week of 2022. While there is no official standard for replacement intervals for tires, many experts recommend that tires be replaced, regardless of thread depth, when they are older than ten years.

and the 26 means that it was built during the 26th week of 1994. Starting with tires manufactured after January 1, 2000, the tire build date includes four digits rather than three digits. A new code such as "3406" means the 34th week of 2006. ● **SEE FIGURE 108–15**.

TIRE CONICITY AND PLY STEER

Tire **conicity** can occur during the construction of any radial or belted tire when the parts of the tire are badly positioned, causing the tire to be smaller in diameter on one side. When this tire is installed on a vehicle, it can cause the vehicle to pull to one side of the road due to the cone shape of the tire. ● **SEE FIGURE 108–16**.

Since the cause of conicity is due to the construction of the tire itself, there is nothing the service technician can do to correct the condition. The exact cause of the conicity is generally due to the slight movement of the belt and tread in the mold during inflation. If a vehicle pulls to one side of the road, the service technician should switch tires left to right (left-side tires to the right side and right-side tires to the left side of the vehicle). If this swap of tires corrects the pulling condition, then tire conicity was the possible cause.

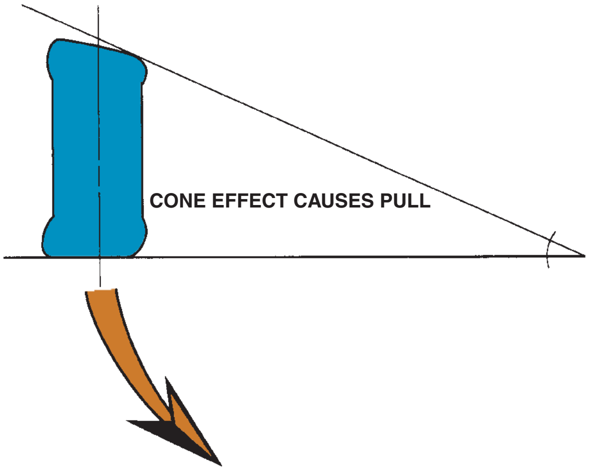


FIGURE 108–16 Conicity is a fault in the tire that can cause the vehicle to pull to one side due to the cone effect (shape) of the tire.

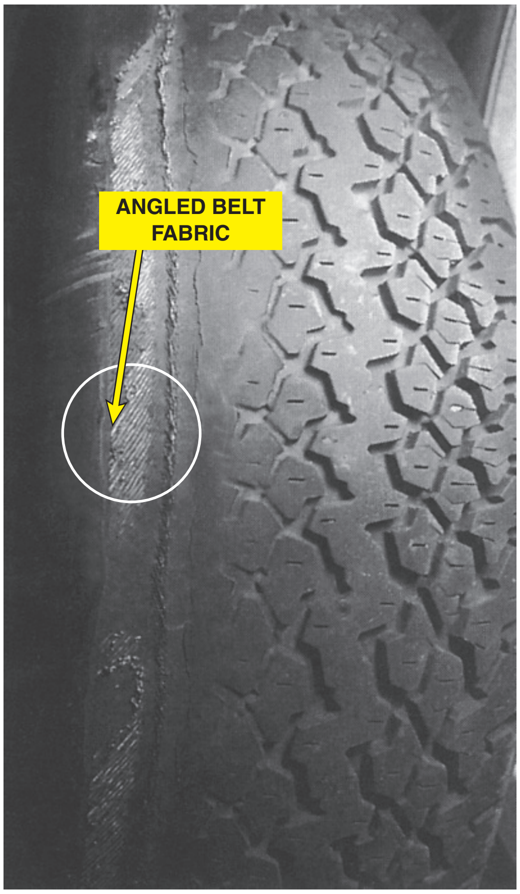


FIGURE 108–17 Notice the angle of the belt material in this worn tire. The angle of the belt fabric can cause a "ply steer" or slight pulling force toward one side of the vehicle.

NOTE: *Radial pull* or *radial tire pull* are other terms often used to describe tire conicity.

Ply steer is another term that describes a slight pulling force on a vehicle due to tire construction. Ply steer is due to the angle of the cords in the belt layers, as seen in ● **FIGURE 108–17**, and not in the ply layer of the carcass (body), as the name implies. Ply steer will cause a slight drift regardless of its direction of rotation. Switching tires left to right will *not* correct a ply steer condition.

NOTE: Whenever a wheel and tire assembly is switched from one side of a vehicle to the other, the tire revolves in the opposite direction.

Ply steer is built into the tire during construction. There is nothing a service technician can do to correct ply steer, except to compensate for it with alignment angles or replace the tire.

SPARE TIRES

Most vehicles today come equipped with space-saver spare tires that are smaller than the wheels and tires that are on the vehicle. The reason for the small size is to reduce the size and weight of the entire vehicle and to increase fuel economy by having the entire vehicle weigh less by not carrying a heavy spare tire and wheel around. The style and type of these spare tires have changed a great deal over the last several years, and different makes and types of vehicles use various types of spare tires.

CAUTION: Before using a spare tire, always read the warning label (if so equipped) and understand all use restrictions. For example, some spare tires are not designed to exceed 50 MPH (80 km/h) or be driven more than 500 miles (800 km).

Many small, space-saving spare tires use a higher-than-normal air inflation pressure, usually 60 PSI (414 kPa). Even though the tire often differs in construction, size, diameter, and width from the vehicle's original tires, it is amazing that the vehicle usually handles the same during normal driving. Obviously, these tires are not constructed with the same durability as a full-size tire and should be removed from service as soon as possible.

NOTE: When was the last time you checked the tire pressure in your spare tire? The spare tire pressure should be checked regularly.

RUN-FLAT TIRES

Run-flat tires (abbreviated RFT) are designed to operate without any air for a limited distance (usually 50 miles at 55 MPH). This feature allows vehicle manufacturers to build vehicles without the extra room and weight of a spare tire and jack assembly.

A typical run-flat tire (also called *extended mobility tire* [EMT] or *zero pressure* [ZP] *tire*) requires the use of an air pressure sensor/transmitter and a dash-mounted receiver to warn the driver that a tire has lost pressure. Because of the reinforced sidewalls, the vehicle handles almost the same with or without air pressure. ● **SEE FIGURES 108–18 AND 108–19**.

CAUTION: Tire engineers warn that rapid cornering should be avoided if a run-flat tire has zero air pressure. The handling during quick maneuvers is often unpredictable and could be dangerous.

WHEELS

The concept of a wheel has not changed in the last 5,000 years, but the style and materials used have changed greatly. Early automotive wheels were constructed from wood with a steel band as the tire.

Today's wheels are constructed of steel or aluminum alloy. The center section of the wheel that attaches to the hub is called the **center section** or **spider** because early wheels used wooden spokes that resembled a spider's web. The rubber tire attaches to the rim of the wheel. The rim has two *bead flanges* where the bead of the tire is held against the wheel when the tire is inflated. The shape of this flange is very important and is designated by Tire and Rim Association letters. For example, a wheel designated 14 × 6JJ means that the diameter of the wheel is 14 inch and the wheel is 6 inch wide measured from inside to inside of the flanges. The letters JJ indicate the *exact* shape of the flange area. ● **SEE FIGURE 108–20**. This flange area shape and the angle that the rim drops down from the flange are important because of the following reasons:

- They permit a good seal between the rim and the tire.
- They help retain the tire on the rim in the event of loss of air. This is the reason why modern wheels are called "safety rim wheels." ● **SEE FIGURE 108–21**.
- Run-flat tires (tires that are designed to operate without air for a limited distance without damage) often require a specific wheel rim shape.

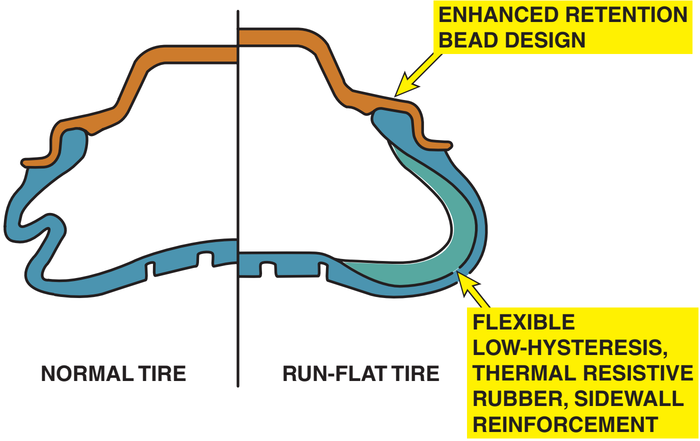

ENHANCED RETENTION BEAD DESIGN
NORMAL TIRE
RUN-FLAT TIRE
FLEXIBLE LOW-HYSTERESIS, THERMAL RESISTIVE RUBBER, SIDEWALL REINFORCEMENT

FIGURE 108–19 A conventional tire on the left and a run-flat tire on the right, showing what happens when there is no air in the tire.

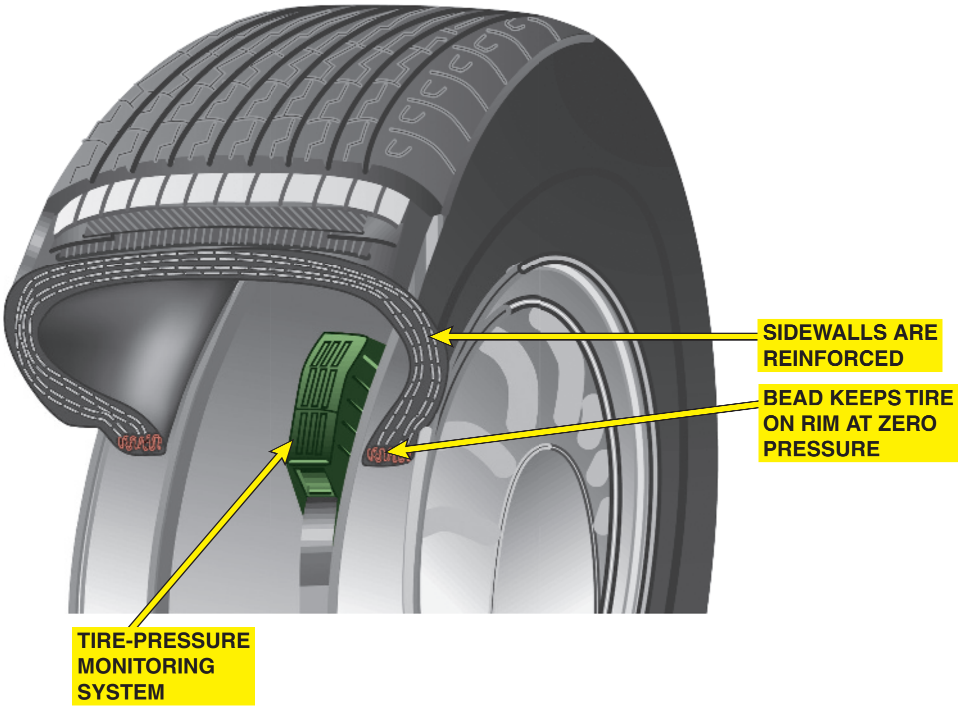

SIDEWALLS ARE REINFORCED
BEAD KEEPS TIRE ON RIM AT ZERO PRESSURE
TIRE-PRESSURE MONITORING SYSTEM

FIGURE 108–18 Cutaway of a run-flat tire showing the reinforced sidewalls and the required pressure sensor.

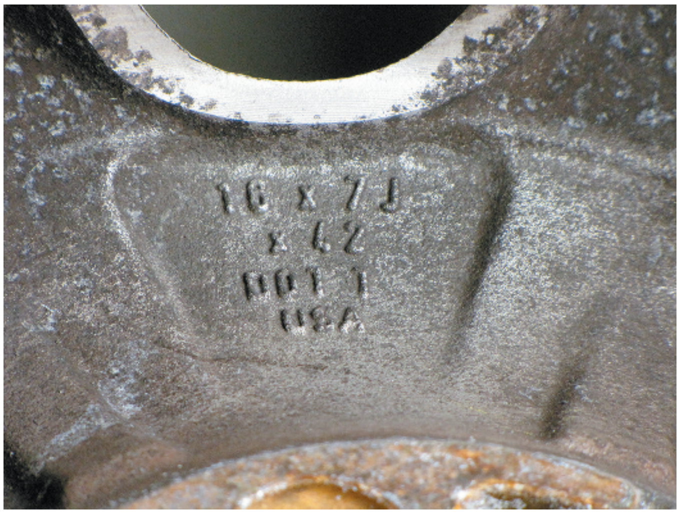

16 x 7J
x 42
USA

FIGURE 108–20 The size of the wheel is usually cast or stamped into the wheel. This wheel is 7 inch wide. The letter “J” refers to the contour of the bead seat area of the wheel.

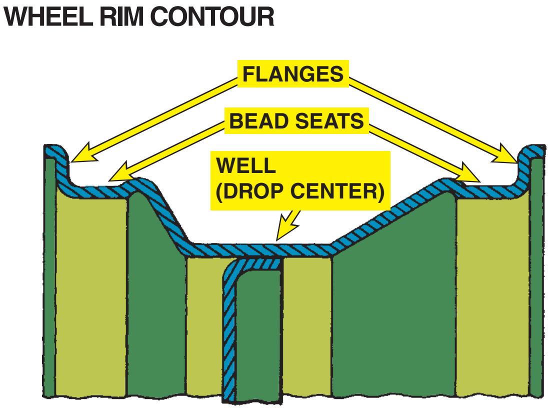

WHEEL RIM CONTOUR
FLANGES
BEAD SEATS
WELL
(DROP CENTER)

FIGURE 108–21 The wheel rim well provides a space for the tire to fit during mounting; the bead seat provides a tire-to-wheel sealing surface; the flange holds the beads in place.

WHEEL OFFSET

Offset is a very important variable in wheel design. If the center section (spider) is centered on the outer rim, the offset is zero. Wheel offset is often referred to as ET, which stands for *Einpress Tieffe* in German. ● **SEE FIGURE 108–22**.

POSITIVE OFFSET The wheel has a positive offset if the center section is outward from the wheel centerline. Front-wheel-drive vehicles commonly use positive-offset wheels to improve the loading on the front wheels and to help provide for a favorable scrub radius.

NEGATIVE OFFSET The wheel has a negative offset if the center section is inboard (or “dished”) from the wheel centerline. ● **SEE FIGURE 108–23**. Avoid using replacement wheels that differ from the original offset.

BACK SPACING

Back spacing, also called *rear spacing* or *backside setting,* is the distance between the back rim edge and the wheel center section mounting pad. *This is not the same as offset.* Back spacing can be measured directly with a ruler, as shown in ● **FIGURE 108–24**.

DETERMINING BOLT CIRCLE

On four-lug axles and wheels, the **bolt circle** measurement is simply taken from center to center on opposite studs or holes, as shown in ● **FIGURE 108–25**.

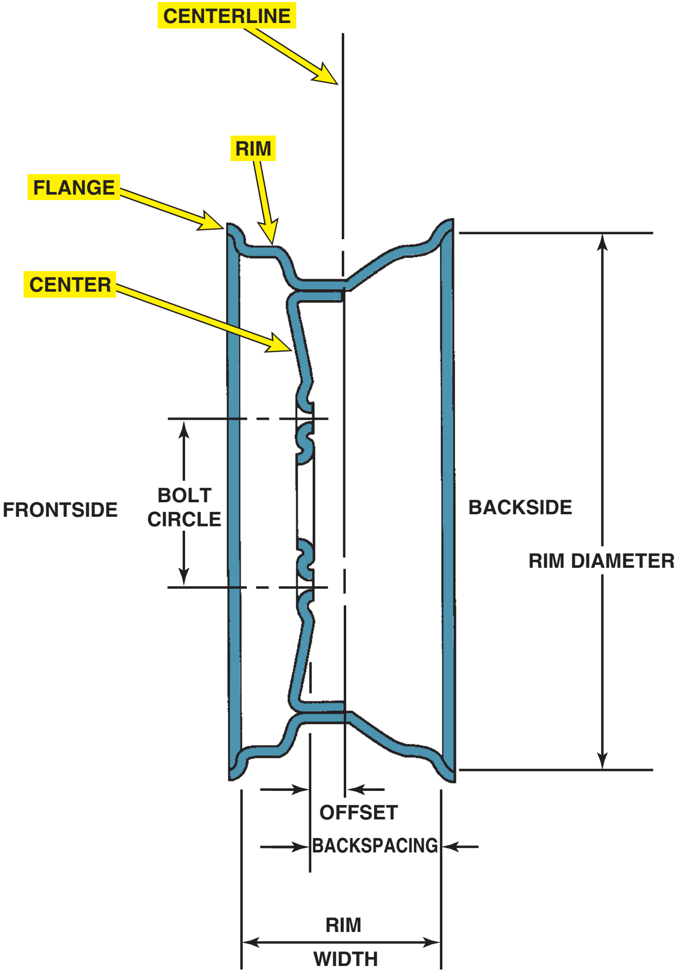

CENTERLINE
RIM
FLANGE
CENTER
FRONTSIDE
BOLT
CIRCLE
BACKSIDE
RIM DIAMETER
OFFSET
BACKSPACING
RIM
WIDTH

FIGURE 108–22 A cross section of a wheel showing part designations.

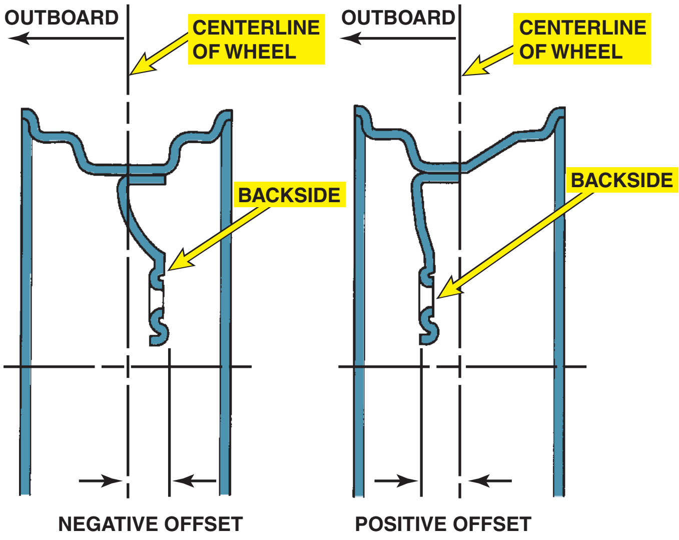

OUTBOARD
CENTERLINE
OF WHEEL
BACKSIDE
NEGATIVE OFFSET
OUTBOARD
CENTERLINE
OF WHEEL
BACKSIDE
POSITIVE OFFSET

FIGURE 108–23 Offset is the distance between the centerline of the wheel and the wheel mounting surface.

On five-lug axles and wheels, it is a little harder to determine bolt circle. One method is to measure from the far edge of one bolt hole to the center of the hole two over from the first, as shown in ● **FIGURE 108–26**. Another method for a five-lug wheel is to measure from center to center between two adjacent studs and convert this measurement into bolt circle diameter, as in the following chart. ● **SEE FIGURE 108–27**.

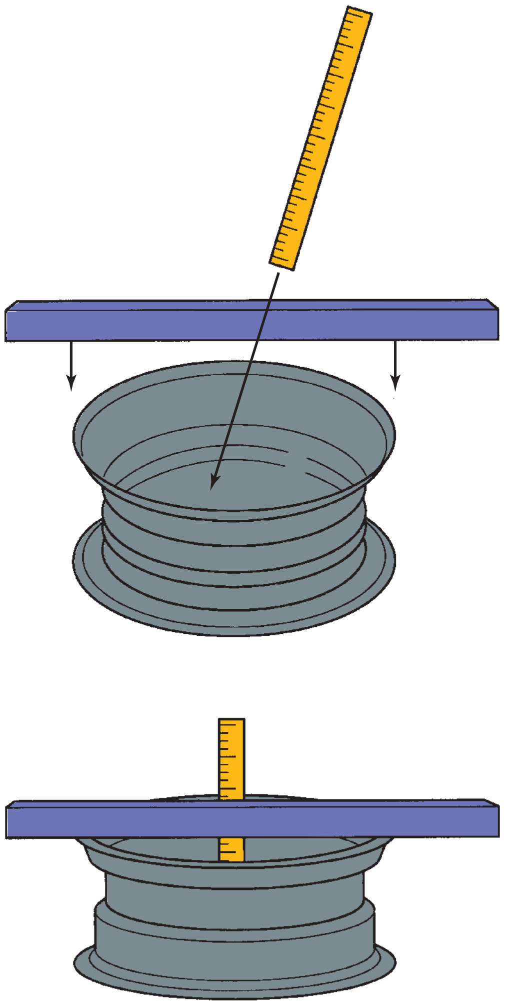


FIGURE 108–24 Back spacing (rear spacing) is the distance from the mounting pad to the edge of the rim. Most custom wheels use this measurement method to indicate the location of the mounting pad in relation to the rim.

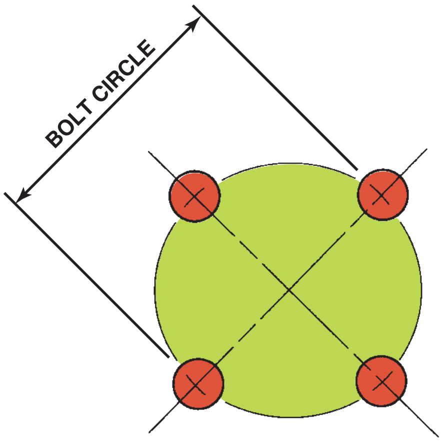


FIGURE 108–25 Bolt circle is the diameter of a circle that can be drawn through the center of each lug hole or stud. The bolt circle is sometimes referred to as PCD for pitch circle diameter.

Center-to-Center Distance	Bolt Circle Diameter
2.645 inch	41/2 inch bolt circle
2.792 inch	43/4 inch bolt circle
2.939 inch	5 inch bolt circle
3.233 inch	51/2 inch bolt circle

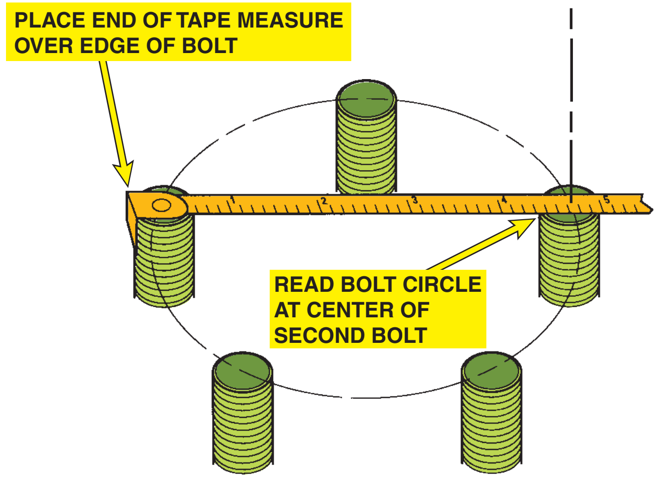

PLACE END OF TAPE MEASURE OVER EDGE OF BOLT
READ BOLT CIRCLE AT CENTER OF SECOND BOLT

FIGURE 108–26 Measuring the bolt circle on a five-lug wheel is difficult, but a quick and easy way includes measuring as shown to determine the approximate bolt circle of a five-lug wheel.

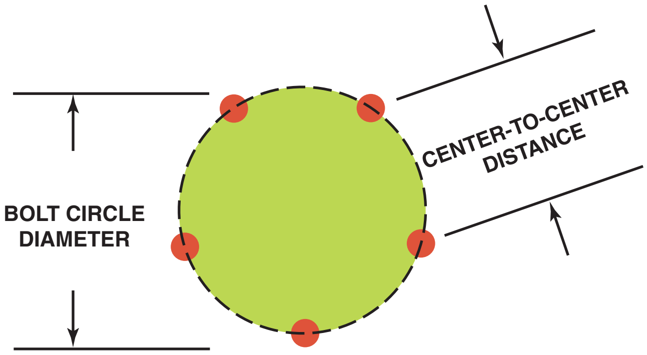


FIGURE 108–27 Measure center-to-center distance and compare the distance to the figures in the chart in the text to determine the diameter for a five-lug bolt circle.

STEEL WHEELS Steel is the traditional wheel material. A steel wheel is very strong due to its designed shape and the fact that it is *work hardened* during manufacturing. In fact, most of the strength of a steel wheel is due to its work hardening. Painting and baking cycles also increase the strength of a steel wheel. Steel wheels are formed from welded hoops that are flared and joined to stamped spiders.

ALUMINUM WHEELS Forged and cast aluminum wheels are commonly used on cars and trucks. *Forged* means that the aluminum is hammered or forged under pressure into shape. A forged aluminum wheel is much stronger than a *cast* aluminum wheel.

A cast aluminum wheel is constructed by pouring liquid (molten) aluminum into a mold. After the aluminum has cooled, the

FREQUENTLY ASKED QUESTION

What Does This Mark in a Wheel Mean?

The symbol **JWL**, for Japan Wheel Light Metal, means that the wheel meets the technical standards for passenger-car light-alloy disc wheels. See the mark in ● **FIGURE 108–28**.

The manufacturer is responsible for conducting the inspections set forth in the technical standard, and the JWL mark is displayed on those products that pass the inspection.

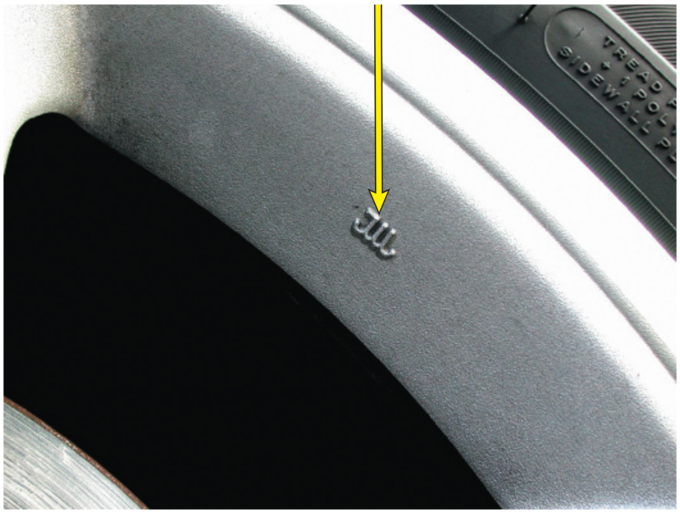


FIGURE 108–28 A typical JWL symbol for the Japan Wheel Light Metal standard mark.

cast aluminum wheel is removed from the mold and machined. Aluminum wheels are usually thicker than steel wheels and require special wheel weights when balancing. Coated or covered wheel weights should be used when balancing aluminum wheels to prevent galvanic corrosion damage to the wheel. Most aluminum wheels use an alloy of aluminum. Aluminum can be combined (alloyed) with copper, manganese, silicon, or other elements to achieve the physical strength and characteristics for the exact product. Aluminum alloy wheels are often called alloy wheels.

Some racing wheels are made from a lighter-weight metal called magnesium. These wheels are called *mag* wheels (an abbreviation for *magnesium*). True magnesium wheels are not practical for production because their cost and corrosion are excessive compared with steel or aluminum alloy wheels. The term *mag wheel*, however, is still heard when referring to alloy (aluminum) wheels.

NOTE: If purchasing replacement aftermarket wheels, check that they are certified by the SFI. SFI is the Specialty Equipment Manufacturers Association (SEMA) Foundation, Incorporated. SEMA and SFI are nongovernment agencies that were formed by the manufacturers themselves to establish standards for safety.

CHROME CLAD WHEELS Chrome clad wheels have become an increasingly popular option on many vehicles. This type of wheel has the following construction features:

- A chrome-plated plastic cladding applied to the front of the wheel.
- The cladding is permanently attached to the aluminum wheel with adhesive foam.
- The foam material is not present near the conical seat area (center) of the wheel.

NOTE: Without the support of the backing foam around the mounting stud holes, it is possible to damage the cladding when mounting the wheel on a balancer. Always follow the vehicle manufacturer's instructions when working with chrome clad wheels.

TIRE VALVES

All tires use a tire valve, called a **Schrader valve**, to hold air in the tire. The Schrader valve was invented in New York in 1844 by August Schrader for the Goodyear Brothers: Charles, Henry, and Nelson. Today, Schrader valves are used not only as valves in tires but on fuel-injection systems, air-conditioning systems, and air shock (ride control) systems. Most tire experts agree that the valve stem (which includes the Schrader valve) should be replaced whenever tires are replaced—tires can last four or more years, and in that time the valve stem can become brittle and crack. A defective or leaking valve stem is a major cause of air loss. Low tire pressure can cause the tire to become overheated. Replacement valve stems are therefore a wise investment whenever purchasing new tires. Aluminum (alloy) wheels often require special metal valve stems that use a rubber washer and are actually bolted to the wheel. ● **SEE FIGURE 108–29.**

NOTE: If the vehicle is equipped with a tire-pressure monitoring system, a nickel tire valve is used. See Chapter 109 for details.

LUG NUTS

Lug nuts are used to hold a wheel to the brake disc, brake drum, or wheel bearing assembly. Most manufacturers use a stud in the brake or bearing assembly with a lug nut to hold the wheel. Some models of VW, Audi, and Mazda use a lug *bolt* that is threaded into a hole in the brake drum or bearing assembly.

NOTE: Some aftermarket manufacturers offer a stud conversion kit to replace the lug bolt with a conventional stud and lug nut.

Typical lug nuts are tapered so that the wheel stud will center the wheel onto the vehicle. Another advantage of the taper of the lug nut and wheel is to provide a suitable surface to prevent the nuts from loosening. The taper, usually 60 degrees, forms a wedge that helps ensure that the lug nut will not loosen. Steel wheels are deformed slightly when the lug nut is torqued down against the wheel mounting flange; be certain that the taper is *toward* the vehicle.

Many alloy wheels use a *shank-nut*-type lug nut that has straight sides without a taper. This style of nut must be used with wheels designed for this nut type. If replacement wheels are used on any vehicle, check with the wheel manufacturer as to the

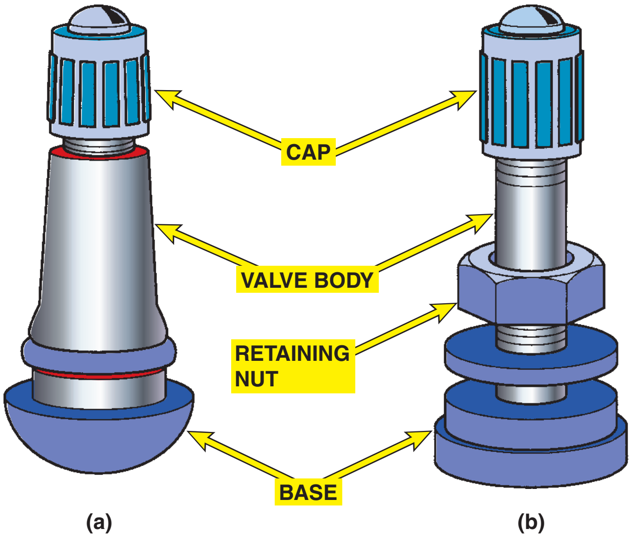


FIGURE 108–29 (a) A rubber snap-in style tire valve assembly. (b) A metal clamp-type tire valve assembly used on most high-pressure (over 60 PSI) tire applications such as is found on many trucks, RVs, and trailers. The internal Schrader valve threads into the valve itself and can be replaced individually, but most experts recommend replacing the entire valve assembly every time the tires are replaced to help prevent air loss.

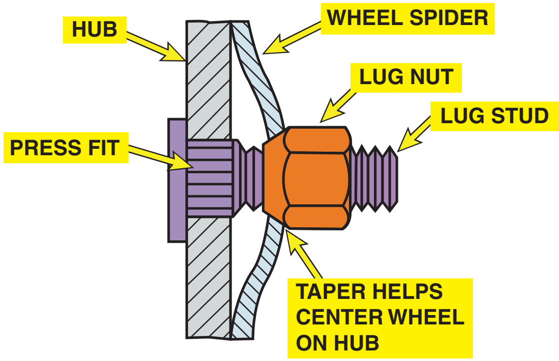

HUB
WHEEL SPIDER
LUG NUT
LUG STUD
PRESS FIT
TAPER HELPS CENTER WHEEL ON HUB

FIGURE 108–30 The tapered end of the lug nut is installed toward the wheel so that it wedges into the taper of the wheel hub.

proper type and style of lug nut. ● **FIGURE 108–30** shows several of the many styles of lug nuts that are available.

SIZE Lug nuts are sized to the thread size of the stud onto which they screw. The diameter and the number of threads per inch are commonly stated. Since some vehicles use left-hand threads, RH and LH are commonly stated, indicating "right-hand" and "left-hand" threads. A typical size is 7/16-20RH, where the 7/16 indicates the diameter of the wheel stud and 20 indicates that there are 20 threads per inch. Another common fractional size is 1/2 × 20. Metric sizes such as M12 × 1.5 use a different sizing method.

M	metric
12	12 mm diameter of stud
1.5	1.5 mm distance from one thread peak to another

Other commonly used metric lug sizes include M12 × 1.25 and M14 × 1.5 Obviously, metric wheel studs require metric lug nuts.

LUG STUDS Lug studs are usually installed in hubs or drums using a press fit. Serrations on the shoulder of the stud provide support. Most studs are replaceable and should be replaced if the threads are damaged. ● **SEE FIGURES 108–31 AND 108–32**.

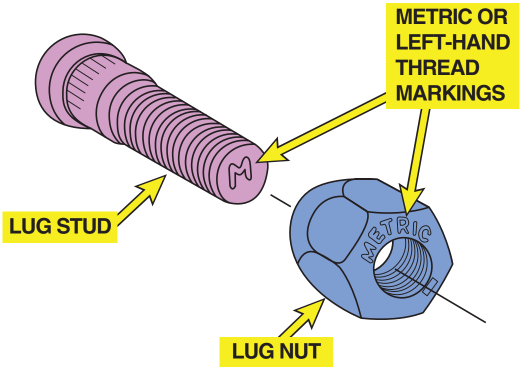

METRIC OR LEFT-HAND THREAD MARKINGS
M
METRIC
LUG STUD
LUG NUT

FIGURE 108–31 Look carefully on the end of the wheel studs or on the lug nut for metric or left-hand thread marks.

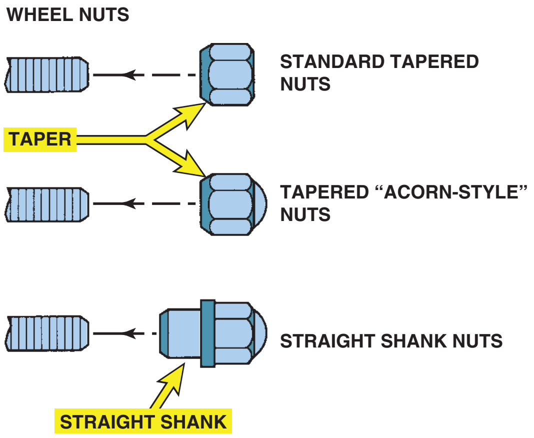

WHEEL NUTS
STANDARD TAPERED NUTS
TAPER
TAPERED "ACORN-STYLE" NUTS
STRAIGHT SHANK NUTS
STRAIGHT SHANK

FIGURE 108–32 Various styles of lug nuts.

FREQUENTLY ASKED QUESTION

What Is a "Knock-Off" Wheel?

A knock-off design wheel is retained to the axle hub using one large retaining nut that has three arms that are used to loosen and tighten them. They are mostly found on older European sports cars and race cars. The wheel is removed by using a lead hammer which has the weight to loosen the nut yet soft enough to not damage the aluminum spokes of the nut. ● **SEE FIGURE 108–33**.

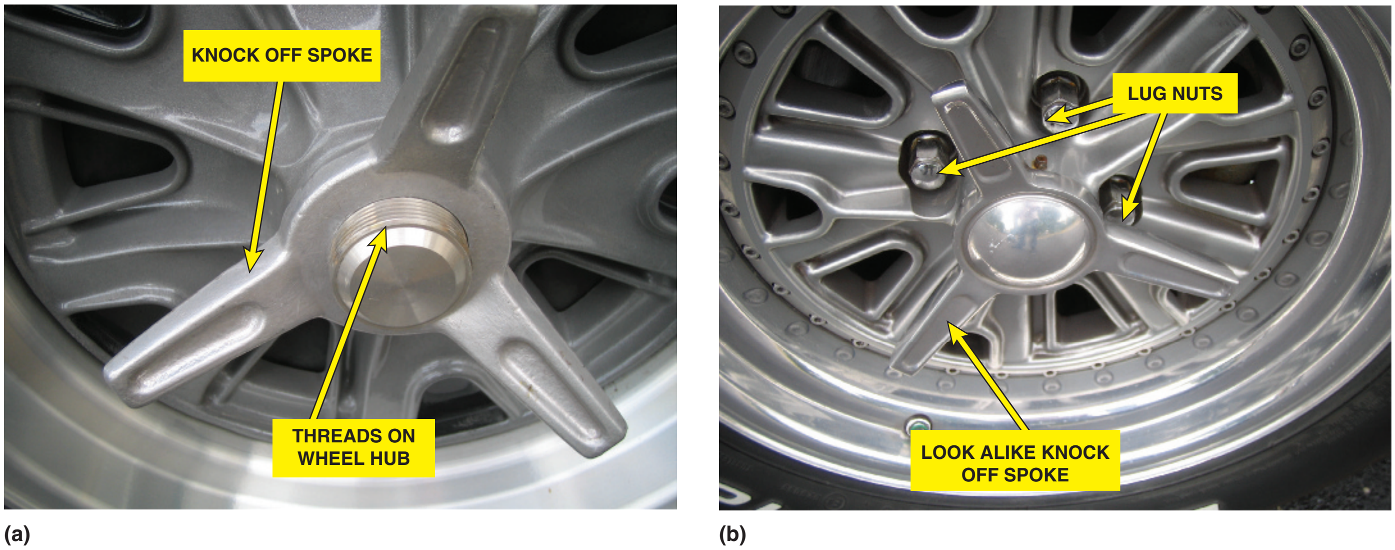
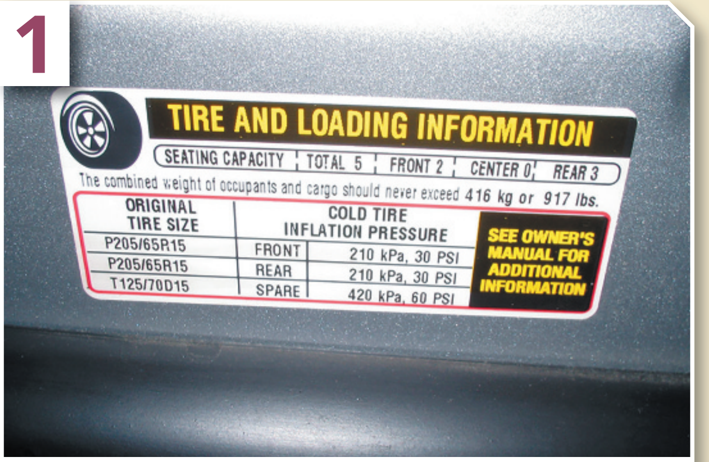

KNOCK OFF SPOKE
THREADS ON WHEEL HUB
(a)
LUG NUTS
LOOK ALIKE KNOCK OFF SPOKE
(b)

FIGURE 108–33 (a) A typical knock-off-type wheel showing the large three prong wing nuts and the threads on the wheel hub. (b) A look-alike knock-off wheel that looks like a knock-off but uses lug nuts.

TIRE INSPECTION

STEP BY STEP

1



TIRE AND LOADING INFORMATION

SEATING CAPACITY | TOTAL 5 | FRONT 2 | CENTER 0 | REAR 3

The combined weight of occupants and cargo should never exceed 416 kg or 917 lbs.

ORIGINAL TIRE SIZE	COLD TIRE INFLATION PRESSURE		SEE OWNER'S MANUAL FOR ADDITIONAL INFORMATION
P205/65R15	FRONT	210 kPa, 30 PSI	
P205/65R15	REAR	210 kPa, 30 PSI	
T125/70D15	SPARE	420 kPa, 60 PSI	

Check the tire information placard, usually located on the driver's door or door jamb, for the specified tire size and inflation pressure.

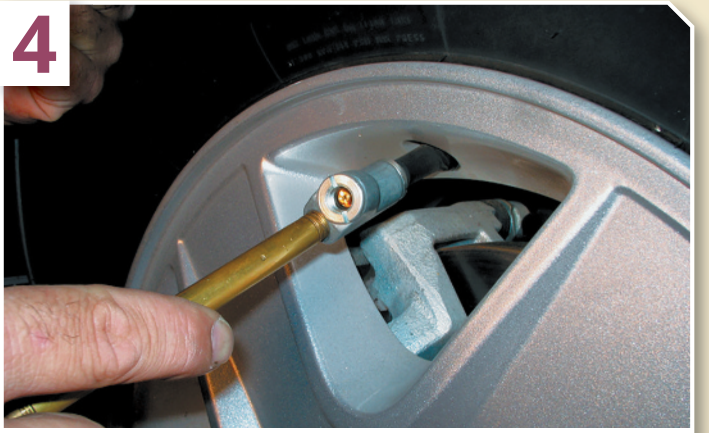
2

Visually check the tires for abnormal wear or damage.

3

Remove the tire valve cap and visually check the condition of the valve stem.

4

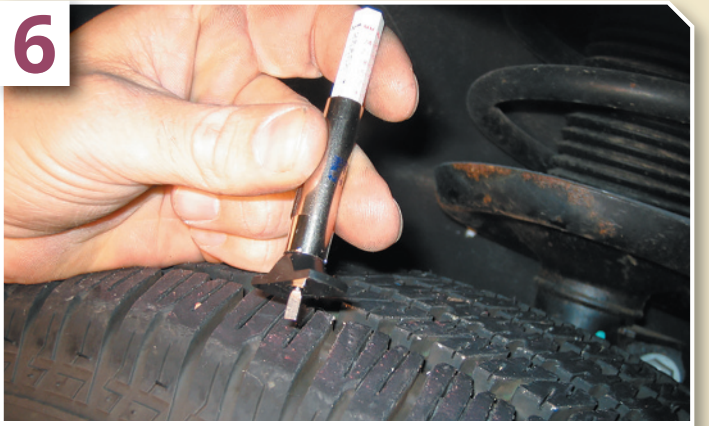


Check inflation pressure by pushing the tire-pressure gauge straight onto the end of the tire valve. If a "hissing" sound is heard, then the reading will not be accurate.

5

Read the pressure and compare to specifications. Use an analog or digital gauge if possible which have been proven to be more accurate than a mechanical pencil-type gauge.

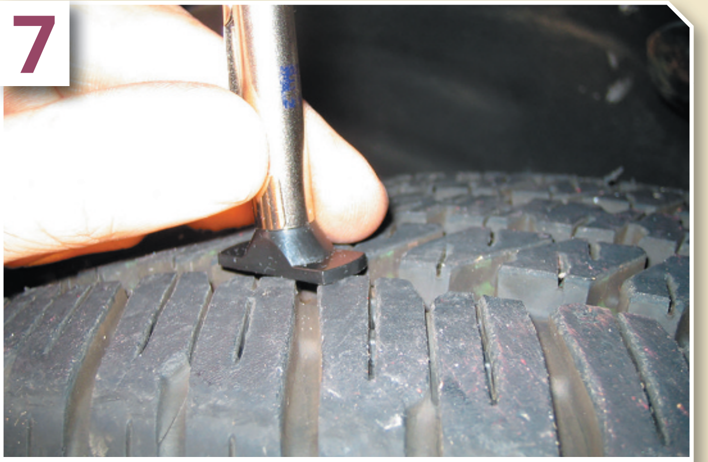
6



A typical tire tread depth gauge.

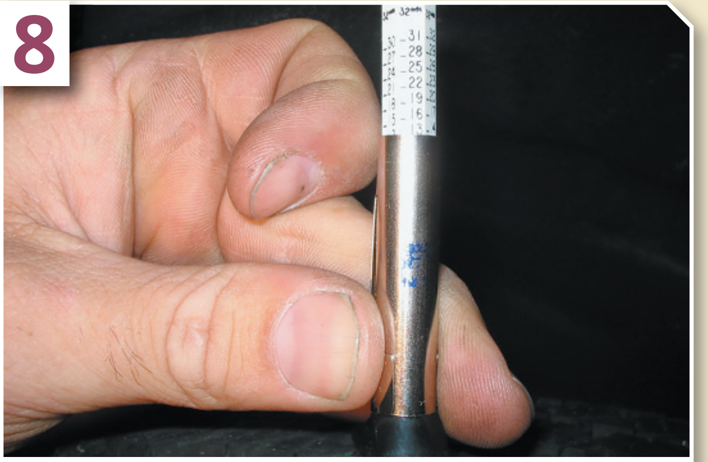
TIRE INSPECTION

7



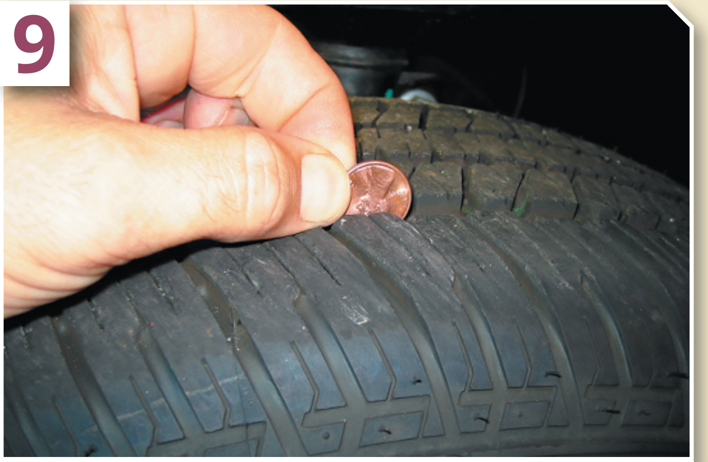
The blade of the tire tread depth gauge is pushed down into the groove of the tire at the lowest part.

8



Remove the gauge from the tire and read the tread depth at the metal housing. Tread depth is usually measured in 1/32's of an inch.

9



If the top of Lincoln's head is visible, then the tread depth is lower than 2/32 inch, which is the legal limit in many states. Most tire experts recommend replacing tires when they reach 4/32 inch instead of 2/32. To check for this depth, use a quarter instead of a penny and look for the top of Washington's head.

REVIEW QUESTIONS

1. How is a tire constructed?
2. What is the aspect ratio?
3. What materials are used for the tire belts?
4. What are the three major areas of the Uniform Tire Quality Grading System?
5. What is the difference between wheel back spacing and offset?

CHAPTER QUIZ

1. A defective tire can cause which of the following?
   - **a.** Pulling to one side
   - **b.** Erratic steering
   - **c.** Darting or jumping
   - **d.** Any of the above
2. The part of the tire that is under just the tread of a radial tire is called the ______________.
   - **a.** bead
   - **b.** body (carcass) ply
   - **c.** belt
   - **d.** inner liner
3. A tire is labeled 215/60R × 15 92T; the T indicates __________.
   - **a.** its speed rating
   - **b.** its tread wear rating
   - **c.** its load rating
   - **d.** its temperature resistance rating
4. The Uniform Tire Quality Grading System (UTQGS) includes ______________.
   - **a.** tread wear
   - **b.** braking traction performance
   - **c.** temperature resistance
   - **d.** All of the above
5. Which size lug nut would fit a metric wheel stud?
   - **a.** 7/16-20 LH
   - **b.** 1/2 × 20
   - **c.** M12 × 1.5
   - **d.** 7/16-20RH
6. Radial tires can cause a vehicle to pull to one side while driving. This is called "radial tire pull" and is often due to ______________.
   - **a.** the angle of the body (carcass) plies
   - **b.** tire conicity
   - **c.** tread design
   - **d.** bead design
7. What precautions should the driver of a vehicle equipped with run-flat tires adhere to?
   - **a.** Should not be inflated to more than 10 PSI
   - **b.** Should not be driven over 50 at 55 MPH with zero PSI of inflation pressure
   - **c.** Rapid cornering should be avoided if the tire has zero air pressure
   - **d.** Both b and c
8. All tires use a tire valve, called a(n) ______________ valve, to hold air in the tire.
   - **a.** zerk
   - **b.** Schrader
   - **c.** snap-in
   - **d.** inflation
9. What do the letters JJ mean in a wheel designation size labeled 14 × 7JJ?
   - **a.** The offset of the rim
   - **b.** The bolt circle code
   - **c.** The back spacing of the rim
   - **d.** The shape of the flange area
10. The DOT tire code on the sidewall of the tire indicates ______________.
    - **a.** the week and year of manufacture
    - **b.** the type of tire valve needed
    - **c.** the diameter of the wheel (rim)
    - **d.** the width of the wheel (rim)

Chapter

109

TIRE-PRESSURE MONITORING SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain why a tire-pressure monitoring system (TPMS) is used.
- Discuss the TREAD Act.
- Explain indirect TPMS.
- Explain direct TPMS.
- List the two types of TPMS pressure sensors.
- Discuss TPMS sensor operation.
- Discuss the TPMS receiver.
- Explain direct TPMS diagnosis.
- Explain TPMS sensor activations.
- Describe TPMS diagnostic tools.
- List replacement options for TPMS sensors.
- Describe how to relearn TPMS sensors.
- Describe the tools needed to service a TPMS.

KEY TERMS:

Active mode 1314 • Alert mode 1315 • Delta pressure method 1317 • Placard cold inflation pressure 1310 • Sleep mode 1314 • Storage mode 1315 • Transmitter ID 1318 • TREAD Act 1311 • Tire-pressure monitoring system (TPMS) 1310

NEED FOR TIRE PRESSURE MONITORING

BACKGROUND A **tire-pressure monitoring system (TPMS)** is a system that detects a tire that has low inflation pressure and warns the driver. A tire-pressure monitoring system was first used when run-flat tires were introduced in the 1990s. A driver was often not aware that a tire had gone flat after a puncture. Because a run-flat tire is designed to be driven a limited distance and at limited speed after it loses air pressure, a method of alerting the driver had to be found. There were two systems used:

1. **Indirect**—Commonly used until the 2008 model year and then from 2010 on, there are some vehicles that use the indirect system.
2. **Direct**—A direct-reading pressure system that uses a pressure sensor in each tire is the most commonly used system at this time.

LOW TIRE-PRESSURE EFFECTS Low tire-inflation pressures lead to the following issues:

- Reduces fuel economy due to increased rolling resistance of the tires—3 PSI below specifications results in an increase of 1% in fuel consumption.
- Reduces tire life—3 PSI below specifications results in a decrease of 10% of tire life.
- Increases the number of tire-related faults, which have been estimated to be 90% of all vehicle faults.
- Reduces handling and braking efficiency.
- Hundreds of deaths and thousands of personal injuries are due to problems associated with low tire inflation pressure.

PLACARD COLD INFLATION PRESSURE The term **placard cold inflation pressure** is used in service information to indicate the specified tire inflation pressure. The "placard" is the driver's side door jamb sticker that shows the tire size and the specified tire inflation pressure. It is also normal for a tire to lose one PSI per month just through normal leakage that occurs in any tire. Therefore, it is very important to check and correct inflation pressures regularly. The pressure stated is measured when the tires are cold or at room temperature, which is about 70°F (21°C). ● **SEE FIGURE 109–1**.

TEMPERATURE AND INFLATION PRESSURE The tires become warmer while the vehicle is being driven, so tires should be checked before the vehicle has been driven or allowed to cool after being driven. Tire inflation pressure changes 1 PSI for every 10 degrees. ● **SEE CHART 109–1**.

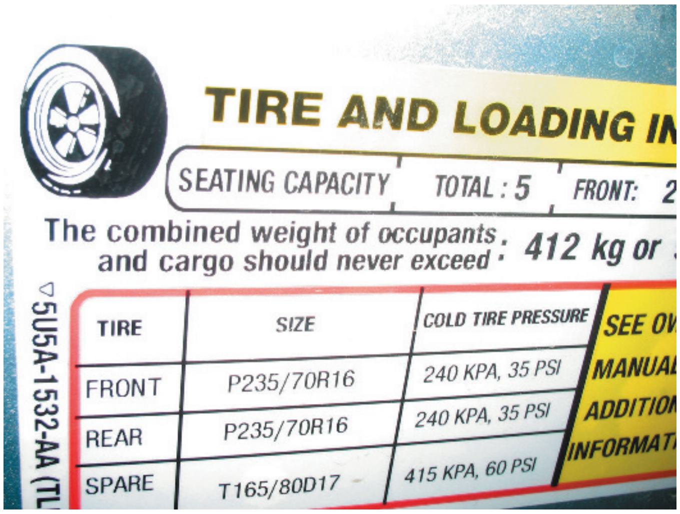


FIGURE 109–1 The tire-pressure placard (sticker) on the driver's side door or door jamb indicates the specified tire pressure.

TEMPERATURE	TIRE PRESSURE (PSI)	CHANGE FROM PLACARD COLD INFLATION PRESSURE
120°F (49°C)	37	+5
110°F (43°C)	36	+4
100°F (38°C)	35	+3
90°F (32°C)	34	+2
80°F (27°C)	33	+1
70°F (21°C)	32	0
60°F (16°C)	31	−1
50°F (10°C)	30	−2
40°F (4°C)	29	−3
30°F (−1°C)	28	−4
20°F (−7°C)	27	−5
10°F (−12°C)	26	−6
0°F (−18°C)	25	−7
−10°F (−23°C)	24	−8
−20°F (−29°C)	23	−9

CHART 109–1

The effects of outside temperature on tire inflation, assuming a placard inflation pressure of 32 PSI. The tire inflation pressure changes 1 PSI for each 10 degrees change in temperature.

TECH TIP

Add 2 to 4 PSI

When servicing tires, it is often not practical to allow the time needed for the tires to cool after the vehicle has been driven. To help compensate for the higher pressures due to higher temperature, add 2 to 4 PSI to the cold inflation pressures. ● **SEE FIGURE 109–2**.

TREAD ACT

The **Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act** requires that all vehicles be equipped with a tire-pressure monitoring system that will warn the driver in the event of an underinflated tire. This act was passed due to many accidents that were caused at least in part to underinflated tires, which resulted in many deaths.

Congress passed the TREAD Act on November 1, 2000. The National Highway Traffic Safety Administration (NHTSA) requires the installation of tire-pressure monitoring systems (TPMSs) in passenger vehicles and light trucks manufactured after September 1, 2007 (2008 model year).

The NHTSA ruling is part one of a two-part final ruling.

- Part one establishes a new Federal Motor Vehicle Safety Standard (FMVSS) 138 that requires tire-pressure monitoring systems be installed in passenger vehicles and light trucks to warn the driver when a tire is 25% below the cold placard pressure.
- Part two includes the requirement to equip vehicles with a tire-pressure monitoring system that was phased-in starting in 2004 with 100% of the vehicles by September 1, 2007 (2008 model-year vehicles).

FMVSS 138 requires all cars, trucks, and vans with a gross vehicle weight rating (GVWR) of 10,000 pounds or less to illuminate a warning lamp within 10 minutes when the inflation pressure drops 25% or more from the vehicle manufacturer's specified cold tire inflation pressure as printed on the door placard.

WARNING LAMP The FMVSS 138 specifies that the driver must be warned of a low tire inflation pressure by turning on an amber warning lamp. The warning lamp must also come on during a bulb check. The spare tire is not required to be monitored, but many vehicle manufacturers do equip full-size spare tires with a pressure sensor.

- If the TPMS warning lamp is on after start-up, the system has detected a tire with low inflation pressure.
- If the TPMS warning lamp is flashing for 60 to 90 seconds, a system fault has been detected.

TWENTY-FIVE PERCENT RULE The TREAD Act specifies that the driver be warned if any tire inflation pressure drops by 25% or more from the placard cold inflation pressure. ● **SEE CHART 109–2**.

INDIRECT TPMS

FUNCTION Indirect TPMSs do not measure the actual tire pressure. Instead, the system uses the wheel speed sensors to detect differences in the speed of the wheels. If a tire is underinflated, the following occurs:

- A tire that is underinflated will have a smaller diameter than a properly inflated tire. ● **SEE FIGURE 109–3**.
- An underinflated tire will rotate faster than a properly inflated tire.

COMPENSATION FOR CORNERING When a vehicle turns a corner, the outside wheels rotate faster than the inside wheels. To compensate for this normal change in wheel rotation speed,

FIGURE 109–2 Inflation pressure increases as the temperature increases. When checking or correcting inflation pressure when the tires are hot, add 2 to 4 PSI to the placard cold inflation pressure. Most experts recommend the use of an electronic tire pressure gauge that is accurate to 0.1 PSI so that all tires can be equally matched and inflated to the specified pressure.

PLACARD COLD INFLATION PRESSURE (PSI)	WARNING LIGHT PRESSURE (−25%)	PSI LOW
40	30.0	10.0
39	29.3	9.7
38	28.5	9.5
37	27.8	9.2
36	27.0	9.0
35	26.3	8.7
34	25.5	8.5
33	24.8	8.2
32	**24.0**	**8.0**
31	23.3	7.7
30	22.5	7.5
29	21.8	7.2
28	21.0	7.0

CHART 109–2

Placard inflation pressure compared with the pressure when the TPMS triggers a warning light assuming a cold placard inflation pressure of 32 PSI.

the indirect tire-pressure monitoring system checks the diagonally opposed wheels. ● **SEE FIGURE 109–4**.

If the calculation of the diagonal wheel speed indicates that one of the wheels is rotating faster than the other, the TPMS warning light is illuminated.

DIAGNOSIS OF INDIRECT TPMS The diagnosis of an indirect TPMS system includes the following steps:

STEP 1 Verify the fault.

- If the TPMS warning light is on but not flashing, this indicates that the system has detected a tire with low inflation pressure.

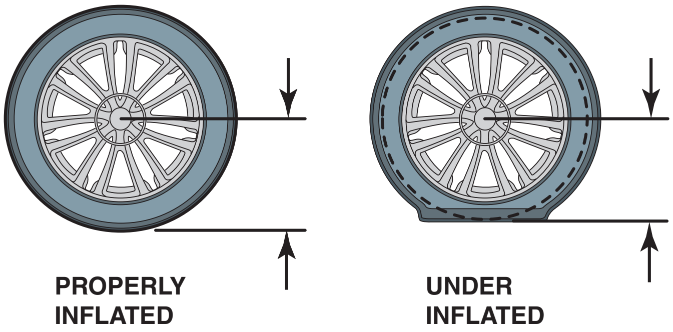


FIGURE 109–3 A tire with low inflation will have a shorter distance (radius) between the center of the wheel and the road and will therefore rotate faster than a tire that is properly inflated.

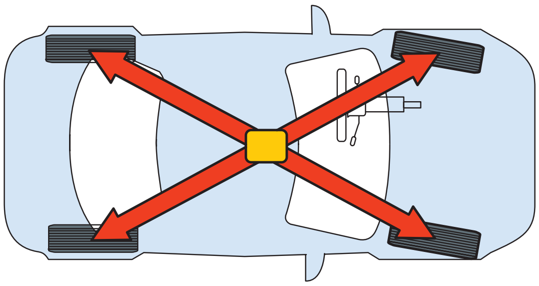


FIGURE 109–4 The speeds of the diagonally opposed wheels are added together and then compared to the other two wheels to check if one tire is rotating faster.

- If the TPMS warning light flashes, this indicates that the system has detected a fault. Check service information for the specified steps to follow.

STEP 2 If the system has detected low tire pressure, check and adjust the tire pressure to that listed on the door pillar

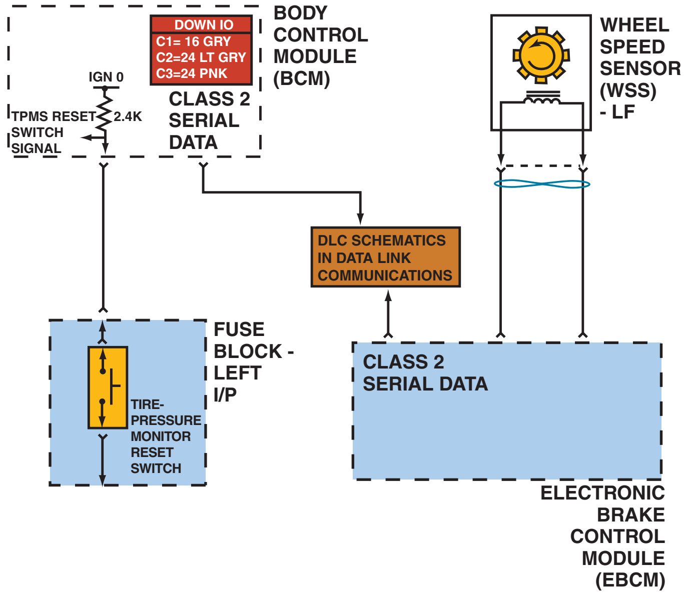

DOWN IO
C1= 16 GRY
C2=24 LT GRY
C3=24 PNK
BODY CONTROL MODULE (BCM)
IGN 0
TPMS RESET SWITCH SIGNAL
2.4K
CLASS 2 SERIAL DATA
WHEEL SPEED SENSOR (WSS) - LF
DLC SCHEMATICS IN DATA LINK COMMUNICATIONS
FUSE BLOCK - LEFT I/P
TIRE-PRESSURE MONITOR RESET SWITCH
CLASS 2 SERIAL DATA
ELECTRONIC BRAKE CONTROL MODULE (EBCM)

FIGURE 109–5 The indirect TPMS has a reset switch that should be depressed after rotating or replacing tires.

placard or factory specifications as stated in the owner's manual or service information.

STEP 3 Determine and correct the cause of the underinflated tire.

INDIRECT TPMS RELEARN PROCEDURES After checking that all four tires are the same size and condition, the system may require resetting, also called relearn or initialization. Check service information for the exact steps to follow, which could include driving the vehicle over an extended period of time. The procedure usually includes the following steps:

- Inflate all four tires to the placard inflation pressure.
- Depress and hold the reset switch for three seconds. ● **SEE FIGURE 109–5.** The TPMS warning lamp should flash three times.
- Drive the vehicle so the ABS (antilock braking system) controller can learn the new "good" values. Typical driving times include

  Ford—20 minutes of driving
  Toyota—30 to 60 minutes of driving
  General Motors—60 minutes of driving
  Check service information for the exact procedure to follow.

Many service technicians ask the vehicle owner to drive the vehicle instead of taking the technician's time.

DIRECT TPMS

FUNCTION Direct tire-pressure monitoring systems (TPMSs) use individual pressure sensors located in each wheel to measure the inflation pressure.

IDENTIFYING THE SYSTEM All vehicles sold in the United States since the 2008 model year must be equipped with a tire-pressure monitoring system. Often because some vehicles use an indirect system, it is sometimes difficult to determine what type of system is being used by visual inspection only. Therefore, service information is needed to determine what type of system should be on the vehicle before service work is started.

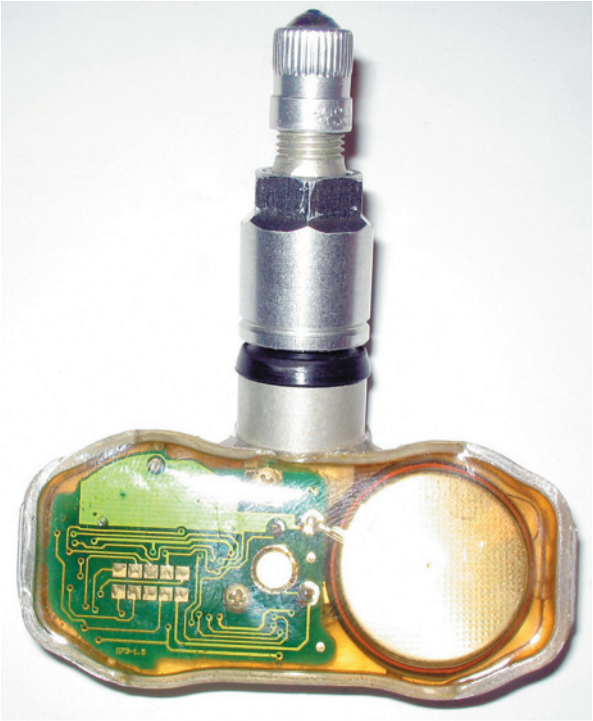


FIGURE 109–6 A clear plastic valve-stem tire-pressure monitoring sensor, showing the round battery on the right and the electronic sensor and transistor circuits on the left.

FREQUENTLY ASKED QUESTION

How Can an Indirect System Meet the TREAD Act Requirements?

Some newer vehicles such as 2009 and newer Audis, plus many models of Honda after 2013 and some Mazda models, use active wheel speed sensors to measure the slight change in vehicle speed compared to the speed in the internal memory of the TPMS module. Always check service information for the exact procedure to follow when a newer vehicle appears to not be equipped with a tire-pressure monitoring system because of no visible signs of a tire pressure sensor.

- Many early (prior to 2008) and some newer vehicles (2010+) use indirect TPMS so there is no visual indication that the vehicle is equipped with a tire-pressure monitoring system.
- If the tire/wheel assembly has a TPMS valve-type sensor, it can usually be identified by the threaded portion of the valve stem. ● **SEE FIGURE 109–6.**

TPMS PRESSURE SENSORS

MANUFACTURERS All direct TPMS sensors transmit tire inflation pressures to a module using a radio frequency (RF) signal. These sensors are manufactured by a variety of manufacturers, including those listed here:

- Beru
- Lear

- Pacific
- Schrader
- Siemens
- TRW

Each sensor uses a 3-volt lithium ion battery that has a service life of 7 to 10 years or 60,000 to 100,000 miles (97,000 to 161,000 km).

TYPES There are two basic types of pressure sensors used in direct pressure-sensing systems.

- **Valve-stem-mounted sensor**—This type of sensor uses the valve stem as the transmitter. The correct (nickel-plated) valve core *must* be used in the aluminum valve stem. If a conventional brass valve is used, moisture in the air will cause corrosion between the two different metals. There are two designs of stem-mounted sensors including
  1. **Snap-in**—This design looks like a rubber valve stem but it uses a tapered brass section and a longer cap. ● **SEE FIGURE 109–7**.

If the cap is short then it does not have a stem-mounted tire pressure sensor. However, the wheel may be equipped with a wheel-mounted (banded) sensor, so care should still be taken to avoid damaging the sensor during service.

  2. **Clamp–in**—This design uses anodized aluminum housing and is held to the wheel using a threaded cap, which must be properly tightened to the specified torque to provide the necessary clamping force. The valve stem itself is the antenna for the sensor. ● **SEE FIGURE 109–8**.

- **Banded sensors**—Banded sensors are installed in the drop well of the wheel and banded or clamped to keep them secure. Early banded sensors, such as those used in Corvettes equipped with run-flat tires, were piezoelectric and did not require a battery. All newer banded sensors include a battery. ● **SEE FIGURE 109–9**.

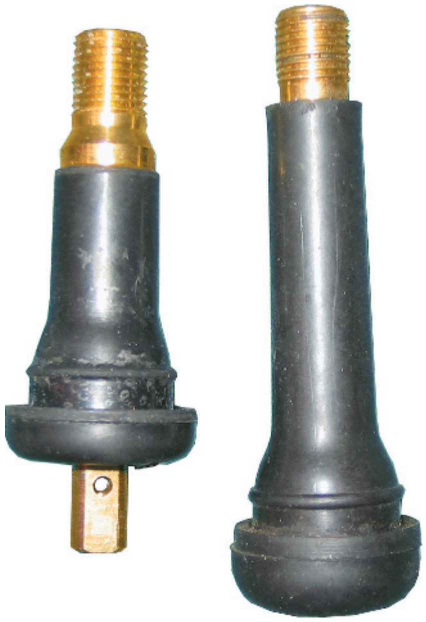


FIGURE 109–7 A conventional valve stem is on the right compared with a rubber TPMS sensor stem on the left. Notice the tapered and larger brass stem. The rubber TPMS sensor also uses a longer cap that makes it easy for a technician to spot that this is not a conventional rubber valve stem.

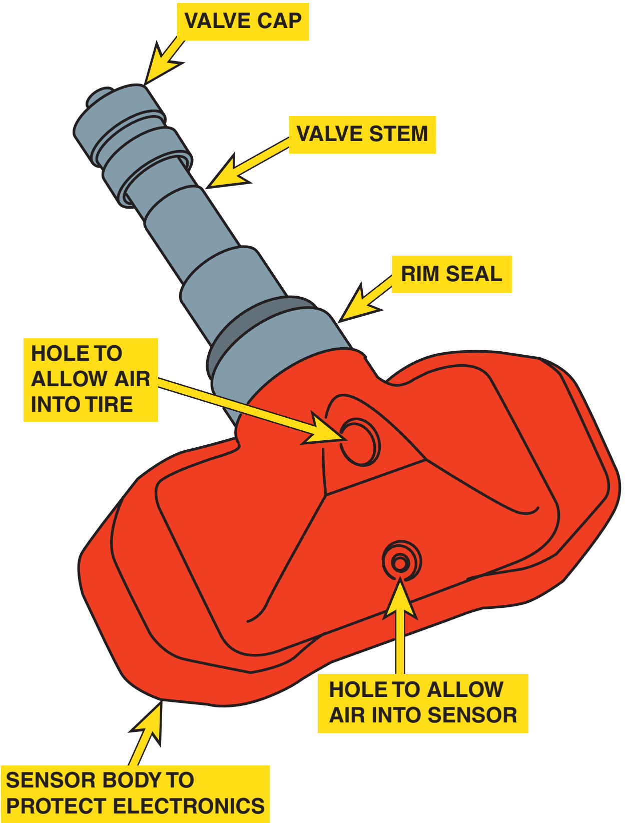

VALVE CAP
VALVE STEM
RIM SEAL
HOLE TO ALLOW AIR INTO TIRE
HOLE TO ALLOW AIR INTO SENSOR
SENSOR BODY TO PROTECT ELECTRONICS

FIGURE 109–8 The parts of a typical clamp-in TPMS sensor. Notice the small hole used to monitor the inflation pressure. The use of stop leak can easily clog this small hole.

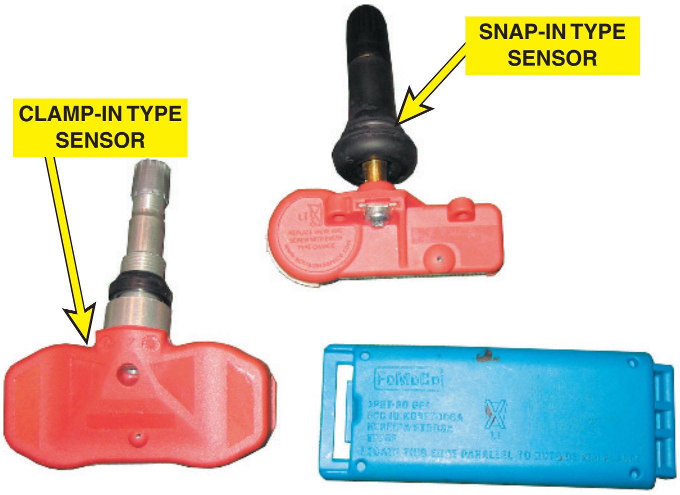


FIGURE 109–9 The three types of TPMS sensors most commonly found include the two stem-mounted rubber (snap-in) and aluminum (clamp-in), left and top, and the banded sensors (right).

MODES OF OPERATION Tire-pressure sensors have three modes of operation:

1. **Active mode**—When the sensor inside detects that the vehicle is traveling above 20 mph (32 km/h), the sensor transmits once every minute.
2. **Sleep mode**—When the vehicle is stopped, the sensor "goes to sleep" to help improve battery life. In this mode, the transmitter still will broadcast tire inflation information every hour or every six hours, depending on the sensor.

3. **Alert mode**—Alert mode is triggered if a rapid change in inflation pressure is detected. In alert (or rapid mode), the tire inflation pressure is sent about every second (every 800 milliseconds on some sensors).

TPMS SENSOR OPERATION

DESIGNS Depending on the type and manufacturer, tire-pressure monitoring sensors can be any of several different designs. The TREAD Act does not specify the type or operation of the pressure sensors, only that the system must be capable of measuring tire inflation pressure and light the TPMS warning lamp. The types of sensors are:

- **Continuous-wave-type sensor**—Designed to signal a tester when exposed to five to seven seconds of continuous 125 kHz wave signal.
- **Magnetically triggered-type sensor**—Designed to trigger a tester if exposed to a powerful magnetic force.
- **Pulse-width-modulated-type sensor**—Designed to be triggered when exposed to modulated wave 125 kHz signal.

The sensor can also vary according to the frequency at which it transmits tire-pressure information to the receiver in the vehicle. The two most commonly used frequencies are:

- 315 kHz
- 433.92 MHz (commonly listed as 434 MHz)

TPMS RECEIVER

LOCATIONS The wireless TPMS receiver is housed in one of the following locations, depending on the vehicle:

- Remote keyless entry (RKE) receiver
- Body control module (BCM)
- Door module
- Individual antennas near each wheel well. These individual antennas then transmit tire-pressure information to the driver information center. ● **SEE FIGURES 109–10 AND 109–11**.

FREQUENTLY ASKED QUESTION

Does a TPMS Sensor Work before Being Installed?

No. New tire-pressure warning sensors (transmitters) are shipped in **storage mode**. This mode prevents the battery from becoming discharged while in storage. When the transmitter is installed in a wheel/tire assembly and the tire is inflated to more than 14 PSI (97 kPa), the transmitter automatically cancels storage mode. Once a transmitter has canceled storage mode, it cannot enter this mode again. Therefore, once a sensor has been installed and the tire inflated above 14 PSI, the clock is ticking on battery life.

CASE STUDY

The TPMS Warning Lamp

The owner of a six-year-old Honda Civic was concerned that the tire-pressure warning lamp was on even though all of the tires had the proper inflation pressure. The technician noted that the TPMS warning lamp was not the one that indicates a low tire, but it was the one that indicates that a fault with the system has been detected. ● **SEE FIGURE 109–12**.

The technician used a factory-level aftermarket scan tool and retrieved several diagnostic trouble codes for "pressure sensor signal failures." ● **SEE FIGURE 109–13**.

The technician also noted that the tires were relatively new and recommended to the owner that all four TPMS sensors be replaced. The major reason why the technician recommended that all of them be replaced is that the battery life is normally 7 to 10 years so the life of the sensors is near the end of their useful life. Also, the technician thought that one or more of the sensors may have been damaged when the new tires were replaced. The vehicle owner approved the replacement of the sensors and the system was restored to normal operation.

Summary:

Complaint—TPMS warning lamp was on.
Cause—Most of the tire-pressure warning system sensors had a stored diagnostic trouble code.
Correction—All four tire-pressure sensors were replaced and the system relearned to the new sensors. The codes were cleared and the system was restored to normal operation.

TECH TIP

Check the TPMS Sensors before and after Service

It is wise to check that all of the TPMS sensors are working before beginning service work. This is commonly called "test before you touch." For example, if the tires need to be rotated, the sensors will have to be reprogrammed for their new location. If a tire-pressure monitoring sensor is defective, the procedure cannot be performed. Use an aftermarket or original equipment tire-pressure monitoring sensor tester to check that the sensors respond. ● **SEE FIGURE 109–14**.

Then the tire-pressure sensors should be checked again after the service to make sure that they are working correctly before returning the vehicle to the customer.

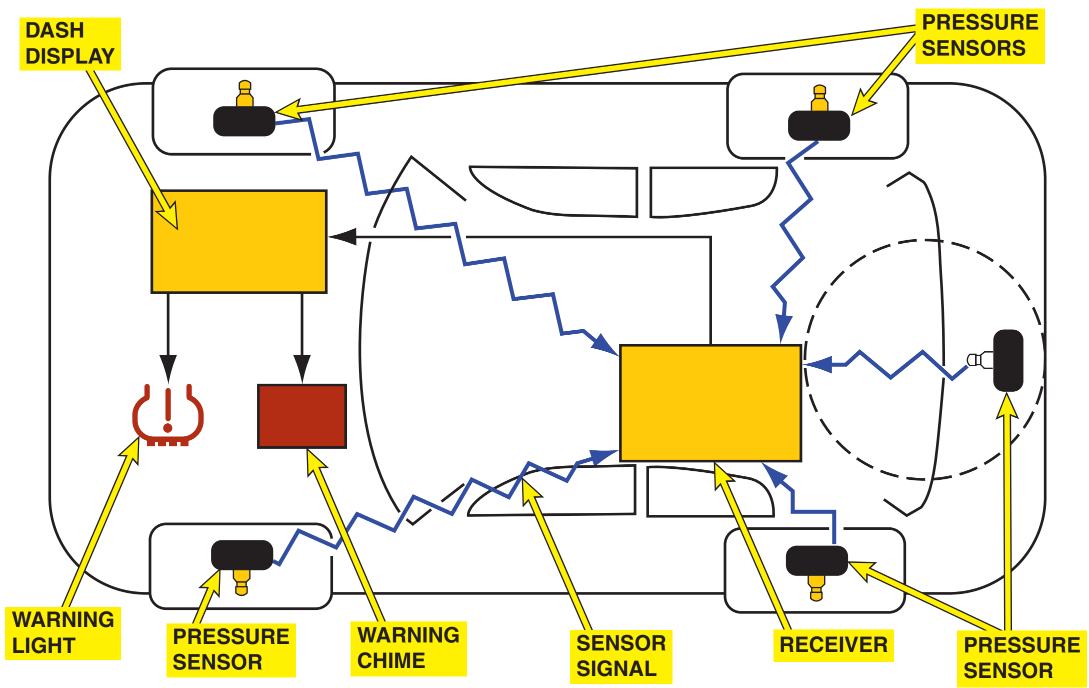

DASH DISPLAY
PRESSURE SENSORS
WARNING LIGHT
PRESSURE SENSOR
WARNING CHIME
SENSOR SIGNAL
RECEIVER
PRESSURE SENSOR

FIGURE 109–10 The individual pressure sensors transmit tire inflation pressure data to a receiver, usually the remote keyless entry (RKE) module. Many vehicles equipped with a full-size spare tire also have a tire pressure sensor in the spare tire.

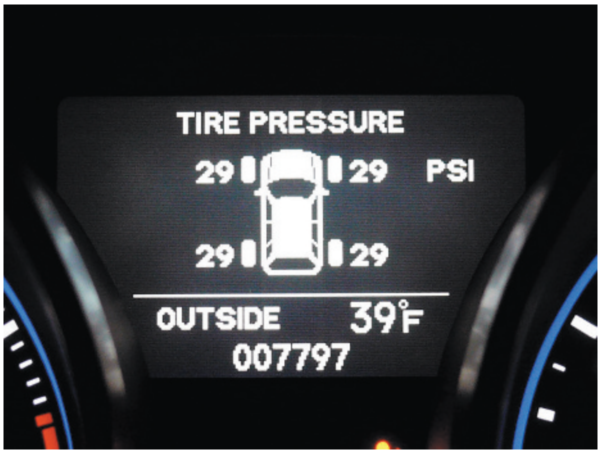
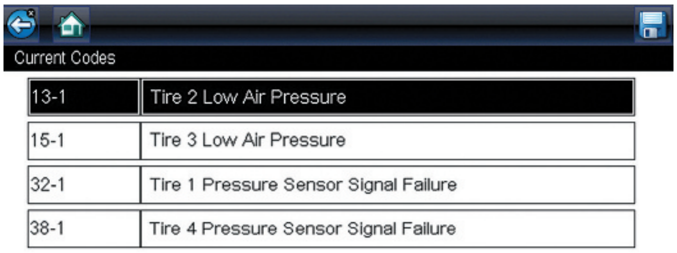

TIRE PRESSURE
29
29
PSI
29
29
OUTSIDE
39°F
007797

FIGURE 109–11 A dash display showing the inflation pressures of all four tires.


Current Codes

13-1	Tire 2 Low Air Pressure
15-1	Tire 3 Low Air Pressure
32-1	Tire 1 Pressure Sensor Signal Failure
38-1	Tire 4 Pressure Sensor Signal Failure

FIGURE 109–13 The codes set were for low pressure and sensor signal failure.

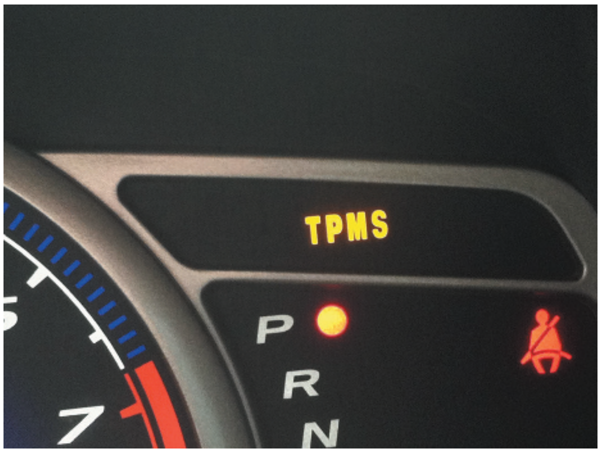


FIGURE 109–12 The TPMS warning lamp on this vehicle is a separate light from the tire icon light that warns of low tire pressure. In this case, both warning lights were on all of the time.

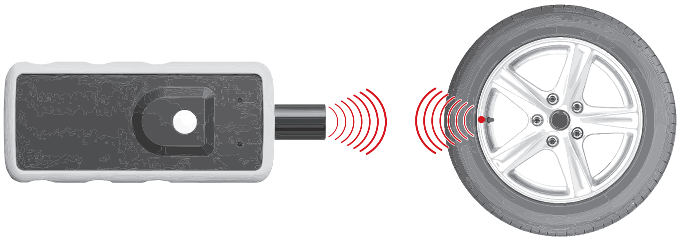


FIGURE 109–14 A typical TPMS tester. The unit should be held near the tire and opposite the valve stem if equipped with a wheel-mounted sensor, and near the valve stem if equipped with a valve-stem-type sensor.

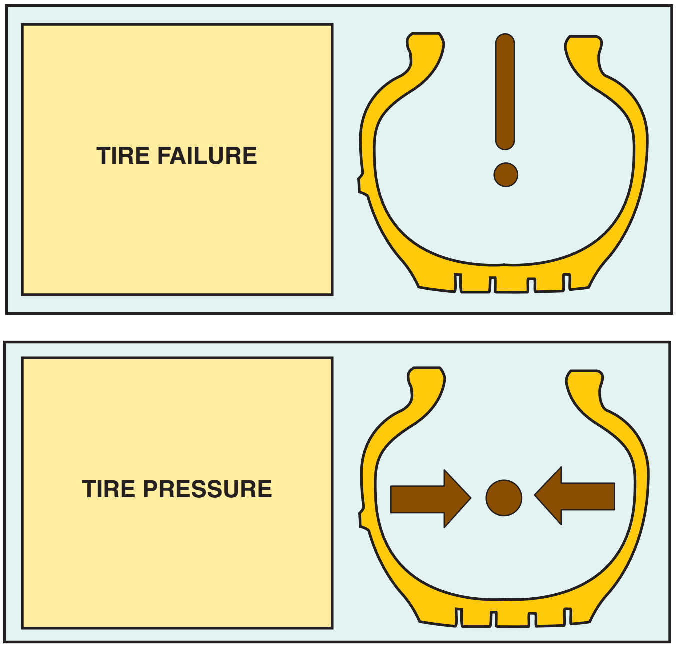


FIGURE 109–15 A tire-pressure warning light can vary depending on the vehicle, but includes a tire symbol.

TPMS DIAGNOSIS

WARNING LIGHT ON If the TPMS warning light is on and not flashing, the system has detected a tire that has low inflation pressure. ● **SEE FIGURE 109–15**.

If the TPMS light is on, perform the following steps:

STEP 1 Check the door placard for the specified tire inflation pressure.

STEP 2 Check all tires using a known-accurate tire-pressure gauge.

STEP 3 Inflate all tires to the specified pressure.

NOTE: Some systems will trigger the TPMS warning light if a tire is overinflated. An overinflated tire is also a safety-related problem.

WARNING LIGHT FLASHING If the TPMS warning lamp is flashing on and off or if a separate TPMS system warning light is on, the system has detected a fault. Faults could include the following issues:

- Defective wheel sensors, such as a sensor with a dead battery.
- A fault in the receiver, such as in the remote keyless entry module.

TECH TIP

Check the Spare

Many vehicles equipped with a full-size spare tire also have a TPMS sensor. If the inflation pressure decreases enough, the system will trigger the TPMS warning light. This is confusing to many vehicle owners who have checked all four tires and found them to be properly inflated. This fault often occurs during cold weather when the tire inflation pressure drops due to the temperature change. Most 2008 and newer vehicles with a full-size spare tire will come equipped with a TPMS sensor in the spare.

Check service information for the exact procedure to follow if the TPMS warning lamp is flashing. Always follow the specified diagnostic and service procedures.

CAUTION: Stop leak should never be used in a tire that is equipped with the TPMS sensor because the sensor can be damaged.

TPMS SENSOR ACTIVATIONS

ACTIVATING THE SENSOR A tire-pressure monitoring system (TPMS) sensor needs to be activated to verify that the sensor actually works. This should be performed before any tire or wheel service is performed. There are three methods used to activate a TPMS sensor to cause it to send a signal that can be captured to verify proper operation. These activation methods include those listed here:

1. Using a magnet (aluminum wheels and stem-mounted sensors only). ● **SEE FIGURE 109–16**.
2. Changing inflation pressure (usually requires lowering the inflation pressure by 5 to 10 PSI). This method is called the **delta pressure method**. The term *delta* refers to a change and is named for the Greek letter delta (Δ).
3. Triggered by a handheld TPMS tester that transmits a signal to wake up the sensor.

There are two formats used, depending on the sensor. They include the following:

- 125 kHz constant or continuous pulse
- 125 kHz pulse-width-modulated pulse

TPMS DIAGNOSTIC TOOLS

SCAN TOOLS Scan tools can be used for TPMS service if the scan tool is an original equipment tool for the vehicle make or if an aftermarket scan tool has original equipment compatible

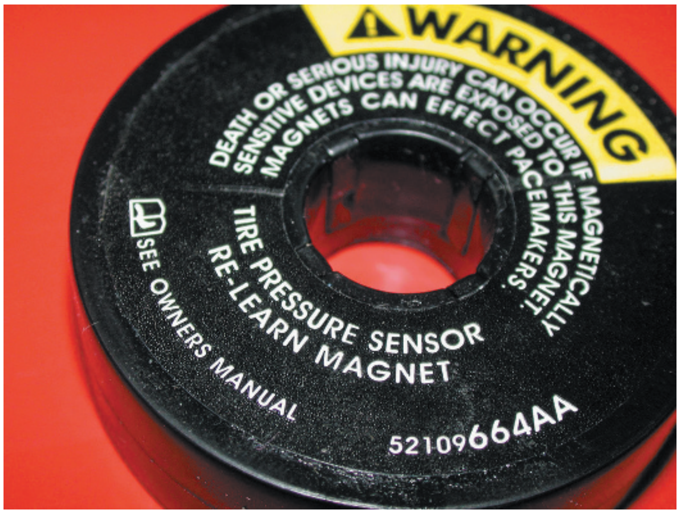

WARNING
DEATH OR SERIOUS INJURY CAN OCCUR IF MAGNETICALLY SENSITIVE DEVICES ARE EXPOSED TO THIS MAGNET. MAGNETS CAN EFFECT PACEMAKERS.
SEE OWNERS MANUAL
TIRE PRESSURE SENSOR RE-LEARN MAGNET
52109664AA

FIGURE 109–16 A magnet is placed around the valve stem to reprogram some stem-mounted tire-pressure sensors.

CASE STUDY

The Acura Dash Display Problem

The tires were rotated on an Acura equipped with a direct-type TPMS. The published relearn procedure included driving the vehicle above 15 MPH for at least 40 seconds. However, even after driving for over 10 miles, the pressures were not being displayed on the instrument panel cluster (IPC). The technician thought that maybe there was fault with the IPC. The owner decided to think it over what to do and drove the vehicle home. The next day, when the vehicle was driven, the tire pressure display worked as designed. Apparently the system needed to be powered down and allowed to go to sleep before it would start to transmit the new locations to the IPC.

Summary:

Complaint—The tire pressures for each wheel were not being displayed on the dash after the tires were rotated.
Cause—The TPMS apparently needed to go to sleep and then awaken before the tire pressure would be displayed on the dash.
Correction—No action was required by the service technician because the system started to transmit after going to sleep, and the display operated as designed.

software to access the chassis or body functions of the vehicle. A scan tool is used to perform the following functions:

1. **Register TPMS sensors**—A replacement TPMS transmitter has an eight-digit number, called the **transmitter ID**, on each valve/transmitter assembly. ● **SEE FIGURE 109–17**.
2. **Perform initialization**—This step assigns a transmitter ID to the correct position on the vehicle, such as right front (RF).
3. **Monitor sensor values**—TPMS transmitters send information to the controller on the following operations:
    - Sensor identification
    - Tire inflation pressure
    - Tire air temperature (some sensors)
    - Sensor battery voltage (some sensors)

HANDHELD TESTERS Several manufacturers produce handheld testers to reset the sensors. These tools are used to perform the following functions:

- TPMS sensor activation
- TPMS sensor relearn
- To program a new TPMS sensor

Tools are available from the following companies:

- OTC (**http://www.otctools.com**)
- Bartec (**http://www.bartecusa.com**)
- Snap-on (**http://www.snapon.com**)

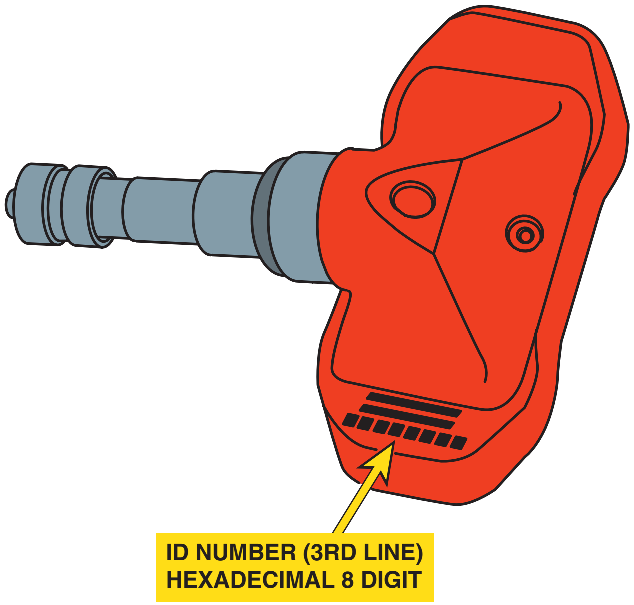


FIGURE 109–17 When replacing a TPMS sensor, be sure to record the sensor ID because this needs to be entered into the system through the use of a tester or scan tool.

SENSOR REPLACEMENT OPTIONS

ORIGINAL EQUIPMENT-BASED SENSORS These sensors are made by the original equipment (OE) manufacturer and usually are direct replacement for the factory unit.

- They are electronically identical to the original sensor.
- The relearn procedure is the same.
- May be a different color.

These sensors are usually tested and validated according to OE specifications, but one part number may cover many factory part numbers.

AFTERMARKET SENSORS There are many aftermarket TPMS sensors and these can be divided into several groups including:

- OE-based replacement
- Multiple protocol sensors that can be programmed to match whatever the vehicle needs
- Fully programmable sensor—also called *clones.* This type needs a separate programming device.

If using aftermarket tire-pressure monitoring system pressure sensors, always check and follow the instructions that came with the sensors to properly program the vehicle being serviced.

TPMS SENSOR RELEARN

TERMS USED Service information should always be checked when performing a relearn procedure. The relearn procedure may be called any of the following terms:

- Calibrate
- Recalibration

- Initialization
- Reprogramming
- Relearn
- Training

CATEGORIES Most relearn procedures fall into four categories:

1. **Auto relearn**—Install sensors, drive the vehicle for a prescribed amount of time and rate of speed. The vehicles that often can be automatically relearned usually include:
    - Chrysler
    - Dodge
    - Ram
    - Jeep
    - Jaguar
    - Land Rover
2. **European relearn**—Install sensors, put the vehicle in reset mode through the driver information center (DIC), and drive the vehicle for a prescribed amount of time and rate of speed. Used on many European brands including those listed here:
    - VW
    - Audi
    - Mercedes Benz
    - BMW
3. **Manual relearn**—Enter the vehicle into learn mode by following the instructions found in the owner's manual, trigger all four sensors with an activation tool or scan tool. Used on many domestic vehicles including the following brands:
    - Chevrolet
    - Buick
    - GMC
    - Ford
    - Lincoln
4. **OBD relearn**—Scan all four sensors with a scan tool, input the electronic serial number (ESN), and download the ESN into the TPMS ECU. Required on many Japanese brands including the brands listed here:
    - Toyota
    - Lexus
    - Nissan
    - Infiniti
    - Subaru
    - Honda

Always check service information for the exact procedures to follow on the vehicle being serviced.

FREQUENTLY ASKED QUESTION

How Does a Vehicle Learn Where the Sensor Is Located?

Vehicles that are capable of automatically learning their new position after a tire rotation or after being replaced can detect their location by the following procedures:

- Some vehicles use an initiator located in each wheel well. The TPMS sensor broadcasts the pressure information which is detected by each initiator and then transmitted over a bus network to the TPMS or body control module. The module then will know where the sensor is located by its unique serial number.
- An accelerometer in the sensor allows the sensor to "know" which side of the vehicle the sensor is located. When a tire revolves, it turns in an opposite direction than a wheel on the opposite side of the vehicle. By using the accelerometer, the TPMS controller can detect which side the sensor is located.
- Then the TPMS module checks for the relative strength of the signal being transmitted by the sensor. If the receiver is located at the rear of the vehicle, and two sensors are showing stronger signal, then these two must be the two rear wheels.

GENERAL MOTORS EXAMPLE The following procedure will allow the service technician to reprogram the TPMS after tire rotation on a General Motors vehicle without using a scan tool:

STEP 1 With KOEO (key on, engine off), the "lock" and "unlock" buttons on the key fob should be simultaneously pressed and held. The horn will chirp within 10 seconds, indicating the receiver is in programming mode. The programming procedure must now be completed within five minutes, with no more than one minute between programming.

NOTE: If the horn does not chirp at the start of this procedure, the TPMS option has not been enabled. A scan tool is needed to enable the system.

STEP 2 At the left front wheel, the special magnet tool must be held over the valve stem to force the sensor to transmit its code. The horn will chirp once, indicating the system has recognized the sensor. The next sensor must be programmed within one minute.

STEP 3 The remaining sensors should be programmed in the following order: RF, RR, LR. The horn will chirp once when each sensor has been detected. It will chirp twice to indicate completion of the programming process. ● **SEE FIGURE 109–18**.

TECH TIP

All Sensors Will Fail

All TPMS pressure sensors will fail because they contain a battery that has a service life of 7 to 10 years. What does this mean to the service technician? This means that if new tires are being installed on a five or six-year-old vehicle equipped with tire-pressure sensors, then the customer should be notified that the TPMS sensors could fail almost anytime.

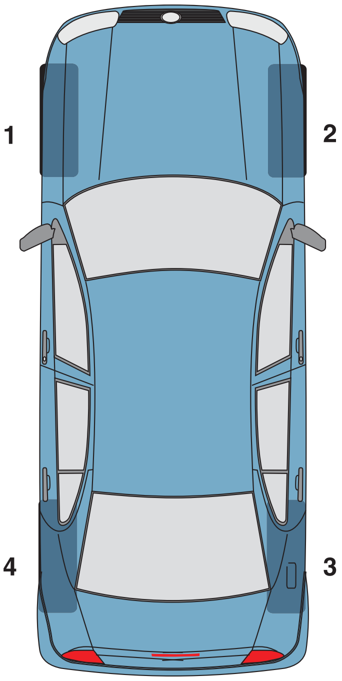


FIGURE 109–18 The sensor relearn procedure is performed in the following order after the system has been placed in learn mode: LF, RF, RR, and then LR.

FREQUENTLY ASKED QUESTION

Can TPMS Sensors Be Switched to New Wheels?

Maybe. It depends on the style of the new or replacement wheels as to whether the sensors will fit or not. Some vehicles are designed to allow for a second set of sensors such as for winter tires. Many Lexus vehicles can be programmed to use set #1 or set #2. It is best to check before purchasing new wheels. Another set of TPMS sensors could be a major added expense.

TPMS SENSOR SERVICE TOOLS

ITEMS NEEDED Whenever servicing a tire/wheel assembly that has a direct TPMS system, certain items are needed:

1. **Information**—Check service information for the exact procedures to follow for the vehicle being serviced. Vehicles and sensors are different for different vehicles.
2. **Digital tire-pressure gauge**—Many mechanical tire-pressure gauges are not accurate. An old mechanical gauge may be used to ensure that all tires are inflated to the same pressure, but the pressure may not be accurate. ● **SEE FIGURE 109–19**.
3. **Tire valve core torque wrench**—This calibrated tool ensures that the valve core is tightened enough to prevent air loss, but not too tight to cause harm. The recommended torque is 3 to 5 inch-pounds (0.34 to 0.56 N-m [Newton meters]). ● **SEE FIGURE 109–20**.
4. **Tire valve nut torque wrench**—Most are 11 or 12 mm in size and the torque ranges from 30 to 90 inch-pounds (4 to 10 N-m).
5. **Sensor service kit**—If a pressure sensor is going to be reused, the following service parts must be replaced:
   - Cap
   - Valve core (nickel-plated only)
   - Nut
   - Grommet

These parts are usually available individually or in an assortment package. Pressure sensor and kit information can be found at the following websites:

- **http://www.schrader-bridgeport.com**
- **http://www.myerstiresupply.com**
- **http://www.rubber-inc.com**

● **SEE FIGURES 109–21 AND 109–22**.

FIGURE 109–19 Always use an accurate, known-good tire-pressure gauge. Digital gauges are usually more accurate than mechanical gauges.

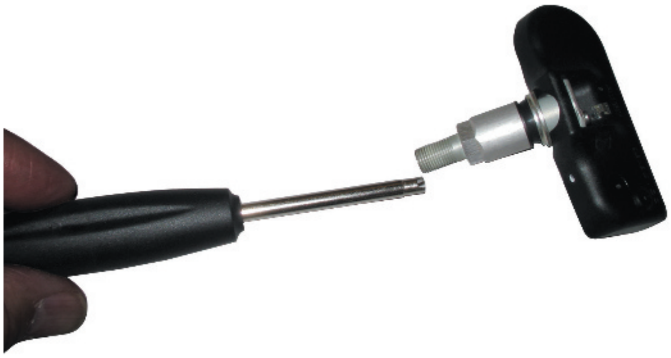


FIGURE 109–20 A clicker-type valve core tool ensures that the valve core is tightened to factory specifications.

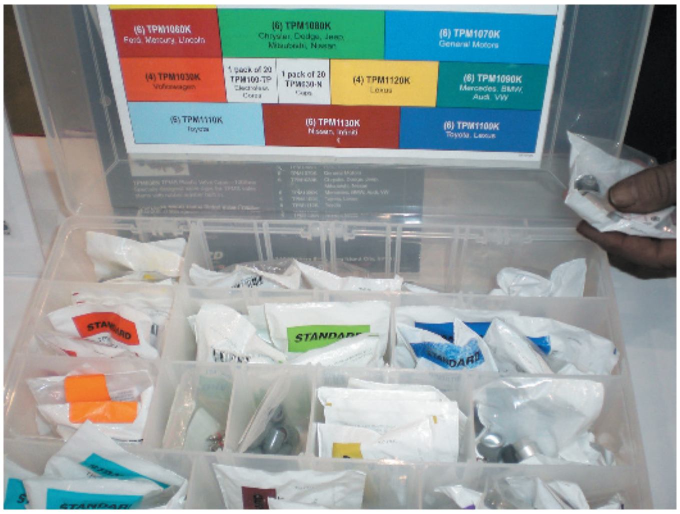

(6) TPM1060K
Ford, Mercury, Lincoln
(6) TPM1080K
Chrysler, Dodge, Jeep, Mitsubishi, Nissan
(6) TPM1070K
General Motors
(4) TPM1030K
Volkswagen
1 pack of 20
TPM100-TP
Electrolux, Corsa
1 pack of 20
TPM030-N
Caps
(4) TPM1120K
Lexus
(6) TPM1090K
Mercedes, BMW, Audi, VW
(6) TPM1110K
Toyota
(6) TPM1130K
Nissan, Infiniti
(6) TPM1100K
Toyota, Lexus
STANDARD

FIGURE 109–21 An assortment of service parts that include all of the parts needed to service a stem-mounted TPMS sensor being installed after removal for a tire replacement or repair.

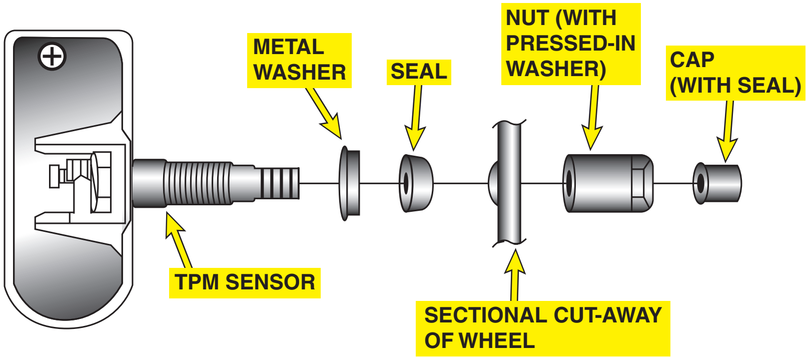

METAL WASHER
SEAL
NUT (WITH PRESSED-IN WASHER)
CAP (WITH SEAL)
TPM SENSOR
SECTIONAL CUT-AWAY OF WHEEL

FIGURE 109–22 The parts of a typical clamp-in type TPMS sensor showing the relationship of the parts used to install one in a wheel.

REVIEW QUESTIONS

1. How does the use of wheel speed sensors detect a tire with low inflation pressure?
2. What is the difference between faults when the TPMS warning lamp is on compared with when it is flashing?
3. What is the difference between indirect and direct tire-pressure monitoring system?
4. TPMS pressure sensors can be made by what manufacturer?
5. What are the three modes of sensor operation?

CHAPTER QUIZ

1. What is the purpose of the TPMS system?
   - **a.** To detect a tire that has low inflation pressure
   - **b.** To inflate a low tire if needed
   - **c.** To flash a warning light if a tire with low inflation pressure is detected
   - **d.** All of the above
2. Technician A says that tire pressure will drop 1 PSI for every 10 degrees drop in temperature. Technician B says that the two type of TPMS pressure sensors are snap-in and clamp-in. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. The FMVSS 136 law (TREAD Act) requires that the driver be notified if the tire inflation pressure drops how much?
   - **a.** 30%
   - **b.** 25%
   - **c.** 20%
   - **d.** 15%
4. Two technicians are discussing the indirect tire-pressure monitoring system. Technician A says that it was used by some vehicle manufacturers. Technician B says that it uses the speeds of the RF and LR tires and compares the rotating speeds of the LF and RR tires to detect a low tire. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. What mode does a direct pressure sensor enter when the vehicle is stopped?
   - **a.** Sleep mode
   - **b.** Storage mode
   - **c.** Alert mode
   - **d.** Active mode

6. What tools and supplies are needed to service TPMS?
   - **a.** Tire pressure gauge
   - **b.** Tire valve core torque wrench
   - **c.** Sensor service kit
   - **d.** All of the above
7. The tire pressure sensor sends a signal to the ____________.
   - **a.** door module
   - **b.** RKE receiver
   - **c.** BCM
   - **d.** Any of the above, depending on the vehicle
8. What does the "delta pressure method" mean?
   - **a.** Change the inflation pressure
   - **b.** Activate the sensor so it broadcasts the pressure to the scan tool
   - **c.** Inflate the tire to the specified pressure
   - **d.** Use a handheld tester to read the pressure as reported by the sensor
9. When a TPMS sensor needs replacement, which of the following is *not* an option?
   - **a.** Replace with an OE sensor
   - **b.** Replace with a programmable aftermarket sensor
   - **c.** Replace the sensor battery and program it to the vehicle
   - **d.** Replace with a multiple protocol sensor
10. To activate or learn a direct pressure sensor, what does the service technician need to do?
   - **a.** Enter learn mode and use a magnet.
   - **b.** Enter learn mode and decrease inflation pressure.
   - **c.** Use a handheld tester.
   - **d.** Any of the above depending on the vehicle and system.

Chapter 110

TIRE AND WHEEL SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- State the importance of proper tire inflation.
- Discuss nitrogen inflation.
- Describe tire inspection.
- Describe the correct sequence for lug nut removal, tightening procedure, and torque for wheel installation.
- State the purpose of tire rotation.
- Discuss radial runout.
- Discuss lateral runout.
- List the steps for replacing a tire.
- Discuss tire balancing.
- Discuss wheel weights.
- Discuss wheel/tire balancers.
- Discuss how to repair tires using internal patch.

KEY TERMS:

Lateral runout 1329 • Match mounting 1332 • Modified X 1328 • Radial force variation (RFV) 1329 • Radial runout 1329 • Shimmy 1329 • Tire rotation 1327 • Tramp 1329

TIRE SERVICE AND PROPER INFLATION

NEED FOR SERVICE Proper tire service is extremely important for the safe operation of any vehicle. Premature wear can often be avoided by checking and performing routine service, such as frequent rotation and monthly inflation checks. Avoid overloading the vehicle and have any leaks repaired as soon as possible. ● **SEE FIGURE 110–1**.

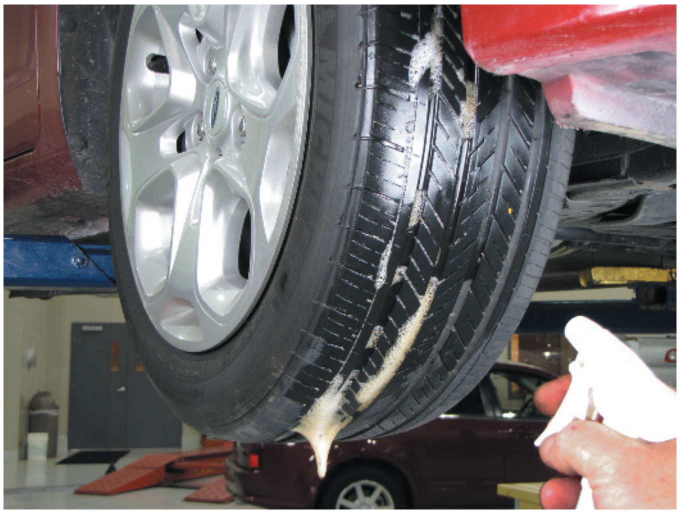


FIGURE 110–1 Using soapy water from a spray bottle is an easy method to find the location of an air leak from a tire.

TIRE INFLATION PRESSURE Tires should always be inflated to the pressure indicated on the driver's door or pillar sticker. Tires should be checked when cold, before the vehicle has been driven, because driving on tires increases the temperature and therefore the pressure of the tires. Proper tire inflation is important for the following reasons:

- **Inflation pressure carries the load of the vehicle.** If the pressure is low, the load capacity of the tire is decreased. ● **SEE FIGURE 110–2**.
- **Inflation pressure varies with temperature.** Tires lose 1 PSI for every 10 degree drop in temperature. This means that as the temperatures and seasons change, so does the inflation pressure inside the tires. For example, if tires were inflated to 35 PSI on the first day of summer (June 21) when the temperature was 90°F (32°C) then the following pressures would occur, assuming no air loss at all:
  - Summer (June 21) 90°F—35 PSI
  - Fall (September 21) 70°F—33 PSI

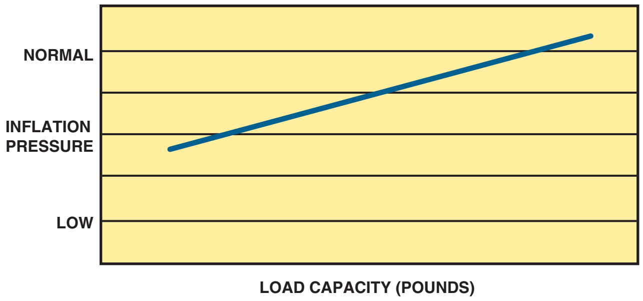


FIGURE 110–2 Chart showing the relationship between tire inflation pressure and load capacity of the tire.

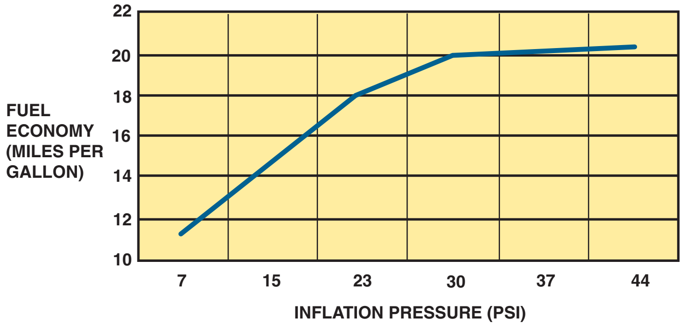


FIGURE 110–3 Note that a drop in inflation pressure has a major effect on fuel economy.

- Winter (December 21) 30°F—29 PSI
- Spring (March 21) 60°F—32 PSI

Also, it is normal for a tire to lose 1 PSI per month just through normal leakage that occurs in any tire. Therefore, it is very important to check and correct inflation pressures regularly.

- **Tire inflation affects fuel economy.** A drop in inflation pressure from 30 to 23 PSI can result in a drop of fuel economy from 20 miles per gallon to 18 miles per gallon. ● **SEE FIGURE 110–3**.
- **Tire inflation affects tire life.** Even a slight drop in air pressure can have a major effect on the life of a tire. If, for example, the inflation pressure dropped 10 PSI, the life of the tire would be reduced by 40%. ● **SEE FIGURE 110–4**.
- **The TREAD Act specifies** that the driver be notified if the inflation of a tire drops by 25%. However, 25% represents a loss of air pressure of about 8 PSI. A drop of 8 PSI means an approximate 2 mpg (miles per gallon) decrease in fuel economy as well as about a 25% reduction in tread wear.

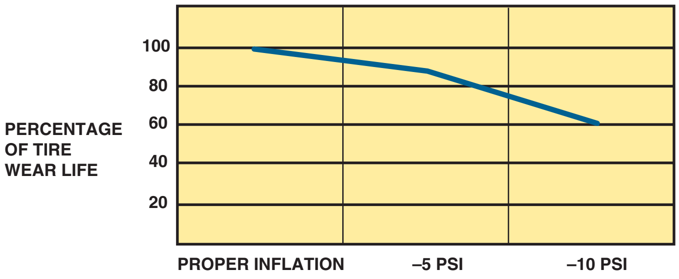


FIGURE 110–4 Note that if a tire is underinflated by 5 PSI, the life expectancy is reduced by 20% and by about 40% if the inflation pressure is less than specified by 10 PSI.

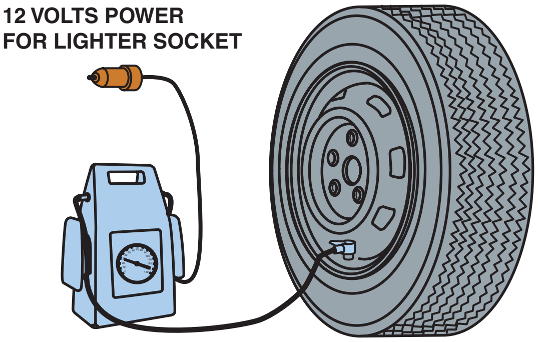

12 VOLTS POWER FOR LIGHTER SOCKET

FIGURE 110–5 A temporary inflation pump that uses 12 volts from the cigarette lighter to inflate the tire.

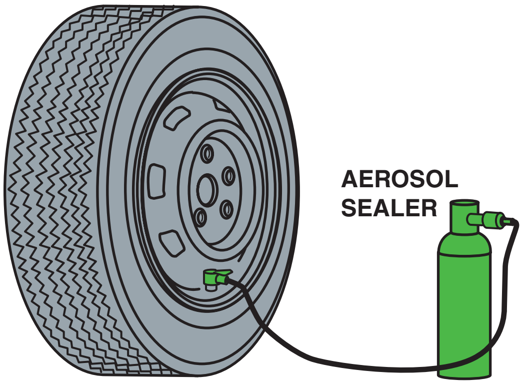


FIGURE 110–6 Many vehicle manufacturers include an aerosol can of sealer on vehicles that are not equipped with a conventional spare tire.

FREQUENTLY ASKED QUESTION

What Is a "Temporary Mobility Kit"?

A temporary mobility kit is a system to inflate a flat tire supplied by the vehicle manufacturer instead of a spare tire. A temporary mobility kit can include

- An electric compressor powered by the cigarette lighter and a can of stop leak. ● **SEE FIGURE 110–5**.
- An aerosol spray can that provides inflation and sealer. ● **SEE FIGURE 110–6**.

Either type can be found in many vehicles because such devices save weight, increase trunk space, and cost less than a conventional spare tire and jack. However, these kits are designed to be a temporary repair only because the cause of the low tire was never determined. If the tire appears to be fixed, many vehicle owners may think that the tire has been repaired. However, the tire should be carefully inspected inside and out for damage and properly repaired.

NITROGEN INFLATION

DEFINITION Air contains about 78% nitrogen, 21% oxygen, and 1% other gases. When tires are inflated using air, oxygen as well as some moisture is included. Some shops recommend and inflate tires using nitrogen instead of using compressed air.

REASONS TO USE NITROGEN The reasons include

- The nitrogen molecule is slightly larger than the oxygen molecule so the tire will lose pressure faster if air is used instead of nitrogen.

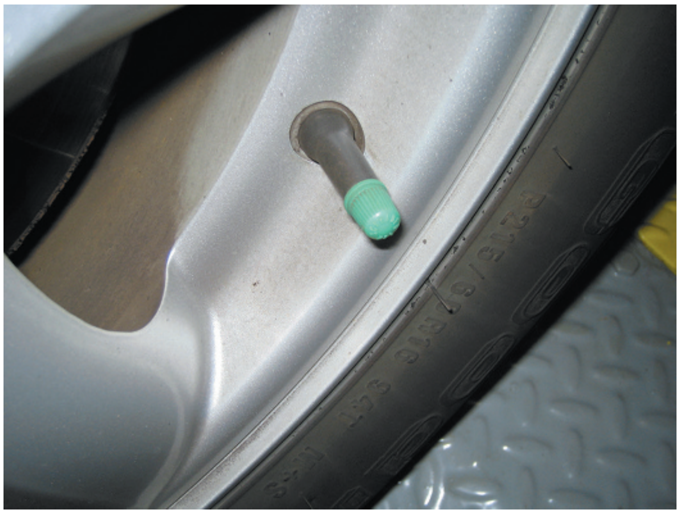


FIGURE 110–7 Most shops that use nitrogen inflation install a green tire valve cap to let others know that nitrogen, rather than air, has been used to inflate the tire.

- Compressed nitrogen contains less moisture than compressed air. When the tire heats up, moisture in the tire vaporizes and expands, causing the pressure inside the tire to increase. Even small changes in tire pressure can noticeably affect the handling of the vehicle.
- Race teams use nitrogen because they come to the track with a cylinder of nitrogen to power the air tools.
- Race teams also have more control over how much the pressure will increase when the tires heat up, because nitrogen is less likely to change pressure with temperature change.
- Some oxygen in the tires could, over a long period of time, cause the oxidation of the inner liner of the tire and the corrosion of the wheel.
- Many shops use green valve caps when they fill the tires with nitrogen. ● **SEE FIGURE 110–7**.

TECH TIP

Fine-Tune Handling with Tire-Pressure Changes

The handling of a vehicle can be changed by changing tire pressures between the front and rear tires.

- **Understeer—**A term used to describe how a vehicle handles when cornering where additional steering input is needed to maintain the corner, or resisting turning into a corner. This is normal handling for most vehicles.
- **Oversteer—**A term used to describe handling where correction while cornering is often necessary because the rear tires lose traction before the front tires.

Tire Pressure	To Decrease Understeer	To Decrease Oversteer
Front tire inflation pressure	Increase	Decrease
Rear tire inflation pressure	Decrease	Increase

CAUTION: Do not exceed the maximum inflation pressure as imprinted on the tire sidewall.

FREQUENTLY ASKED QUESTION

What Is the Color Band on a Valve Core?

The red band cores have a seal temperature range of 130 to 250°F (54 to 121°C), and are mainly for use in trucks or high-performance applications. The valve cores with a black band are rated for 107 to 225°F (54 to 107°C). Brass tire valve cores are for standard rubber stems, whereas nickel plated cores are for TPMS sensors to prevent corrosion.

TIRE INSPECTION

VISUAL INSPECTION All tires should be carefully inspected for faults in the tire itself or for signs that something may be wrong with the steering or suspension systems of the vehicle. Check all tires for the following signs:

- Excessive wear. ● **SEE FIGURE 110–8**.
- Sidewall faults. ● **SEE FIGURE 110–9**.

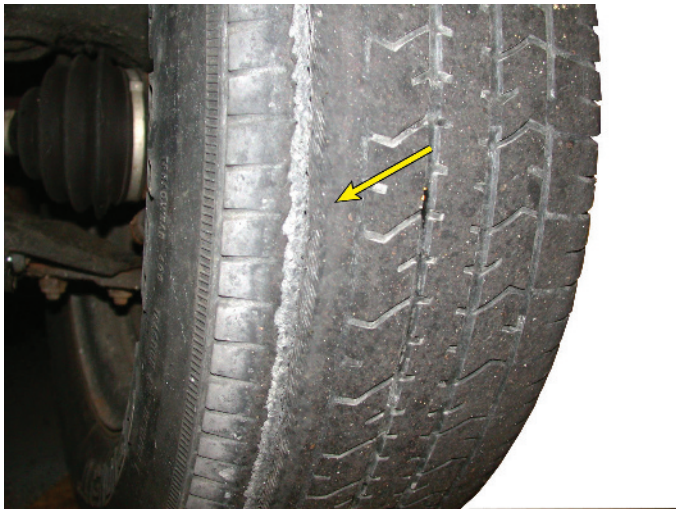


FIGURE 110–8 Excessively worn tire showing the belt material on the inside edge. This tire requires replacement.

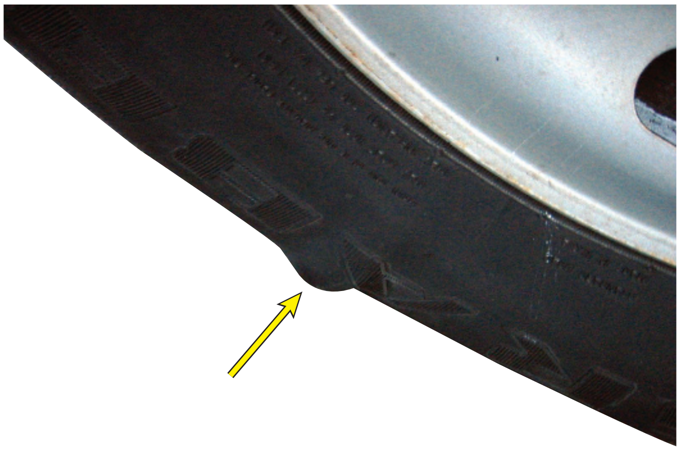


FIGURE 110–9 A bulge in a tire as a result of either an injury to the sidewall, such as contact with a curb, or an internal fault in the tire. This tire requires replacement.

- Underinflation, which shows as wear on both the inside and outside edges of the tread.
- Overinflation, which shows as excessive wear in the center of the tread.
- Wear on the inner or outer part of the tire only which usually indicates alignment problem. ● **SEE FIGURE 110–10**.

TREAD DEPTH Tread depth should always be measured when inspecting tires and the results recorded in the work order. Typical tread depth and what they mean are as follows:

- New tires = 9/32-11/32 (7–9 mm)
- 6/32 inch (5 mm) or more—No need to replace the tire
- 4/32 to 5/32 inch (3 to 4 mm) Consider replacement
- 2/32 inch (2 mm) or less Replace (2/32 in. is the legal limit) ● **SEE FIGURE 110–11**.

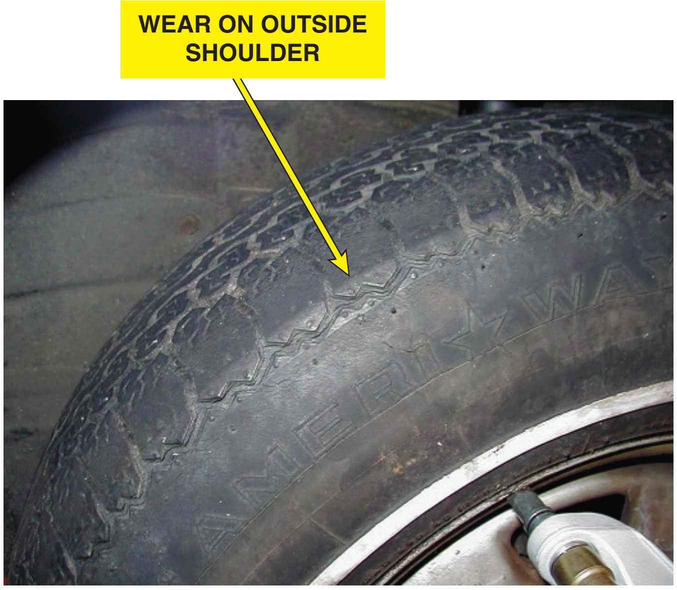
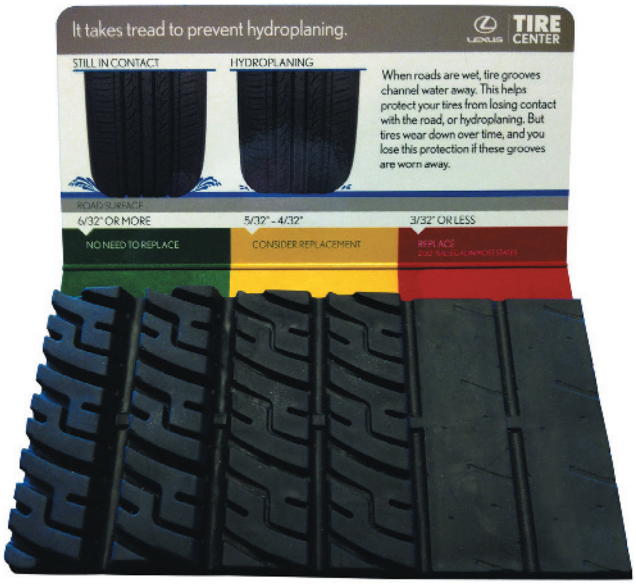


FIGURE 110–10 Wear on the outside shoulder only is an indication of an alignment problem.



When roads are wet, tire grooves channel water away. This helps protect your tires from losing contact with the road, or hydroplaning. But tires wear down over time, and you lose this protection if these grooves are worn away.

FIGURE 110–11 A display at a Lexus dealer used to show customers a visual representation of what a tire looks like at various tread depth amounts. This display helps vehicle owners understand tire tread depth measurements.

TECH TIP

Stop and Inform the Customer

If a lug nut is hard to turn when removing a wheel, stop. Inform the customer before proceeding because there may be an issue with damaged or corroded wheel studs. If a wheel stud breaks, the service technician is often blamed and the shop may be responsible for the repair. By informing the customer, this issue is fully documented and the customer will have a say whether or not to proceed with the wheel service.

WHEEL REMOVAL/ INSTALLATION

LUG NUTS When removing lug nuts, notice the amount of force needed to remove the nuts. If a wrench or impact wrench is needed to unscrew the nuts, the threads are damaged and should be repaired or the stud replaced. Always start wheel lug nuts by hand. Be certain that all wheel nut threads have been engaged at least three threads before tightening the nut with a wrench or impact.

LUG NUT TORQUE For wheel mounting torque, make certain that the wheel studs are clean and dry, and torqued to the manufacturer's specifications.

CAUTION: Most manufacturers warn that the wheel studs should not be oiled or lubricated with grease; this can cause the wheel lug nuts to loosen while driving. Always follow the vehicle manufacturer's recommended service procedures.

TIGHTENING SEQUENCE Always tighten lug nuts gradually in the proper sequence—star pattern (tighten one nut, skip one, and tighten the next nut). This helps prevent warping the brake drums or rotors, or bending a wheel. ● **SEE FIGURE 110–12**.

Many factory-installed and aftermarket wheels use anti-theft wheel lug nuts, usually on only one wheel stud. When removing or installing a locked lug nut, be sure the key is held square to the lug nut to prevent damaging either the nut or the key. ● **SEE FIGURE 110–13**.

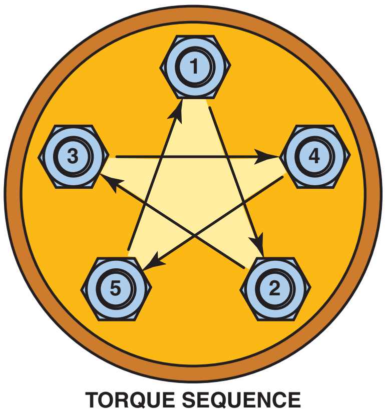


FIGURE 110–12 Always tighten wheel lug nuts (or studs) in a star pattern to ensure even pressure on the axle flange, brake rotors or drums, and the wheel itself.

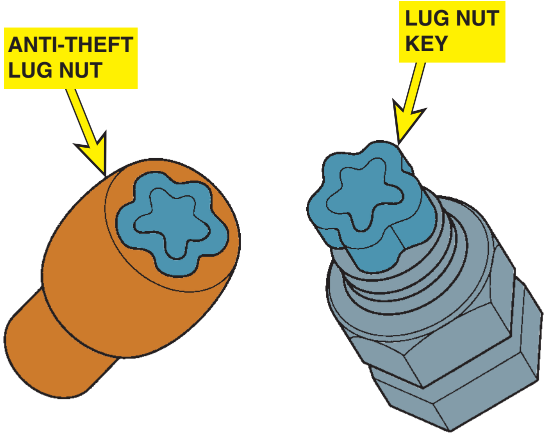


FIGURE 110–13 Most manufacturers recommend using hand tools rather than an air impact wrench to remove and install lock-type lug nuts to prevent damage. If either the key or the nut is damaged, the nut may be very difficult to remove.

TIGHTENING TORQUE All vehicle manufacturers recommend that the lug nuts be tightened to factory specifications using a *torque wrench*. To properly use a torque wrench to tighten wheel lug nuts, perform the following steps:

STEP 1 Check service information for the specified torque for the lug nuts on the vehicle being serviced. For most passenger vehicles, this torque is usually 80 to 100 lb-ft.

STEP 2 With the vehicle raised to a good working height, place the wheel/tire assembly over the lug studs.

STEP 3 Start all lug nuts by hand at least three threads to help assure that the threads are not damaged or cross threaded which can affect the tightening torque.

STEP 4 Snug the lug nuts in a star pattern using a ratchet and socket or a battery-powered impact set to a light torque. Snug the lug nuts in a star pattern (snug one, skip one, then snug another). This method helps insure that the wheel is installed straight onto the hub.

STEP 5 Lower the vehicle to the ground.

STEP 6 Set the torque wrench to the specified torque. This is usually achieved on a "clicker" type torque wrench by twisting the end of the handle until the specified torque setting is reached and then the lock is set to prevent it from changing.

STEP 7 Using the torque wrench with the correct socket, slowly and gently tighten the lug nuts. Do not jerk or move the torque wrench rapidly as this will affect the torque applied to the lug nuts. The torque wrench will click when the wrench reaches the preset to tightening torque. When the click occurs, release the force on the torque wrench. Another click will be heard when the torque is relieved. ● **SEE FIGURE 110–14**.

STEP 8 Double-check that all lug nuts are correctly tightened.

STEP 9 When finished, set the torque setting on the torque wrench to its lowest setting to keep pressure off the internal spring when it is stored. This helps prevent inaccurate torque readings the next time it is used.

Whenever you install brand-new aluminum wheels, retorque the wheels after the first 25 miles. The soft aluminum often compresses slightly, loosening the torque on the wheels.

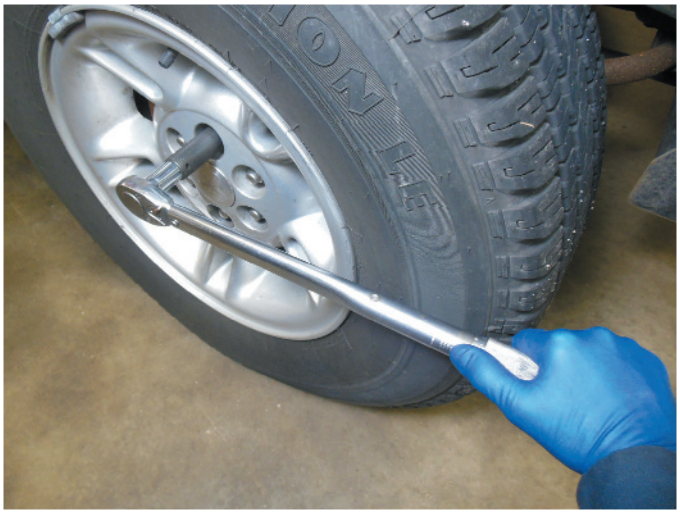


FIGURE 110–14 A torque wrench being used to tighten lug nuts on a pickup truck.

The use of torque-absorbing adapters (*torque sticks*) on lug nuts with an air impact wrench properly set has proved to give satisfactory results as long as the specified air pressure is used and that they are used according to the torque-absorbing instructions. ● **SEE FIGURE 110–15**.

If the exact torque value is not available, ● **SEE CHART 110–1** as a guide for the usual value based on the size (diameter) of the lug studs.

TIRE ROTATION

PURPOSE **Tire rotation** is essential to ensure long life and even tire wear. It is important to rotate each tire to another location. Some rear-wheel-drive vehicles, for example, may show premature tire wear on the front tires. The wear usually starts on the outer tread row. It usually appears as a front-to-back (high and low) wear pattern on individual tread blocks. These *blocks of tread* rubber are deformed during cornering, stopping, and turning. This type of tread block wear can cause tire noise and/or tire roughness.

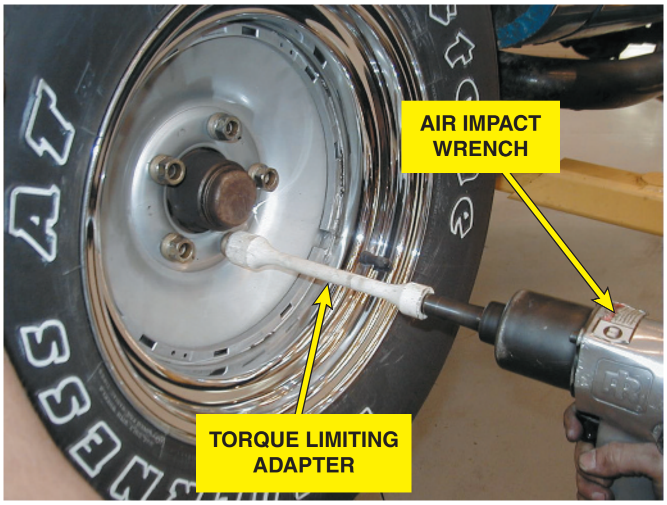


FIGURE 110–15 A torque-limiting adapter (torque stick) used with an air impact wrench still requires care to prevent overtightening. The air pressure to the air impact should be limited to 125 PSI (860 kPa) in most cases, and the proper adapter must be selected for the vehicle being serviced. The torque adapter absorbs any torque beyond its designed rating. Most vehicle manufacturers recommend that final tightening be performed using a torque wrench.

STUD DIAMETER	TORQUE (LB-FT)
3/8 in.	35–45
7/16 in.	55–65
½ in.	75–85
9/16 in.	95–115
5/8 in. (usually only trucks)	125–50
12 mm	70–80
14 mm	85–95

CHART 110–1

Typical lug nut torque based on the diameter of the wheel stud.

CASE STUDY

I Thought the Lug Nuts Were Tight!

Proper wheel nut torque is critical, as one technician discovered when a customer returned complaining of a lot of noise from the right rear wheel. The lug (wheel) nuts had loosened and ruined the wheel. ● **SEE FIGURE 110–16**.

CAUTION: Most vehicle manufacturers also specify that the wheel studs/nuts should not be lubricated with oil or grease. The use of a lubricant on the threads could cause the lug nuts to loosen.

Summary:

Complaint—Customer complained of a lot of noise from the rear of the vehicle after a routine tire rotation.
Cause—The service technician got distracted when installing the wheels during a tire rotation and forgot to properly torque the lug nuts.
Correction—A new wheel was used and the tire mounted and balanced and properly installed.
The technician learned to always keep focused on the job being performed.

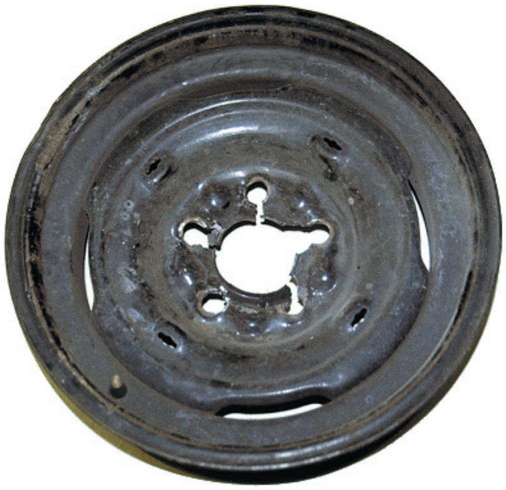


FIGURE 110–16 This wheel was damaged because the lug nuts were not properly torqued.

TECH TIP

All-Wheel-Drive Tire Concerns

It is very important that all-wheel-drive vehicles be equipped with tires that are all the same outside diameter. If, for example, the vehicle has 20,000 miles and the tires are half worn, all of the tires should be replaced in the event of a problem requiring replacement of only one tire. Most vehicle manufacturers specify that all tires must be within 2/32 inch of tread depth without causing a constant strain on the drivetrain.

While some shoulder wear on front tires is normal, it can be reduced by proper inflation, alignment, and tire rotation.

METHODS For best results, tires should be rotated every 6,000 miles or every six months. ● **SEE FIGURE 110–17** for suggested methods of rotation, such as the **modified X**.

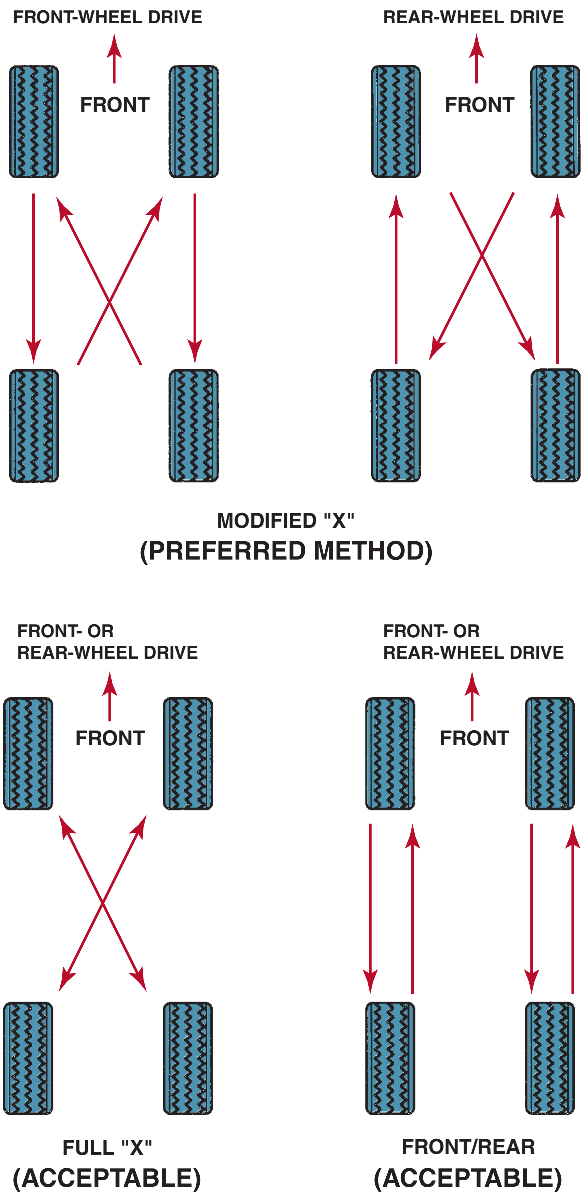


FIGURE 110–17 The method most often recommended is the modified X method. In this method, each tire eventually is used at each of the four wheel locations. An easy way to remember the sequence, whether front-wheel drive or rear-wheel drive, is to say to yourself, "Drive wheels straight, cross the nondrive wheels."

NOTE: Radial tires can cause a radial pull due to their construction. If wheel alignment is correct, attempt to correct a pull by rotating the tires front to rear or, if necessary, side to side.

RADIAL RUNOUT

WHY CHECK Even though a tire has no visible faults, it can be the cause of vibration. If vibration is felt above 45 MPH, regardless of the engine load, the cause is usually due to an out-of-balance or a defective out-of-round tire. Both of these problems cause a **tramp**, which is an up-and-down-type vibration. If the vibration is seen in the hood of the vehicle or felt in the steering wheel, then the problem is usually the *front* tires. If the vibration is felt throughout the entire vehicle or in the seat of your pants, then the rear tires (or drive shaft, in rear-wheel-drive vehicles) are the problem.

CHECKING RADIAL RUNOUT This can be checked by using a runout gauge. ● **SEE FIGURES 110–18 AND 110–19**.

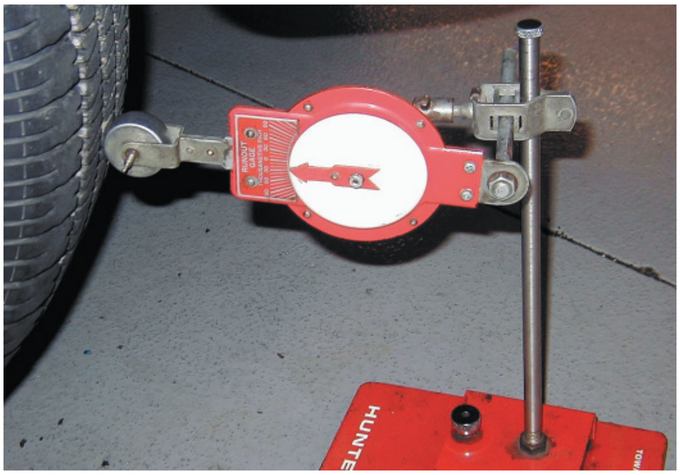


FIGURE 110–18 A tire runout gauge being used to measure the radial runout of a tire.

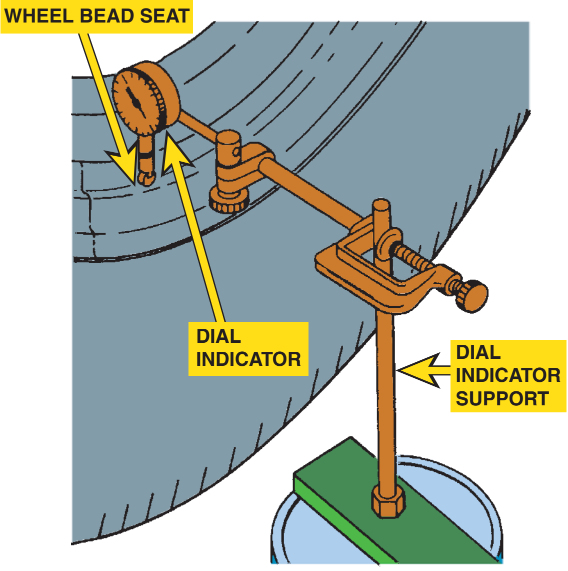


FIGURE 110–19 To check wheel radial runout, the dial indicator plunger tip rides on a horizontal surface of the wheel, such as the bead seat.

To check **radial runout** (checking for out of round) and **lateral runout** (checking for side-to-side movement), perform the following steps:

STEP 1 Raise the vehicle so that the tires are off the ground approximately 2 inches (5 cm).

STEP 2 Place the runout gauge against the tread of the tire in the center of the tread and, while rotating the tire, observe the gauge reading.

STEP 3 Note that maximum radial runout should be less than 0.060 inch (1.5 mm). Little, if any, tramp will be noticed with less than 0.030 inch (0.8 mm) runout. If the reading is over 0.125 inch (3.2 mm), replacement of the tire is required.

STEP 4 Check all four tires.

CORRECTING RADIAL RUNOUT Excessive radial runout may be corrected by one of several methods:

Method **#1.** Try relocating the wheel on the mounting studs. Mark one stud and remount the wheel two studs away from its original position. Excessive wheel hole and/or stud tolerance may be the cause. If the radial runout is now satisfactory, remark the stud and wheel to prevent a future occurrence of the problem.

Method **#2.** Remount the tire on the wheel 180 degrees from its original location. This can solve a runout problem, especially if the tire was not match mounted to the wheel originally.

Method **#3.** If runout is still excessive, remove the tire from the wheel and check the runout of the *wheel.* If the wheel is within 0.035 inch (0.9 mm), yet the runout of the tire/wheel assembly is excessive, the problem has to be a defective tire and it should be replaced.

Sometimes a problem within the tire itself can cause a vibration, and yet not show up as being out of round when tested for radial runout. A condition called **radial force variation (RFV)** can cause a vibration even if correctly balanced. Many tire balancers are equipped with a roller that is pressed against the tread of the tire to measure radial force variations. Follow the instructions as shown on the balancer display to correct for excessive radial force variations. ● **SEE FIGURE 110–20**.

LATERAL RUNOUT

WHY CHECK A possible problem that tires can cause is a type of vibration called **shimmy**, which is the rapid back-and-forth motion transmitted through the steering linkage to the steering wheel. Excessive lateral runout is usually noticeable by the driver of the vehicle as a side-to-side vibration, especially at low speeds between 5 and 45 mph (8 and 72 km/h). Shimmy can be caused by an internal defect of the tire or a bent wheel.

CHECKING LATERAL RUNOUT This can be checked by using a runout gauge on the side of the tire or wheel. Place the runout gauge against the side of the tire and rotate the wheel. Observe the readings.

- Most manufacturers specify a maximum lateral runout of 0.035 inch (0.9 mm) for alloy wheels and 0.045 inch (1.1 mm) for steel wheels. ● **SEE FIGURE 110–21**.

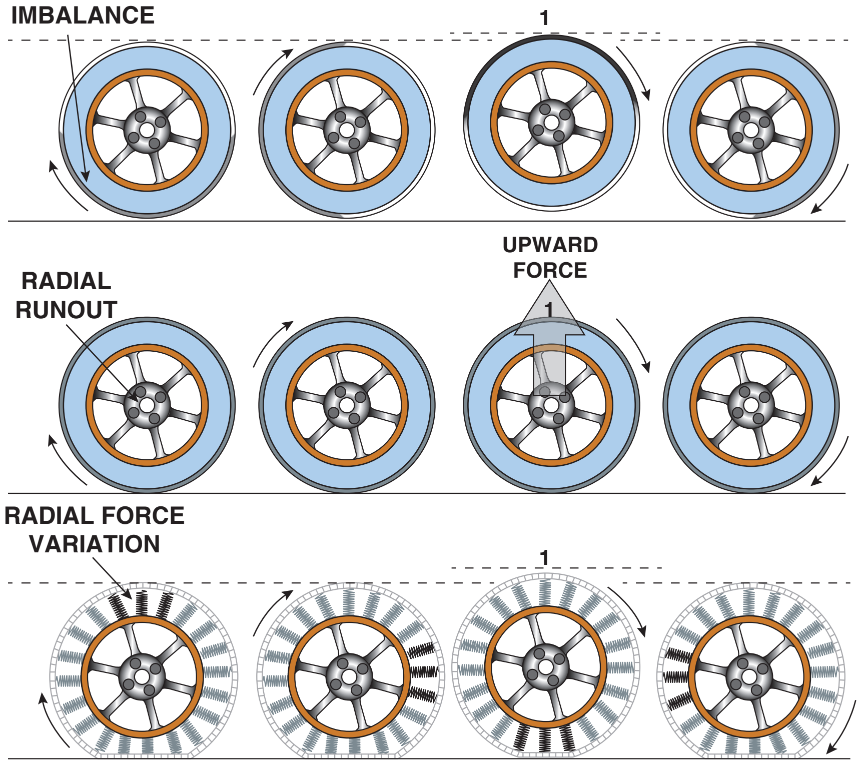


FIGURE 110–20 Out-of-balance causes the wheel/tire to move vertically as it rotates causing a tramp-type vibration. Excessive radial runout also causes a tramp-type vibration. Excessive radial force variation (RFV) can cause a vibration due to the varying stiffness of the tire carcass.

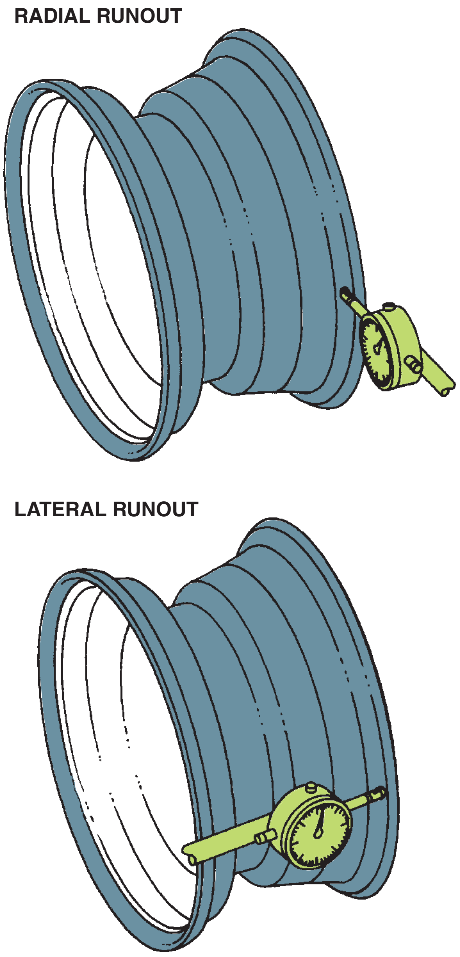


FIGURE 110–21 The most accurate method of measuring wheel runout is to dismantle the tire and take dial indicator readings on the inside of the wheel rim.

CORRECTING LATERAL RUNOUT Excessive lateral runout may be corrected by one of several methods:

Method **#1—**Re-torque the wheel in the proper star pattern to the specified torque. Unequal or uneven wheel torque can cause excessive lateral runout.

Method **#2—**Remove the wheel and inspect the wheel-mounting flange for corrosion or any other reason that could prevent the wheel from seating flat against the brake rotor or drum surface.

Method **#3—**Check the condition of the wheel or axle bearings. Looseness in the bearings can cause the wheel to wobble.

TIRE REPLACEMENT

REMOVING WHEEL/TIRE ASSEMBLY When removing a wheel from a vehicle for service, perform the following steps:

STEP 1 Check the operation of the tire-pressure monitoring system (TPMS) sensor using a handheld tester before removing the wheel so the customer can be warned about a defective sensor before the wheels are removed from the vehicle.

STEP 2 Make certain that the wheel has a good, clean metal-to-metal contact with the brake drum or rotor. Grease, oil, or dirt between these two surfaces could cause the wheel lug nuts to loosen while driving.

TIRE REMOVAL FROM THE WHEEL Tire removal from a wheel procedure includes the following steps:

STEP 1 Before the tire can be removed from the wheel, the air must be removed by removing the valve core. Removing the valve core allows the air to escape.

TECH TIP

Spin the Tires

When performing a vehicle inspection and the vehicle has been hoisted on a frame-type lift, check the tires by rotating them by hand. The tires on the non-drive wheels should spin freely.

- On front-wheel-drive vehicles, rear wheels should rotate easily.
- On rear-wheel-drive vehicles, front wheels should rotate easily.
- On all-wheel-drive vehicles, all four wheels may require effort to rotate.

What to Look For?

- When rotating the wheels, look at the tires from the front or rear and check that the tread of the tires does not change or look as if the tread is moving inward or outward. If the tread is moving, this indicates an internal fault with the tire and it should be replaced. This type of fault can cause a vibration even though the tire/wheel assembly has been correctly balanced.
- Look from the side of the vehicle as the wheel/tire assembly is being rotated. Look carefully at the tread of the tire and see if the tire is round. If the tire is out of round, the tread will appear to move up and down as the tire is being rotated.

TECH TIP

Think Like a Wheel

When mounting directional tires, keep in mind which direction the wheels will be rotating when the vehicle is moving forward.

- When looking at the right side of the vehicle, the wheels will be rotating in a clockwise direction.
- When looking at the left side of the vehicle, the wheels will be rotating counterclockwise.

STEP 2 After the air has been removed from the tire, the beads are broken from both sides. Use caution when working on a wheel that has TPMS so as to not harm the sensor. Position the valve stem 90 degrees away from the bead breaker shovel to protect the sensor.

STEP 3 Remove the tire from the rim following the tire machine instructions for proper use.

INSTALLING NEW TIRES

STEP 1 Clean the wheel flange (seat bead) of any dirt, scale, corrosion, or loose or flaked rubber buildup prior to mounting the tire to insure of a proper seal. ● **SEE FIGURE 110–22.**

STEP 2 Install the tire-pressure monitoring system in the specified position. ● **SEE FIGURE 110–23.**

STEP 3 Many tires have been marked with a paint dot or sticker. ● **SEE FIGURE 110–24.** This mark represents the largest diameter (high point) and/or stiffest portion of the tire. This variation is due to the overlapping of carcass and belt fabric layers, as well as tread and sidewall rubber splices. The tire should

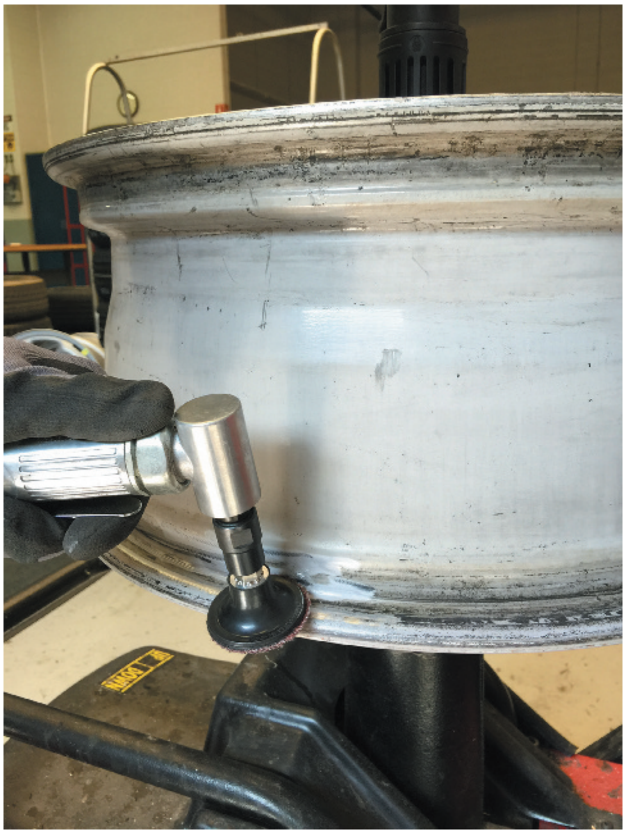


FIGURE 110–22 Cleaning the bead seat of an alloy wheel using an abrasive pad.

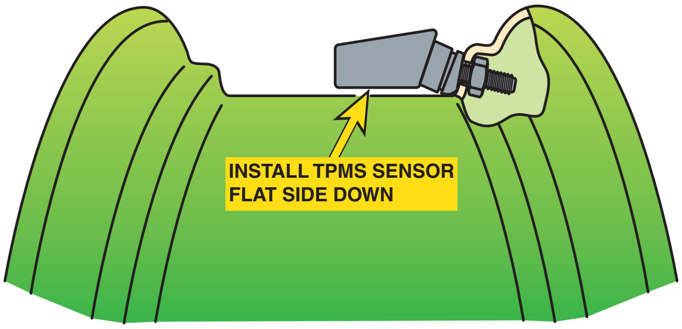


FIGURE 110–23 When installing a tire-pressure monitoring system sensor, be sure that the flat part of the sensor is parallel to the center section of the rim.

TECH TIP

Dispose of Old Tires Properly

Old tires cannot be thrown out in the trash but instead must be disposed of properly. Tires cannot be buried because they tend to come to the surface. They also trap and hold water, which can be a breeding ground for mosquitoes. Used tires should be sent to a local or regional recycling center where the tires will be ground up and used in asphalt paving or other industrial uses. Because there is often a charge to dispose of old tires, it is best to warn the customer of the disposal fee.

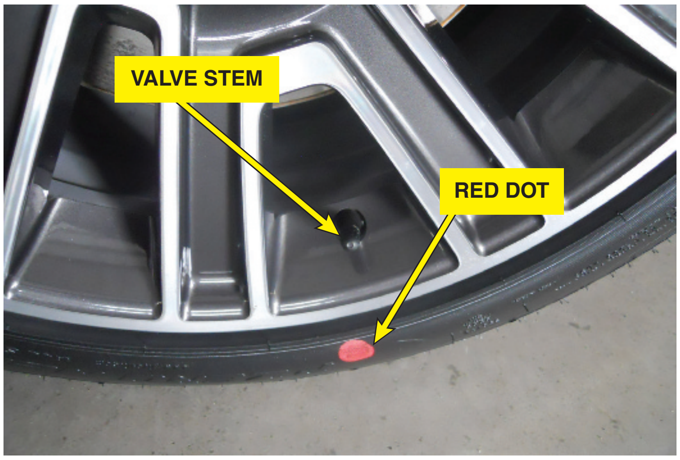


FIGURE 110–24 Many new tires have painted dots placed there at the tire manufacturer. Yellow Dot Indicates the light (static) balance point of the tire. Red Dot Indicates the "radial force variation first harmonic maximum." If a tire has both red and yellow dots, the red dot has priority so ignore the yellow dot. Match the yellow dot to the wheel valve stem if no red dot. Just remember "red rules." If any other color of dot is seen, ignore them as they are used for factory purposes only.

be mounted to the rim with this mark lined up with the valve stem.

- The valve stem hole is typically drilled at the smallest diameter (low point) of the wheel.
- The major splice is usually at the largest diameter of the tire.
- On steel rims, align the mark on the tire with the dimple on the rim (if used). This is called **match mounting**. ● **SEE FIGURE 110–25**.

STEP 4 Check for directional and asymmetric tires.

- Directional tires have the direction of rotation arrow on the sidewall of the tire.

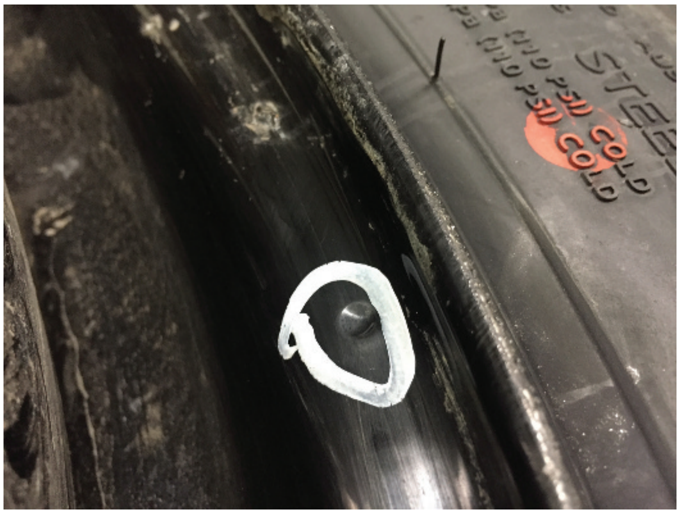


FIGURE 110–25 Most steel wheels are not as round as alloy wheels that are machined as part of the production process. Look for a "dimple" on the steel wheel and align the red dot of the tire with this dimple when match mounting tires on steel wheels. If there is no dimple, align the red dot with the valve stem.

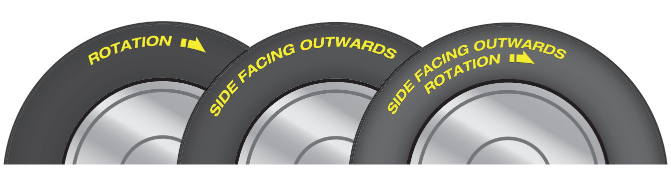


FIGURE 110–26 Always check the wording on tires and install them correctly to insure that the tire performs as designed.

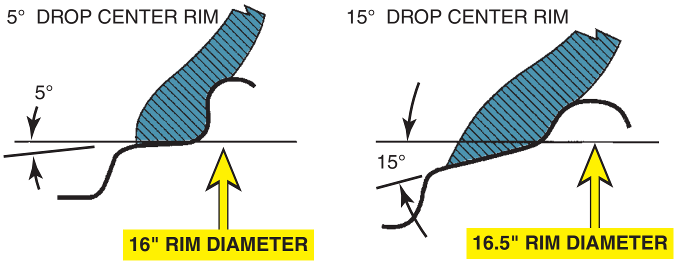


FIGURE 110–27 Note the difference in the shape of the rim contour of the 16 inch and 16 1/2 inch diameter wheels. While it is possible to mount a 16 inch tire on a 16 inch rim, it cannot be inflated enough to seat against the rim flange. If an attempt is made to seat the tire bead by overinflating (over 40 PSI), the tire bead can break, resulting in an explosive force that could cause serious injury or death.

- Asymmetric tires have sidewall lettering indicating which side of the tire has to face outward.
- Directional and asymmetric tires have "side facing outwards" and a rotation arrow showing the direction of rotation when the vehicle is traveling forward. ● **SEE FIGURE 110–26**.

CAUTION: Always check the rim size. For example, simply by looking, it is hard to distinguish a 16 inch wheel from a 16.5 inch wheel used on some older trucks. The rim size is marked on the sidewall of the tire, and the rim's diameter and width are stamped somewhere on the wheel. ● SEE FIGURE 110–27.

STEP 5 When mounting new tires, use only special lubricant such as rendered (odorless) animal fat or rubber lubricant to help prevent tire rotation on the rim. This rubber lube is a water-based soap product that is slippery when wet (coefficient of friction when less than 0.3) and acts almost as an adhesive when dry (coefficient of friction when dry of over 0.5 for natural products and over 1.0 for synthetic products). ● **SEE FIGURE 110–28**.

STEP 6 Inflate the tire but never use more than 40 PSI (275 kPa) to seat a tire bead.

NOTE: Many experts recommend that when a new tire is installed, the vehicle should be driven at less than 50 mph (80 km/h) for the first 50 miles (80 km) to allow the tires to adhere to the rim. During this break-in period, the rubber lube used to mount the tire is drying and the tire is becoming fully seated on the rim. By avoiding high speeds, rapid acceleration, and fast braking, the driver is helping to prevent the tire from rotating on the rim.

FIGURE 110–28 Rendered (odorless) animal fat is recommended by some manufacturers of tire changing equipment for use as a rubber lubricant.

TIRE BALANCING

PURPOSE Proper tire balance is important for tire life, ride comfort, and safety. Tire balancing is needed because of the lack of uniform weight and stiffness (due to splices) and a combination of wheel runout and tire runout. While balancing a tire can compensate for most of these conditions, if a tire or wheel is excessively out of round or bent, then replacement of the wheel or tire is required.

STATIC BALANCE The term *static balance* means that the weight mass is evenly distributed around the axis of rotation. For example:

- If a wheel is spun and stops at different places with each spin, then the tire is statically balanced.
- If the static balance is not correct, wheel tramp-type (vertical up and down shake) vibration and uneven tire wear can result.

DYNAMIC BALANCE The term *dynamic balance* means that the centerline of weight mass is in the same plane as the centerline of the wheel. ● **SEE FIGURE 110–29**.

- Dynamic balance must be checked while the tire and the wheel are rotated to determine side-to-side as well as up-and-down out of balance.
- Incorrect dynamic balance causes shimmy. Shimmy-type vibration causes the steering wheel to shake from side to side.

Computer tire balance machines balance tires for both static and dynamic balance at the same time.

PREBALANCE CHECKS Before attempting to balance any tire, the following should be checked and corrected to ensure good tire balance:

1. Check the wheel bearing adjustment for looseness or wear.
2. Check the radial runout.
3. Check the lateral runout.
4. Remove stones from the tread.

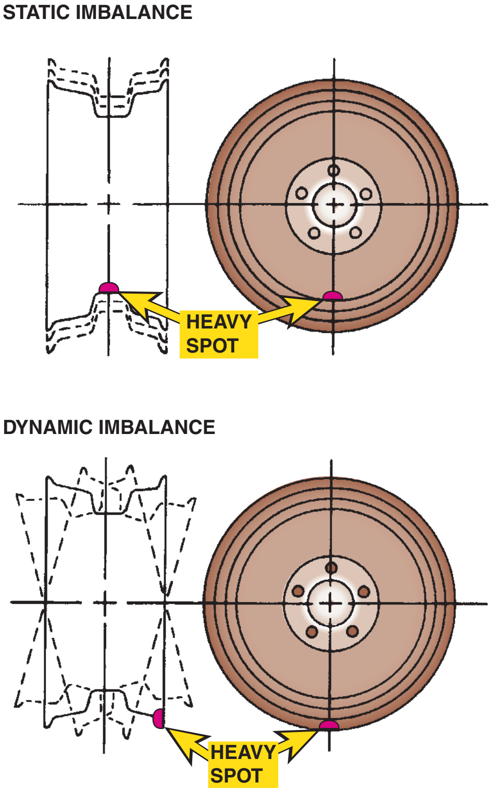


FIGURE 110–29 A wheel balancer detects heavy spots on the wheel and tire, and indicates where to place weight to offset both static and dynamic imbalance.

5. Remove grease or dirt buildup on the inside of the wheel.
6. Check for dragging or misadjusted brakes.
7. Check for loose or backward lug nuts.
8. Check for proper tire pressures.
9. Remove all of the old weights.
10. Check for bent or damaged wheel covers.

WHEEL WEIGHTS

PURPOSE AND FUNCTION The purpose and function of wheel weights is to correct any imbalance that can normally occur in a tire/wheel assembly. This imbalance can cause the wheels to hop when rotating causing a vibration that is felt by the driver in the steering wheel, and often the entire vehicle, especially if the rear wheels are out of balance.

WHEEL WEIGHT MATERIALS Lead was the most common material used for wheel weights until the early 2000s when they started to be phased out due to environmental concerns of lead on the ground from lost wheel weights.

Wheel balancing materials include

- **Lead** (chemical symbol PB)—being phased out (stick-on and clip-on designs)
- **Zinc** (chemical symbol ZN)—(stick-on and clip-on designs)
- **Steel** (chemical symbol FE)—(stick-on and clip-on designs)
- **Thermoplastic Polypropylene**—high specific gravity plastic (stick-on only)

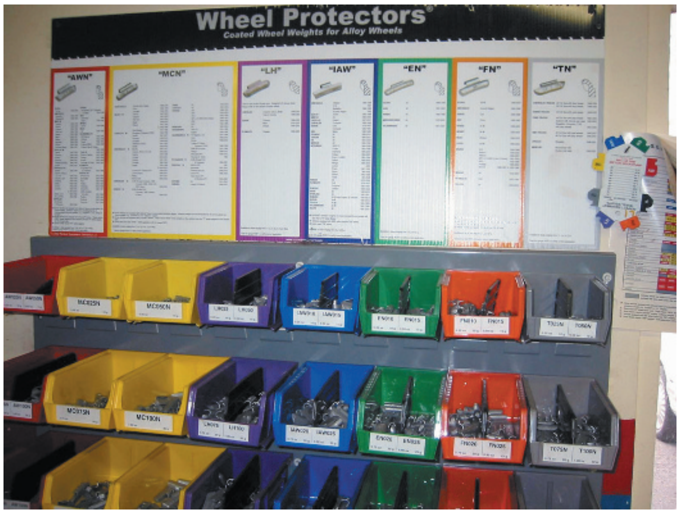


FIGURE 110–30 An assortment of wheel weights designed to fit different shaped rims.

Steel wheel weights are usually coated with a nylon or polyester-type material that often matches the color of the aluminum wheels to prevent rust and corrosion of the steel.

CLIP-ON WHEEL WEIGHTS Clip-on wheel weights must match the flange of the rim to fit properly. Use wheel weight pliers to help ensure proper installation and removal of wheel weights. ● **SEE FIGURE 110–30**.

FREQUENTLY ASKED QUESTION

Does "MC" Mean "Most Cars"?

Maybe. MC is the wheel flange shape that is used on most domestic alloy rims. The next most popular shape is "AW," which is used on older GM, Ford, and Chrysler alloy rim and then "FN" which is used on many Acura, Honda, Nissan, and Toyotas since about 1990. To be sure, always use a rim flange gauge to determine the exact shape before using clip-on wheel weights. ● **SEE FIGURE 110–31**.

● **SEE CHART 110–2** for the wheel rim flange shape for most vehicles.

STICK-ON WHEEL WEIGHTS Adhesive (stick-on) wheel weights are used on the inside of the rim where they do not show. Stick-on weights come with an adhesive backing that is most often used on alloy wheels. ● **SEE FIGURES 110–32 AND 110–33**.

Most wheel weights come in 1/4 ounce (0.25 oz.) increment (oz. × 28 = grams). ● **SEE CHART 110–3** for a conversion between ounces and grams.

Use wheel weight pliers to help ensure proper installation and removal of wheel weights.

VEHICLE MAKE	WHEEL FLANGE CODE
Acura	FN
Audi	EN
BMW	IAW
Buick	MC
Cadillac	MC (most)
Chevrolet	MC (except for import brands)
Chrysler	LH or MC (depending on model and year)
Dodge	LH or MC (depending on model and year)
Ford	MC or IAW (depending on model and year)
Honda	FN
Hummer	MC
Hyundai	IAW or MC (depending on model and year)
Isuzu	MC
Jaguar	IAW
Jeep	MC
Kia	IAW
Land Rover	IAW
Lexus	FN
Lincoln	MC
Mazda	MC or FN (depending on model and year)
Mercedes-Benz	EN
Mercury	MC
Mini	IAW
Mitsubishi	IAW or MC (depending on model and year)
Nissan/Infiniti	FN
Oldsmobile	MC
Plymouth	LH or MC (depending on model and year)
Pontiac	MC—except Vibe (FN)
Porsche	Stick-on only
RAM	LH or MC (depending on model and year)
Saab	IAW
Saturn	MC
Scion	FN
Smart	IAW
Subaru	IAW or MC or FN (depending on model and year)
Suzuki	IAW or MC or FN (depending on model and year)
Toyota	FN
Volkswagen	EN
Volvo	IAW

CHART 110–2

Wheel weight flange code chart for alloy wheels. Steel wheels require "P series" for passenger cars or "T-series" for truck wheel weights deigned to fit the rim of steel wheels. Use a flange shape gauge before selecting the clip-on weights to make sure that they are correct for the vehicle.

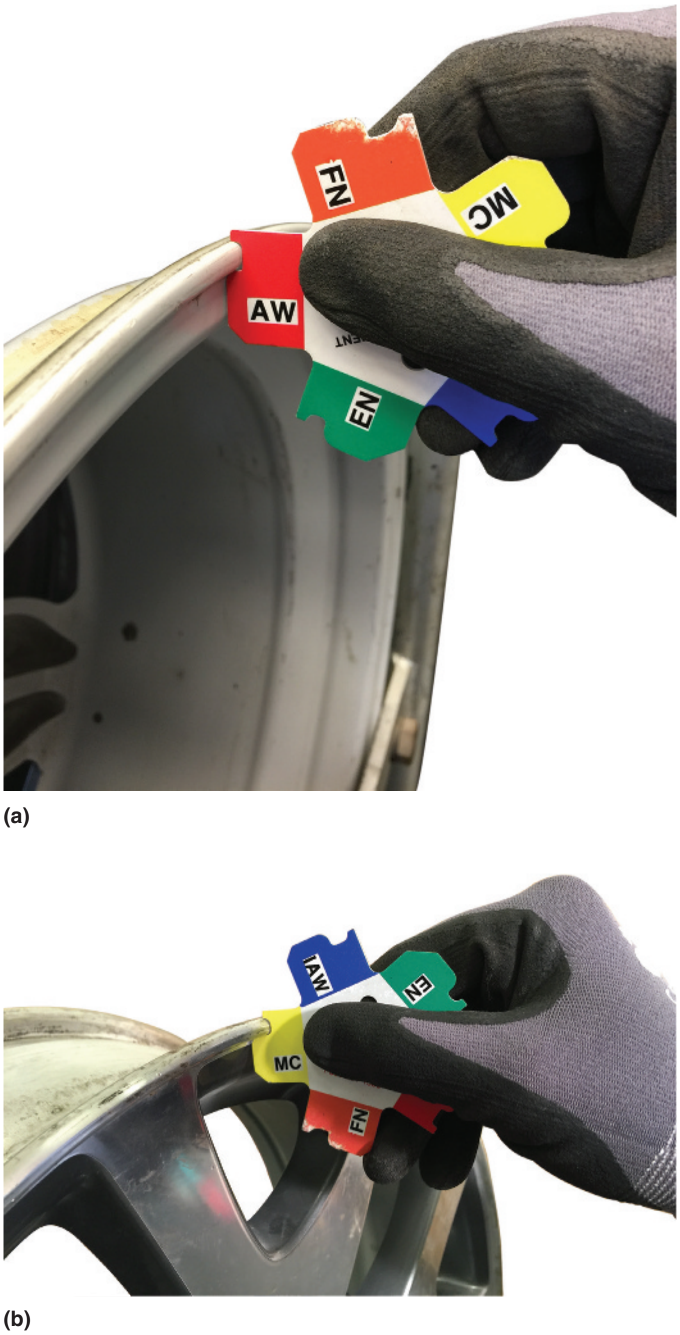


FIGURE 110–31 (a) Using a rim gauge can be a little tricky as the shape may appear to match several patterns on the rim gauge. This "AW" shape is not a good match. (b) Using the gauge shape for "MC" appears to be a perfect match to their rim flange.

FREQUENTLY ASKED QUESTION

How Much Is Too Much Weight?

Whenever balancing a tire, it is wise to use as little amount of weight as possible. For most standard-size passenger vehicle tires, most experts recommend that no more than 5.5 ounces of total weight be added to correct an imbalance condition. If more than 5.5 ounces total or more than 3 ounces on either side is needed, remove the tire from the wheel (rim) and carefully inspect for damage to the tire or the wheel. If the tire still requires more than 5.5 ounces and the wheel is not bent or damaged, replace the tire.

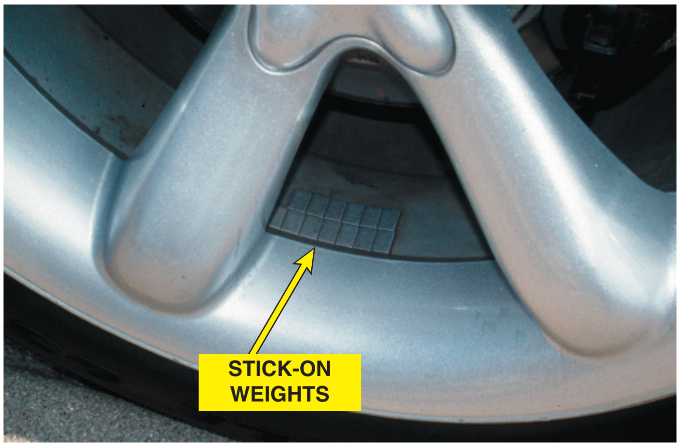


FIGURE 110–32 Stick-on weights are used from the factory to balance the alloy wheels of this vehicle.

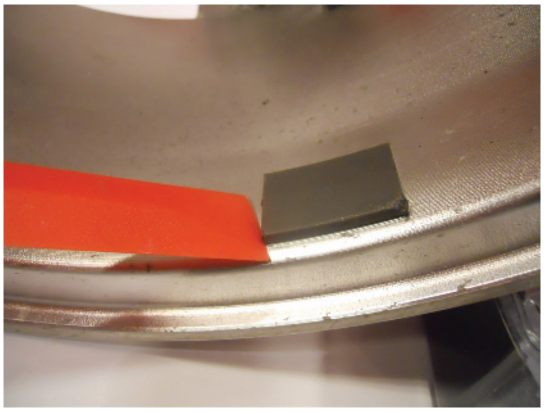


FIGURE 110–33 3M high density Polypropylene plastic wheel weighs are an excellent choice to use instead of lead wheel weighs and can be used on any type of wheel using one part number.

OUNCES (OZ.)	GRAMS (GM)
0.25	7
0.50	14
0.75	21
1.00	28
1.25	35
1.50	42
1.75	49
2.00	56
2.25	63
2.50	70
2.75	77
3.00	84

CHART 110–3

Ounces to grams conversion chart.

WHEEL/TIRE BALANCERS

BUBBLE BALANCER A bubble balancer is portable and can be easily stored away when not in use. It is also easy to use and is relatively inexpensive but not as accurate as a professional tire balancing machine.

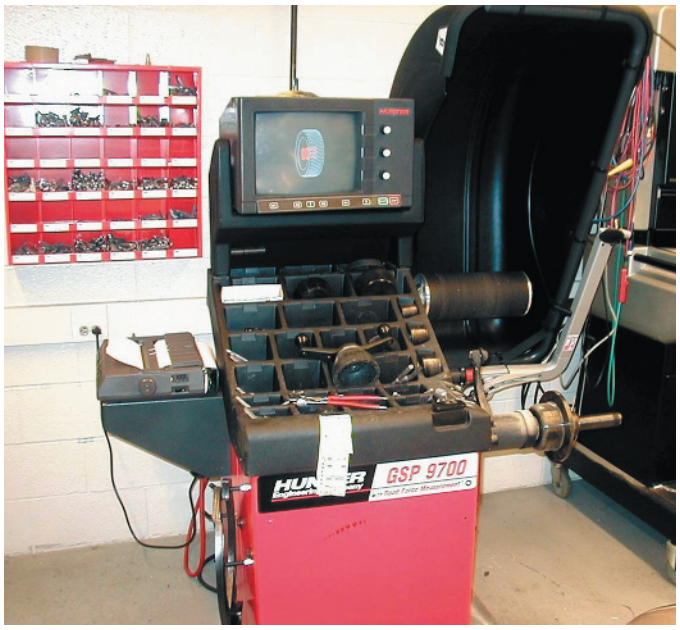


FIGURE 110–34 A tire balancer that can also detect radial and lateral force variation and instruct the operator where to rotate the tire to achieve the best ride, or indicate a bent wheel.

COMPUTER BALANCER The most popular type of tire balancer is the computer dynamic balancer. Computer balancers are designed to balance wheels and tires off the vehicle. Computer dynamic balancers spin the tire at a relatively slow speed (approximately 20 mph). Sensors attached to the spindle of the balancer determine the amount and location of weights necessary to balance the tire statically and dynamically. All computer balancers must be programmed with the actual rim size and tire location for the electronic circuits to calibrate the required weight locations. Some computer balancers can perform loaded radial force and lateral force variation testing on the tire/wheel assembly and display corrective actions. ● **SEE FIGURE 110–34**.

Most computer balancers will be accurate to within 1/4 ounce (0.25 oz.), while some are accurate to within 1/8 ounce

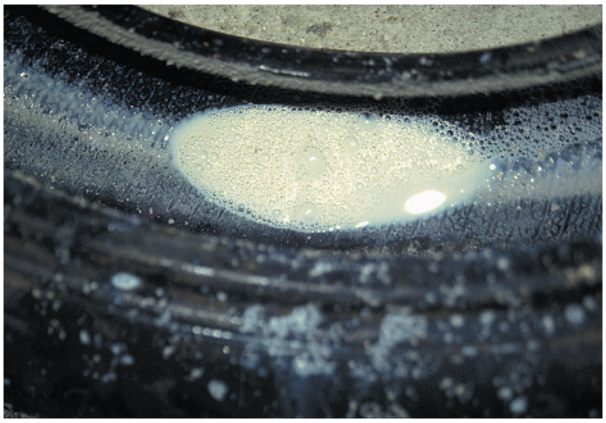


FIGURE 110–35 Liquid tire stop leak was found in all four tires. This liquid caused the tires to be out of balance.

FREQUENTLY ASKED QUESTION

When Are Pin Plates Used When Tire Balancing?

Pin plates are often specified to attach a chrome clad wheel to the tire balancers to insure an accurate balance. The chrome cladding is not removable or replaceable and has cladding tabs that extend into the wheel bore. Traditional high-taper cones will come into contact with the cladding tabs rather than properly seat on the hub bore chamfer. Many recent aluminum wheel designs cannot be mounted with traditional cones.

Most vehicle manufacturers recommend using a pin plate clamping method as the only way to properly center and protect clad wheels during the balance process. Most balance manufacturers have clad wheel packages along with standard cone mounting. Some national tire chains use only pin plates when balancing any wheel because they get better results and it eliminates some operator influence when using a cone in the center bore. ● **SEE FIGURE 110–36**.

CASE STUDY

The Vibrating Ford Van

A technician was asked to solve a vibration problem on a rear-wheel-drive Ford van. During a test-drive, the vibration was felt everywhere—the dash, the steering wheel, the front seat, the shoulder belts; everything was vibrating! The technician balanced all four tires on a computer balancer. Even though wheel weights were put on all four wheels and tires, the vibration was even worse than before. The technician rebalanced all four wheels time after time, but the vibration was still present. The shop supervisor then took over the job of solving the mystery of the vibrating van. The supervisor balanced one wheel/tire assembly and then tested it again after installing the weights. The balance was way off! The supervisor broke the tire down and found about 1 quart (1 liter) of liquid in each tire! No wonder the tires couldn't be balanced! Every time the tire stopped, the liquid would settle in another location. The customer later admitted to using a tire stop-leak liquid in all four tires. Besides stop leak, another common source of liquid in tires is water that accumulates in the storage tank of air compressors, which often gets pumped into tires when air is being added. All air compressor storage tanks should be drained of water regularly to prevent this from happening. ● **SEE FIGURE 110–35**.

Summary:

Complaint—Customer complained of a vibration.
Cause—The technician found stop leak liquid in all four tires.
Correction—The stop leak was removed from all the tires and then they were rebalanced. The vibration issues were corrected.

CAUTION: Stop leak should never be used in a tire that is equipped with the TPMS sensor because the sensor can be damaged.

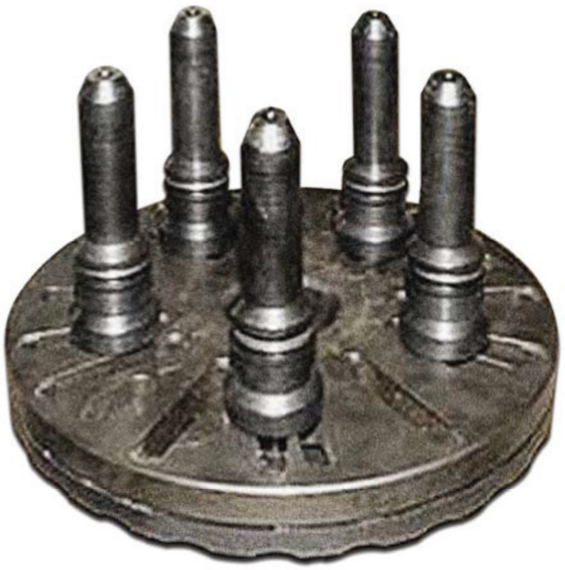


FIGURE 110–36 A pin plate adapter that is designed to support the wheel/tire assembly on a tire balancer instead of using a centering cone.

FREQUENTLY ASKED QUESTION

What Are Hubcentric Wheels?

Most wheels are designed to fit over and be supported by the axle hub. Some wheels use an enlarged center hub section and rely on the wheel studs for support and to keep the wheel centered on the axle. Some aftermarket wheels may be designed to fit several different vehicles. As a result, the wheel manufacturers use plastic hubcentric adapter rings.
● **SEE FIGURE 110–37**.

(0.125 oz.). (Most drivers can feel an out of balance of 1 oz or more, but few can feel a vibration caused by just 1/4 oz.) For sensitive drivers or vehicles used for high speeds, such as racing, most computer balancers can be programmed to balance within 1/8 ounce (0.125 oz.). Refer to the manufacturer's instructions for the exact capabilities and procedures for the balancer being used.

TIRE REPAIR

ACCEPTABLE LOCATION Tread punctures, nail holes, or cuts up to 1/4 inch (2.6 mm) can be repaired only within the tire repair area. ● **SEE FIGURE 110–38**.

Repairs should be done from the inside of the tire using plugs or patches. The tire should be removed from the rim to make the repair. With the tire off the wheel, inspect the wheel and the tire for hidden damage.

TIRE REPAIR PROCEDURE The proper steps to follow for a tire repair are as follows:

STEP 1 Mark the location of the tire on the wheel.

STEP 2 Dismount the tire and use caution around the tire-pressure monitoring system (TPMS) pressure sensor.

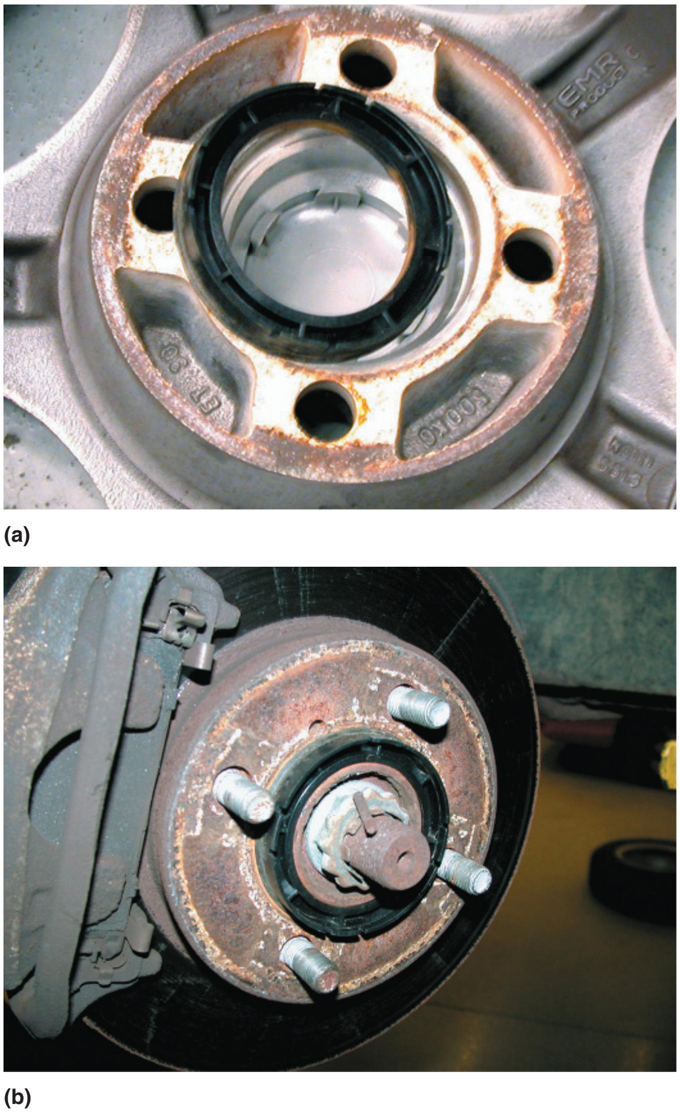


FIGURE 110–37 (a) A hubcentric plastic ring partially removed from an aftermarket wheel. (b) A hubcentric plastic ring left on the hub when removing a wheel.

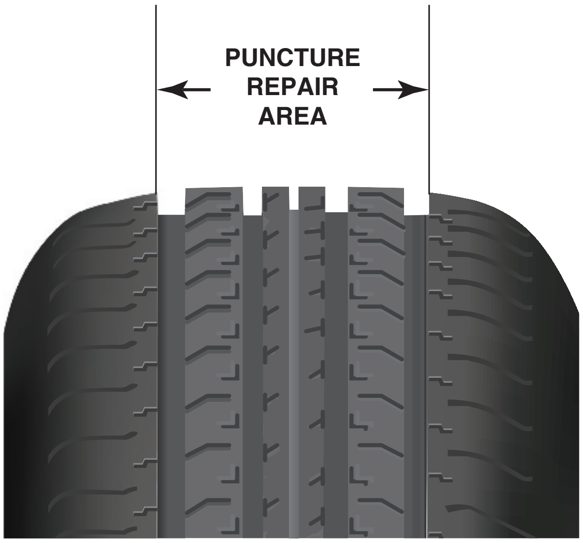


FIGURE 110–38 A tire should only be repaired if the hole is within the tire puncture repair area. Do not make a repair that is located in the shoulder or belt edge part of the tire. If a tire is punctured outside of the area, the tire will require replacement.

WARNING

Most experts agree that tire repairs should be done from the inside. Many technicians have been injured and a few killed when the tire they were repairing exploded as a steel reamer tool was inserted into the tire. The reamer can easily create a spark as it is pushed through the steel wires of a steel-belted tire. This spark can ignite a combustible mixture of gases inside the tire caused by using stop leak or inflator cans. Since there is no way a technician can know if a tire has been inflated with a product that uses a combustible gas, always treat a tire as if it could explode.

STEP 3 Inspect and clean the punctured area with a pre-buff cleaner. DO NOT USE GASOLINE!

STEP 4 Buff the cleaned area with sandpaper or a tire-buffing tool until the rubber surface has a smooth, velvet finish.

STEP 5 Ream the puncture with a fine reamer from the inside. Cut and remove any loose wire material from the steel belts.

STEP 6 Fill the puncture with contour filling material, and cut or buff the material flush with the inner liner of the tire.

STEP 7 Apply chemical vulcanizing cement and allow to dry until it is no longer sticky.

STEP 8 Apply the patch and use a stitching tool from the center toward the outside of the patch to work any air out from between the patch and the tire. ● **SEE FIGURE 110–39**.

Another excellent tire repair procedure uses a rubber plug. Pull the stem through the hole in the tire, as shown in ● **FIGURE 110–40**.

STEP 9 Remount the tire on the rim, aligning the marks made in step 1. Inflate to the recommended pressure and check for air leaks.

STEP 10 Balance the wheel before reinstalling it on the vehicle.

NOTE: Most vulcanizing (rubber) cement is highly flammable. Use out of the area of an open flame. Do not smoke when making a tire repair. There are many tire repair products on the market. Always follow the installation and repair procedures exactly per the manufacturer's instructions.

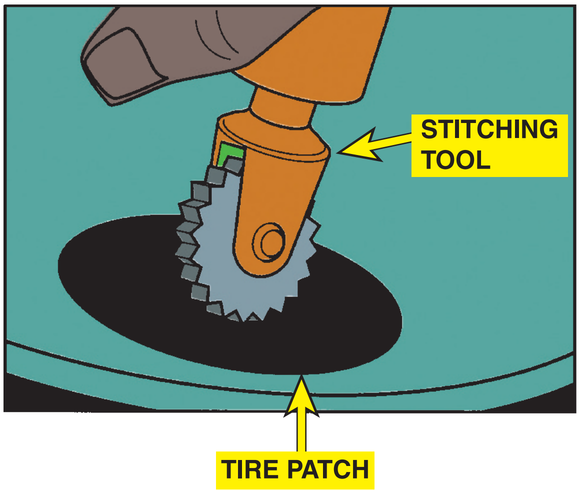


FIGURE 110–39 A stitching tool being used to force any trapped air out from under the patch.

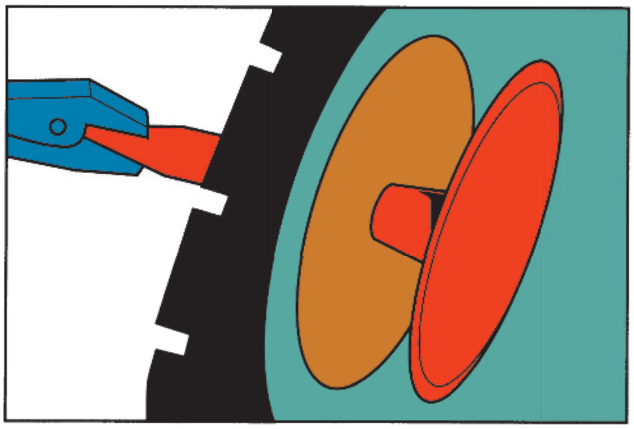


FIGURE 110–40 A rubber plug being pulled through a hole in the tire. The stem is then cut off flush with the surface of the tire tread.

TECH TIP

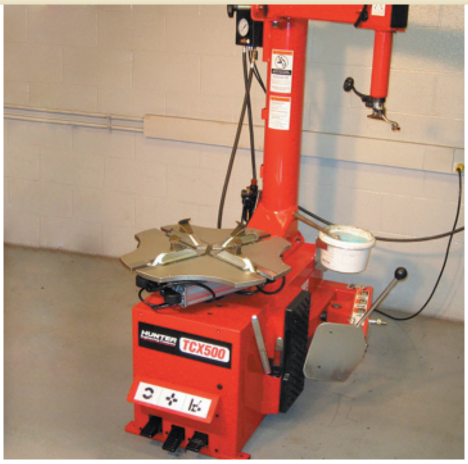
Open-End Wrenches Make It Easier

Tire repair is made easier if two open-end wrenches are used to hold the beads of the tire apart. See step 4 in the tire repair photo sequence.

TIRE MOUNTING

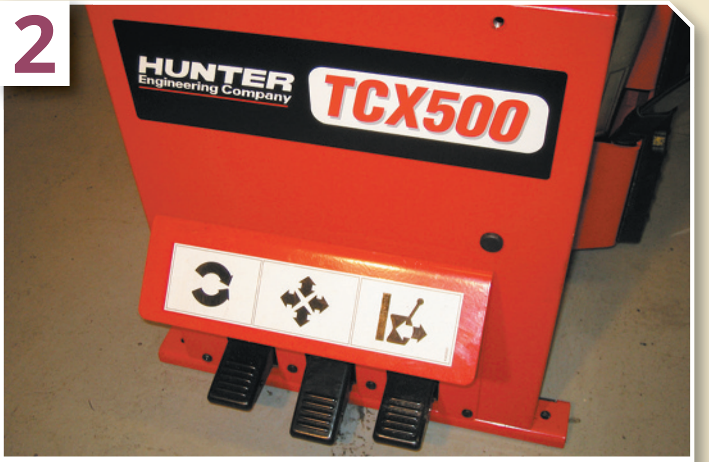
STEP BY STEP

1



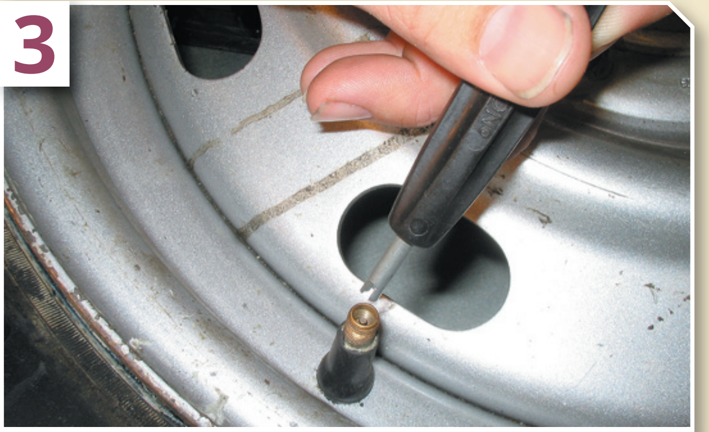
A typical tire-changing machine showing the revolving table and movable arm used to remove a tire from the wheel.

2



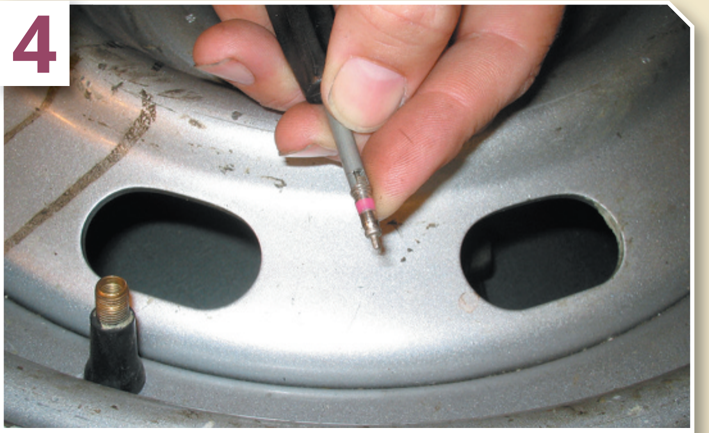
The foot-pedal controls allow the service technician to break the tire bead, damp the wheel (rim) to the machine, rotate the tire/wheel assembly, and still have both hands free.

3



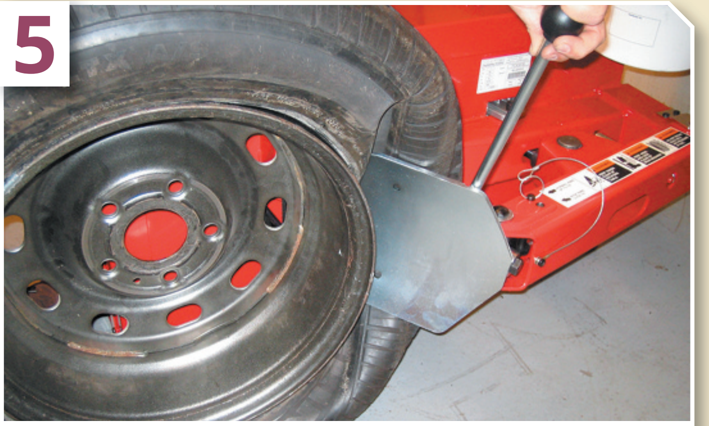
Using a tire valve removal tool, unscrew the valve core using extreme caution because the valve is under pressure and can be forced outward and cause personal injury.

4



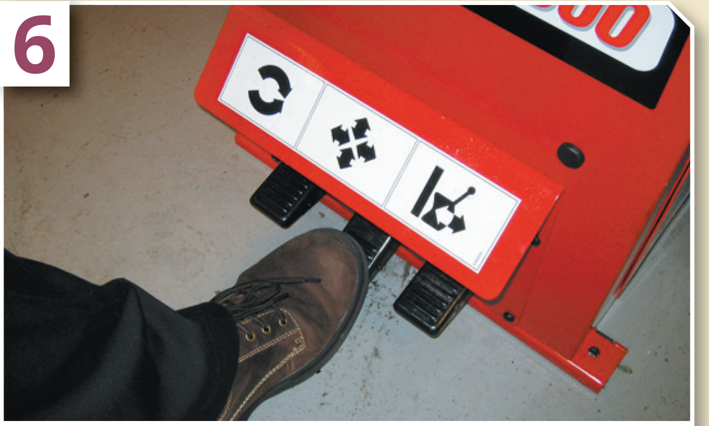
The valve core removed from the tire valve. Allow all of the air in the tire to escape.

5



A bead breaker is being used to separate the tire from the bead seat of the wheel. Repeat as needed to break the bead on both sides of the wheel.

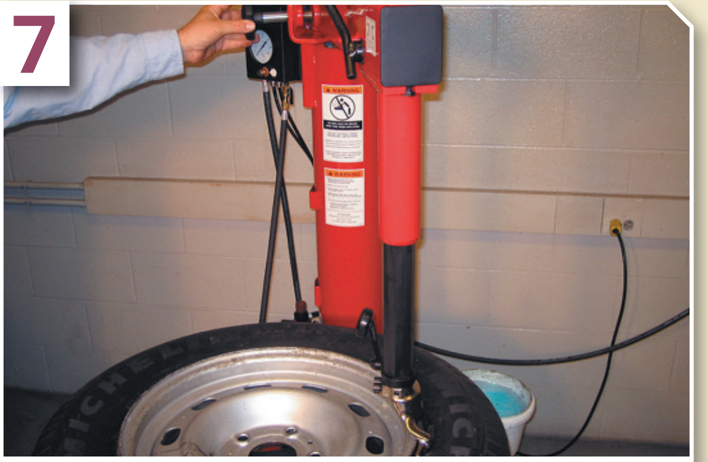
6



After breaking the beads from both sides of the tire, install the wheel/tire assembly flat onto the machine and, using the foot-pedal control, lock the wheel to the changer.

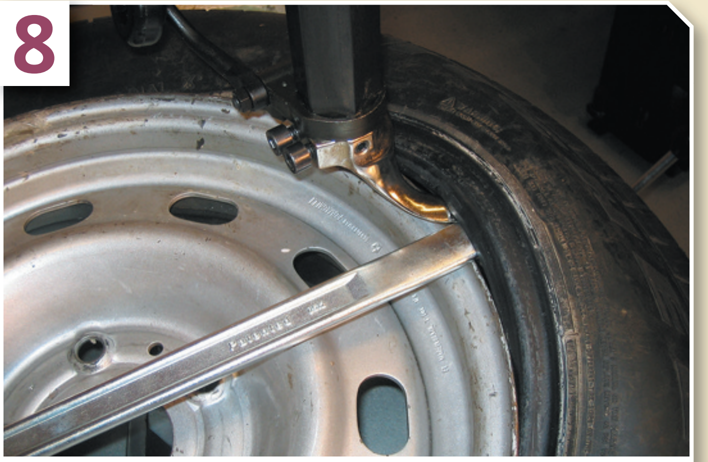
TIRE MOUNTING

7



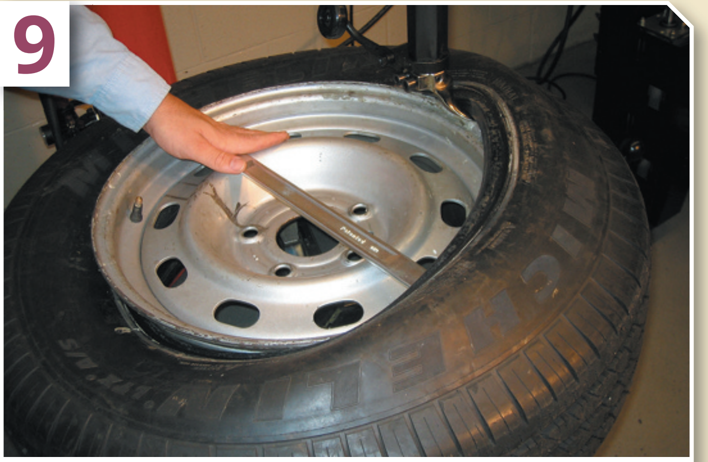
To remove the tire from the wheel, position the arm of the changer against the rim of the wheel and lock in position.

8



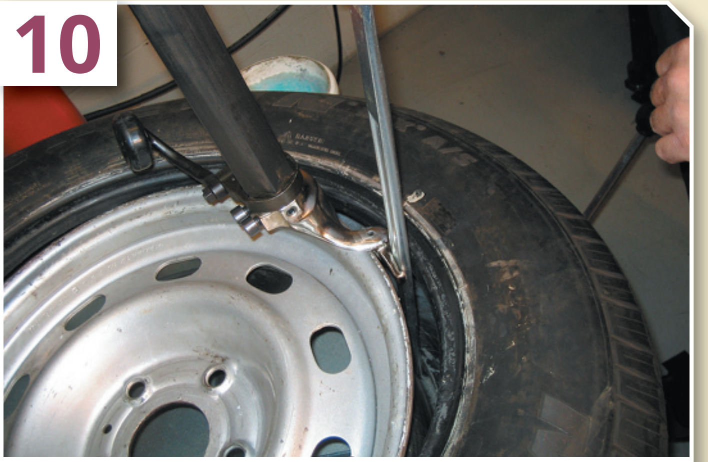
The tire tool (flat bar) is placed between the bead of the tire and the wheel. Using tire lubricant can help prevent damage to the tire.

9



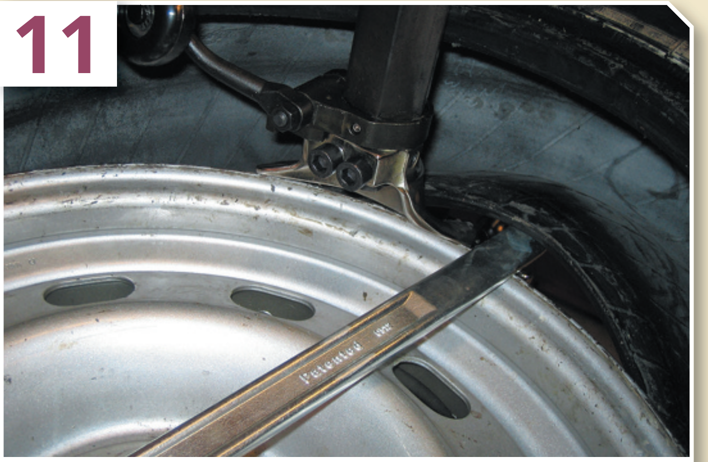
The foot-pedal that causes the table to rotate is depressed and the tire is removed from the wheel.

10



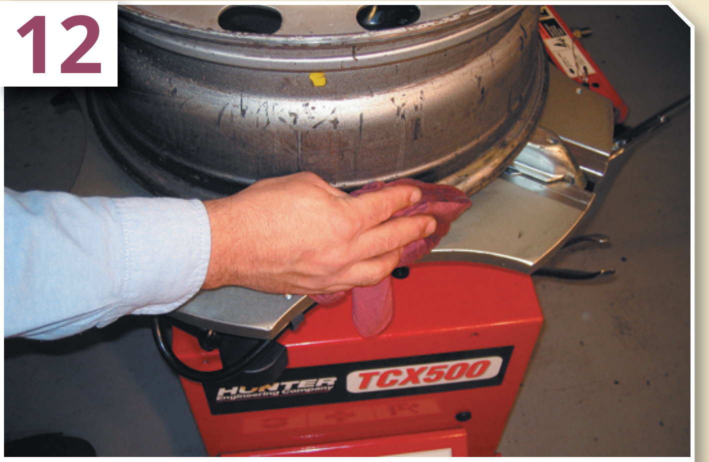
Reposition the tire tool to remove the lower bead of the tire from the wheel.

11



As the table of the tire changer is rotated, the tire is released from the wheel and can be lifted off the wheel.

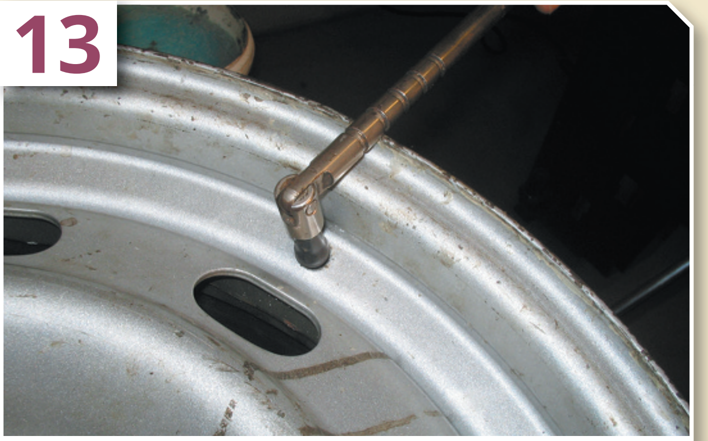
12



Before installing a tire, inspect and clean the bead seat.

STEP BY STEP

13

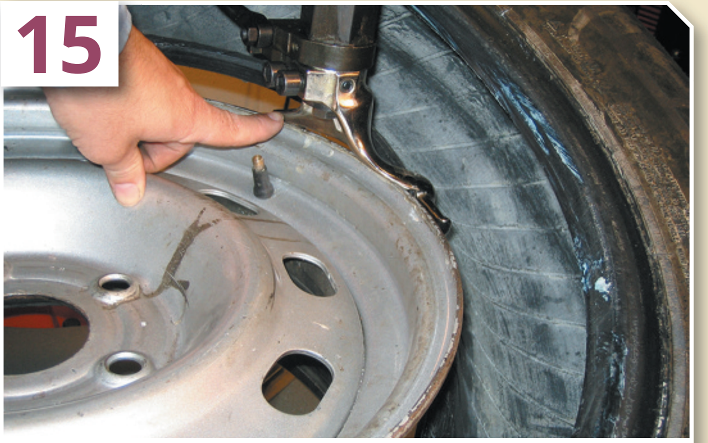


Before installing a new tire, most experts recommend replacing the tire valve, being installed here, using a tool that pulls the valve through the hole in the wheel.

14

Apply tire soap or rubber lubricant to both beads of the tire.

15



Rotate the tire on the wheel and position the arm so that the tire will be guided onto the rim as the wheel is rotated.

16

Repeat for the upper bead.

17

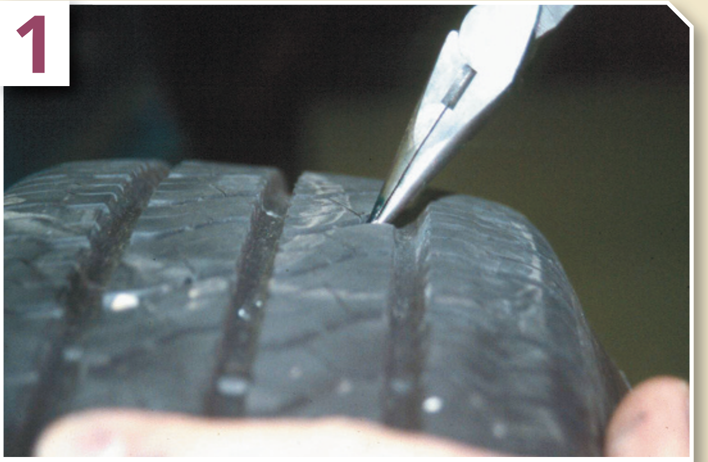
Inflate the tire, being careful to not exceed 40 PSI. Experts suggest that a tire be in a cage during the initial bead seating inflation to help prevent personal injury if the wheel or tire fails.

18

Install the tire valve core and inflate the tire to specifications.

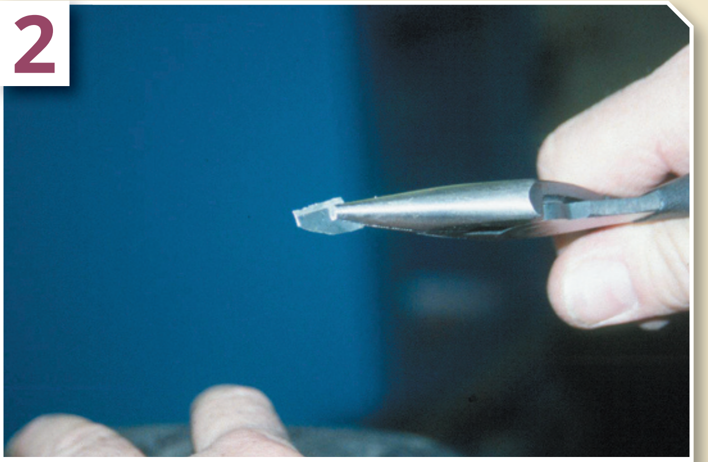
TIRE REPAIR

1



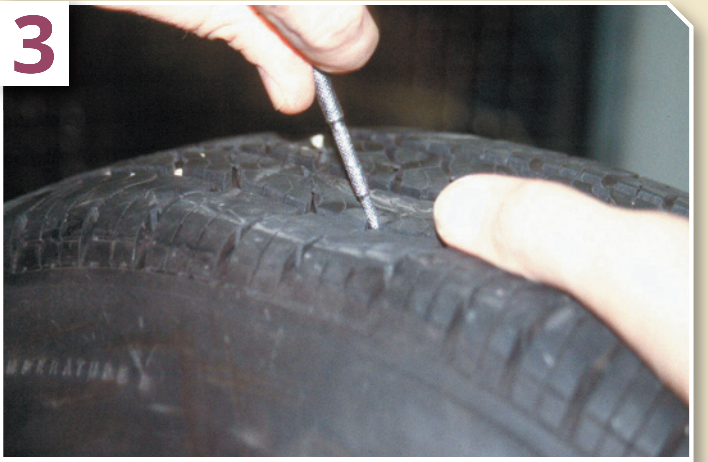
The source of the leak was detected by spraying soapy water on the inflated tire. Needle-nose pliers are being used to remove the object that caused the flat tire.

2



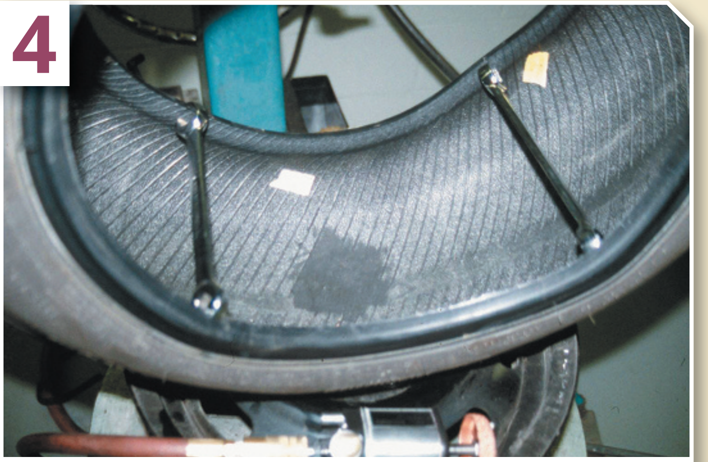
A part of a razor blade was found to be the cause of the flat tire.

3



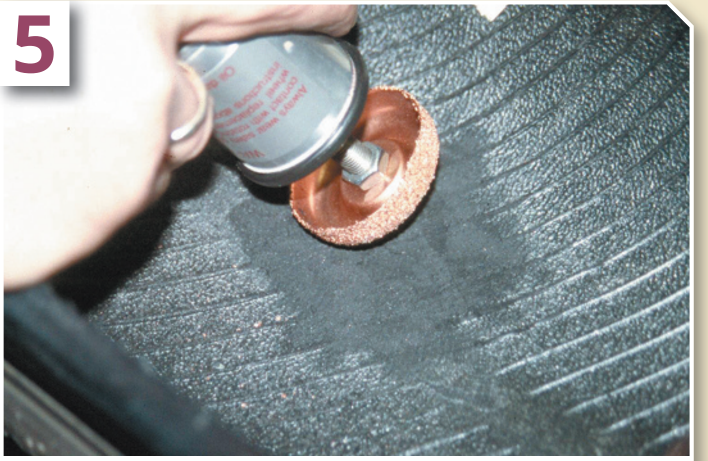
A reamer is being used to clean the puncture hole.

4



This technician is using two open-end wrenches to hold the tire beads apart if a tire bead spreader is not available.

5



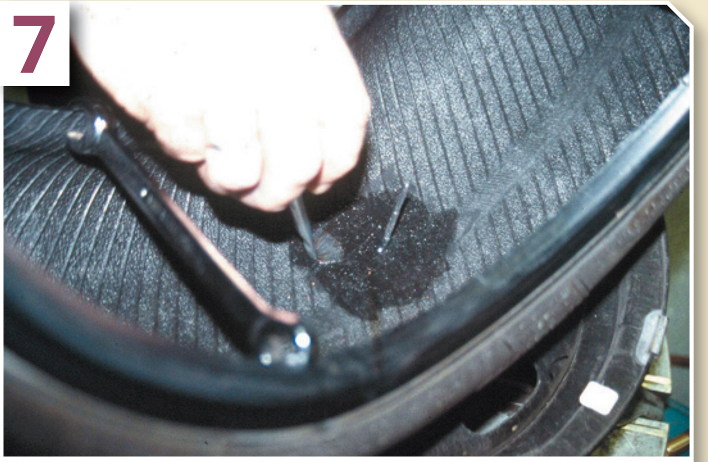
The surrounding area is being buffed using an air-powered die grinder equipped with a special buffing tool specifically designed for this process.

6

CAL CEMENT
patches, cold patches, boots and inserts
⚠ DANGER
EXTREMELY FLAMMABLE
Read warning on back panel

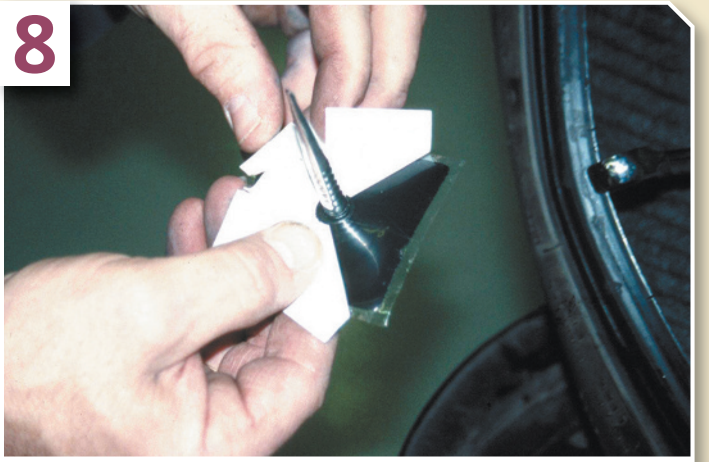
After using a vacuum on all debris and rubber after buffing, apply rubber cement to the area.

7



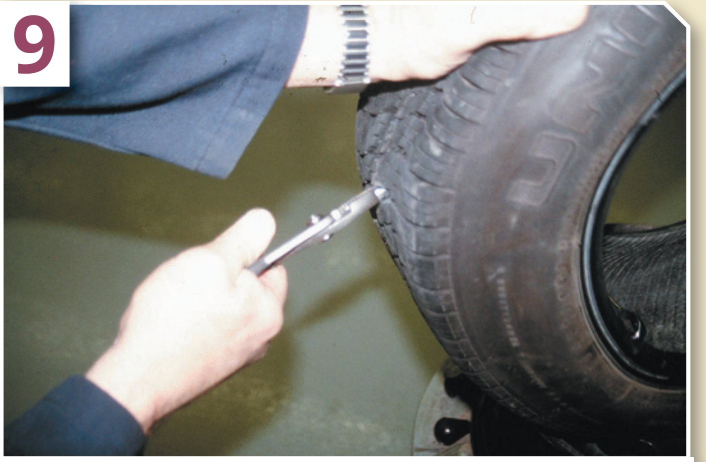
The brush included with the rubber cement makes the job easy. Be sure to cover the entire area around the puncture.

8



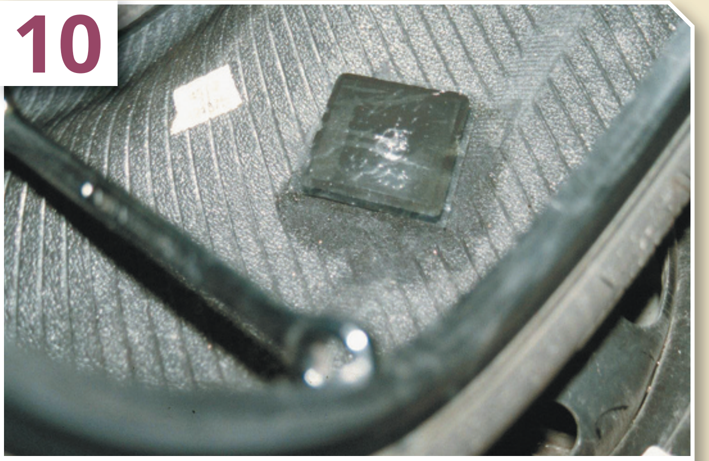
Peel off the paper from the adhesive on the patch. Insert the tip of the patch through the puncture from the inside of the tire.

9



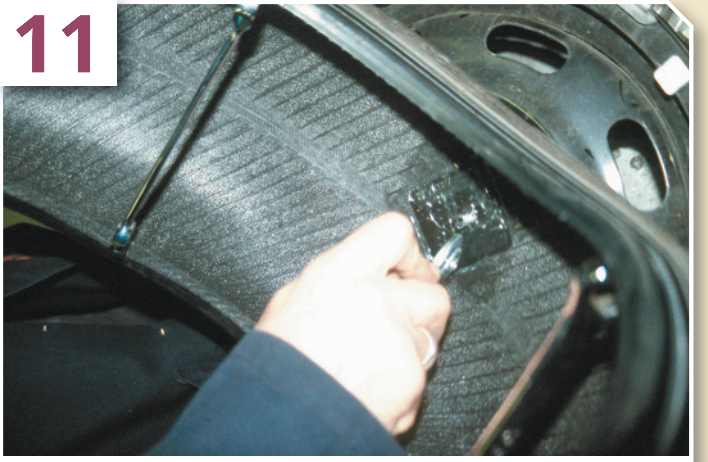
Use a pair of pliers to pull the plug of the patch through the puncture.

10



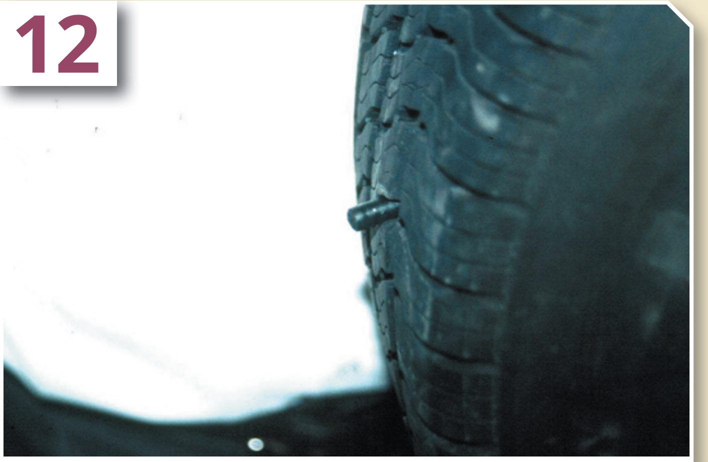
This view of the patch is from the inside of the tire.

11



To be assured of an airtight patch, the adhesive of the patch should be "stitched" to the inside of the tire using a serrated roller called a stitching tool.

12



A view of the plug from the outside of the tire after metal covering used to pierce the puncture is removed from the patch plug. The plug can be trimmed to the level of the tread using side cutters or a knife.

REVIEW QUESTIONS

1. What are the precautions and recommendations regarding tire maintenance?
2. What are the most commonly used tire rotation methods?
3. How are lateral and radial runout of wheels and tires checked?
4. What is the difference between static and dynamic balance?
5. Why is a pin plate used on some wheels when attaching it to a balancer?

CHAPTER QUIZ

1. Proper tire inflation pressure information is found ___________.
   a. on the driver's door or post
   b. under the hood on the VECI sticker
   c. on the sidewall of the tire
   d. Both a and b
2. A tire is worn excessively on both edges. The most likely cause of this type of tire wear is ___________.
   a. overinflation
   b. underinflation
   c. excessive radial runout
   d. excessive lateral runout
3. Lug nuts should be evenly tightened in a(n) ___________ pattern.
   a. linear
   b. star
   c. opposing
   d. random
4. Tire replacement involves all of the following except ___________.
   a. remove the air from the tire
   b. remove the TPMS sensor from the wheel
   c. remove the tire from the rim (wheel)
   d. install the tire on the rim (wheel)
5. Using the modified X method of tire rotation on a front-wheel-drive vehicle, where should the left front wheel be placed?
   a. Right front
   b. Right rear
   c. Left rear
   d. Left front
6. Which statement is *false*?
   a. Excessive radial runout can cause a tramp-type vibration.
   b. Excessive lateral runout can cause a tramp-type vibration.
   c. A tire out of balance dynamically can cause a shimmy-type vibration.
   d. A tire out of balance statically can cause a tramp-type vibration.
7. When seating a bead of a tire, never exceed ___________ PSI.
   a. 30
   b. 40
   c. 50
   d. 60
8. When balancing a tire/wheel assembly, what should the technician do?
   a. Use the proper contour wheel weights.
   b. Set up the tire balancer machine with the location of the wheel as well as the diameter and width.
   c. Clean the rim flange.
   d. All of the above
9. A vehicle vibrates at highway speed. Technician A says that water in the tire(s) could be the cause. Technician B says that an out-of-round tire could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A tire has a nail in the shoulder area. What should the technician do?
    a. Replace the tire.
    b. Repair the tire with a double patch.
    c. Repair the tire with a rubber plug.
    d. Install an inner tube.

Chapter 111

SUSPENSION SYSTEM COMPONENTS AND OPERATION

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss vehicle frames.
- Discuss vehicle platforms.
- Discuss types of suspensions.
- Define Hooke's law.
- Explain how coil springs work.
- Explain how leaf springs work.
- Explain how torsion bars work.
- Explain suspension principles and the components of a suspension system.
- Describe how shock absorbers work.
- Discuss how struts work.
- Describe the function of bump stops.

KEY TERMS:

Air spring 1362 • Anti-dive 1354 • Anti-squat 1354 • Ball joints 1357 • Bulkhead 1347 • Bump stop 1366 • Center bolt 1351 • Coil springs 1348 • Composite leaf spring 1352 • Control arms 1356 • Cradle 1345 • Full frame 1345 • GVW 1346 • Hooke's law 1347 • Independent suspension 1347 • Insulators 1350 • Kingpin 1356 • Ladder frame 1345 • Lateral links 1354 • Leaf springs 1350 • Load-carrying ball joint 1357 • Mono leaf 1351 • Non-load-carrying ball joint 1357 • Perimeter frame 1345 • Platforms 1346 • Rebound clips 1351 • Shackles 1351 • Shock absorbers 1359 • Space frame 1346 • Spring pocket 1350 • Spring rate 1348 • Springs 1347 • Stabilizer bars 1358 • Steering knuckles 1356 • Stress riser 1350 • Strut rods 1358 • Struts 1364 • Stub-type frame 1345 • Torsion bar 1353 • Unit-body 1345 • Wheel rate 1350

FRAME CONSTRUCTION

TERMINOLOGY Frame construction usually consists of channel-shaped steel beams welded and/or fastened together. The frame of a vehicle supports all the "running gear" of the vehicle, including the engine, transmission, rear axle assembly (if rear-wheel drive), and all suspension components.

This frame construction, referred to as **full frame**, is so complete that most vehicles can usually be driven without the body. Most trucks and larger rear-wheel-drive cars use a full frame.

LADDER FRAME A **ladder frame** is a common name for a type of perimeter frame where the transverse (lateral) connecting members are straight across. ● **SEE FIGURE 111–1**. When viewed with the body removed, the frame resembles a ladder. Most pickup trucks are constructed with a ladder-type frame.

PERIMETER FRAME A **perimeter frame** consists of welded or riveted frame members around the entire perimeter of the body. This means that the frame members provide support underneath the sides as well as for the suspension and suspension components. ● **SEE FIGURE 111–2.**

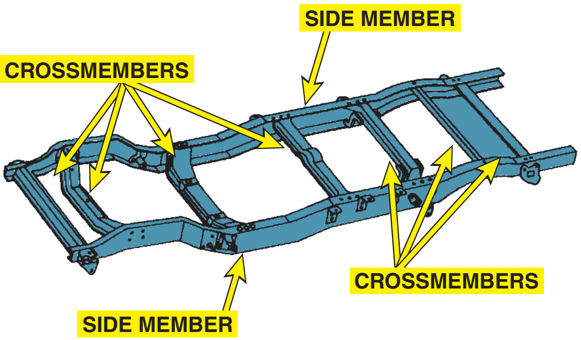


FIGURE 111–1 A typical truck frame is an excellent example of a ladder-type frame. The two side members are connected by crossmembers.

STUB-TYPE FRAMES A **stub-type frame** is a partial frame often used on unit-body vehicles to support the power train and suspension components. It is also called a **cradle** on many front-wheel-drive vehicles. ● **SEE FIGURE 111–3**.

UNIT-BODY CONSTRUCTION **Unit-body** construction (sometimes called *unibody*) is a design that combines the body with

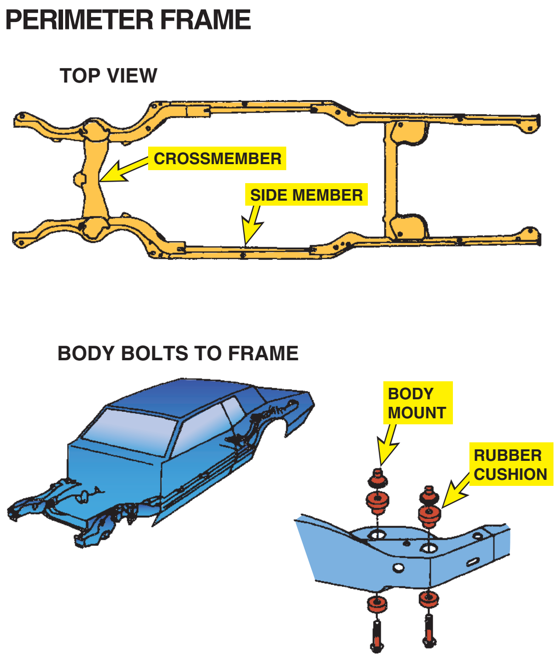


FIGURE 111–2 Rubber cushions used in Body-On-Frame (BOF) construction isolate noise and vibration from traveling to the passenger compartment.

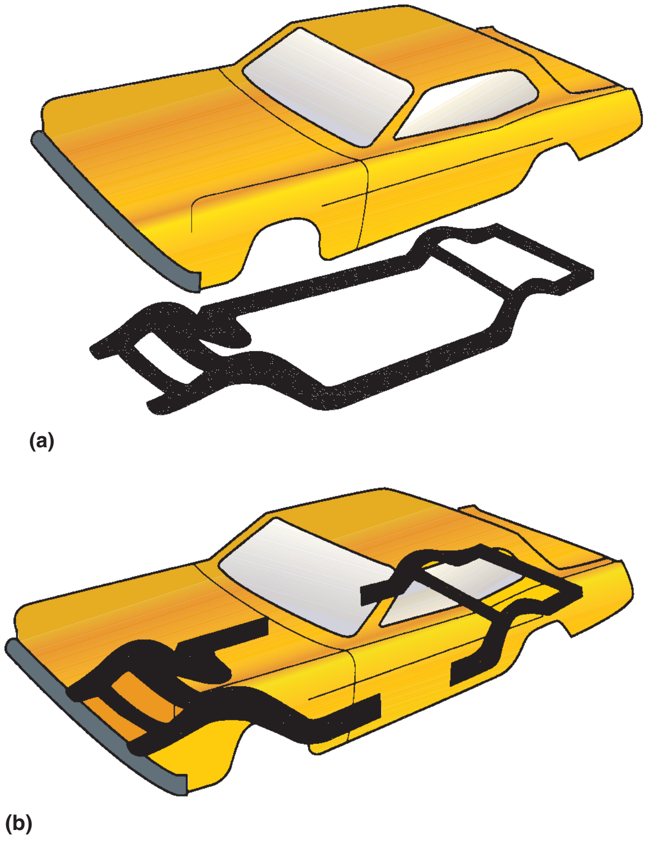


FIGURE 111–3 (a) Separate body and frame construction; (b) stub-type frame: the small frame members are for support of the engine and suspension components. Many vehicles attach the suspension components directly to the reinforced sections of the body and do not require the rear frame section.

the structure of the frame. The body supports the engine and driveline components, as well as the suspension and steering components. The body is composed of many individual stamped-steel panels welded together.

FREQUENTLY ASKED QUESTION

What Does GVW Mean?

GVW, gross vehicle weight, is the weight of the vehicle plus the weight of all passengers the vehicle is designed to carry (× 150 lb [68 kg] each), plus the maximum allowable payload or luggage load. *Curb weight* is the weight of a vehicle when *wet*, meaning with a full tank of fuel and all fluids filled, but without passengers or cargo (luggage). *Model weight* is the weight of a vehicle wet and with passengers.

The GVW is found stamped on a plate fastened to the door jamb of most vehicles. A high GVW rating does not mean that the vehicle itself weighs a lot more than other vehicles. For example, a light truck with a GVW of 6,000 lbs (2,700 kg) will not ride like an old 6,000 pound luxury car. In fact, a high GVW rating usually requires stiff springs to support the payload; these stiff springs result in a harsh ride. Often technicians are asked to correct a harsh-riding truck that has a high GVW rating. The technician can only check that everything in the suspension is satisfactory and then try to convince the owner that a harsher-than-normal ride is the result of a higher GVW rating.

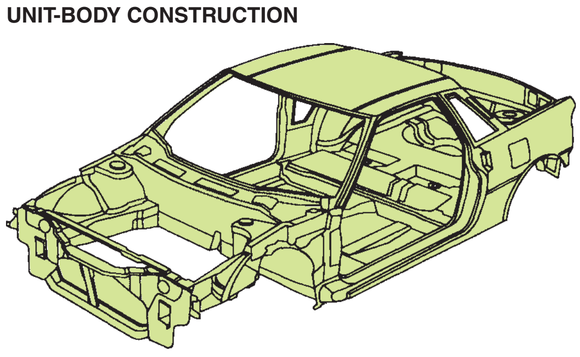


FIGURE 111–4 Welded metal sections create a platform that combines the body with the frame using unit-body construction.

The strength of this type of construction lies in the *shape* of the assembly. The typical vehicle uses 300 separate and different stamped-steel panels that are spot-welded to form a vehicle's body. ● **SEE FIGURE 111–4**.

NOTE: A typical vehicle contains about 10,000 individual parts.

SPACE FRAME CONSTRUCTION **Space frame** construction consists of formed sheet steel used to construct a framework for the entire vehicle. The vehicle is drivable without the body, which uses plastic or steel panels to cover the steel framework.

PLATFORMS

TERMINOLOGY The **platform** of any vehicle is its basic size and shape. Various vehicles of different makes can share the same platform, and therefore many of the same drivetrain (engine, transmission, and final drive components) and suspension and steering components.

A platform of a unit-body vehicle includes all major sheet-metal components that form the load-bearing structure of the vehicle, including the front suspension and engine-supporting sections. The area separating the engine compartment from the passenger compartment is called the **bulkhead**. The height and location of this bulkhead panel to a large degree determines the shape of the rest of the vehicle.

Other components of vehicle platform design that affect handling and ride are the track and wheelbase of the vehicle. *The track of a vehicle is the distance between the wheels, as viewed from the front or rear.* A wide-track vehicle is a vehicle with a wide wheel stance; this increases the stability of the vehicle, especially when cornering. *The wheelbase of a vehicle is the distance between the center of the front wheel and the center of the rear wheel, as viewed from the side.* A vehicle with a long wheelbase tends to ride smoother than a vehicle with a short one.

Examples of common platforms include the following:

1. Chevrolet Impala and Cadillac XTS
2. Toyota Camry and Lexus ES 350
3. Honda CRV and Acura RDX

TYPES OF SUSPENSIONS

Early suspension systems on old horse wagons, buggies, and older vehicles used a solid axle for front and rear wheels. ● **SEE FIGURE 111–5**. If one wheel hit a bump, the other wheel was affected, as shown in ● **FIGURE 111–6**.

Most vehicles today use a separate control-arm-type of suspension for each front wheel, which allows for movement of one front wheel without affecting the other front wheel. This type of front suspension is called **independent suspension**. ● **SEE FIGURE 111–7**.

Many rear suspensions also use independent-type suspension systems. Regardless of the design type of suspension, all suspensions use springs in one form or another.

SPRINGS A suspension **spring** serves two purposes. First, it acts as a buffer between the suspension and frame to absorb vertical wheel and suspension movement without passing it on to the frame. Second, each spring transfers part of the vehicle weight to the suspension component it rests on, which transfers it to the wheels.

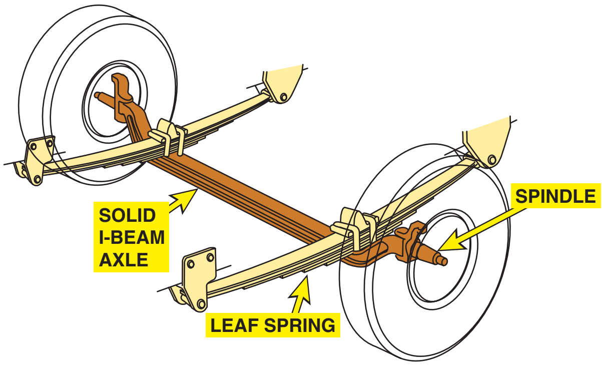


FIGURE 111–5 Solid I-beam axle with leaf springs.

The basic method by which springs absorb road shocks varies according to the type of spring. Simply stated, leaf springs flatten, coil springs and air springs compress, and torsion bars twist. What all springs have in common is that they somehow give way to absorb the vertical force of the moving wheel during jounce, then release that force during rebound as they return to their original shape and position.

SPRING MATERIALS Most springs are made of a tempered steel alloy known as spring steel, usually chrome silicon or chrome vanadium alloy. Tempering is a process of heating and cooling metal under controlled conditions, which increase the resilience of the metal. Resilience is the ability of the metal to return to, or spring back to, its original shape after being twisted or compressed.

HOOKE'S LAW

DEFINITION Regardless of type, all suspensions use springs that share a common characteristic described by **Hooke's law**. Robert Hooke (1635–1703), an English physicist, discovered the

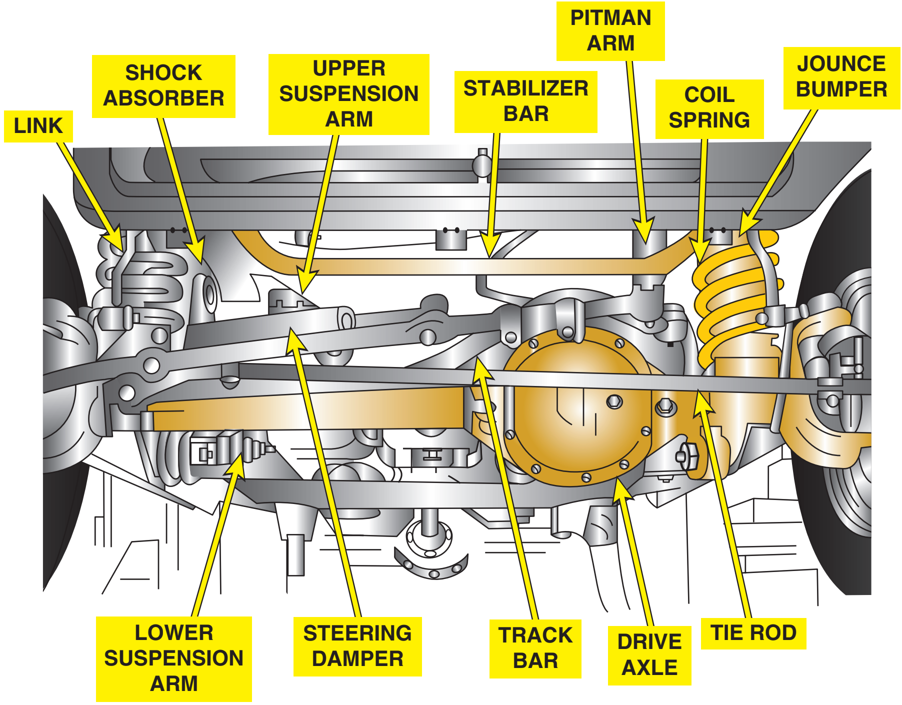


FIGURE 111–6 The front drive axle on a Jeep is a type of solid axle. When one wheel hits a bump or drops into a hole, both left and right wheels are moved. Because both wheels are affected, the ride is often harsh and feels stiff.

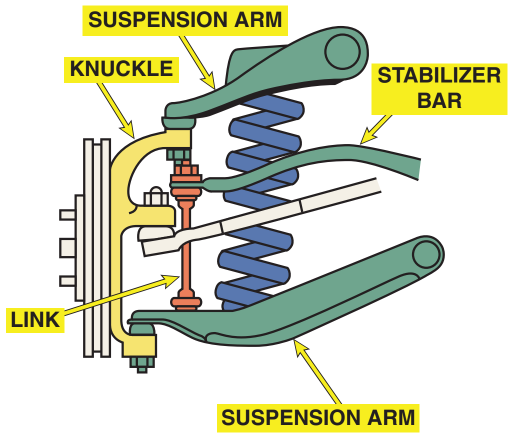

SUSPENSION ARM
KNUCKLE
STABILIZER BAR
LINK
SUSPENSION ARM

FIGURE 111–7 A typical independent front suspension used on a rear-wheel-drive vehicle. Each wheel can hit a bump or hole in the road independently without affecting the opposite wheel.

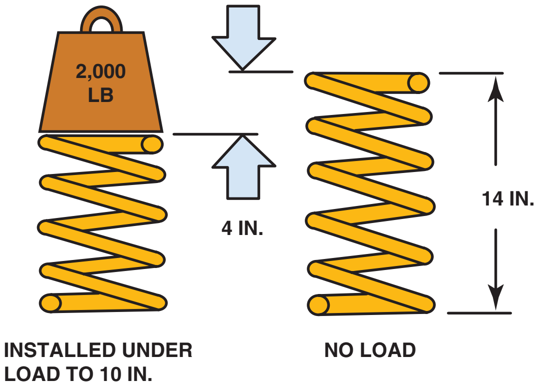

2,000 LB
4 IN.
14 IN.
INSTALLED UNDER LOAD TO 10 IN.
NO LOAD

FIGURE 111–8 This spring was depressed 4 inches due to a weight of 2,000 pounds. This means that this spring has a spring rate (*K*) of 500 pounds per inch (2,000 ÷ 4 in. = 500 lb./ in.).

force characteristics of springs: *The deflection (movement or deformation) of a spring is directly proportional to the applied force.*

What this means is that when a coil spring, for example, is depressed 1 inch, it pushes back with a certain force (in pounds), such as 400 pounds. If the spring is depressed another inch, the force exerted by the spring is increased by another 400 pounds. The **spring rate** or force constant for this spring is therefore “400 pounds per inch,” usually symbolized by the letter K. Since the force constant is the force per unit of displacement (movement), it is a measure of the stiffness of the spring. The higher the spring rate (*K*), the stiffer the spring. ● **SEE FIGURE 111–8**.

COIL SPRINGS

TERMINOLOGY **Coil springs** are made of special round spring steel wrapped in a helix shape. The strength and handling characteristics of a coil spring depend on the following:

1. Coil diameter
2. Number of coils
3. Height of spring
4. Diameter of the steel coil that forms the spring. ● **SEE FIGURE 111–9**.

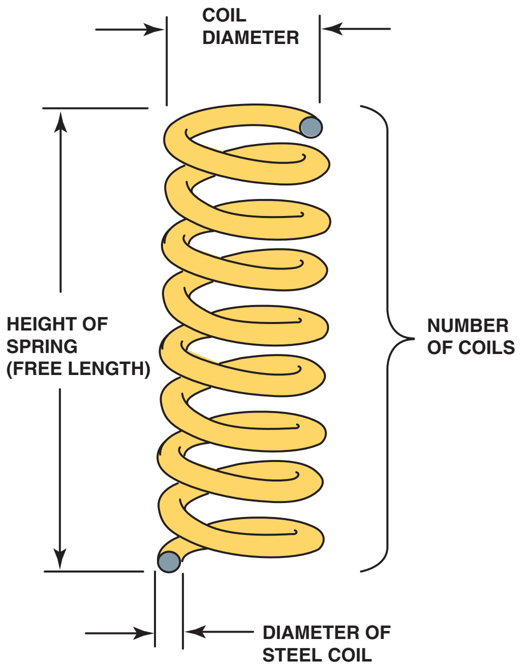

COIL DIAMETER
HEIGHT OF SPRING (FREE LENGTH)
NUMBER OF COILS
DIAMETER OF STEEL COIL

FIGURE 111–9 The spring rate of a coil spring is determined by the diameter of the spring and the diameter of the steel used in its construction, plus the number of coils and the free length (height).

The spring rate (*K*) for coil springs is expressed by the formula:

$$K = \frac{Gd4}{8ND3}$$

where

G = **11,250,000 (constant for steel)**

d = **diameter of wire**

N = **number of coils**

D = **diameter of the coil**

Coil springs are used in front and/or rear suspensions.

The larger the diameter of the steel, the “stiffer” the spring.

The shorter the height of the spring, the stiffer the spring.

The fewer the coils, the stiffer the spring.

Springs are designed to provide desired ride and handling and come in a variety of spring ends, as shown in ● **FIGURE 111–10**.

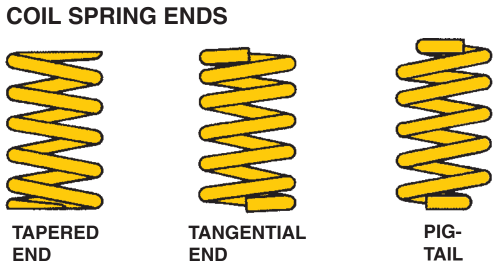

COIL SPRING ENDS
TAPERED END
TANGENTIAL END
PIG-TAIL

FIGURE 111–10 Coil spring ends are shaped to fit the needs of a variety of suspension designs.

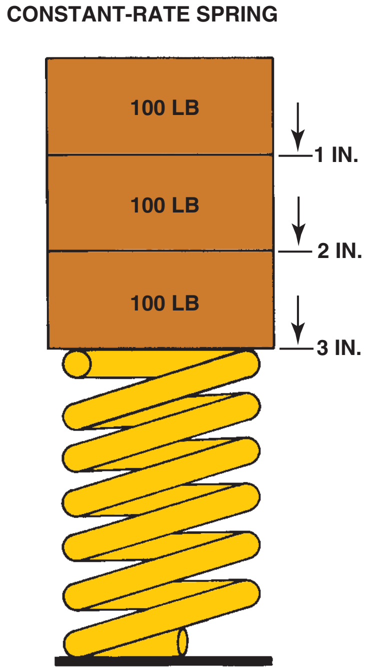


FIGURE 111–11 A constant-rate spring compresses at the same rate regardless of the amount of weight that is applied.

CAUTION: The use of spacers between the coils of a coil spring is *not* recommended because the force exerted by the spacers on the springs can cause spring breakage. When a spacer is installed between the coils, the number of coils is reduced and the spring becomes stiffer. The force exerted on the coil spring at the contact points of the spacer can cause the spring to break.

SPRING RATE Spring rate, also called *deflection rate*, is a value that reflects how much weight it takes to compress a spring a certain amount. Generally, spring rate is specified in pounds per inch, which is the weight in pounds it takes to compress the spring 1 inch. In other words, if a 100 pound weight causes a spring to compress 1 inch, the spring has a spring rate of 100 pounds.

A constant-rate spring continues to compress at the same rate throughout its complete range of deflection. For example, if a constant-rate spring compresses 1 inch under a 100 pound load, it will compress 2 inches under a 200 pound load, and so on. ● **SEE FIGURE 111–11.** Many automotive suspension springs, both coil and leaf, compress at a variable rate. That is, they become stiffer and exert more force the farther they compress. For example, a variable-rate spring may compress 1 inch under a 100 pound load, but only compress an additional 1/2 inch under a 200 pound load. Variable-rate springs offer a soft, comfortable ride under normal circumstances but will not bottom out as quickly when adverse road conditions compress them farther. ● **SEE FIGURE 111–12.**

Before a spring is installed on a vehicle or any load is placed on it, it is at its uncompressed length, or free length. Once installed, the weight of the corner of the vehicle resting on the spring is called its *static load*. The static load constantly compresses the spring. Therefore, the uncompressed length and the spring rate must be such that the spring has room to compress and keep the vehicle at the correct ride height *after* the static load is applied. ● **SEE FIGURE 111–13.**

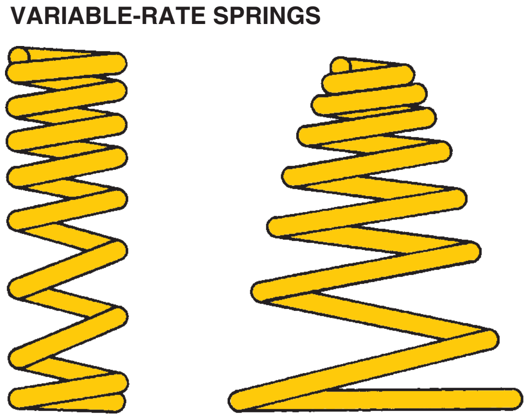


FIGURE 111–12 Variable-rate springs come in a variety of shapes and compress more slowly as weight is applied.

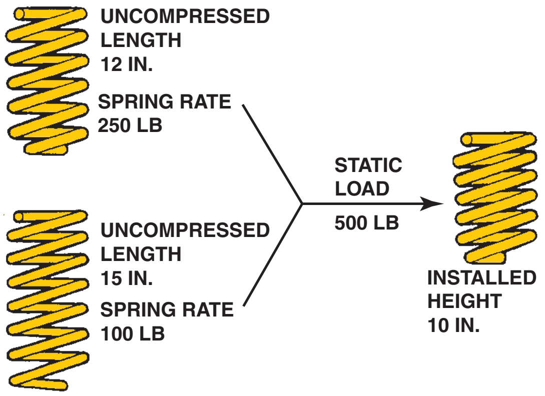


FIGURE 111–13 Two springs, each with a different spring rate and length, can provide the same ride height even though the higher rate spring will give a stiffer ride.

FREQUENTLY ASKED QUESTION

Does the Spring Rate Change as the Vehicle Gets Older?

No, the spring rate of a spring does not change, but the spring load can change due to fatigue. The spring rate is the amount of force it takes to compress the spring 1 inch. The spring load is the amount of weight that a spring can support at any given compressed height. When a spring fatigues, the spring's load capacity decreases and the vehicle will sag.

Typical Front-Wheel-Drive Sedan Springs

	Force @ Height	Spring Rate
LF	1,343 lb @ 7.6 in.	256 lb in.
RF	1,300 lb @ 7.6 in.	254 lb in.
LR	638 lb @ 9.38 in.	200 lb in.
RR	610 lb @ 9.38 in.	195 lb in.

Notice that each of the four coil springs used on this vehicle is unique. The higher spring rate on the left is used to help support the weight of the driver. Because each spring is designed for each location on the vehicle, they should be marked if they are removed from a vehicle during service.

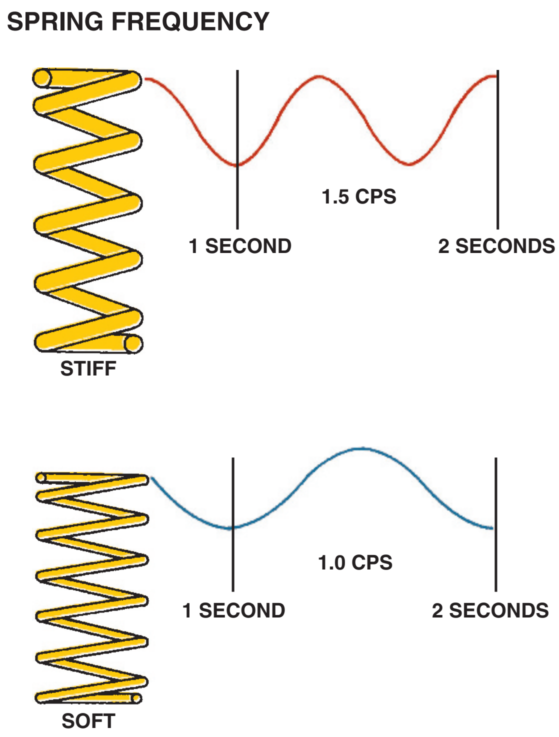


FIGURE 111–14 Stiffer springs bounce at a higher frequency than softer springs.

SPRING FREQUENCY Spring frequency is a value that reflects the speed at which a spring oscillates, or bounces, after it is released from compression or extension. Frequency is typically measured in cycles per second (CPS) or hertz (Hz). ● **SEE FIGURE 111–14**. There is a direct correlation between spring rate and spring frequency: the higher the spring rate, the higher the spring frequency. This means that stiffer springs bounce at a higher frequency, while softer springs bounce more slowly.

WHEEL RATE Depending on the suspension design, springs are installed a certain distance away from the wheel, which determines the ratio of wheel travel to spring travel, or **wheel rate**. ● **SEE FIGURE 111–15**. For example, if a coil spring is mounted on the midpoint of a control arm, or halfway between the center of the wheel and the arm pivot points, it compresses approximately 1 inch when the wheel travels vertically 2 inches. On a strut-type suspension, the coil spring has a more direct ratio because it is closer to the wheel, so when the wheel of a strut travels vertically 2 inches, the spring also compresses 2 inches. This means that a coil spring used on a strut-type suspension is less than half the spring rate of a coil spring used on suspensions that use control arms.

COIL SPRING MOUNTING Coil springs are usually installed in a **spring pocket** or spring seat. Hard rubber or plastic cushions or **insulators** are usually mounted between the coil spring and the spring seat. ● **SEE FIGURE 111–16**. The purpose of these insulators is to isolate and dampen road noise and vibration from the vehicle body. The type of end on the coil spring also varies and determines the style of the spring mount.

SPRING COATINGS All springs are painted or coated with epoxy to help prevent breakage. A scratch, nick, or pit caused by corrosion can cause a **stress riser** that can lead to spring failure. The service technician should be careful not to remove any of the protective coating. Whenever a service operation requires the spring to be compressed, always use a tool that will not scratch or nick the surface of the spring.

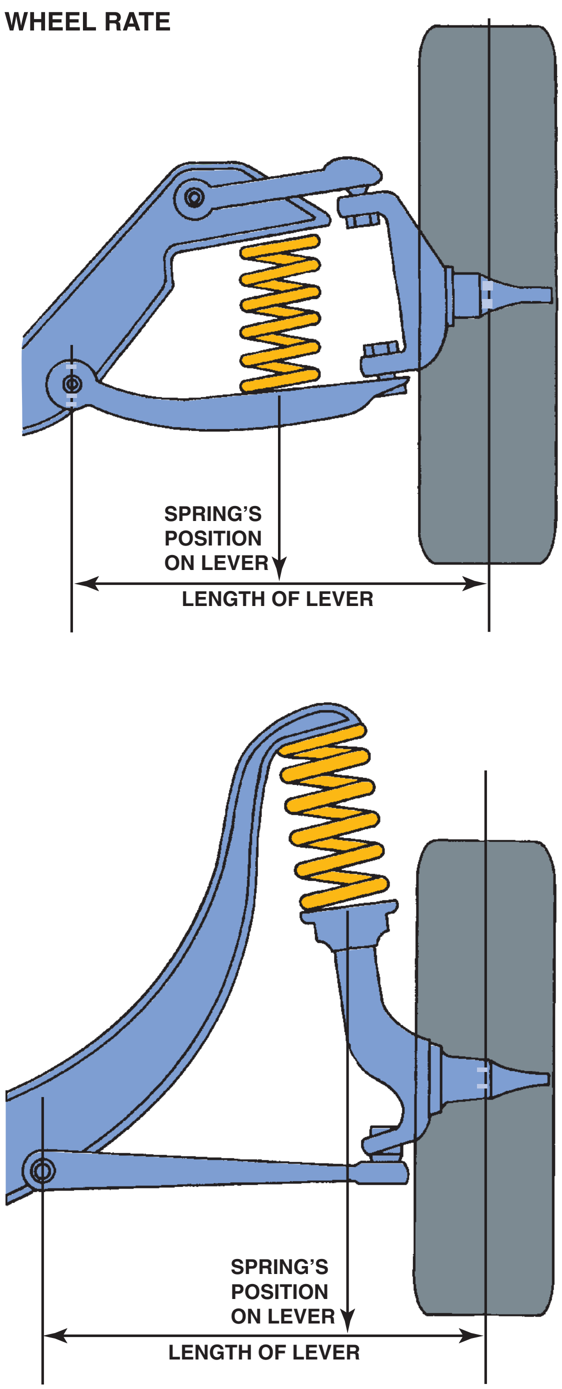


FIGURE 111–15 The wheel and arm act as a lever to compress the spring. The spring used on the top picture must be stiffer than the spring used on the strut-type suspension shown on the bottom because the length of the lever arm is shorter.

LEAF SPRINGS

TERMINOLOGY **Leaf springs** are constructed of one or more strips of long, narrow spring steel. These metal strips, called leaves, are assembled with plastic or synthetic rubber insulators

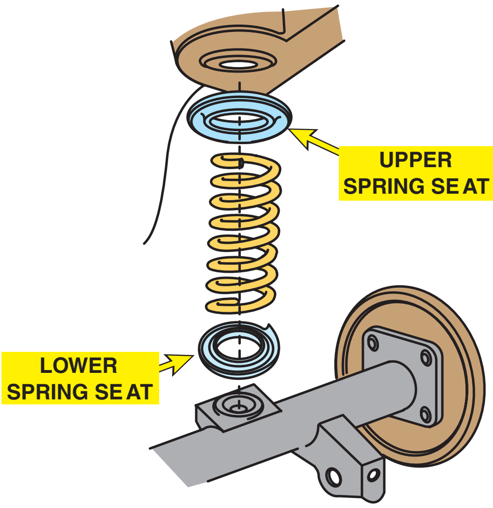


FIGURE 111–16 The spring cushion helps isolate noise and vibration from being transferred to the passenger compartment.

TECH TIP

Don't Cut Those Coil Springs!

Chassis service technicians are often asked to lower a vehicle. One method is to remove the coil springs and cut off half or more coils from the spring. While this *will* lower the vehicle, this method is generally *not* recommended for the following reasons:

1. A coil spring could be damaged during the cutting-off procedure, especially if a torch is used to do the cutting.
2. The spring will get stiffer when shortened, often resulting in a very harsh ride.
3. The amount the vehicle is lowered is *less* than the amount cut off from the spring. This is because as the spring is shortened, it becomes stiffer. The stiffer spring will compress less than the original.

Instead of cutting springs to lower a vehicle, several preferable methods are available if the vehicle *must* be lowered:

1. There are replacement springs designed specifically to lower that model vehicle. A change in shock absorbers may be necessary because the shorter springs change the operating height of the stock (original) shock absorbers. Consult spring manufacturers for exact installation instructions and recommendations. ● **SEE FIGURE 111–17**.
2. There are replacement spindles designed to *raise* the location of the wheel spindle, thereby lowering the body in relation to the ground. Except for ground clearance problems, this is the method recommended by many chassis service technicians. Replacement spindles keep the same springs, shock absorbers, and ride, while lowering the vehicle without serious problems.

FIGURE 111–17 This replacement coil spring is coated to prevent rust and corrosion and colored to help identify the spring and/or spring manufacturer.

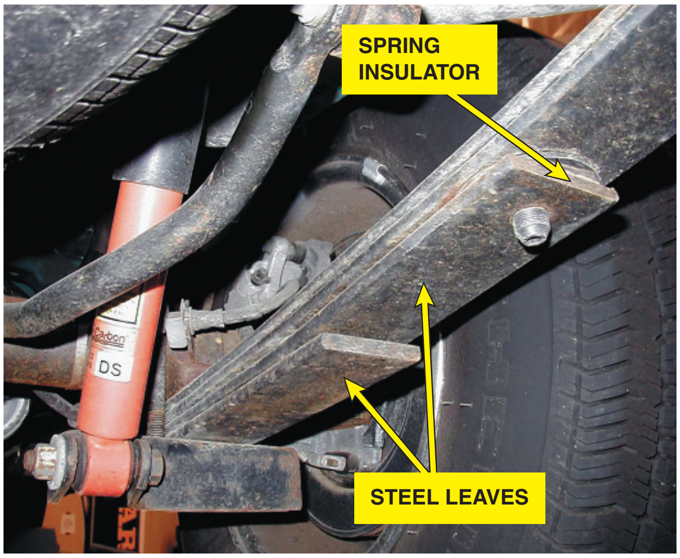


FIGURE 111–18 A typical leaf spring used on the rear of a pickup truck showing the plastic insulator between the leaves, which allows the spring to move without creating wear or noise.

between the leaves, allowing for freedom of movement during spring operation. ● **SEE FIGURE 111–18**.

The ends of the spring are rolled or looped to form eyes. Rubber bushings are installed in the eyes of the spring and act as noise and vibration insulators. Leaf spring rate increases when the thickness increases and decreases as the length increases. ● **SEE FIGURE 111–19**.

The leaves are held together by a **center bolt**, also called a *centering pin*. ● **SEE FIGURE 111–20**.

One end of a leaf spring is mounted to a hanger with a bolt and rubber bushings directly attached to the frame. The other end of the leaf spring is attached to the frame with movable mounting hangers called **shackles**. ● **SEE FIGURE 111–21**.

The shackles are necessary because as the spring hits a bump, the slightly curved spring (semi-elliptical) becomes longer and straighter, and the shackles allow for this rearward movement. **Rebound clips**, or spring alignment clips, help prevent the leaves from separating whenever the leaf spring is rebounding from hitting a bump or rise in the roadway. ● **SEE FIGURE 111–22**.

Single-leaf steel springs, called **mono leaf**, are used on some vehicles. A single or mono leaf spring is usually tapered

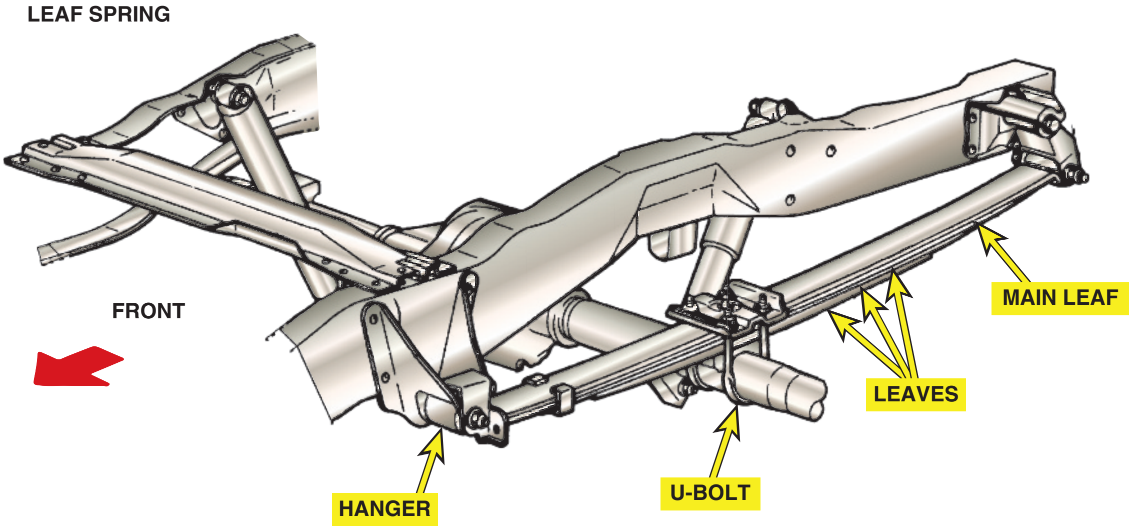


FIGURE 111–19 A typical leaf spring installation. The longest leaf, called the *main leaf*, attaches to the frame through a shackle and a hanger.

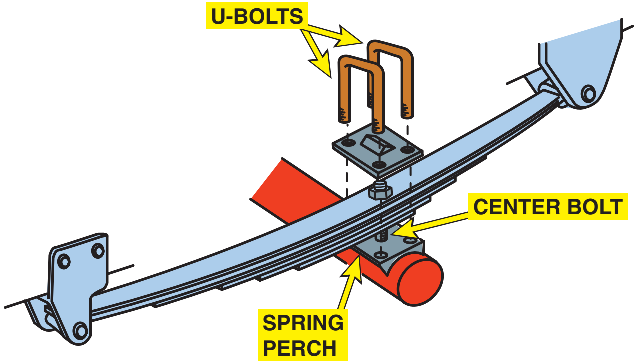


FIGURE 111–20 All multileaf springs use a center bolt to not only hold the leaves together but also help retain the leaf spring in the center of the spring perch.

to produce a variable spring rate. Leaf springs are used for rear suspensions on cars and many light trucks. A variable rate can be accomplished with a leaf-spring suspension by providing contacts on the mount that effectively shorten the spring once it is compressed to a certain point. This provides a smoother ride when the load is light and still provides a stiffer spring when the load is heavy. ● **SEE FIGURE 111–23**.

To provide additional load-carrying capacity, especially on trucks and vans, auxiliary or *helper* leaves are commonly used. This extra leaf becomes effective only when the vehicle is heavily loaded. ● **SEE FIGURE 111–24**.

Leaf springs are used on the front suspension of many four-wheel-drive trucks, especially medium and heavy trucks.

COMPOSITE LEAF SPRINGS Since the early 1980s, fiberglass–reinforced epoxy plastic **composite leaf springs** have been used on production vehicles. They save weight: an 8 pound spring can replace a conventional 40 pound steel leaf spring. The secret to making a strong plastic leaf spring is the glass fibers running continuously from one end of the spring to the other and the use of 70% fiberglass with 30% epoxy composite. The single-leaf composite spring helps isolate road noise and vibrations. It is more efficient than a multileaf spring because it eliminates the interleaf friction of the steel leaves and requires less space. ● **SEE FIGURE 111–25**.

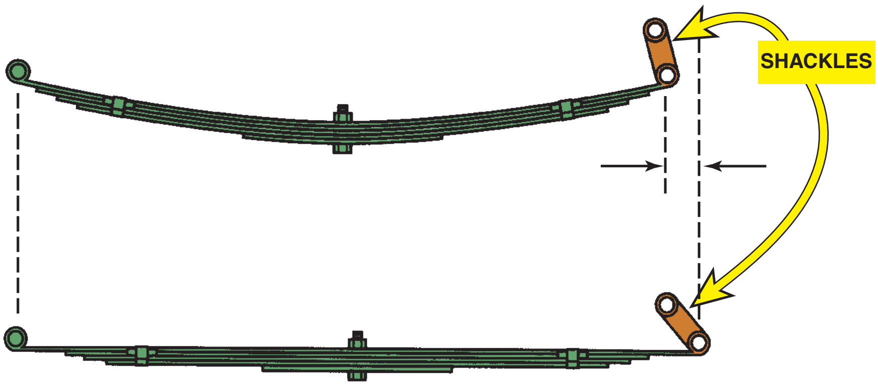


FIGURE 111–21 When a leaf spring is compressed, the spring flattens and becomes longer. The shackles allow for this lengthening. Rubber bushings are used in the ends of the spring and shackles to help isolate road noise from traveling into the passenger compartment.

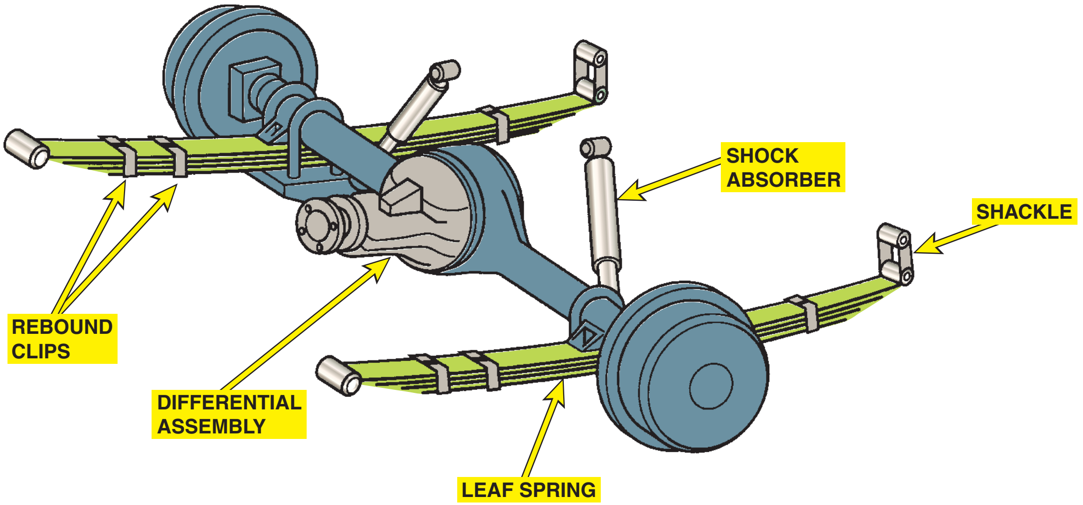


FIGURE 111–22 Typical rear leaf—spring suspension of a rear-wheel-drive vehicle.

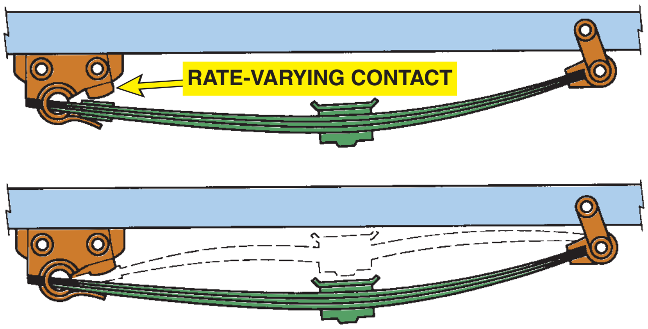


FIGURE 111–23 As the vehicle is loaded, the leaf spring contacts a section of the frame. This shortens the effective length of the spring, which makes it stiffer.

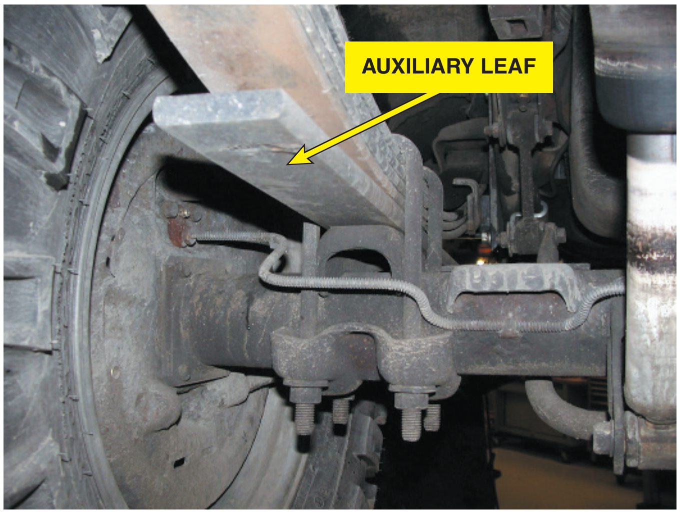


FIGURE 111–24 Many pickup trucks, vans, and sport-utility vehicles (SUVs) use auxiliary leaf springs that contact the other leaves when the load is increased.

TORSION BARS

TERMINOLOGY A **torsion bar** is a spring that is a long, *round,* hardened steel bar similar to a coil spring except that it is a *straight* bar. ● **SEE FIGURE 111–26.** One end is attached to the lower control arm of a front suspension and the other end to the frame. When the wheels hit a bump, the bar twists and then untwists. General Motors pickup trucks use torsion-bar front suspension longitudinally. ● **SEE FIGURE 111–27.**

Many manufacturers of pickup trucks currently use torsion-bar-type suspensions, especially on their four-wheel-drive models. Torsion bars allow room for the front drive axle and constant velocity joint and still provide for strong suspension.

As with all automotive springs, spring action is controlled by the shock absorbers. Unlike other types of springs, torsion bars may be adjustable for correct ride height. ● **SEE FIGURE 111–28.**

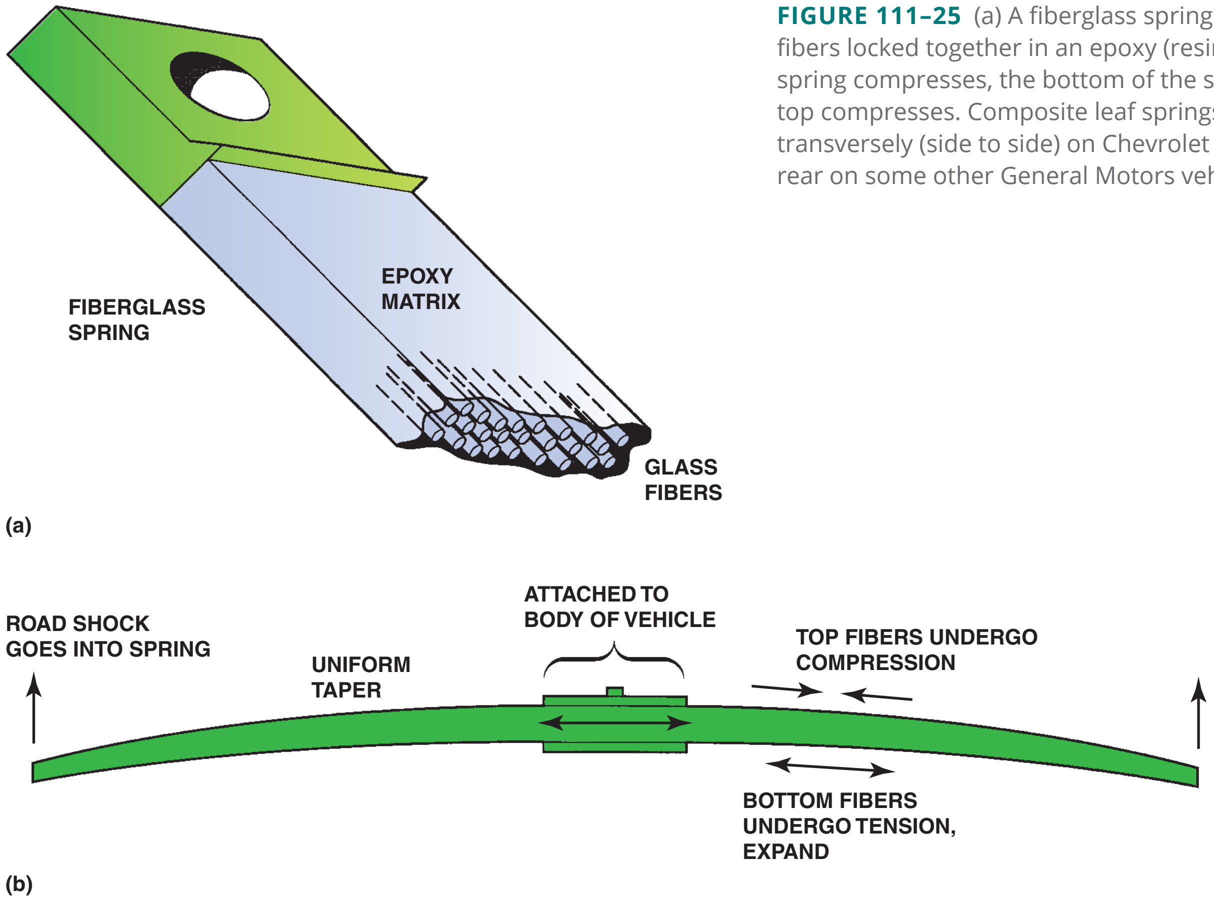
Most torsion bars are labeled *left* or *right,* usually stamped into the end of the bars. The purpose of this designation is to make sure that the correct bar is installed on the original side of the vehicle. Torsion bars are manufactured without any built-in direction or preload. However, after being in a vehicle, the bar takes a set; reversing the side the torsion bar is used on causes the bar to be twisted in the opposite direction. Even though the bars are usually interchangeable, proper ride height can be accomplished even if the bars were installed on the side opposite from the original. But because the bar is being "worked" in the opposite direction, it can weaken and break. If a torsion bar breaks, the entire suspension collapses; this can cause severe vehicle damage, as well as a serious accident.

SUSPENSION PRINCIPLES AND COMPONENTS

Suspensions use various links, arms, and joints to allow the wheels to move freely up and down; front suspensions also have to allow the front wheels to turn. All suspensions must provide for the following supports:

1. **Transverse (or side-to-side) wheel support.** As the wheels of the vehicle move up and down, the suspension must accommodate this movement and still keep the wheel from moving away from the vehicle or inward toward the center

FIGURE 111–25 (a) A fiberglass spring is composed of long fibers locked together in an epoxy (resin) matrix. (b) When the spring compresses, the bottom of the spring expands and the top compresses. Composite leaf springs are used and mounted transversely (side to side) on Chevrolet Corvettes and at the rear on some other General Motors vehicles.


EPOXY MATRIX
FIBERGLASS SPRING
GLASS FIBERS
(a)
ATTACHED TO BODY OF VEHICLE
ROAD SHOCK GOES INTO SPRING
UNIFORM TAPER
TOP FIBERS UNDERGO COMPRESSION
BOTTOM FIBERS UNDERGO TENSION, EXPAND
(b)

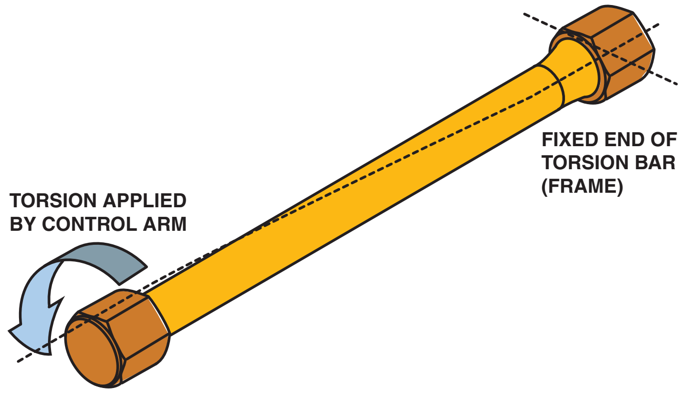

FIXED END OF TORSION BAR (FRAME)
TORSION APPLIED BY CONTROL ARM

FIGURE 111–26 A torsion bar resists twisting and is used as a spring on some cars and many four-wheel-drive pickup trucks and sport-utility vehicles. The larger the diameter, or the shorter the torsion bar, the stiffer the bar. A torsion bar twists very little during normal operation and about a 1/16 of a revolution during a major suspension travel event.

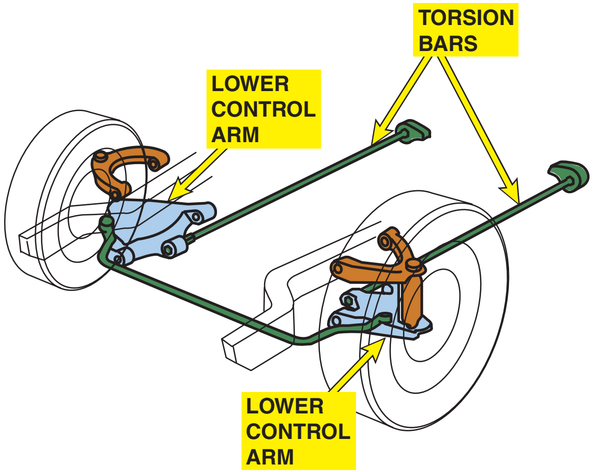

TORSION BARS
LOWER CONTROL ARM
LOWER CONTROL ARM

FIGURE 111–27 Longitudinal torsion bars attach at the lower control arm at the front and at the frame at the rear of the bar.

of the vehicle. ● **SEE FIGURE 111–29**. The control arm pivots on the vehicle frame. The wheels attach to a spindle that attaches to the ball joint at the end of the control arm. Transverse links are also called **lateral links**.

2. **Longitudinal (front-to-back) wheel support.** As the wheels of the vehicle move up and down, the suspension must allow for this movement and still keep the wheels from moving backward whenever a bump is hit. Note in ● **FIGURE 111–29** how the separation of the pivot points, where the control arm meets the frame, provides support to prevent front-to-back wheel movement.

At least two suspension links or arms are required in order to provide for freedom of movement up or down and to *prevent* any in-out or forward-back movement. Some suspension designs use an additional member to control forward-back movement. ● **SEE FIGURE 111–30**.

The design of the suspension and the location of the suspension mounting points on the frame or body are critical to proper vehicle handling. Two very important design factors are called **anti-squat** and **anti-dive**.

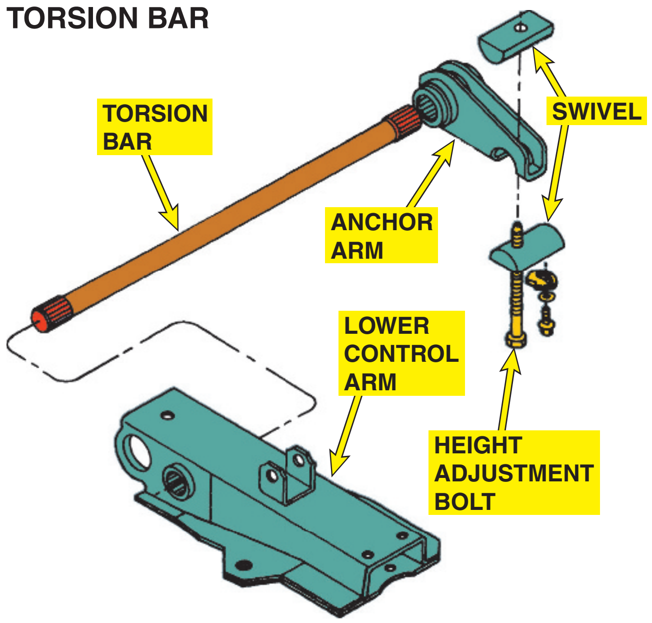

TORSION BAR
TORSION BAR
ANCHOR ARM
SWIVEL
LOWER CONTROL ARM
HEIGHT ADJUSTMENT BOLT

FIGURE 111–28 One end of the torsion bar attaches to the lower control arm and the other to an anchor arm that is adjustable.

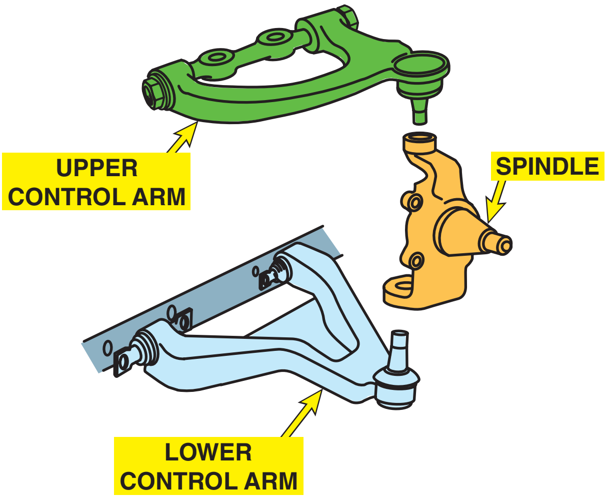

UPPER CONTROL ARM
SPINDLE
LOWER CONTROL ARM

FIGURE 111–29 The spindle supports the wheels and attaches to the control arm with ball-and-socket joints called ball joints. The control arm attaches to the frame of the vehicle through rubber bushings to help isolate noise and vibration between the road and the body.

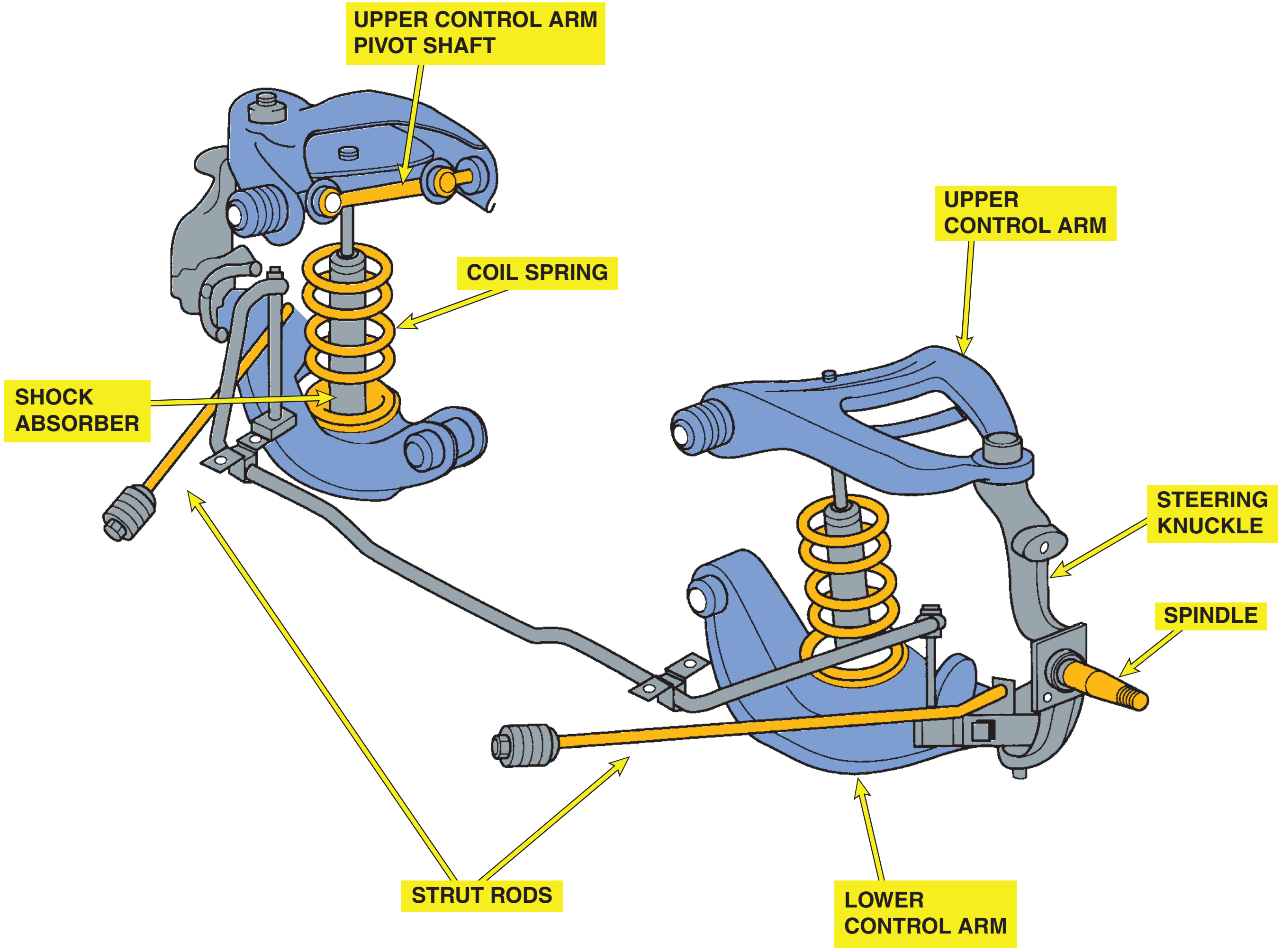

UPPER CONTROL ARM PIVOT SHAFT
COIL SPRING
SHOCK ABSORBER
UPPER CONTROL ARM
STEERING KNUCKLE
SPINDLE
STRUT RODS
LOWER CONTROL ARM

FIGURE 111–30 The strut rods provide longitudinal support to the suspension to prevent forward or rearward movement of the control arms.

1. **Anti-squat.** Anti-squat refers to the reaction of the body of a vehicle during acceleration. It is normal in most designs for the vehicle to squat down at the rear while accelerating. Most drivers feel comfortable feeling this reaction, even on front-wheel-drive vehicles. Anti-squat refers to the degree to which this normal force is neutralized. If 100% anti-squat were designed into the suspension system, the vehicle would remain level while accelerating.
2. **Anti-dive.** Anti-dive refers to the force that causes the front of the vehicle to drop down while braking. Some front-nose dive feels normal to most drivers. If 100% anti-dive were designed into a vehicle, it would remain perfectly level while braking.

The service technician cannot, and should not, attempt to change anti-squat or anti-dive characteristics built into the design of the vehicle. However, if the customer notices more squat or dive than normal, then the technician should carefully inspect all suspension components, especially those mounting points to the frame or body.

STEERING KNUCKLES

Steering knuckle is hard to classify either as part of the suspension or as part of the wheel. A knuckle serves two purposes:

- To join the suspension to the wheel
- Usually includes the spindle where the front wheel bearings are attached
- To provide pivot points between the suspension and wheel

Knuckles are used with independent suspensions and at the wheels that steer the vehicle. ● **SEE FIGURE 111–31**.

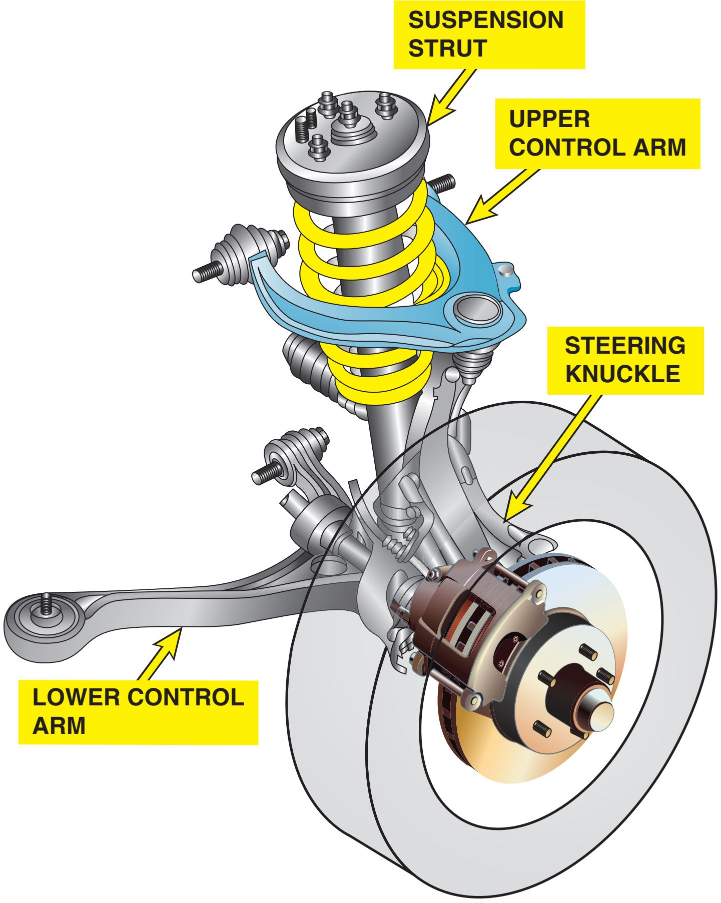


FIGURE 111–31 The steering knuckle used on a short-/long-arm front suspension.

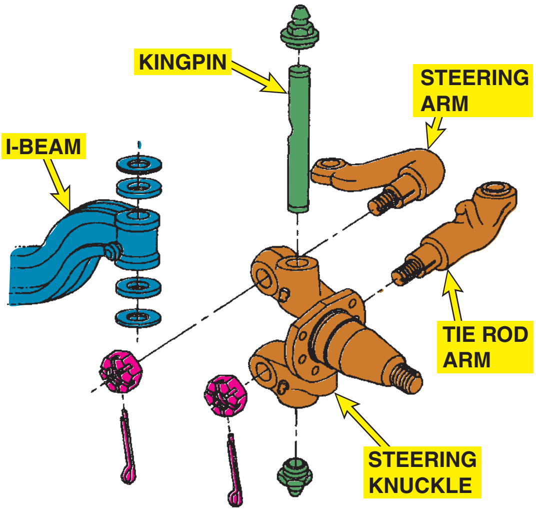


FIGURE 111–32 A kingpin is a steel shaft or pin that joins the steering knuckle to the suspension and allows the steering knuckle to pivot.

The only knuckle that uses a **kingpin** is a steering knuckle on an I-beam or twin I-beam front suspension. ● **SEE FIGURE 111–32**. A kingpin steering knuckle keeps the wheel rigid in relation to the I-beam during up-and-down wheel movement, but rotates around the steering axis to turn the wheels left and right. The steering axis is the vertical center of the kingpin.

CONTROL ARMS

Control arm is a suspension link that connects a knuckle or wheel flange to the frame. One end of a control arm attaches to the knuckle or wheel flange, generally with either a ball joint or bushing. The opposite end of the arm, which attaches to a frame member, usually pivots on a bushing. ● **SEE FIGURE 111–33**. The end attached to the frame must pivot to allow the axle or knuckle to travel vertically.

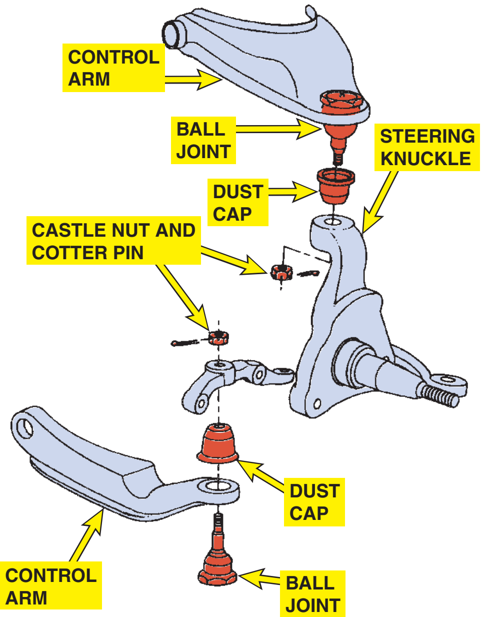


FIGURE 111–33 Control arms are used to connect the steering knuckle to the frame or body of the vehicle and provide the structural support for the suspension system.

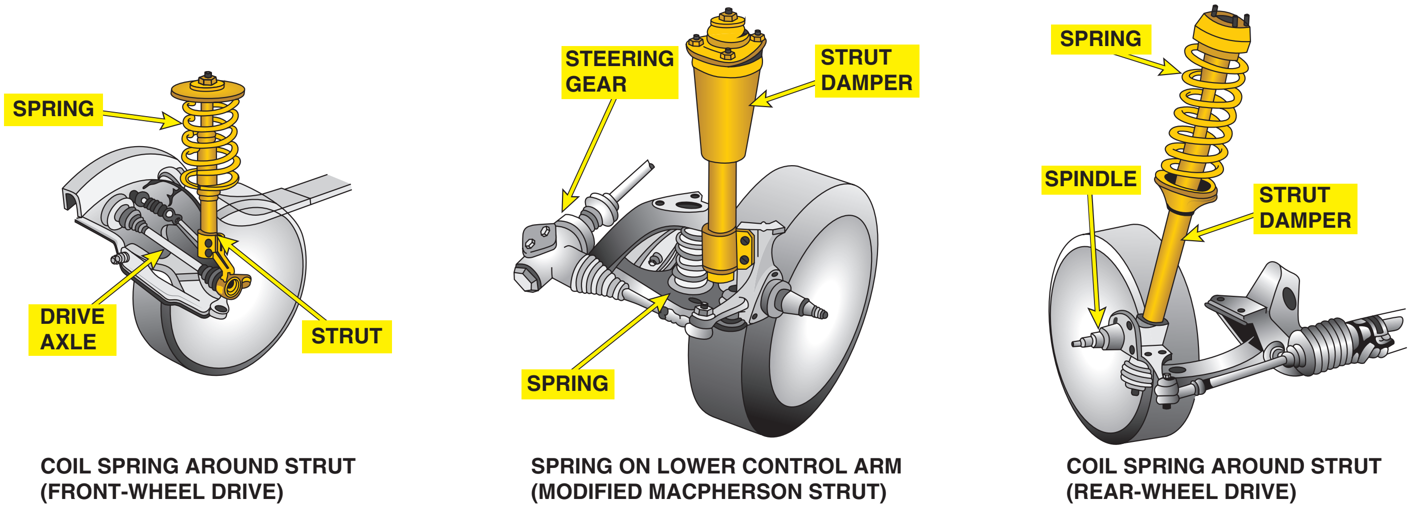

SPRING
DRIVE AXLE
STRUT
COIL SPRING AROUND STRUT (FRONT-WHEEL DRIVE)
STEERING GEAR
STRUT DAMPER
SPRING
SPRING ON LOWER CONTROL ARM (MODIFIED MACPHERSON STRUT)
SPRING
SPINDLE
STRUT DAMPER
COIL SPRING AROUND STRUT (REAR-WHEEL DRIVE)

FIGURE 111–34 Ball joints provide the freedom of movement necessary for steering and suspension movements.

BALL JOINTS **Ball joints** are actually ball-and-socket joints, similar to the joints in a person's shoulder. Ball joints allow the front wheels to move up and down, as well as side to side (for steering).

A vehicle can be equipped with coil springs, mounted either above the upper control arm *or* on the lower control arm. ● **SEE FIGURE 111–34**.

If the coil spring is attached to the top of the upper control arm, then the upper ball joint is carrying the weight of the vehicle and is called the **load-carrying ball joint**. The lower ball joint is called the **non-load-carrying**, or *follower*, ball joint. ● **SEE FIGURE 111–35**.

If the coil spring is attached to the lower control arm, then the lower ball joint is the load-carrying ball joint and the upper joint is the follower ball joint. ● **SEE FIGURE 111–36**.

If a torsion-bar-type spring is used, the lower ball joint is a load-carrying joint because the torsion bar is attached to the lower control arm on most vehicles that use torsion bars.

BALL JOINT DESIGN There are two basic designs of ball joints: compression loaded and tension loaded. If the control arm rests on the steering knuckle, the ball joint is *compressed* into the control arm by the weight of the vehicle. If the knuckle rests on the control arm, the weight of the vehicle tends to pull the ball joint

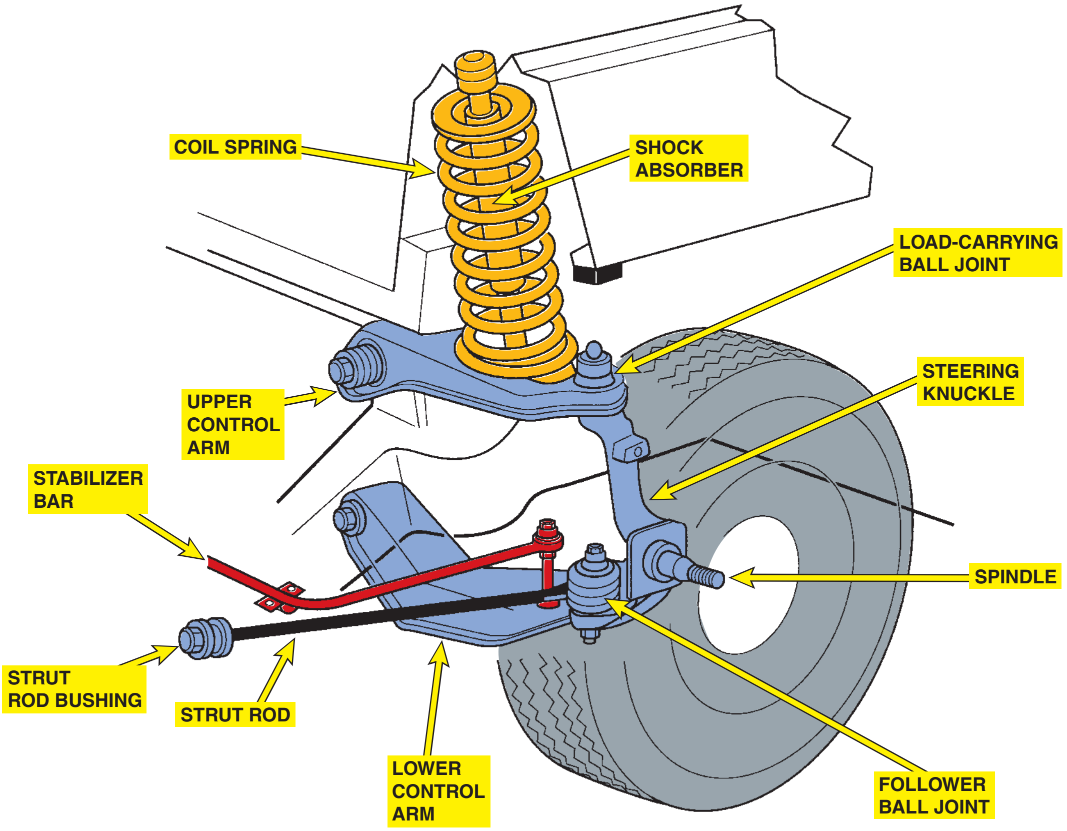

COIL SPRING
SHOCK ABSORBER
LOAD-CARRYING BALL JOINT
STEERING KNUCKLE
UPPER CONTROL ARM
STABILIZER BAR
SPINDLE
STRUT ROD BUSHING
STRUT ROD
LOWER CONTROL ARM
FOLLOWER BALL JOINT

FIGURE 111–35 The upper ball joint is load carrying in this type of suspension because the weight of the vehicle is applied through the spring, upper control arm, and ball joint to the wheel. The lower control arm is a lateral link, and the lower ball joint is called a follower ball joint.

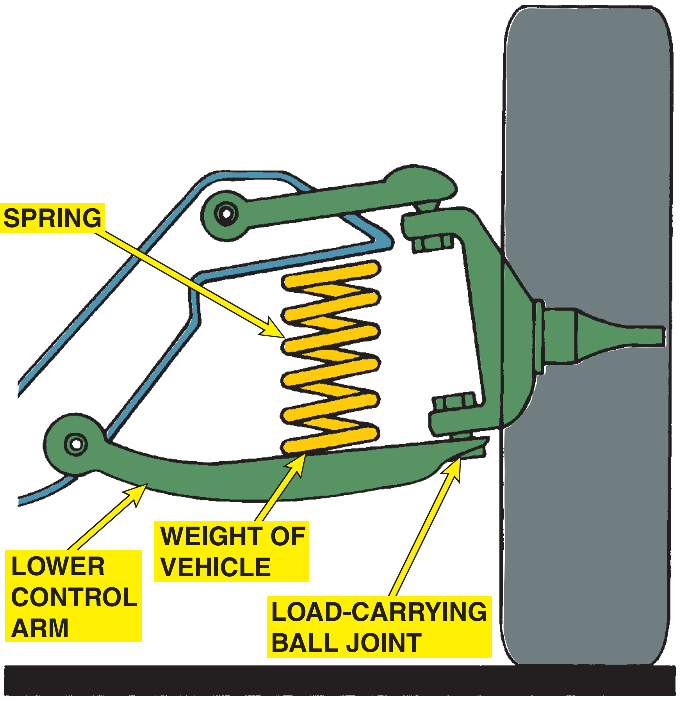


FIGURE 111–36 The lower ball joint is load carrying in this type of suspension because the weight of the vehicle is applied through the spring, lower control arm, and ball joint to the wheel.

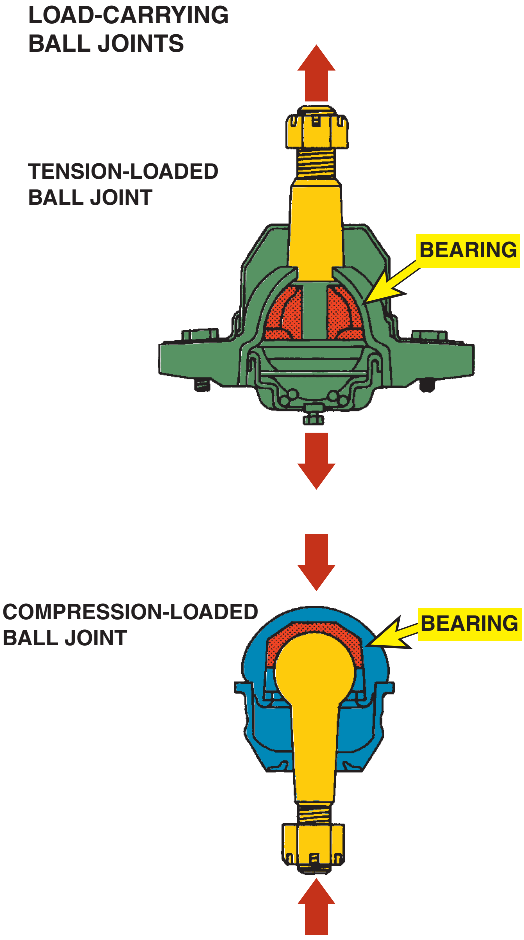

LOAD-CARRYING BALL JOINTS
TENSION-LOADED BALL JOINT
BEARING
COMPRESSION-LOADED BALL JOINT
BEARING

FIGURE 111–37 All ball joints, whether tension or compression loaded, have a bearing surface between the ball stud and socket.

back into the control arm by *tension.* The type used is determined by the chassis design engineer, and the service technician cannot change the type of ball joint used for a particular application. ● **SEE FIGURE 111–37**.

A specific amount of stud-turning resistance is built into each ball joint to stabilize steering. A ball joint that does not support the weight of the vehicle and acts as a suspension pivot is often called a follower ball joint or a friction ball joint. The load-carrying (weight-carrying) ball joint is subjected to the greatest amount of wear and is the most frequently replaced.

STRUT RODS Some vehicles are equipped with round steel rods that are attached between the lower control arm at one end and the frame of the vehicle with rubber bushings, called strut rod bushings, at the other end. The purpose of these **strut rods** is to provide forward/backward support to the control arms. Strut rods are used on vehicles equipped with MacPherson struts and many short-/long-arm-type suspensions. The bushings are very important in maintaining proper wheel alignment while providing the necessary up-and-down movement of the control arms during suspension travel. Strut rods prevent lower control arm movement back and forth during braking. ● **SEE FIGURE 111–38**.

Strut rods are also called tension or compression rods or simply TC rods. Tension rods attach in *front* of the wheels to the body or frame where the rod is being pulled in tension. Compression rods attach to the body or frame *behind* the wheels where the rod is being pushed or compressed. Some vehicle manufacturers call the strut rod a drag rod because it is attached in front of the wheels, and therefore acts on the lower control arm as if to drag the wheels behind their attachment points.

The bushings are replaceable by removing a nut on the frame end of the strut rod. ● **SEE FIGURE 111–39**. If a strut rod has a nut on *both* sides of the bushings, then the strut rod is used to adjust *caster.*

STABILIZER BARS Most cars and trucks are equipped with a **stabilizer bar** on the front suspension, which is a round, hardened steel bar (usually SAE 4560 or 4340 steel) attached to both lower control arms with bolts and rubber bushing washers called stabilizer bar bushings. ● **SEE FIGURE 111–40**.

A stabilizer bar is also called an anti-sway bar (sway bar) or anti-roll bar (roll bar). A stabilizer bar operates by *twisting* the bar if one side of the vehicle moves up or down in relation to the other side, such as during cornering, hitting bumps, or driving over uneven road surfaces. ● **SEE FIGURE 111–41**.

The purpose of the stabilizer bar is to prevent excessive body roll while cornering and to add stability while driving over rough road surfaces. The stabilizer bar is also used as a longitudinal (front/back) support to the lower control arm on many vehicles equipped with MacPherson struts. The effective force of a stabilizer bar is increased with the diameter of the bar. Therefore, optional suspensions often include larger-diameter stabilizer bars and bushings.

Stabilizer links connect the ends of the stabilizer bar to the lower control arm. ● **SEE FIGURES 111–42 AND 111–43**. Careful inspection of the stabilizer bar links is important. Links are commonly found to be defective (cracked rubber washers or broken spacer bolts) because of the great amount of force that is transmitted through the links and the bushings. Defective links and/or bushings can cause unsafe vehicle handling and noise.

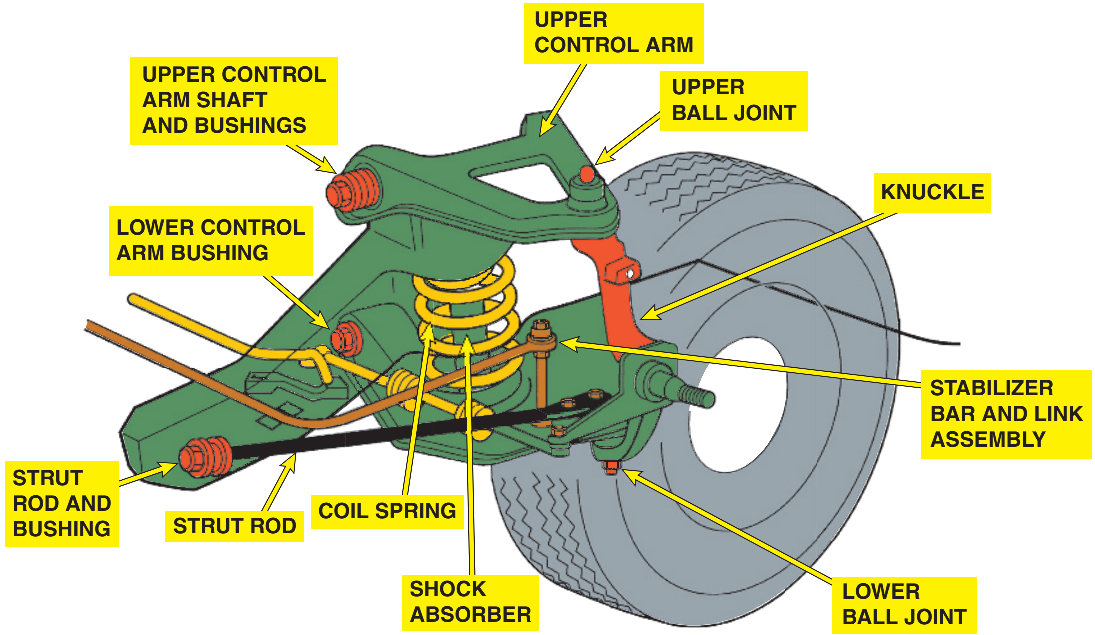

UPPER CONTROL ARM
UPPER CONTROL ARM SHAFT AND BUSHINGS
UPPER BALL JOINT
KNUCKLE
LOWER CONTROL ARM BUSHING
STABILIZER BAR AND LINK ASSEMBLY
STRUT ROD AND BUSHING
STRUT ROD
COIL SPRING
SHOCK ABSORBER
LOWER BALL JOINT

FIGURE 111–38 A strut rod is the longitudinal support to prevent front-to-back wheel movement. Struts rods are used when there is only one lower control arm bushing and not used where there are two lower control arm bushings.

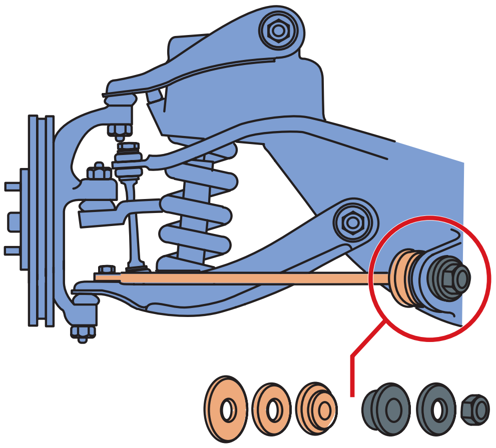


FIGURE 111–39 Strut rod bushings insulate the steel bar from the vehicle frame or body.

SHOCK ABSORBERS

PURPOSE AND FUNCTION **Shock absorbers** are used on all conventional suspension systems to dampen and control the motion of the vehicle's springs. Without shock absorbers (dampers), the vehicle would continue to bounce after hitting bumps. ● **SEE FIGURE 111–44**.

The major purpose of any shock or strut is to control ride and handling. Standard shock absorbers *do not* support the weight of a vehicle. *The springs support the weight of the vehicle; the shock absorbers control the actions and reactions of the springs*. Shock absorbers are also called dampers.

Most shock absorbers are *direct acting* because they are connected directly between the vehicle frame or body and the axles. ● **SEE FIGURE 111–45**.

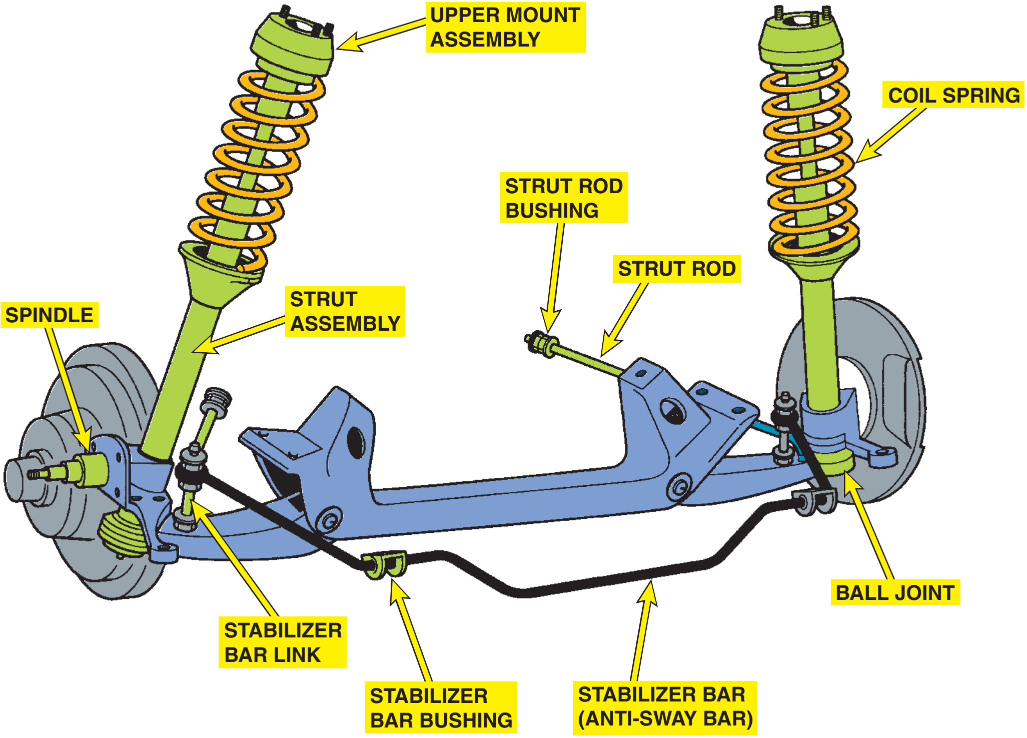

UPPER MOUNT ASSEMBLY
COIL SPRING
STRUT ROD BUSHING
STRUT ROD
SPINDLE
STRUT ASSEMBLY
BALL JOINT
STABILIZER BAR LINK
STABILIZER BAR BUSHING
STABILIZER BAR (ANTI-SWAY BAR)

FIGURE 111–40 Typical stabilizer bar installation.

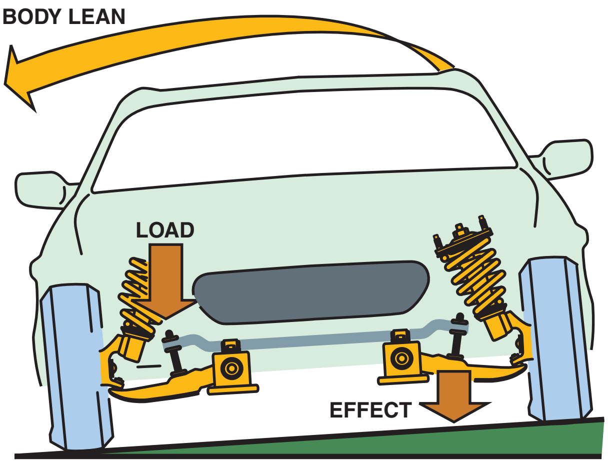

BODY LEAN
LOAD
EFFECT

FIGURE 111–41 As the body of the vehicle leans, the stabilizer bar is twisted. The force exerted by the stabilizer bar counteracts the body lean.

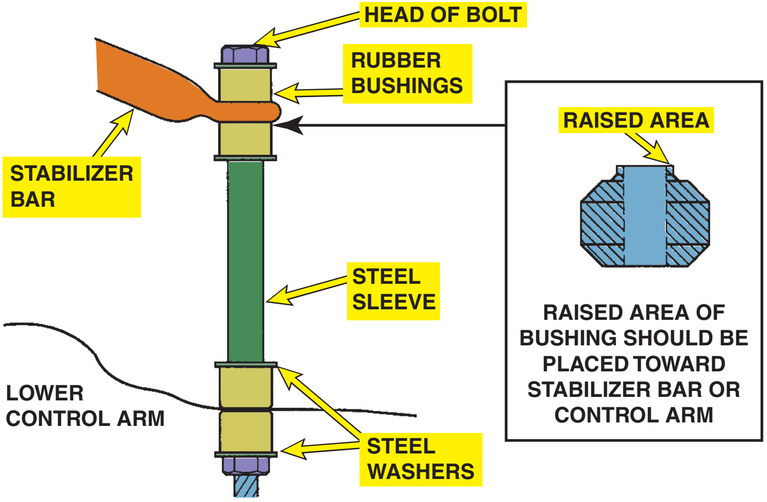

HEAD OF BOLT
RUBBER BUSHINGS
STABILIZER BAR
STEEL SLEEVE
LOWER CONTROL ARM
STEEL WASHERS
RAISED AREA
RAISED AREA OF BUSHING SHOULD BE PLACED TOWARD STABILIZER BAR OR CONTROL ARM

FIGURE 111–42 Stabilizer bar links are sold as a kit consisting of the long bolt with steel sleeve and rubber bushings. Steel washers are used on both sides of the rubber bushings as shown.

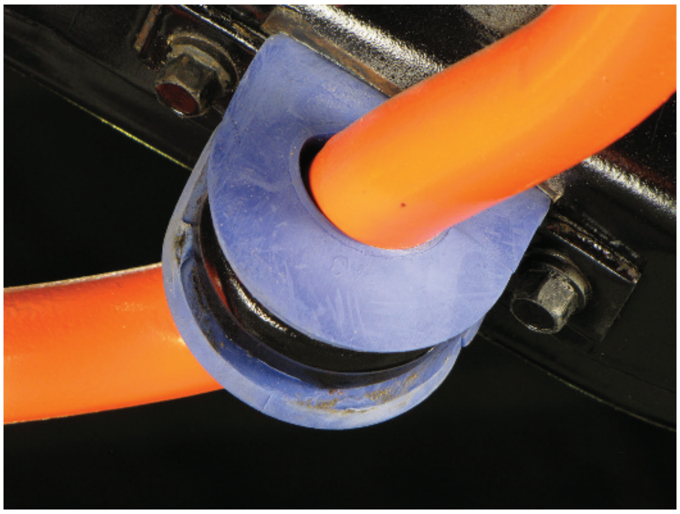


FIGURE 111–43 A high-performance stabilizer bar that uses a urethane bushing instead of a rubber bushing used in most vehicles. However, the urethane bushing tends to transmit road noise and may be objectionable to some vehicle owners.

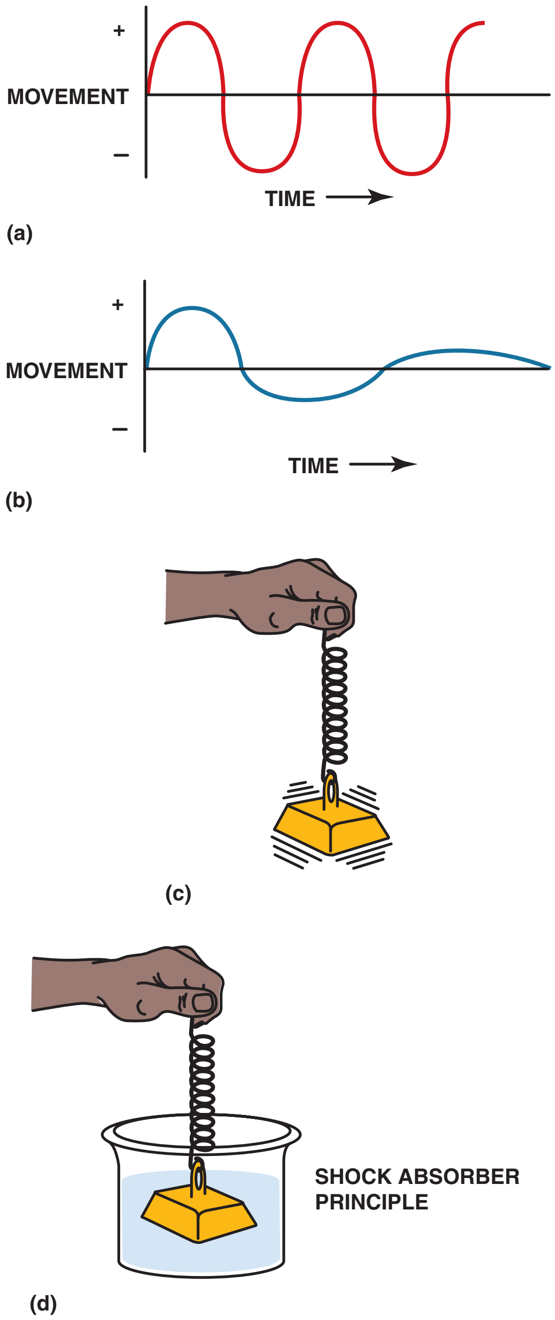

+
MOVEMENT
–
TIME
(a)
+
MOVEMENT
–
TIME
(b)
(c)
SHOCK ABSORBER PRINCIPLE
(d)

FIGURE 111–44 (a) Movement of the vehicle is supported by springs without a dampening device. (b) Spring action is dampened with a shock absorber. (c) The function of any shock absorber is to dampen the movement or action of a spring, similar to using a liquid to control the movement of a weight on a spring (d).

As a wheel rolls over a bump, the wheel moves toward the body and compresses the spring(s) of the vehicle. As the spring compresses, it stores energy. The spring then releases this stored energy, causing the body of the vehicle to rise (rebound). ● **SEE FIGURE 111–46**.

After the energy in the spring is used up, the body starts downward, causing the spring to compress. Without shock absorbers, the energy released from the spring would be very rapid and violent. The shock absorber helps dampen the rapid up-and-down movement of the vehicle springs by converting energy of movement into heat by forcing hydraulic fluid through small holes inside the shock absorber.

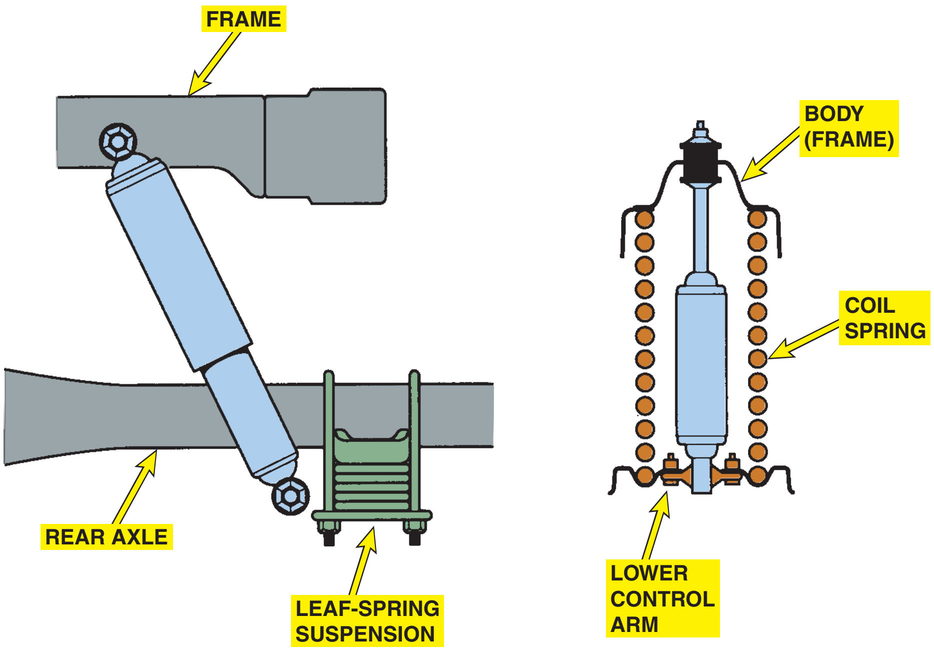


FIGURE 111–45 Shock absorbers work best when mounted as close to the spring as possible. Shock absorbers that are mounted straight up and down offer the most dampening.

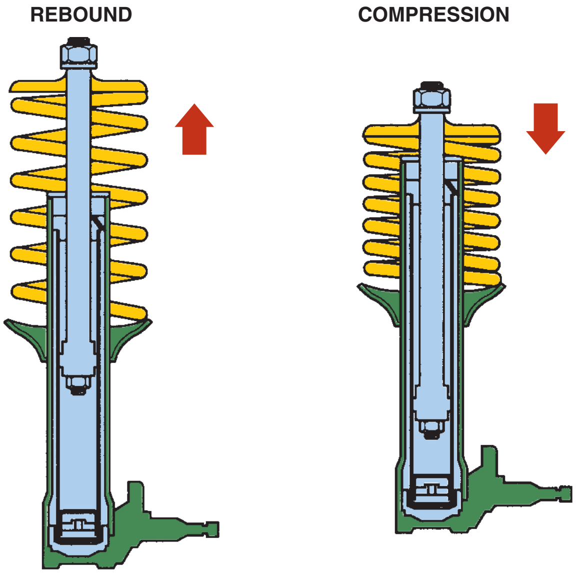


FIGURE 111–46 When a vehicle hits a bump in the road, the suspension moves upward. This is called compression or jounce. Rebound is when the spring (coil, torsion bar, or leaf) returns to its original position.

SHOCK ABSORBER OPERATION The hydraulic shock absorber operates on the principle of fluid being forced through a small opening (orifice). ● **SEE FIGURES 111–47 AND 111–48.** Besides small openings, pressure relief valves are built into most shock absorbers to control vehicle ride under all operating conditions. The greater the pressure drop of the fluid inside the shock and the greater the amount of fluid moved through the orifice, the greater the amount of dampening. Therefore, larger shock absorbers can usually provide better dampening than smaller units.

GAS-CHARGED SHOCKS Most shock absorbers on new vehicles are gas charged. Pressurizing the oil inside the shock absorber helps smooth the ride over rough roads. This pressure helps prevent air pockets from forming in the shock absorber oil as it passes through the small passages in the shock. After the oil is forced through small passages, the pressure drops and the oil expands. As the oil expands, bubbles are created. The oil becomes foamy. This air-filled oil does not effectively provide dampening. The result of all of this aeration (air being mixed with the oil) is lack of dampening and a harsh ride.

The use of higher-pressure radial tires and lighter vehicle weight has created the need for more effective shock absorbers. To meet this need, shock absorber design engineers use a pressurized gas that does not react chemically with the oil in the shock. If a substance does not react with any other substances, it is called *inert.* The gas most often used is nitrogen, which is about 78% of our atmosphere. Typical gas-charged shocks are pressurized with 130 to 150 PSI (900 to 1,030 kPa) to aid in both handling and ride control. Some shocks use higher pressures, but the higher the pressure, the greater the possibility of leaks and the harsher the ride.

Some gas-charged shock absorbers use a single tube that contains two pistons that separate the high-pressure gas from the working fluid. Single-tube shocks are also called monotube or DeCarbon after the French inventor of the principle and manufacturer of suspension components. ● **SEE FIGURE 111–49.**

AIR SHOCKS/STRUTS Air-inflatable shock absorbers or struts are used in the rear of vehicles to provide proper vehicle ride height while carrying heavy loads. Many air shock/strut units are original equipment. They are often combined with a built-in air compressor and ride height sensor(s) to provide automatic ride height control.

Air-inflatable shocks are standard shock absorbers with an air chamber with a rubber bag built into the dust cover (top) of the shock. ● **SEE FIGURE 111–50.**

Air pressure is used to inflate the bag, which raises the installed height of the shock. As the shock increases in height, the rear of the vehicle is raised. Typical maximum air pressure in air shocks ranges from 90 to 150 PSI (620 to 1,030 kPa). As the air pressure increases in the air-inflatable reservoir of the shock, the stiffness of the suspension increases. This additional stiffness is due to the shock taking weight from the spring, and therefore the air in the air shock becomes an air spring. Now, with two springs

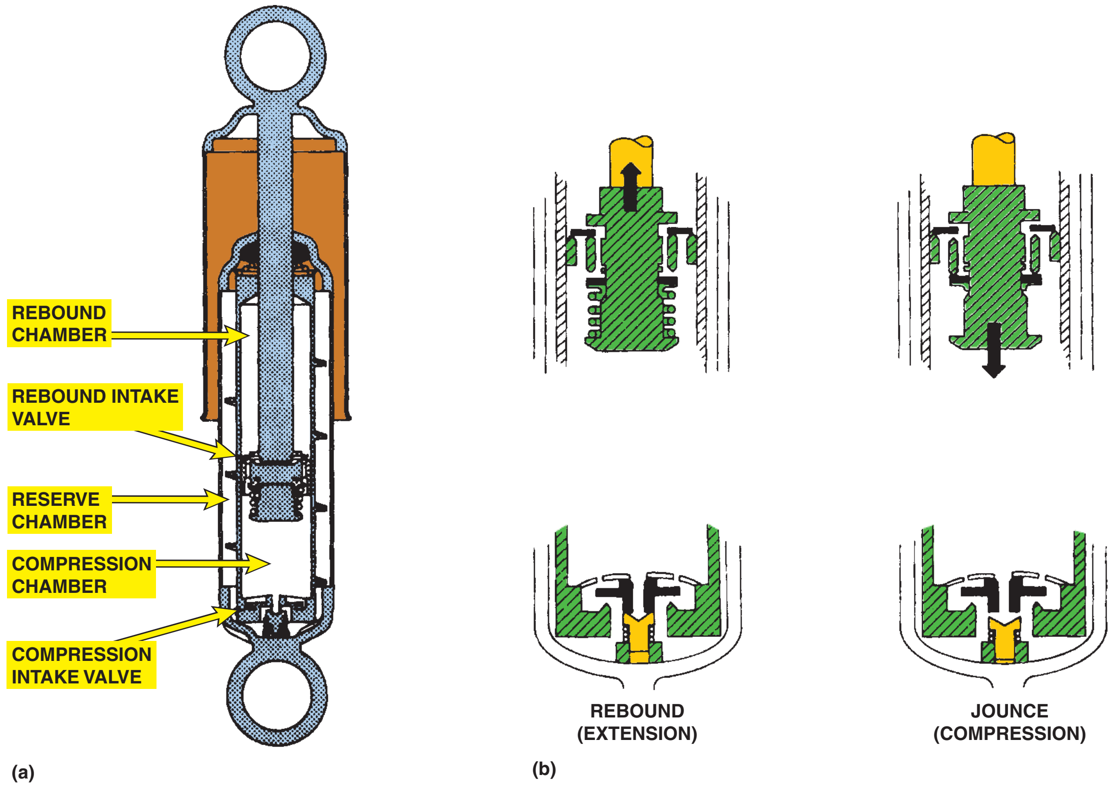

REBOUND CHAMBER
REBOUND INTAKE VALVE
RESERVE CHAMBER
COMPRESSION CHAMBER
COMPRESSION INTAKE VALVE
(a)
REBOUND (EXTENSION)
JOUNCE (COMPRESSION)
(b)

FIGURE 111–47 (a) A cutaway drawing of a typical double-tube shock absorber. (b) Notice the position of the intake and compression valve during rebound (extension) and jounce (compression).

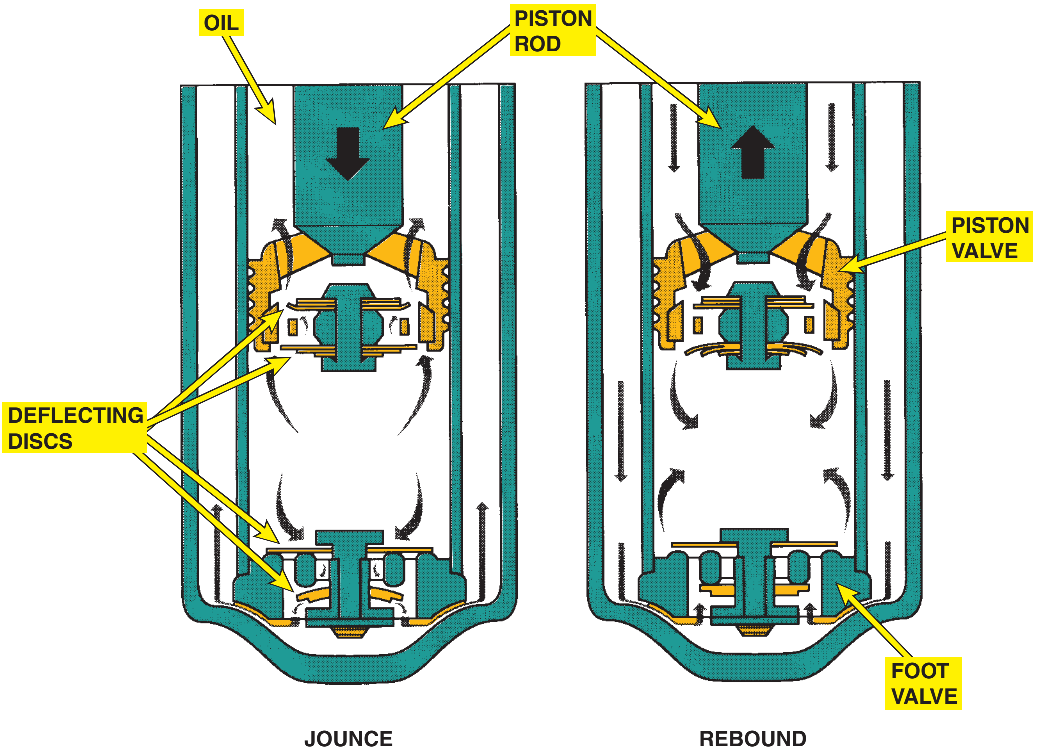

OIL
PISTON ROD
PISTON VALVE
DEFLECTING DISCS
FOOT VALVE
JOUNCE
REBOUND

FIGURE 111–48 Oil flow through a deflected disc-type piston valve. The deflecting disc can react rapidly to suspension movement. For example, if a large bump is hit at high speed, the disc can deflect completely and allow the suspension to reach its maximum jounce distance while maintaining a controlled rate of movement.

to support the vehicle, the spring rate increases and a harsher ride often results. *It is important that the load capacity of the vehicle not be exceeded or serious damage can occur to the vehicle's springs, axles, bearings, and shock support mounts*.

AIR SPRINGS Some electronically controlled suspension systems use air springs. A basic **air spring** consists of a rubber air chamber, generally closed at the bottom by a piston fitted into a control arm, or by a strut shock absorber. ● **SEE FIGURE 111–51**.

Electronically controlled suspension systems that use air springs as the only springs are available on some Hummer and many Ford, Mercury, and Lincoln vehicles.

Some air springs are in effect auxiliary springs inside a coil-spring strut. In these designs, the coil spring supports the

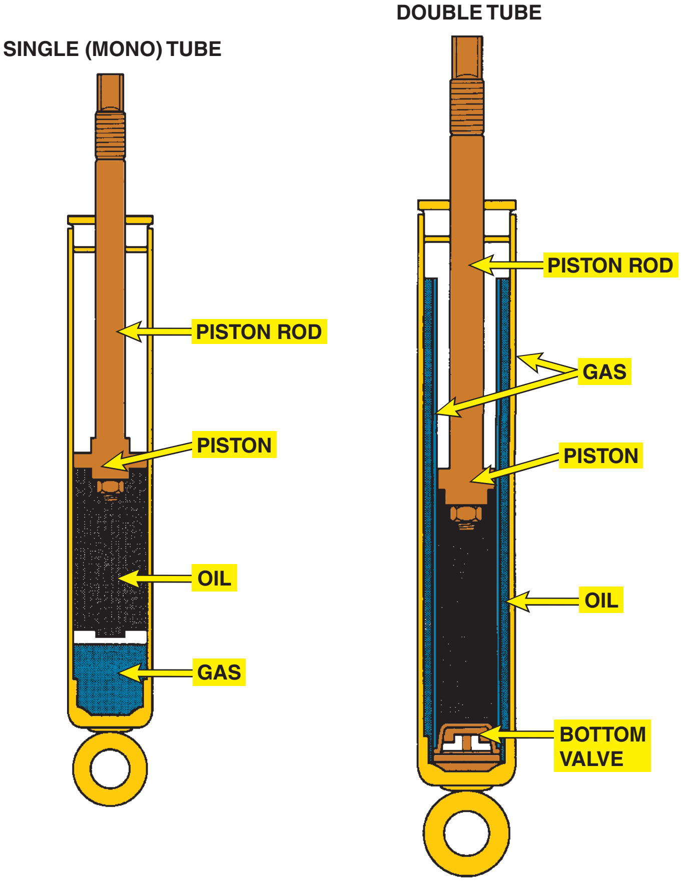

SINGLE (MONO) TUBE
DOUBLE TUBE
PISTON ROD
PISTON
OIL
GAS
PISTON ROD
GAS
PISTON
OIL
BOTTOM VALVE

FIGURE 111–49 Gas-charged shock absorbers are manufactured with a double-tube design similar to conventional shock absorbers and with a single or monotube design.

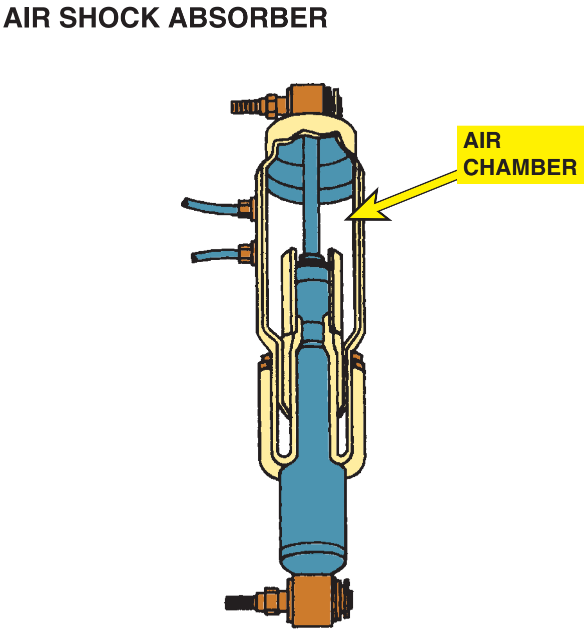
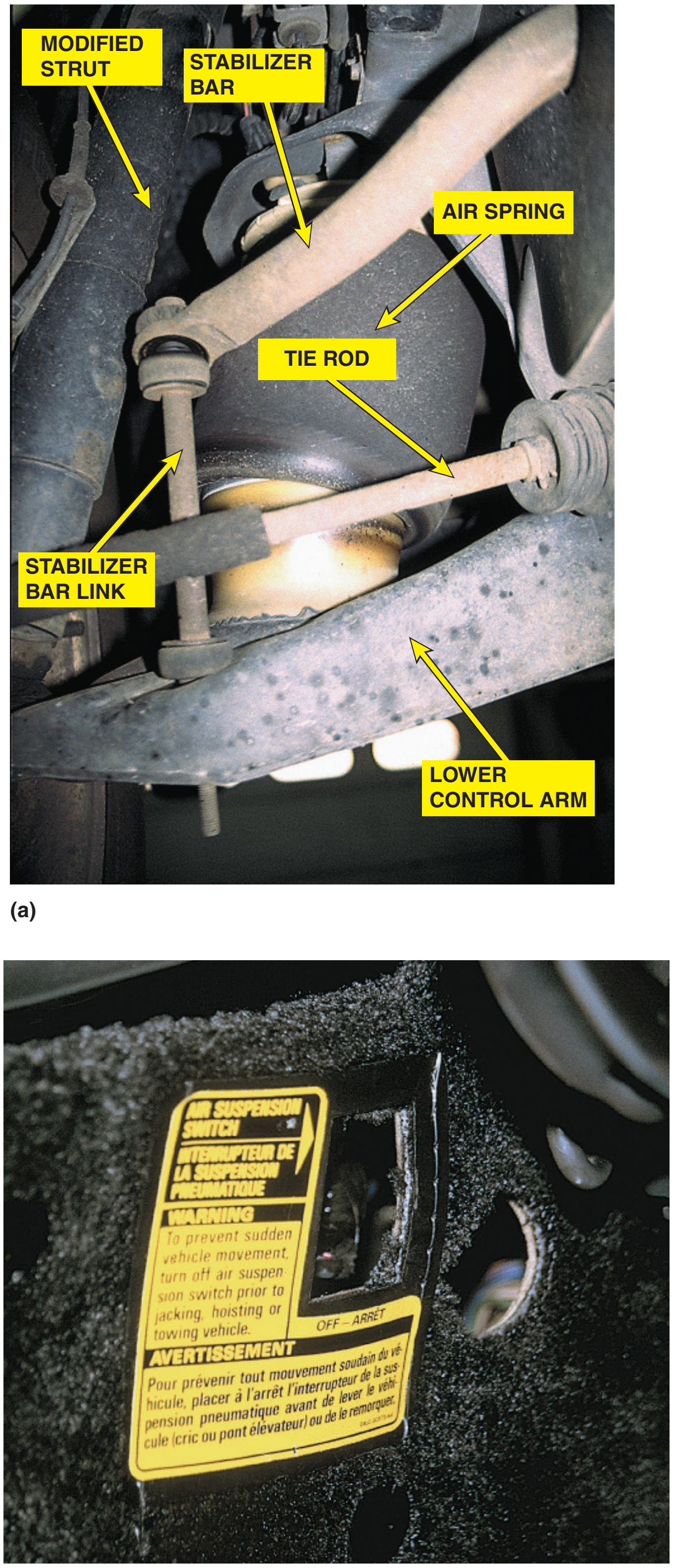

AIR SHOCK ABSORBER
AIR CHAMBER

FIGURE 111–50 A rubber tube forms an inflatable air chamber at the top of an air shock. The higher the air pressure in the chamber, the stiffer the shock.


MODIFIED STRUT
STABILIZER BAR
AIR SPRING
TIE ROD
STABILIZER BAR LINK
LOWER CONTROL ARM

(a)

AIR SUSPENSION SWITCH

INTERRUPTEUR DE LA SUSPENSION PNEUMATIQUE

WARNING

To prevent sudden vehicle movement, turn off air suspension switch prior to jacking, hoisting or towing vehicle.

OFF – ARRÊT

AVERTISSEMENT

Pour prévenir tout mouvement soudain du véhicule, placer à l'arrêt l'interrupteur de la suspension pneumatique avant de lever le véhicule (cric ou pont élévateur) ou de le remorquer.

(b)

FIGURE 111–51 (a) The front suspension of a Lincoln with an air-spring suspension. (b) Always check in the trunk for the cutoff switch for a vehicle equipped with an air suspension before hoisting or towing the vehicle.

weight of the vehicle, while the air spring raises or lowers the body to adjust ride height according to load. ● **SEE FIGURE 111–52**.

COIL-OVER SHOCKS A coil-over shock absorber uses the force of an external coil spring to boost the performance of the basic shock absorber. ● **SEE FIGURE 111–53**. The spring usually extends from the upper shock mount to a seat on the lower portion of the cylinder. The spring rate added to the hydraulic resistance makes the shock stiffer.

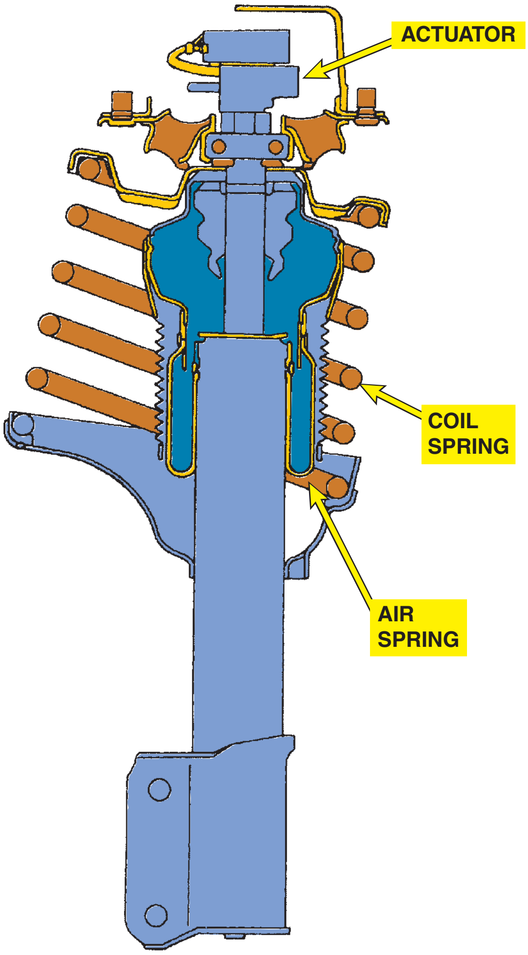


FIGURE 111–52 Some air springs are auxiliary units to the coil spring and are used to control ride height while the coil spring is the weight-bearing unit.

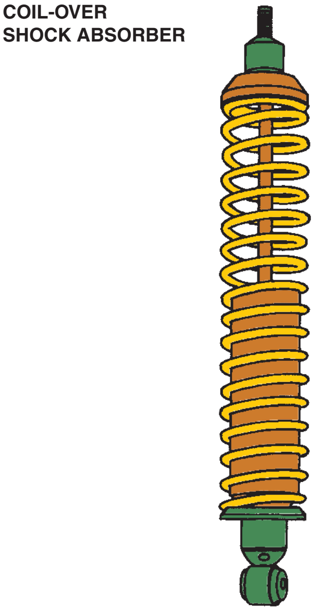


FIGURE 111–53 A coil-over shock is a standard hydraulic shock absorber with a coil spring wrapped around it to increase stiffness and/or take some of the carrying weight off of the springs.

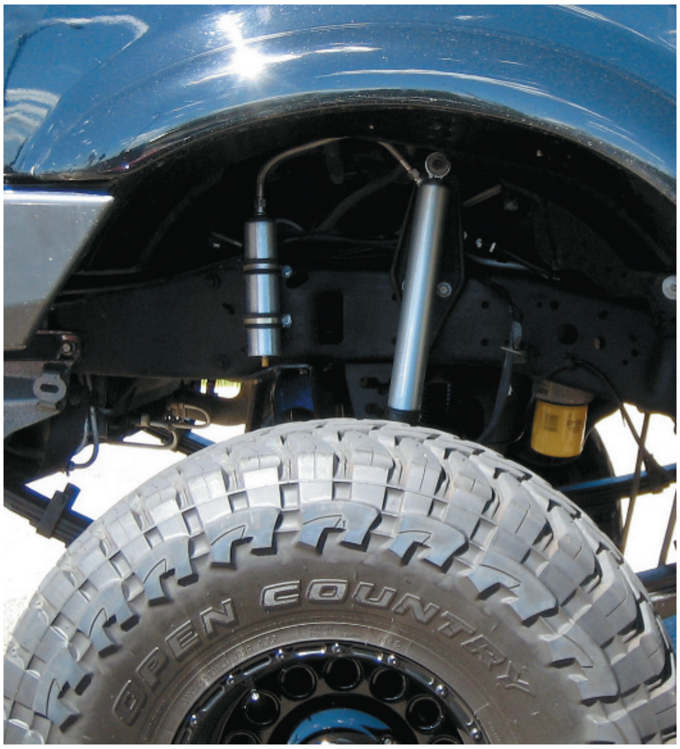


FIGURE 111–54 The shock absorber is on the right and the fluid reservoir for the shock is on the left.

FREQUENTLY ASKED QUESTION

What Are Remote Reservoir Shocks?

Remote reservoir shock absorbers are units designed for heavy-duty use that use a separate container for the working fluid. ● **SEE FIGURE 111–54**.

The purpose of the remote fluid reservoir is to keep the temperature of the fluid stable, which helps the shock absorber provide consistent dampening under all conditions.

STRUTS

PURPOSE AND FUNCTION A **strut** is a sturdy shock absorber that is also a structural component of the suspension. A strut is a suspension link as well as a shock absorber. The casing of a strut must be strong and rigid to function as a suspension link. The shock absorber assembles inside the casing of a strut and may be either a removable cartridge or an integral part of the strut.

MACPHERSON STRUTS The MacPherson strut, which is named after Earle S. MacPherson, who developed the suspension design in the late 1940s and patented it in 1953, is the most commonly used type. A MacPherson strut includes the suspension spring—a coil spring that surrounds the strut casing—so that it transfers the weight of the body to the wheel. ● **SEE FIGURE 111–55**.

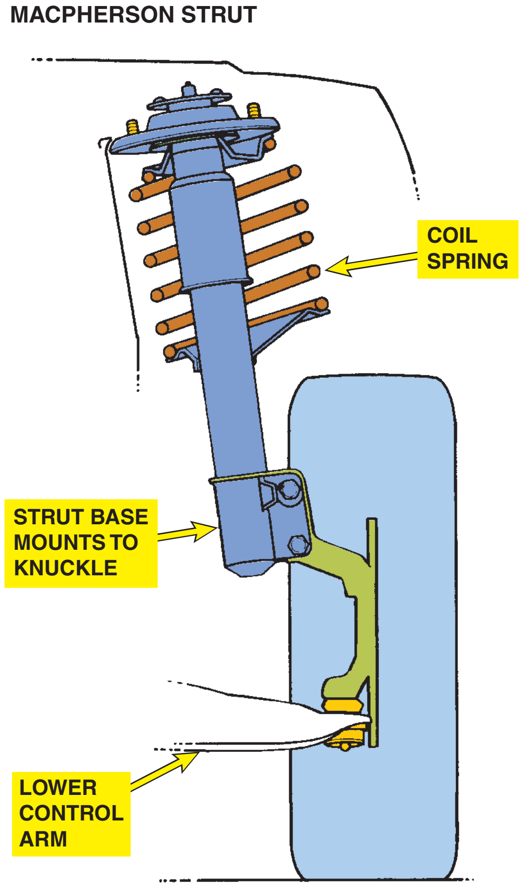


FIGURE 111–55 A strut is a structural part of the suspension and includes the spring and shock absorber in one assembly.

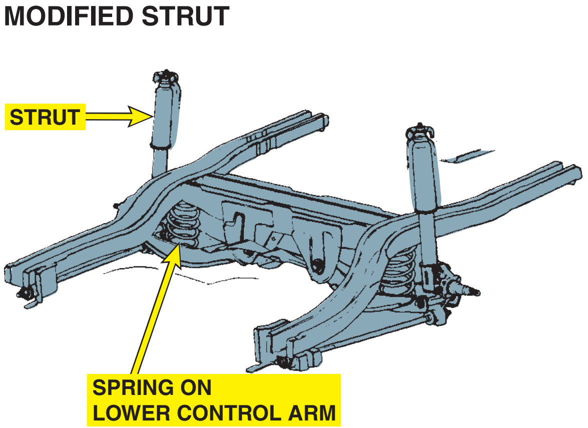


FIGURE 111–56 A modified strut used on the rear suspension; it is the structural part of the assembly.

A MacPherson strut typically incorporates an upper and a lower spring seat, a shock absorber mount and dust cap, a dust cover for the piston rod, and a bump stop. The upper mount secures the upper spring seat to the strut tower. A rubber bushing at the top of the strut absorbs vibrations. A bearing on a front-wheel strut allows it to rotate on the vertical steering axis without rubbing against the strut tower when the steering knuckle turns. The lower spring seat is attached to the strut casing.

MODIFIED STRUTS Unlike a MacPherson unit, a modified strut does not include a spring as part of the assembly and is used in the front on some vehicles and on the rear of others. ● **SEE FIGURE 111–56**. Most modified strut rear suspensions use coil springs mounted on the lower control arm.

BUMP STOPS

PURPOSE AND FUNCTION All suspension systems have a limit of travel. If the vehicle hits a large bump in the road, the wheels are forced upward toward the vehicle with tremendous force. This force is absorbed by the springs of the suspension system. If the bump is large enough, the suspension is compressed to its mechanical limit. Instead of allowing the metal components of the suspension to hit the frame or body of the vehicle, a rubber or foam bumper is used to absorb and isolate the suspension from the frame or body. ● **SEE FIGURES 111–57 AND 111–58**.

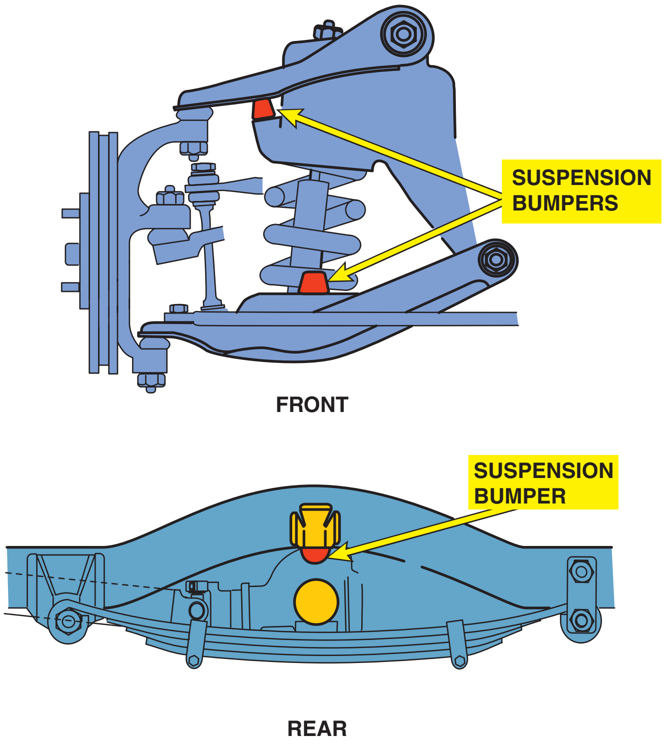


FIGURE 111–57 Suspension bumpers are used on all suspension systems to prevent metal-to-metal contact between the suspension and the frame or body of the vehicle when the suspension "bottoms out" over large bumps or dips in the road.

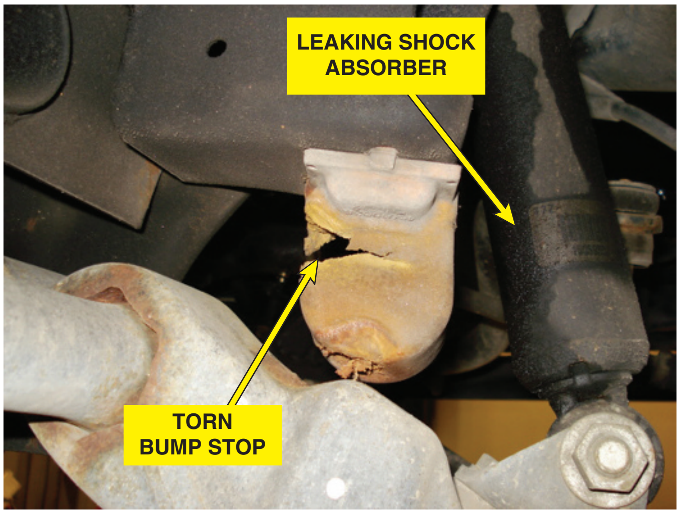


FIGURE 111–58 A bad suspension bumper (strike-out bumper) that was likely caused by a defective shock absorber. Both will require replacement.

These bumpers are called **bump stops**, suspension bumpers, strike-out bumpers, or jounce bumpers. *Jounce* means jolt, or to cause to bounce or move up and down. Bumpers are made from rubber or microcellular urethane. Urethane is a high-strength material with good resistance to wear and tear as well as good chemical resistance to most fluids. Forming urethane foam with small, regular air cells makes the material ideal for jounce bumpers.

Damaged suspension-limiting bump stops can be caused by the following:

1. Sagging springs that result in lower-than-normal ride (trim) height
2. Worn or defective shock absorbers

Most suspensions also use a rubber or foam stop to limit the downward travel of the suspension during rebound. The rebound stop also prevents metal-to-metal contact of the suspension on the frame when the vehicle is on a body-contact-type hoist and the wheels are allowed to hang or droop down. Some stops are built into the shock absorber or strut.

FREQUENTLY ASKED QUESTION

What Is a Track Rod?

A track rod, also called a Panhard rod, is used in the rear of some suspension systems to keep the rear axle centered under the center of the vehicle. It is a straight rod or channel that connects to the frame on one end and the axle on the other end.

REVIEW QUESTIONS

1. What types of springs are used in vehicle suspension systems?
2. What does Hooke's Law state?
3. What is the purpose and function of a stabilizer bar?
4. What is the difference between a load-carrying and a follower (friction) ball joint?
5. What is the purpose and function of bump stops?

CHAPTER QUIZ

1. A truck will typically use a ___________ frame.
   - **a.** perimeter
   - **b.** ladder
   - **c.** stub-type
   - **d.** None of the above
2. All suspension types use ___________ of one form or another.
   - **a.** beam axles
   - **b.** control arms
   - **c.** springs
   - **d.** pivot shafts
3. The spring rate of a spring is measured in units of ___________.
   - **a.** lb per inch
   - **b.** ft-lb
   - **c.** PSI
   - **d.** in.-lb
4. Two technicians are discussing torsion bars. Technician A says that many torsion bars are adjustable to allow for ride height adjustment. Technician B says that torsion bars are usually marked left and right and should not be switched side to side. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. A center bolt is used in what type of spring?
   - **a.** Coil
   - **b.** Leaf
   - **c.** Torsion bar
   - **d.** All of the above
6. What suspension component is used to counteract body lean during cornering?
   - **a.** Torsion bar
   - **b.** Strut rod
   - **c.** Stabilizer bar
   - **d.** Control arm
7. Two technicians are discussing MacPherson struts. Technician A says that in most applications the entire strut assembly rotates when the front wheels are turned. Technician B says a typical MacPherson strut suspension system uses only one control arm and one ball joint per side. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. What type of suspension is normally used on the front of today's vehicles?
   - **a.** Solid axle
   - **b.** Stub axle
   - **c.** Independent suspension
   - **d.** Semi-dependent suspension
9. A ___________ is a structural part of the vehicle.
   - **a.** coil spring
   - **b.** shock absorber
   - **c.** bump stop
   - **d.** MacPherson strut
10. The ___________ of any vehicle is its basic size and shape.
    - **a.** body
    - **b.** platform
    - **c.** frame
    - **d.** suspension

Chapter 112

FRONT SUSPENSION AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe different front suspension types.
- Discuss short-/long-arm (SLA) suspension systems.
- Discuss strut suspension.
- Explain how to service suspension systems, including a road test, a dry park test, and a visual inspection.
- Discuss the diagnosis of ball joints.
- Discuss the diagnosis of shock absorbers and struts.
- Describe how to replace MacPherson struts.
- Explain the diagnosis of stabilizer bar links and bushings.
- Discuss the diagnosis of strut rod bushings.
- Discuss the diagnosis of front coil springs.
- Discuss the diagnosis of steering knuckles.
- Discuss the adjustment of torsion bars.
- Discuss the diagnosis of control arm bushings.

KEY TERMS:

A-arm 1368 • Cow catcher 1381 • Cuppy tire wear 1379 • Dry park test 1373 • Durometer 1386 • Indicator ball joints 1374 • Kingpins 1367 • Pinch bolt 1377 • Radius rod 1368 • Short-/long-arm (SLA) 1368 • Steering knuckle 1367 • Strut suspension 1370 • Twin I-beam 1367

FRONT SUSPENSION TYPES

SOLID AXLES Early cars and trucks used a solid (or *straight*) front axle to support the front wheels. ● **SEE FIGURE 112–1**.

A solid-axle front suspension is very strong and is still being used in the manufacture of medium and heavy trucks. The main disadvantage of solid-axle design is its lack of ride quality. When one wheel hits a bump or dip in the road, the forces are transferred through the axle to the opposite wheel. Solid axles are currently used in the rear of many vehicles.

KINGPINS At the end of many solid I-beam or tube axles are **kingpins** that allow the front wheels to rotate for steering. Kingpins are hardened steel pins that attach the steering knuckle to the front axle, allowing the front wheels to move for steering. Kingpins usually have grease fittings to lubricate the kingpin bushings. Failure to keep these bushings lubricated with chassis grease can cause wear and freeplay or can cause the pins to become galled (seized or frozen), resulting in hard steering and/or loud noise while turning. ● **SEE FIGURE 112–2**.

TWIN I-BEAMS A **twin I-beam** front suspension was used for over 30 years on Ford pickup trucks and vans, beginning in the mid-1960s. Strong steel twin beams that cross provide independent front suspension operation with the strength of a solid front axle. Early versions of the twin I-beam systems used kingpins, while later models used ball joints to support the **steering knuckle** and spindle. Coil springs are usually used on twin I-beam suspensions, even though the original design and patent used leaf springs. ● **SEE FIGURE 112–3**.

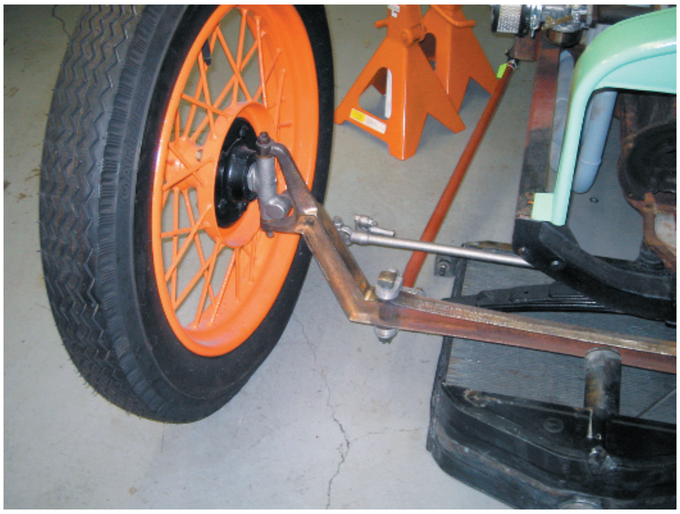


FIGURE 112–1 Most early vehicles used single straight axles.

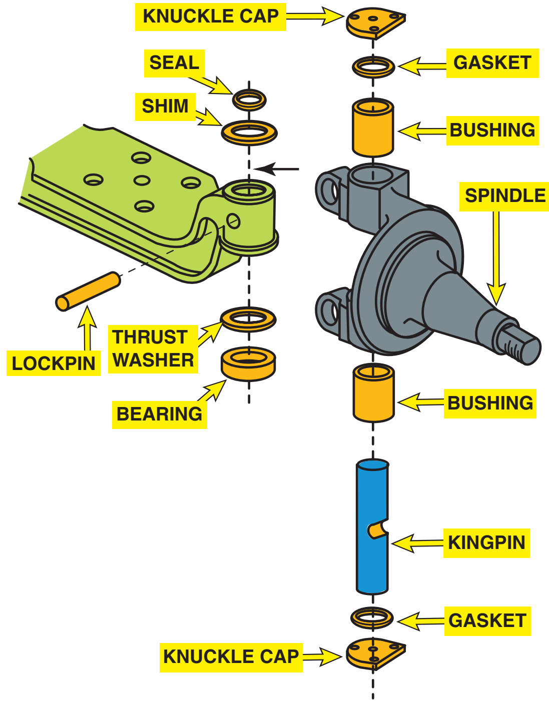


FIGURE 112–2 Typical kingpin used with a solid axle.

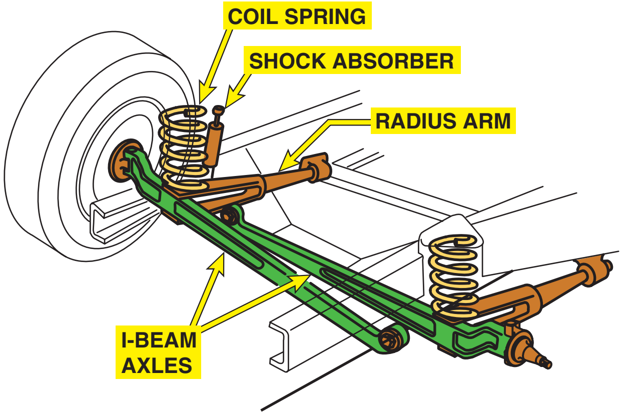


FIGURE 112–3 Twin I-beam front suspension. Rubber bushings are used to support the I-beams to the frame and help isolate road noise.

TECH TIP

Radius Rod Bushing Noise

When the radius rod bushing on a Ford truck or van deteriorates, the most common complaint from the driver is noise. ● **SEE FIGURE 112–4**. Besides causing tire wear, worn or defective radius rod bushing can cause the following:

1. A clicking sound when braking (it sounds as if the brake caliper may be loose).
2. A clunking noise when hitting bumps.

When the bushing deteriorates, the axles move forward and backward with less control. Noise is the first sign that something is wrong. Without proper axle support, handling and cornering can also be affected.

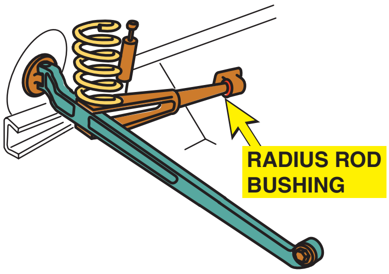


FIGURE 112–4 The rubber radius rod bushing absorbs road shocks and helps isolate road noise.

To control longitudinal (front-to-back) support, a **radius rod** is attached to each beam and is anchored to the frame of the truck using rubber bushings. These bushings allow the front axle to move up and down while still insulating road noise and vibration from the frame and body.

SHORT-/LONG-ARM SUSPENSIONS

TERMINOLOGY The short-/long-arm suspension uses a short upper control arm and a longer lower control arm and is usually referred to as the *SLA-type suspension.*

The two main links in a **short-/long-arm (SLA)** suspension are the upper control arm and the lower control arm. The upper control arm is shorter than the lower one. ● **SEE FIGURE 112–5**. This type of suspension system goes by a variety of names, including unequal-arm suspension, double-wishbone suspension, or **A-arm** suspension. Unequal arm refers to the fact that the two arms are of different lengths, while double-wishbone and A-arm derive from the shape of the arms, which are frequently triangular with one mounting point at the knuckle and two at the frame. When an SLA suspension uses a straight, two-point lower control arm, there is almost always a strut rod that braces the lower arm against the frame. The strut rod can attach to the frame at a point either forward or to the rear of the control arm.

STRUT RODS A strut rod, also called a *reaction rod,* provides support to the axle during braking and acceleration forces.

Using a strut rod provides triangulation between the wheel and the frame. *Triangulation* means that the front suspension has a three-point brace that resists forces from every direction while still allowing the wheels to pivot on the steering axis.

COIL SPRING FRONT SUSPENSIONS Locating the coil spring on the lower control arm is the most common SLA-type suspension configuration. ● **SEE FIGURE 112–6**.

The upper control arm is A-shaped, with two mounting points at the frame side member and one at the steering knuckle. The inboard ends of the arm attach to a pivot bar that is rigidly bolted to the frame, and the outboard end connects to the steering knuckle with a ball joint. Bushings between the inner arm mounts and the pivot bar allow the arm to swing vertically. The lower control arm is also A-shaped with two inboard pivot mounts and a ball joint connection at the knuckle. Bolts attach the inboard ends of the lower arm to brackets that extend from the bottom of the frame crossmember. Bushings on the inboard mounts allow the arm to pivot vertically.

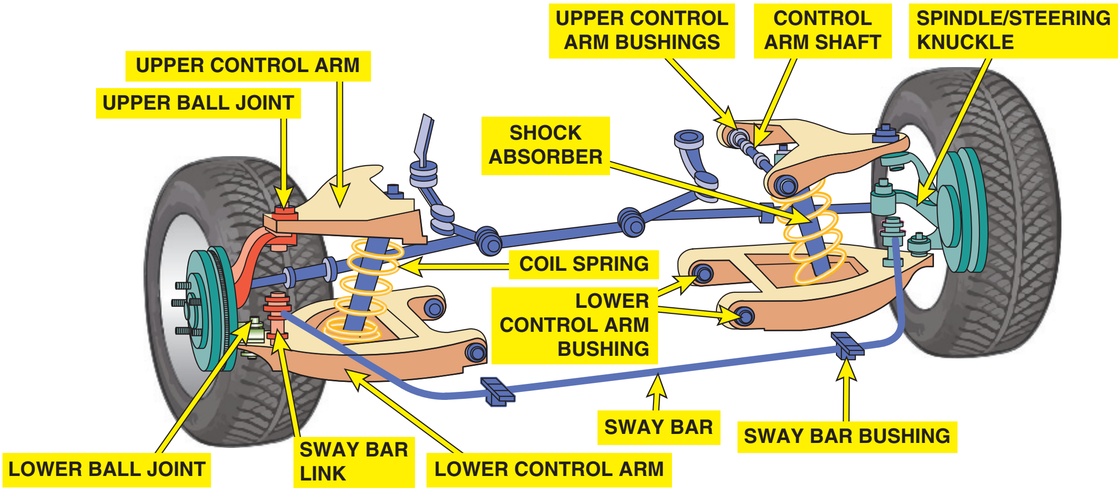

UPPER CONTROL ARM BUSHINGS
CONTROL ARM SHAFT
SPINDLE/STEERING KNUCKLE
UPPER CONTROL ARM
UPPER BALL JOINT
SHOCK ABSORBER
COIL SPRING
LOWER CONTROL ARM BUSHING
SWAY BAR
SWAY BAR BUSHING
LOWER BALL JOINT
SWAY BAR LINK
LOWER CONTROL ARM

FIGURE 112–5 The upper control arm is shorter than the lower control arm on a short-/long-arm (SLA) suspension.

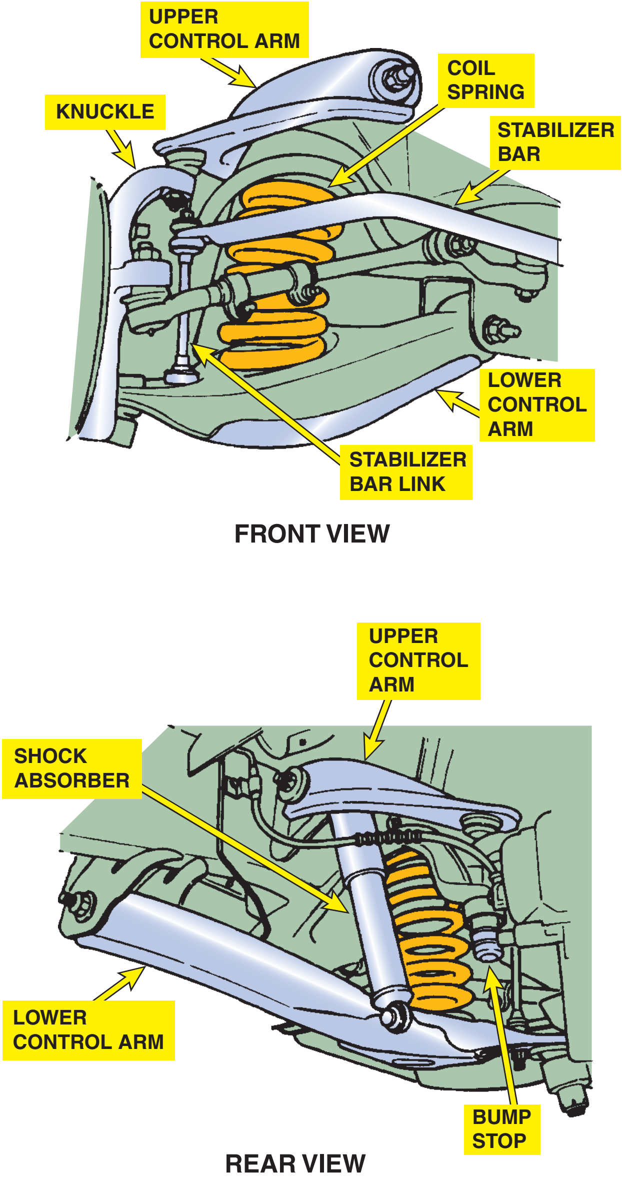

UPPER CONTROL ARM
KNUCKLE
COIL SPRING
STABILIZER BAR
LOWER CONTROL ARM
STABILIZER BAR LINK
FRONT VIEW
UPPER CONTROL ARM
SHOCK ABSORBER
LOWER CONTROL ARM
BUMP STOP
REAR VIEW

FIGURE 112–6 A typical SLA-front suspension using coil springs.

The coil springs seat between the lower control arm and a bracket below the frame side member. The shock absorber attaches to the lower control arm and the frame side member.

In a typical coil spring on the upper control arm design, a portion of the unit-body wheel well is reinforced to withstand spring force and act as the upper spring seats. ● **SEE FIGURE 112–7**.

TORSION BAR FRONT SUSPENSION Short-/long-arm suspensions use longitudinal torsion bars, especially in trucks.

The forward end of the torsion bar has external splines and shares the splined socket of the torque arm with the control arm through a bolt. Because the torque arm is rigidly bolted to the control arm, motion transfers to the torsion bar whenever the control arm pivots. The torsion bar extends rearward from the control arm and connects to an anchor arm that attaches to a frame crossmember. The torsion bar splines to the anchor arm and the anchor arm is secured to the frame by a bolt and adjusting nut. The adjusting nut varies the spring force of the torsion bar to establish the ride height of the vehicle. ● **SEE FIGURE 112–8**.

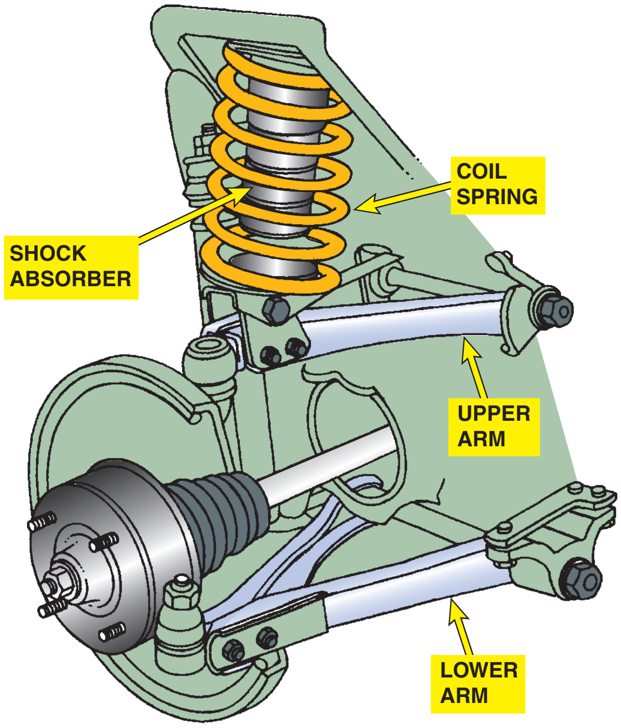

COIL SPRING
SHOCK ABSORBER
UPPER ARM
LOWER ARM

FIGURE 112–7 An SLA-type suspension with the coil spring placed on top of the upper control arm.

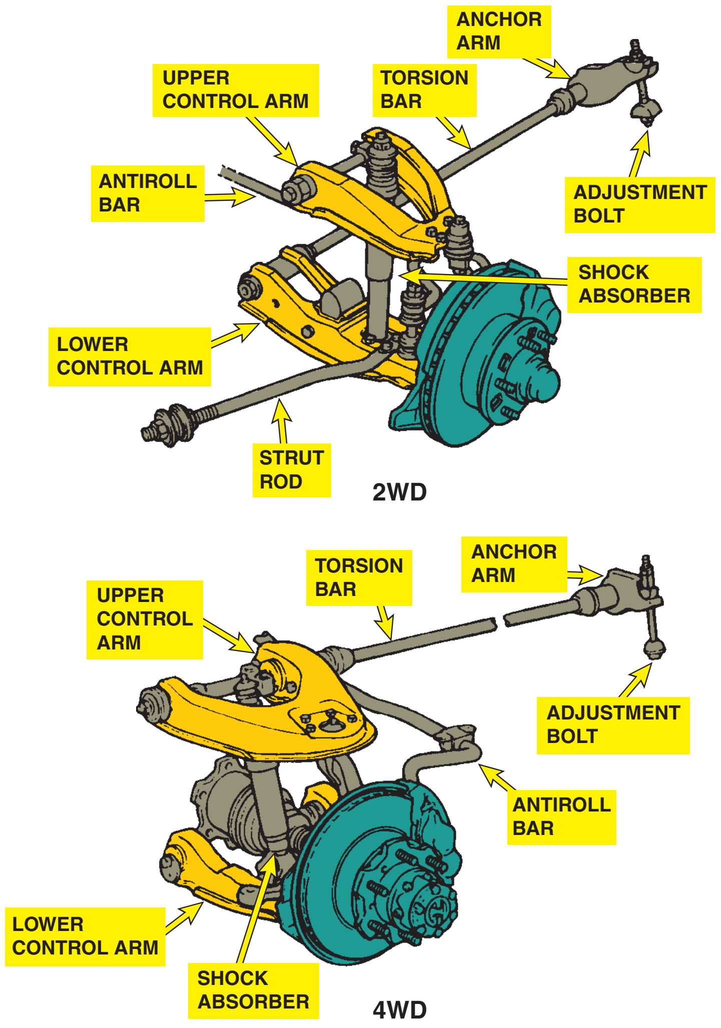

ANCHOR ARM
UPPER CONTROL ARM
TORSION BAR
ANTIROLL BAR
ADJUSTMENT BOLT
SHOCK ABSORBER
LOWER CONTROL ARM
STRUT ROD
2WD
TORSION BAR
ANCHOR ARM
UPPER CONTROL ARM
ADJUSTMENT BOLT
ANTIROLL BAR
LOWER CONTROL ARM
SHOCK ABSORBER
4WD

FIGURE 112–8 A torsion bar SLA suspension can use either the lower or the upper control arm.

FREQUENTLY ASKED QUESTION

What Is a Coil-Over-Shock Suspension?

In some applications, the spring and shock absorber are combined to fit within the upper and lower A-arms. This makes for a simple and lightweight front-type suspension and is used in a variety of vehicles including light pickup trucks. ● **SEE FIGURE 112–9.**

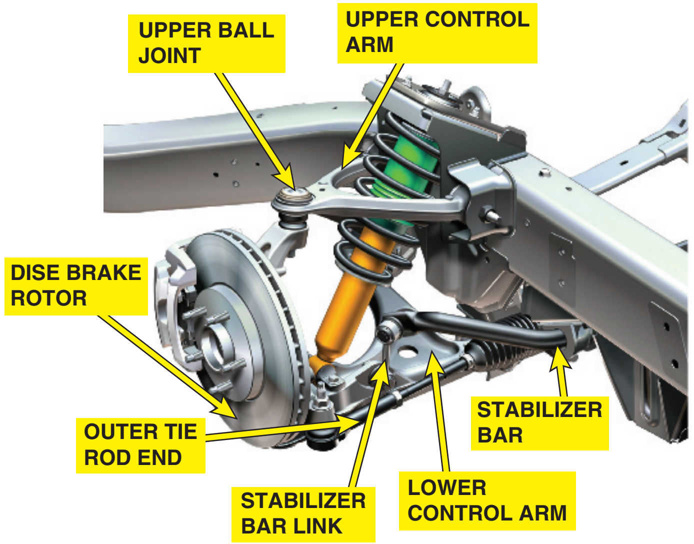

UPPER BALL JOINT
UPPER CONTROL ARM
DISE BRAKE ROTOR
OUTER TIE ROD END
STABILIZER BAR
STABILIZER BAR LINK
LOWER CONTROL ARM

FIGURE 112–9 An SLA-type suspension that uses a coil-over-shock assembly.

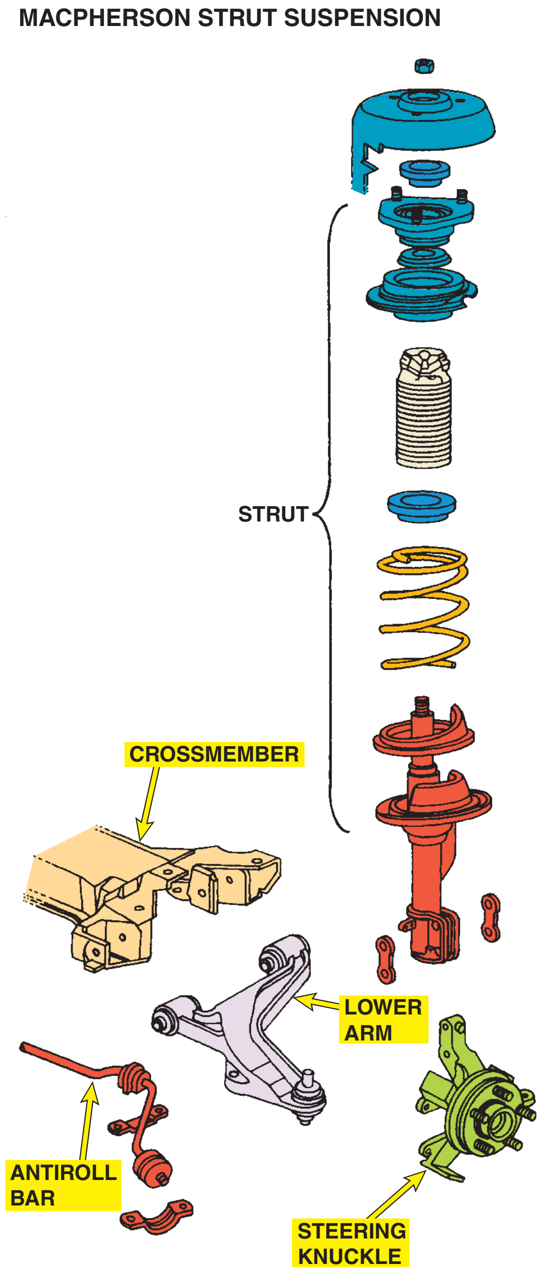

MACPHERSON STRUT SUSPENSION
STRUT
CROSSMEMBER
LOWER ARM
ANTIROLL BAR
STEERING KNUCKLE

FIGURE 112–10 A typical MacPherson strut showing all of the components of the assembly. A strut includes the shock and the spring in one structural assembly.

STRUT SUSPENSION

PARTS AND OPERATION **Strut suspension** can be of several types. A MacPherson strut includes the suspension spring that transfers the weight of the body to the wheel. A MacPherson strut is the main, load-carrying suspension spring. ● **SEE FIGURE 112–10.**

A MacPherson strut typically incorporates an upper and a lower spring seat, a shock absorber mount and dust cap, a dust cover for the piston rod, and a bump stop. The upper mount secures the upper spring seat to the strut tower. A rubber bushing at the top of the strut absorbs vibrations. In most applications, a bearing on the top of a front-wheel strut allows it to rotate on the vertical steering axis without rubbing against the strut tower

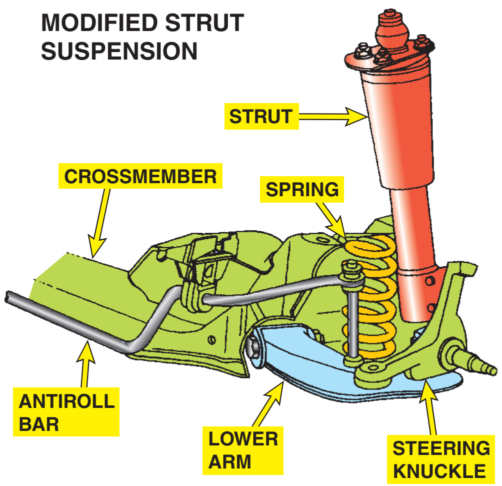


FIGURE 112–11 The modified strut front suspension is similar to a MacPherson strut suspension except that the coil spring is seated on the lower control arm and is not part of the strut assembly.

when the steering knuckle turns. The lower spring seat is attached to the strut casing. The piston rod dust cover is similar to the dust cover on a conventional shock absorber, and a bump stop at the top of the piston rod keeps the strut from bottoming out during suspension jounce.

A modified strut does not include a spring as part of the assembly. ● **SEE FIGURE 112–11**. A modified strut is used on the rear of some GM vehicles. Except for the lack of a spring and spring seats, the construction and function of a modified strut are basically the same as those of a MacPherson strut. When used on the front suspension, a modified strut also rotates on the steering axis when the wheels turn.

A multilink front suspension uses two control arms as well as a structural strut assembly. This type of suspension is also called a strut/SLA or long spindle, and short-/long-arm suspension. ● **SEE FIGURE 112–12**.

SERVICING THE SUSPENSION SYSTEM

Suspension systems are designed and manufactured to provide years of trouble-free service with a minimum amount of maintenance. In fact, the suspension system is often not noticed at all by the driver because the vehicle rides and handles as expected. It is when the driver notices that the vehicle is not riding or handling as it did, or should, that a technician is asked to repair or align the vehicle and fix the problem.

The smart technician should always road test any vehicle before and after servicing (see Tech Tip for details). *The purpose of any diagnosis is to eliminate known good components.* (See the suspension problem symptom chart for a list of components that can cause the problem or customer complaint.)

CAUTION: More than one factor may be the cause of a problem. Be sure to inspect all suspension components, and repair all parts that are worn or damaged. Failure to do so may allow the problem to reoccur and cause premature failure of other suspension components.

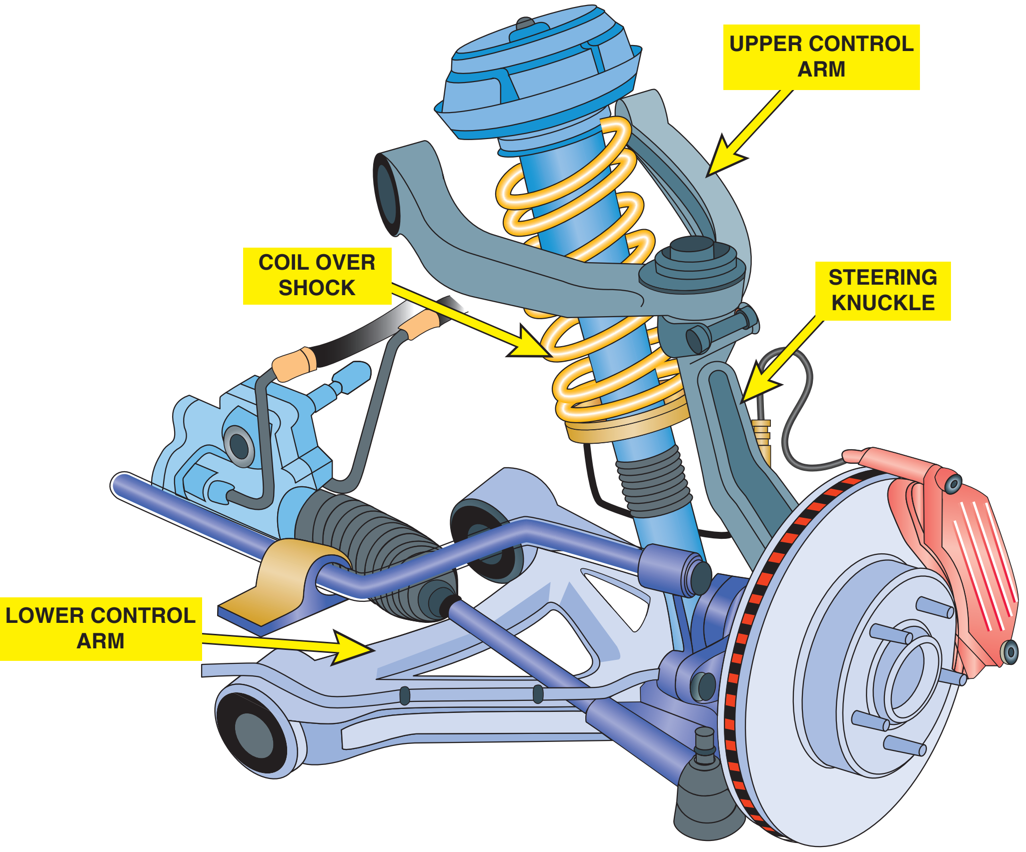


FIGURE 112–12 A typical multilink front suspension system.

ROAD TEST DIAGNOSIS If possible, perform a road test of the vehicle with the owner of the vehicle. It is also helpful to have the owner drive the vehicle. While driving, try to determine when and where the noise or problem occurs, such as the following:

1. In cold or warm weather
2. With cold or warm engine/vehicle
3. While turning, left only, right only

A proper road test for any suspension system problem should include the following:

1. **Drive beside parked vehicles.** Any noise generated by the vehicle suspension or tires is reflected off solid objects, such as a row of parked vehicles along a street. For best results, drive with the windows down and drive close to the parked vehicles or a retaining wall on the left side. Repeat the drive for the right side. Defective wheel bearings or power steering pumps usually make noise and can be heard during this test.
2. **Drive into driveways.** Suspension problems often occur when turning at the same time the suspension hits a bump. This action is best repeated by driving slowly into a driveway with a curb. The curb causes the suspension to compress while the wheels are turned (see the Case Study titled "The Rock-Hard Problem" for an example). Defective stabilizer bar bushings, control arm bushings, and ball joints will usually make noise during this test procedure. ● **SEE CHART 112–1.**
3. **Drive in reverse while turning.** This technique is usually used to find possible defective outer constant-velocity (CV) joints used on the drive axle shaft of front-wheel-drive vehicles. This technique also forces the suspension system to work in reverse of normal. Any excessive clearances in the suspension system are reversed and often make noise or cause a vibration during the test. Besides defective CV joints, this test can often detect worn control arm bushings, ball joints, stabilizer bar bushings, or links. This test can also

SUSPENSION PROBLEM SYMPTOMS CHART

	CONCERN/PROBLEM					
Item or System to Check	**Noise**	**Instability/ Wander**	**Pull to One Side**	**Excessive Steering Play**	**Hard Steering**	**Shimmy**
Tires/Wheels	Road/tire noise	Low/uneven air pressure	Low/uneven air pressure, mismatched tire sizes	Low/uneven air pressure	Low/uneven air pressure	Wheel out of balance/uneven tire wear/ overworn tires
Shock Absorbers (Struts)	Loose/worn mounts/ bushings	Loose/worn mounts/bushings, worn/ damaged struts/shock absorbers	Loose/worn mounts/ bushings		Loose/worn mounts/ bushings on strut assemblies	Worn/damaged struts/shock absorbers
Strut Rods (If Equipped)	Loose/worn mounts/ bushings	Loose/worn mounts/ bushings	Loose/worn mounts/ bushings			Loose/worn mounts/ bushings
Springs	Brakes damaged	Brakes damaged	Brakes damaged, especially rear			
Control Arms	Steering knuckle contacting control arm stop, worn/damaged mounts/bushings	Worn/damaged mounts/ bushings	Worn/damaged mounts/ bushings		Worn/ damaged mounts/ bushings	Worn/damaged mounts/ bushings
Steering System	Component wear/ damage	Component wear/ damage	Component wear/damage	Component wear/damage	Component wear/damage	Component wear/damage
Wheel Alignment		Front and rear, especially caster	Front, camber and caster	Front alignment	Front, especially caster	Front, especially caster
Wheel Bearings	Front-wheel bearings	Loose/worn (front and rear)	Loose/worn (front and rear)	Loose/worn (front and rear)		Loose/worn (front and rear)
Brake System			Stuck caliper/ slide			
Other					Ball joint lubrication	Loose/worn friction ball joints

CHART 112–1

Suspension problem symptoms and possible causes.

detect defective or worn steering system components such as an idler arm, tie rod end, or center link.

4. **Drive over a bumpy road.** Worn or defective suspension (and steering) components can cause the vehicle to bounce or dart side to side while traveling over bumps and dips in the road. Worn or defective ball joints, control arm bushings, stabilizer bar bushings, stabilizer bar links, or worn shock absorbers can be the cause.

Once the problem has been confirmed, a further inspection can be performed in the service bay.

DRY PARK TEST (SUSPENSION) A **dry park test** can also be used to help locate worn or defective suspension components. The dry park test is performed by having an assistant move the steering wheel side to side while feeling and observing for any freeplay in the steering or suspension. For best results, the vehicle should be on a level floor or on a drive-on-type hoist with the front wheels pointing straight ahead. In this suspension analysis using the dry park test, the technician should observe the following for any noticeable play or unusual noise:

1. **Front wheel bearings.** Loose or defective wheel bearings are often overlooked as a possible cause of poor handling or darting vehicle performance.
2. **Control arm bushing wear or movement.** Check for any abnormal movement in upper control arm bushings or lower control arm bushings.
3. **Ball joint movement.** Check for any noticeable play or noise from both load-carrying and follower-type ball joints on both sides of the vehicle.

NOTE: The dry park test (and many other chassis system tests) relies on the experience of the technician to be able to judge normal wear from abnormal wear. It is extremely important that all beginning technicians work closely with an experienced technician to gain this knowledge.

TECH TIP

Road Test—Before and After

Many times, technicians will start to work on a vehicle based on the description of the problem by the driver or owner. A typical conversation was overheard where the vehicle owner complained that the vehicle handled "funny," especially when turning. The owner wanted a wheel alignment, and the technician and shop owner wanted the business. The vehicle was aligned, but the problem was still present. The real problem was a defective tire. The service technician should have road tested the vehicle *before* any service work was done to confirm the problem and try to determine its cause. Every technician should test-drive the vehicle *after* any service work is performed to confirm that the service work was performed correctly and that the customer complaint has been resolved. This is especially true for any service work involving the steering, suspension, or braking systems.

VISUAL INSPECTION All suspension components should be carefully inspected for signs of wear or damage. A thorough visual inspection should include checking all of the following:

1. Shock absorbers and struts. ● **SEE FIGURE 112–13**.
2. Springs. ● **SEE FIGURE 112–14**.
3. Stabilizer bar links
4. Stabilizer bar bushings
5. Upper and lower shock absorber mounting points
6. Bump stops
7. Body-to-chassis mounts
8. Engine and transmission (transaxle) mounts
9. Suspension arm bushings. ● **SEE FIGURE 112–15**.

Alignment equipment and procedures can often determine if a suspension component is bent or has been moved out of position. A careful *visual* inspection can often reveal suspected damaged components by observing scrape marks or rusty sections that could indicate contact with the road or another object.

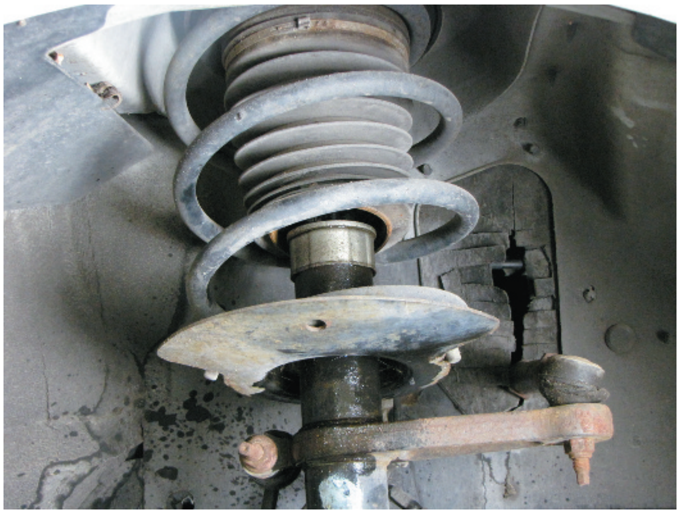


FIGURE 112–13 A leaking strut. Either a cartridge insert or the entire strut will require replacement. If a light film of oil is seen, this is to be considered normal. If oil is dripping, then this means that the rod seal has failed.

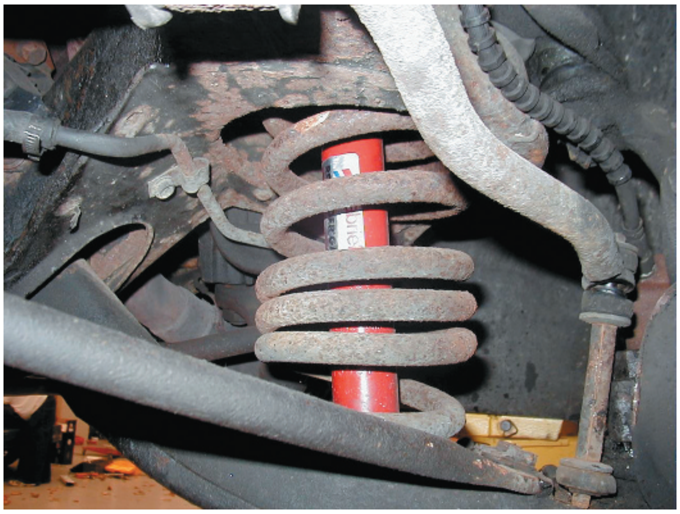


FIGURE 112–14 This front coil spring looks as if it has been heated with a torch in an attempt to lower the ride height of the vehicle. Both front springs will require replacement.

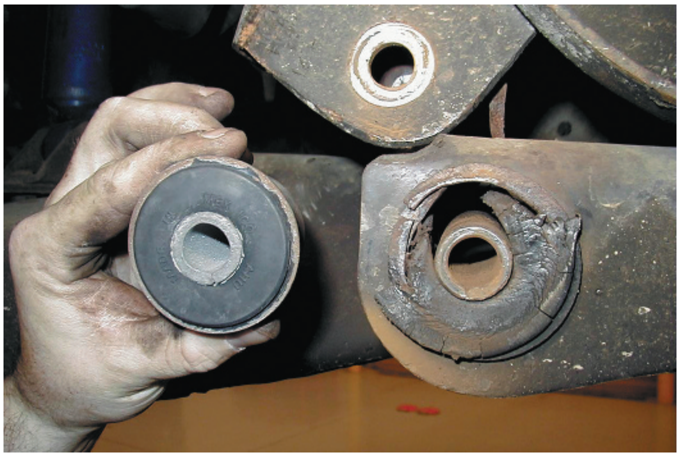


FIGURE 112–15 It is easy to see that this worn control arm bushing needs to be replaced. The new bushing is shown next to the original.

While an assistant bounces the vehicle up and down, check to see if there is any freeplay in any of the suspension components.

BALL JOINTS

DIAGNOSIS AND INSPECTION The life of ball joints depends on driving conditions, vehicle weight, and lubrication. Even with proper care and lubrication, the load-carrying (weight-carrying) ball joints wear more than the follower ball joints. Ball joints should be replaced in pairs, both lower or both upper, to ensure the best handling.

Defective or worn ball joints can cause looseness in the suspension and the following common driver complaints:

1. Loud popping or squeaking whenever driving over curbs, such as into a driveway
2. Shimmy-type vibration felt in the steering wheel
3. Vehicle wander or a tendency not to track straight
4. Excessive freeplay in the steering wheel

A ball joint inspection should also be done when an alignment is performed or as part of any other comprehensive vehicle inspection.

Many load-carrying ball joints have wear indicators with a raised area around the grease fitting, called **indicator ball joints**. ● **SEE FIGURES 112–16 AND 112–17**.

Always check wear-indicator-type ball joints with the wheels of the vehicle on the ground. If the raised area around the grease fitting is flush or recessed with the surrounding area, the ball joint is worn more than 0.050 inch and must be replaced.

NOTE: Most ball joints must be replaced if the joint has more than 0.050 inch axial (up-and-down) movement. To help visualize this distance, consider that the thickness of an American nickel coin is about 0.060 inch. It is helpful to know that maximum wear should be less than the thickness of a nickel. There are dial indicators (gauges) available that screw into the grease-fitting hole of the ball joint that can accurately measure the wear. ● SEE FIGURE 112–18.

To perform a proper non-indicator-type ball joint inspection, the force of the vehicle's springs *must* be *unloaded* from the ball joint. If this force is not relieved, the force of the spring pushes the ball-and-socket joint tightly together and any wear due to movement will not be detected.

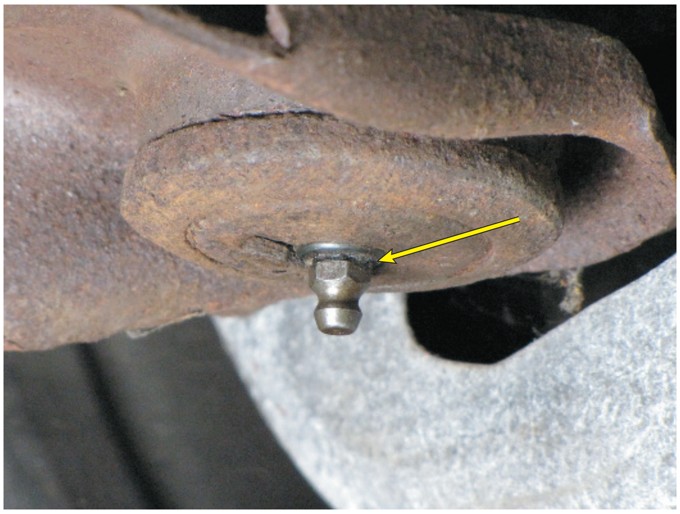


FIGURE 112–16 Grease fitting projecting down from the surrounding area of a ball joint. The ball joint should be replaced when the area around the grease fitting is flush or recessed.

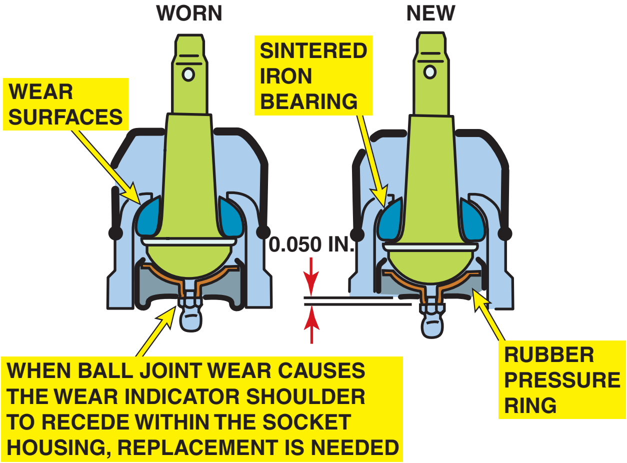

WORN
NEW
WEAR SURFACES
SINTERED IRON BEARING
0.050 IN.
WHEN BALL JOINT WEAR CAUSES THE WEAR INDICATOR SHOULDER TO RECEDE WITHIN THE SOCKET HOUSING, REPLACEMENT IS NEEDED
RUBBER PRESSURE RING

FIGURE 112–17 Indicator ball joints should be checked with the weight of the vehicle on the ground.

NOTE: The location of the load-carrying ball joint is closest to the seat of the spring or torsion bar.

If the coil spring or torsion bar is attached to the *lower* control arm, the *lower* ball joint is the load-carrying ball joint. ● **SEE FIGURE 112–19**. This includes vehicles equipped with modified MacPherson-strut-type suspension. ● **SEE FIGURE 112–20**.

1. Place the jack under the lower control arm as close to the ball joint as possible and raise the wheels approximately 1 to 2 inches (2.5 to 5 cm) off the ground to unload the lower ball joint.
2. Using a prybar under the tire, lift the wheel up. If there is excessive vertical movement in the ball joint itself, it must be replaced. Most manufacturers specify a maximum vertical play of approximately 0.050 inch (1.3 mm), or the thickness of a nickel. Always check the manufacturer's specifications for exact maximum allowable movement. Vertical movement of

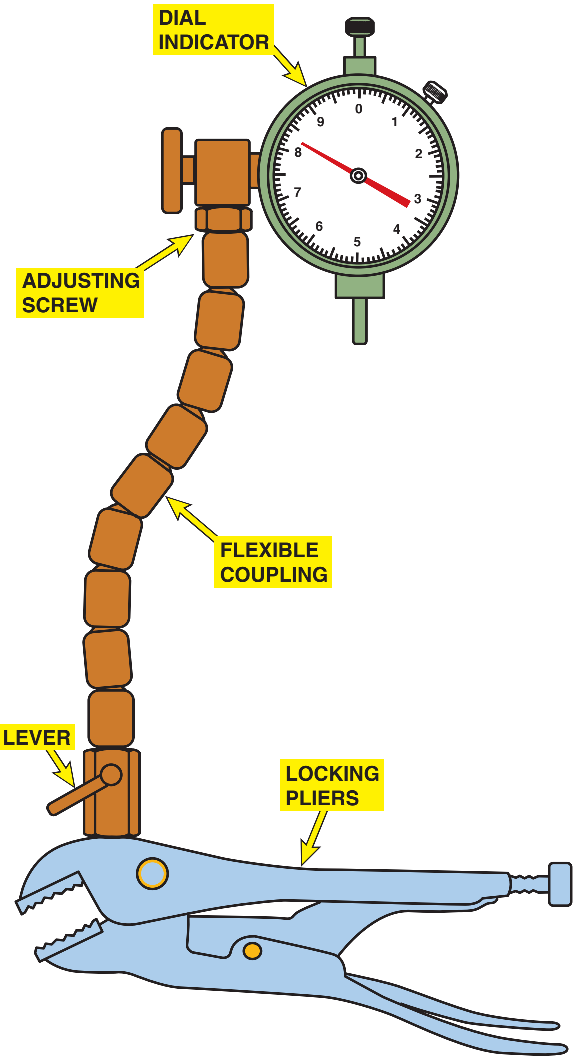

DIAL INDICATOR
0 1 2 3 4 5 6 7 8 9
ADJUSTING SCREW
FLEXIBLE COUPLING
LEVER
LOCKING PLIERS

FIGURE 112–18 Typical dial indicator used to measure the suspension component movement. The locking pliers attach the gauge to a stationary part of the vehicle and the flexible coupling allows the dial indicator to be positioned at any angle.

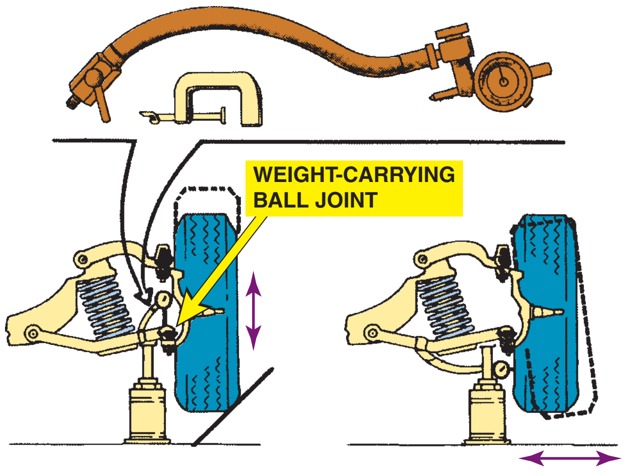

WEIGHT-CARRYING BALL JOINT

FIGURE 112–19 If the spring is attached to the lower control arm as in this SLA suspension, the jack should be placed under the lower control arm as shown. A dial indicator should be used to measure the amount of freeplay in the ball joints. Be sure that the looseness being measured is not due to normal wheel bearing endplay.

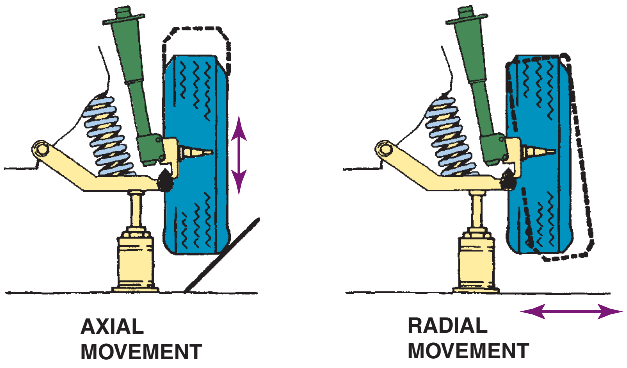

AXIAL MOVEMENT
RADIAL MOVEMENT

FIGURE 112–20 The jack should be placed under the lower control arm of this modified MacPherson-type suspension.

a ball joint is often called axial play because the looseness is in the same axis as the ball joint stud. To check for *lateral* play, grip the tire at the top and bottom and move your hands in opposite directions.

NOTE: Be sure that the cause of any freeplay or looseness is not due to the wheel bearing. Closely observe the exact source of the freeplay movement.

If the coil spring is attached to the *upper* control arm, the *upper* ball joint is the load-carrying ball joint. ● **SEE FIGURE 112–21.**

1. Place a block of wood (2 × 4 in.) between the upper control arm and the frame, or use a special tool designed for this purpose. ● **SEE FIGURE 112–22.**

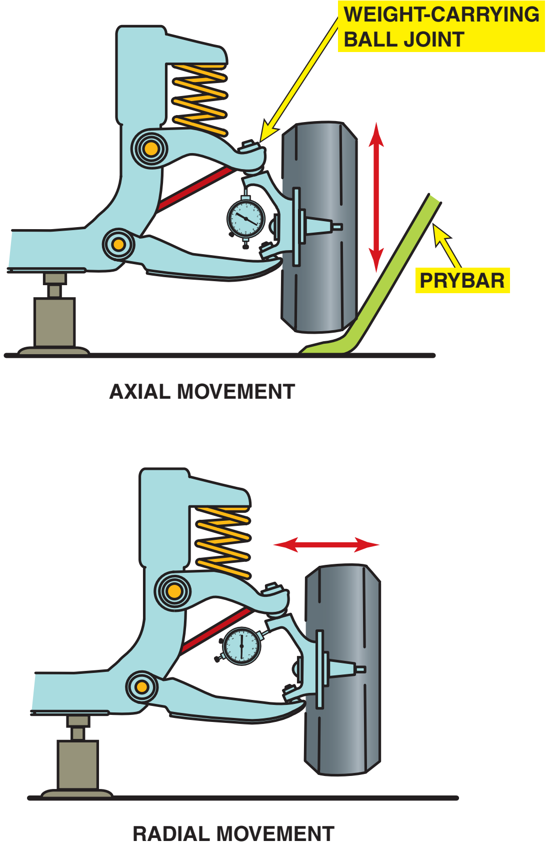

WEIGHT-CARRYING BALL JOINT
PRYBAR
AXIAL MOVEMENT
RADIAL MOVEMENT

FIGURE 112–21 If the spring is attached to the upper control arm, the jack should be placed under the frame to check for ball joint wear.

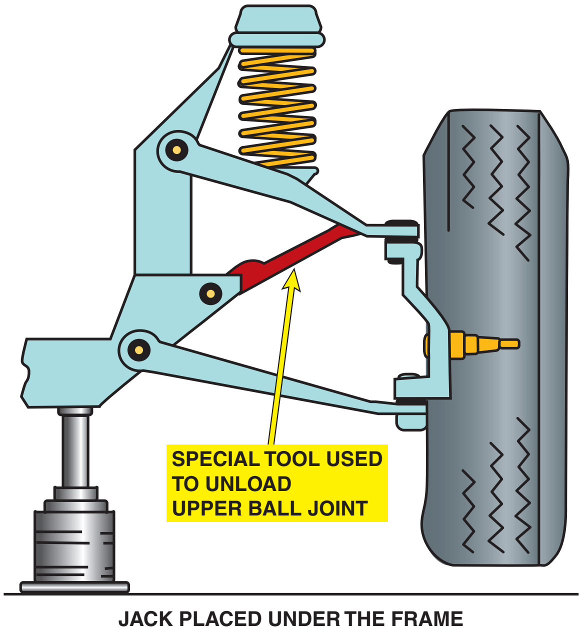


FIGURE 112–22 A special tool or a block of wood should be inserted between the frame and the upper control arm before lifting the vehicle off the ground. This tool stops the force of the spring against the upper ball joint so that a true test can be performed on the condition of the ball joint.

2. Place the jack under the vehicle's *frame* and raise the wheel approximately 1 to 2 inches off the ground. (The wood block or special tool keeps the weight of the vehicle off the upper ball joint.)
3. Using a prybar under the tire, lift the wheel. If there is excessive vertical movement in the ball joint itself, it must be replaced. Always check the manufacturer's specifications for exact maximum allowable movement.

Follower ball joints (friction ball joints) should also be inspected while testing load-carrying ball joints. Grasp the tire at the top and the bottom and attempt to shake the wheel assembly while looking directly at the follower ball joint. Generally, there should be no lateral or axial movement at all in the follower ball joint. However, some manufacturers specify a maximum of 0.250 inch (1/4 in. or 0.6 cm) measured at the top of the tire. Always check the manufacturer's specifications before condemning a ball joint because of excessive play.

MacPherson-strut-equipped vehicles do not have a load-carrying ball joint. The weight of the vehicle is carried through the upper strut mount and bearing assembly. ● **SEE FIGURE 112–23**.

After checking axial play in a ball joint, grasp the tire from the side at the top and bottom and alternately push and pull. *Any* lateral movement at the ball joint should generally be considered a good reason to replace the ball joints. ● **SEE FIGURE 112–24**.

BALL JOINT REMOVAL Take care to avoid damaging grease seals when separating ball joints from their mounts. *The preferred method to separate tapered parts is to use a puller-type tool that applies pressure to the tapered joint as the bolt is tightened on the puller.* ● **SEE FIGURE 112–25**.

Sometimes the shock of a hammer can be used to separate the ball joint from the steering knuckle. For best results, another hammer should be used as a backup while striking the joint to be separated on the side with a heavy hammer.

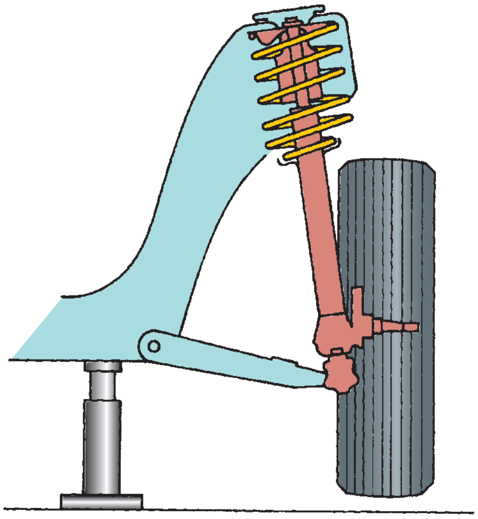


FIGURE 112–23 The jacking point is under the frame for checking the play of a lower ball joint used with a MacPherson strut.

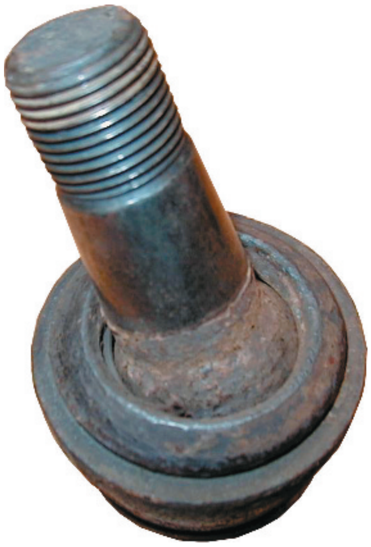


FIGURE 112–24 This worn and rusty ball joint was found by moving the wheel and looking for movement in the joint.

FREQUENTLY ASKED QUESTION

What Is the Difference between a Low-Friction Ball Joint and a Steel-on-Steel Ball Joint?

Before the late 1980s, most ball joints were constructed with a steel ball that rubbed on a steel socket. This design created friction and provided for a tight high-friction joint until wear caused looseness in the joint.

Newer designs use a polished steel ball that is installed in a hard plastic polymer, resulting in a low-friction joint assembly. Because of the difference in friction characteristics, the vehicle may handle differently than originally designed if incorrect-style ball joints are installed. Most component manufacturers state that low-friction ball joints in a vehicle originally equipped with steel-on-steel high-friction ball joints are usually acceptable, but high-friction replacement ball joints should be avoided on a vehicle originally equipped with low-friction ball joints.

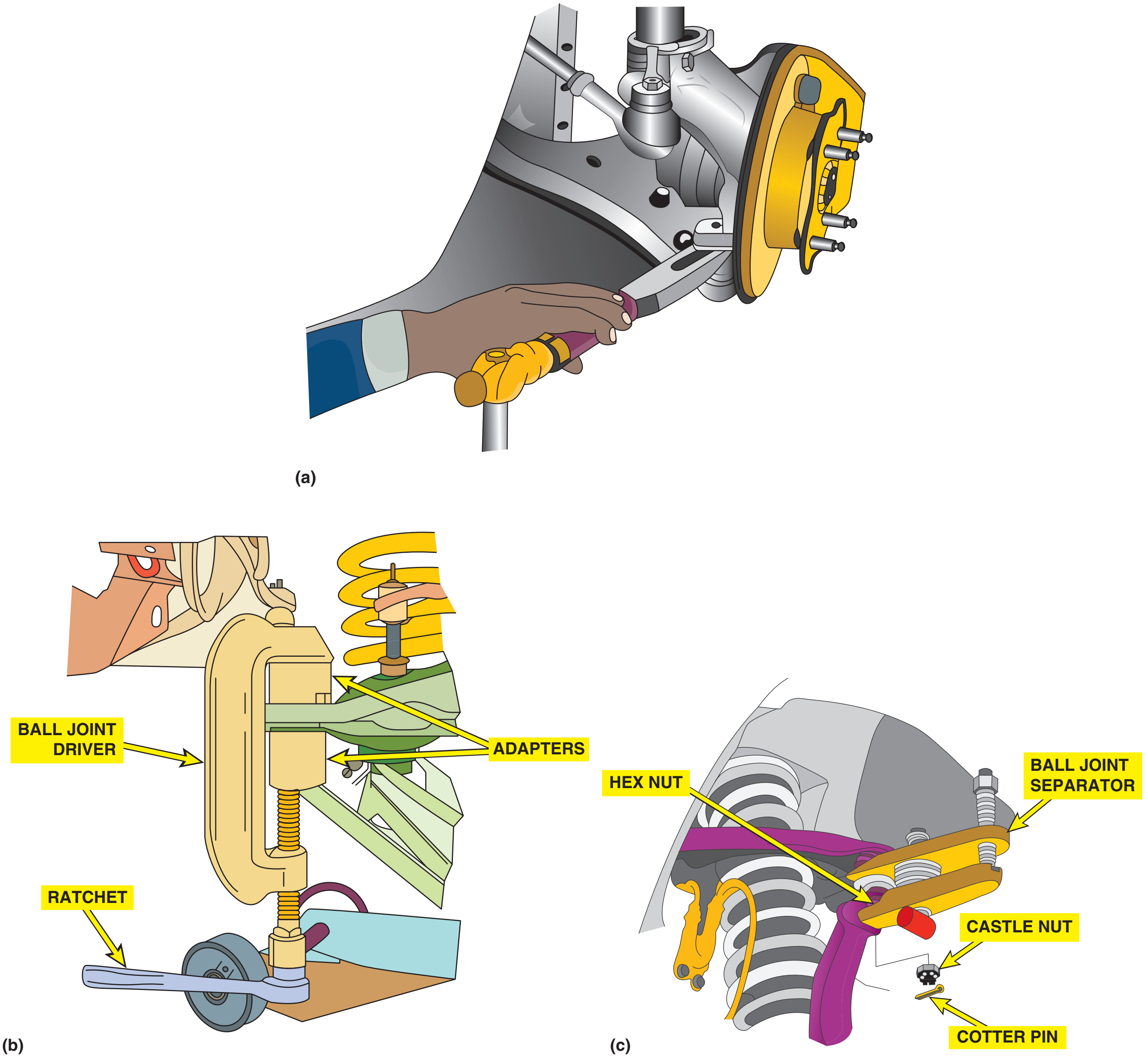


FIGURE 112–25 (a)Taper breaker tool being used to separate the upper ball joint from the steering knuckle. However, this tool will destroy the dust boot and should only be used if the ball joint is going to be replaced. (b) A ball-joint press is the most recommended tool to use when removing or installing ball joints. (c) A spreader-type tool being used to separate the tapered stud from the steering knuckle. Often striking the knuckle with a heavy hammer is enough to "break the taper" of the stud and release it from the knuckle.

CAUTION: The use of tapered "pickle forks" should be avoided, unless the part is to be replaced, because they often damage the grease seal of the part being separated.

Some ball-joint studs have a slot or groove where a **pinch bolt** is used to hold the ball joint to the steering knuckle. ● **SEE FIGURE 112–26**. Use penetrating oil in the steering knuckle groove and rotate the knuckle several times. Do not use a hammer on the pinch bolt because this can cause damage to the bolt and the ball joint. Do not widen the slot in the steering knuckle. Once separated, check the shape of the steering knuckle. ● **SEE FIGURE 112–27**. If the pinch bolt has been deformed by overtightening, the steering knuckle should be replaced.

When removing ball joints that are riveted in place, always cut off or drill rivet heads before separating the ball joint from the spindle. This provides a more solid base to assist in removing rivets. *The preferred method to remove rivets from ball joints is to center punch and drill out the center of the rivet before using a drill or an air-powered chisel to remove the rivet heads.* Be careful not to drill or chisel into the control arms. ● **SEE FIGURES 112–28 THROUGH 112–30**.

Press-in-type ball joints are removed and installed using a special C-clamp-type tool. ● **SEE FIGURE 112–31**.

NOTE: Many replacement press-in-type ball joints are slightly larger in diameter—about 0.050 inch (1.3 mm)—than the original ball joint to provide the same press fit. If the ball joints have been replaced before, then the control arm must be replaced.

Avoid using heat to remove suspension or steering components. Many chassis parts use rubber and plastic that can be

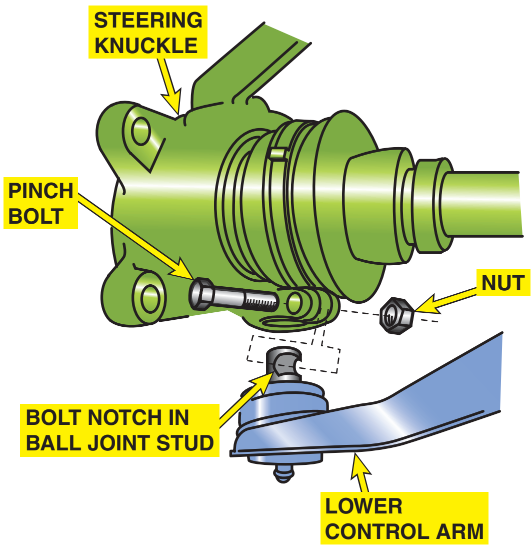

STEERING KNUCKLE
PINCH BOLT
NUT
BOLT NOTCH IN BALL JOINT STUD
LOWER CONTROL ARM

FIGURE 112–26 A pinch bolt attaches the steering knuckle to the ball joint. Remove the pinch bolt by turning the nut, not the bolt.

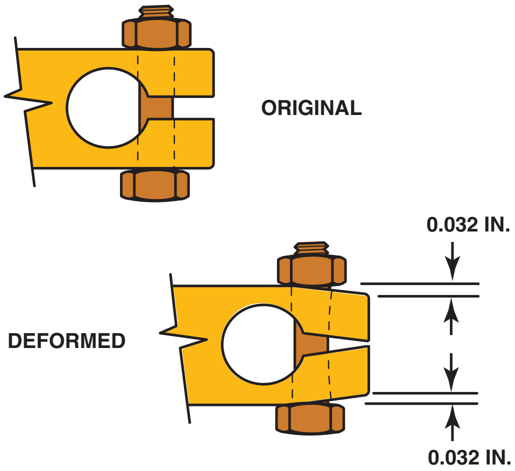

ORIGINAL
DEFORMED
0.032 IN.
0.032 IN.

FIGURE 112–27 If the pinch bolt is overtightened, the steering knuckle can be deformed. A deformed knuckle can cause the pinch bolt to break and the ball joint could become separated from the steering knuckle.

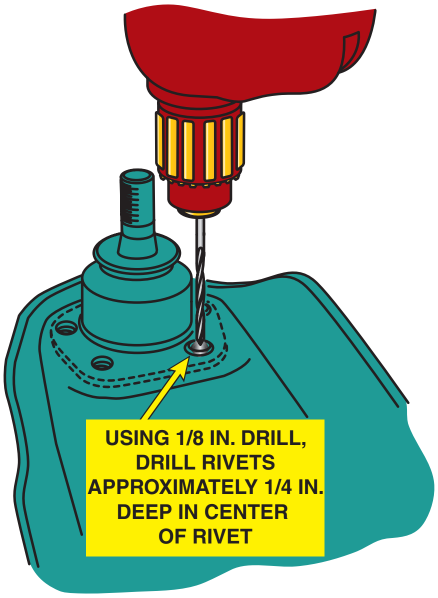

USING 1/8 IN. DRILL, DRILL RIVETS APPROXIMATELY 1/4 IN. DEEP IN CENTER OF RIVET

FIGURE 112–28 By drilling into the rivet, the holding force is released.

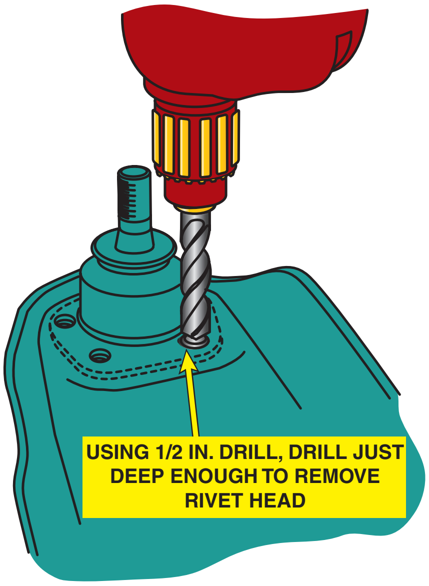

USING 1/2 IN. DRILL, DRILL JUST DEEP ENOUGH TO REMOVE RIVET HEAD

FIGURE 112–29 The head of the rivet can be removed by using a large-diameter drill bit as shown.

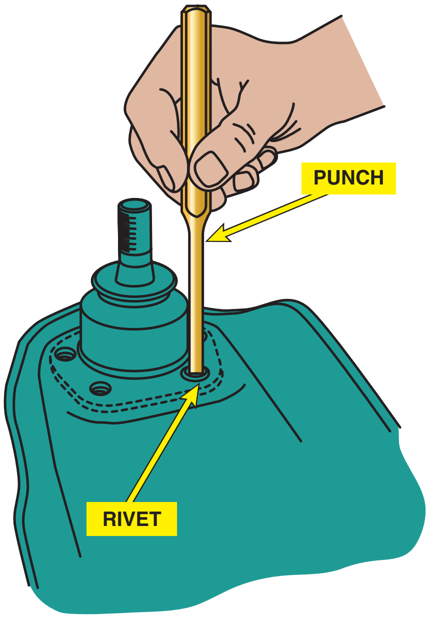

PUNCH
RIVET

FIGURE 112–30 A punch and a hammer being used to remove a rivet after the head has been removed.

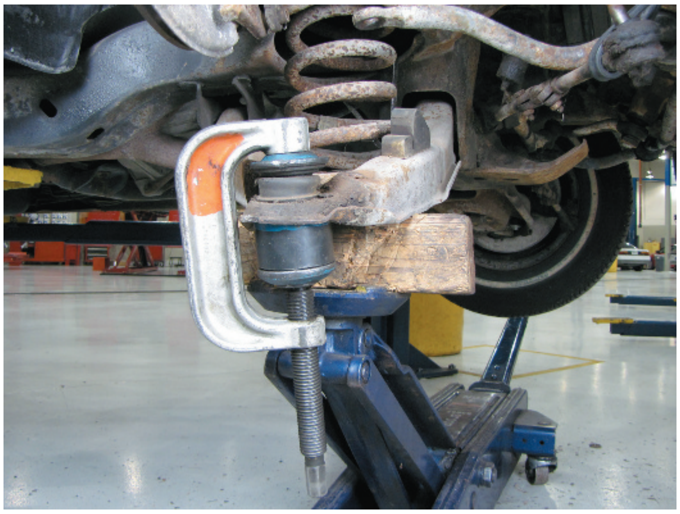


FIGURE 112–31 Press-in ball joints are best removed using a large C-clamp press, as shown.

CASE STUDY

The Rattle Story

A customer complained that a rattle was heard every time the vehicle hit a bump. The noise sounded as if it came from the rear. All parts of the exhaust system and suspension system were checked. Everything seemed okay until the vehicle was raised with a frame-type hoist instead of a drive-on type. Then, whenever the right rear wheel was lifted, the noise occurred. The problem was a worn (elongated) shock absorber mounting hole. A washer with the proper-size hole was welded over the worn lower frame mount and the shock absorber was bolted back into place.

Summary:

Complaint—Vehicle owner complained of a rattle sound from the rear suspension at times.
Cause—The lower shock mount was found to be worn (elongated) causing the noise.
Correction—A steel washer was welded over the worn lower frame mount which restored the shock mount to the correct size and solved the noise issue.

damaged if heated with a torch. *If heat is used to remove a part, it must be replaced.* For best results, try soaking with a penetrating oil and use the proper tools and procedures as specified by the manufacturer.

Many vehicles are equipped with nonreplaceable ball joints, and the entire control arm must be replaced if the ball joint is worn or defective.

CAUTION: Always follow manufacturer's recommended installation instructions whenever replacing any suspension or other chassis component part. Tie rod ends and ball joints use a taper to provide the attachment to other components. Whenever a nut is used to tighten a tapered part, it is important not to back off (loosen) the nut after tightening. As the nut is being tightened, the taper is being pulled into the taper of the adjoining part. The specified torque on the nut ensures that the two pieces of the taper are properly joined. If the cotter key does not line up with the hole in the tapered stud when the nut has been properly torqued, tighten it more to line up a hole—never loosen the nut.

SHOCK ABSORBERS AND STRUTS

DIAGNOSIS Shock absorber life depends on how and where the vehicle is driven. Original equipment (OE) shock absorbers are carefully matched to the vehicle springs and bushings to provide the best ride comfort and control. As the control arm bushings and ball joints age, the energy built up in the springs of the vehicle is controlled less by the friction of these joints and bushings, requiring more control from the shock absorbers. Shock absorber action is also reduced as the seals inside wear.

Replacement of shock absorbers may be required when any or all of the following symptoms appear:

1. **Ride harshness.** As the effectiveness of the shock absorber decreases, the rapid forces of the springs are not as dampened or controlled. Worn shocks can cause ride harshness and yet not cause the vehicle to bounce after hitting a bump.
2. **Frequent bottoming out on rough roads.** Shock absorbers provide a controlled movement of the axle whenever the vehicle hits a bump or dip in the road. As fluid is lost or wear occurs, the shock absorber becomes weaker and cannot resist the forces acting on the axle. The worn shock absorber can allow the spring to compress enough so that the axle contacts the jounce bumper (bump stop) on the body or frame of the vehicle.

NOTE: Frequent bottoming out is also a symptom of reduced ride height due to sagging springs. Before replacing the shock absorbers, always check for proper ride height as specified in the vehicle service manual or any alignment specification booklet available from suppliers or companies of alignment or chassis parts and equipment.

3. **Extended vehicle movement after driving on dips or a rise in the road.** The most common shock absorber test is the bounce test. Push down on the body of the vehicle and let go; the vehicle should return to its normal ride height and stop. Worn shock absorbers can cause poor driver control due to excessive up-and-down suspension movements. If the vehicle continues to bounce two or three times, then the shocks or struts are worn and must be replaced.
4. **Cuppy-type tire wear.** Defective shock absorbers can cause **cuppy tire wear**. This type of tire wear is caused by the tire's bouncing up and down as it rotates.
5. **Leaking hydraulic oil.** When a shock or strut leaks oil externally, this indicates a defective seal. The shock absorber or strut cannot function correctly when low on oil inside.

TECH TIP

The Shock Stud Trick

Front shock absorbers used on many rear-wheel-drive vehicles equipped with an SLA-type front suspension are often difficult to remove because the attaching nut is rusted to the upper shock stub. A common trick is to use a deep-well 9/16 inch socket and a long extension and simply bend the shock stud until it breaks off. At first you would think that this method causes harm, and it does ruin the shock absorber—but the shock absorber is not going to be reused and will be discarded anyway.

The usual procedure followed by many technicians is to simply take a minute or two to break off the upper shock stud, then hoist the vehicle to allow access to the lower two shock bolts, and then the shock can easily be removed. To install the replacement shock absorber, attach the lower bolts, lower the vehicle, and attach the upper rubber bushings and retaining nut.

6. **Springs and shock absorbers should be replaced in pairs.** Both front or both rear shocks should be replaced together to provide the best handling and control.

NOTE: Shock absorbers do not affect ride height except where special air shocks or coil overload carrying shocks are used. If a vehicle is sagging on one side or in the front or the rear, the springs should be checked and replaced if necessary.

Shock absorbers are filled with fluid and sealed during production. They are not refillable; if worn, damaged, or leaking, they must be replaced. A slight amount of fluid may bleed by the rod seal in cold weather and deposit a light film on the upper area of the shock absorber. This condition will not hurt the operation of the shock and should be considered normal. If noisy when driving, always check the tightness and condition of all shock absorber mounts.

Replacement shock absorbers and/or struts should match the original equipment unit in physical size.

FRONT SHOCK REPLACEMENT Front shock absorbers provide ride control and are usually attached to the lower control arm by bolts and nuts. The upper portion of the shock usually extends through the spring housing and is attached to the frame of the vehicle with rubber grommets to help insulate noise, vibration, and harshness.

Most front shock absorbers can be replaced either with the vehicle still on the ground or while on a hoist. The front suspension of most vehicles allows the removal of the shocks without the need to support the downward travel of the lower control arm. The downward travel limit is stopped by a rubber stop or by the physical limit of the suspension arms.

Special sockets and other tools are available to remove the nut from the shocks that use a single mounting stem. The removal of the lower mounting of most front shock absorbers usually involves the removal of two bolts. After removal of the attaching hardware, the shock absorber is simply pulled through the front control arm. ● **SEE FIGURE 112–32**.

Reverse the removal procedure to install replacement shock absorbers. Always consult the manufacturer's recommended procedures and fastener tightening torque.

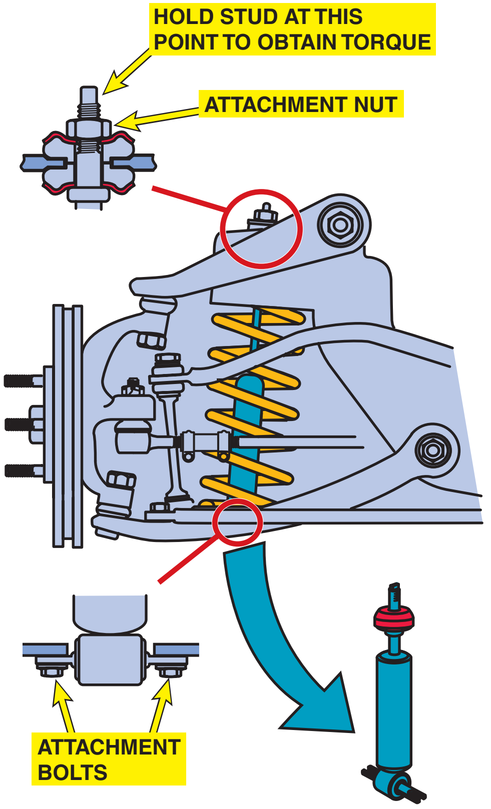


FIGURE 112–32 Most shock absorbers used on the front suspension can be removed from underneath the vehicle after removing the attaching bolts or nuts.

MACPHERSON STRUT REPLACEMENT

CAUTION: Always follow the manufacturer's recommended methods and procedures whenever replacing a MacPherson strut assembly or component.

On most vehicles equipped with MacPherson strut suspensions, strut replacement involves the following steps:

1. Hoist the vehicle, remove the wheels, and mark the attaching bolts/nuts.
2. Remove the upper strut mounting bolts except for one to hold the strut until ready to remove the strut assembly. ● **SEE FIGURE 112–33**.
3. Remove the brake caliper or brake hose from the strut housing. ● **SEE FIGURE 112–34**.

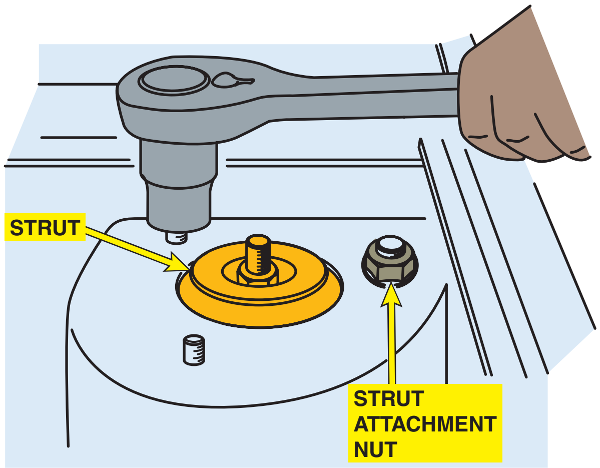


FIGURE 112–33 Removing the upper strut mounting bolts. Some experts recommend leaving one of the upper strut mount nuts loosely attached to prevent the strut from falling when the lower attaching bolts are removed.

4. After removing all lower attaching bolts, remove the final upper strut bolt and remove the strut assembly from the vehicle. Place the strut assembly into a strut spring compressor fixture or use manual spring compressors as shown in ● **FIGURE 112–35**.
5. Compress the coil spring enough to relieve the tension on the strut rod nut. Remove the strut rod nut as shown in ● **FIGURE 112–36**.
6. After removing the strut rod nut, remove the upper strut bearing assembly and the spring. ● **SEE FIGURE 112–37**.

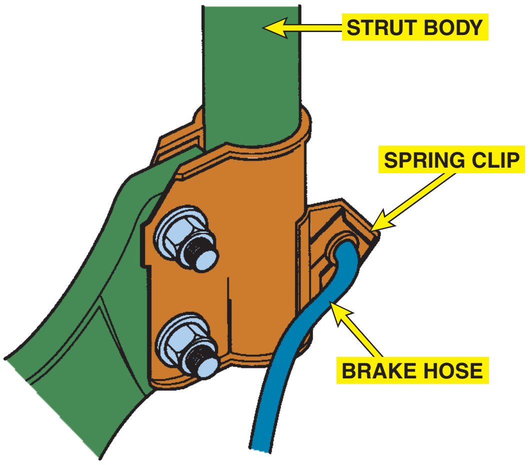

STRUT BODY
SPRING CLIP
BRAKE HOSE

FIGURE 112–34 A brake hydraulic hose is often attached to the strut housing. Sometimes all that is required to separate the line from the strut is to remove a spring clip.

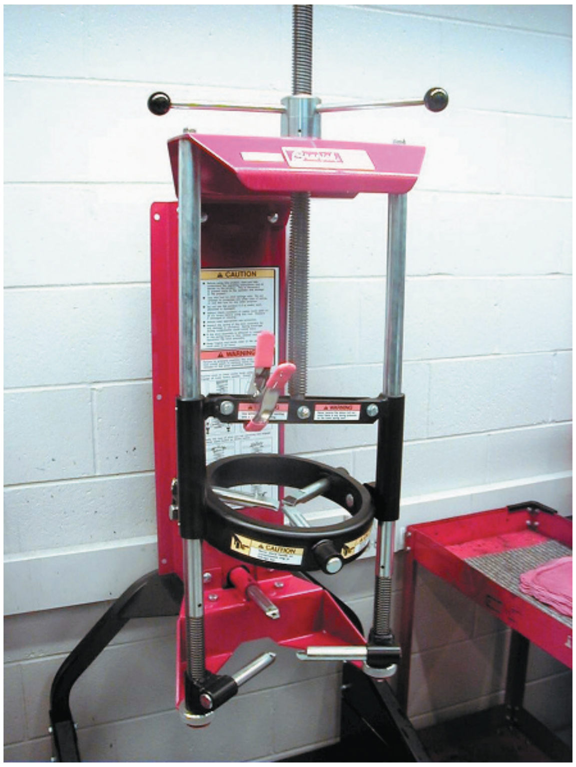


FIGURE 112–35 Use a strut spring compressor fixture to compress the spring on a MacPherson strut before removing the strut retaining nut.

NOTE: The bearing assembly should be carefully inspected and replaced if necessary. Some automotive experts recommend replacing the bearing assembly whenever the strut is replaced.

7. Most MacPherson struts are replaced as an entire unit assembly. Older struts can have the cartridge inside the housing replaced. The cartridge is installed after removing the gland nut at the top of the strut tube and removing the original strut rod, valves, and hydraulic oil. Always replace the cartridge assembly per the manufacturer's recommended procedure. ● **SEE FIGURES 112–38, 112–39, AND 112–40**.
8. Reinstall the strut in the vehicle.

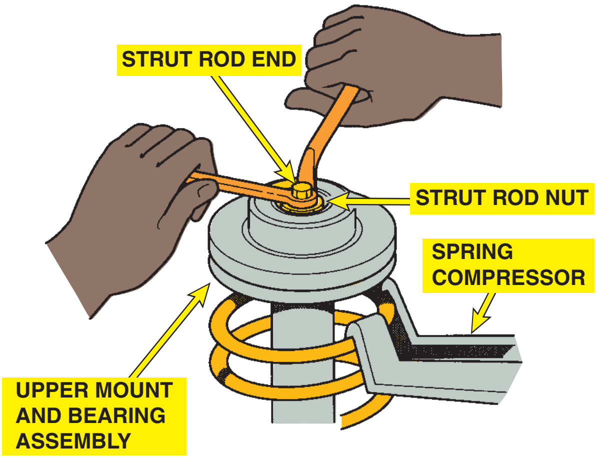

STRUT ROD END
STRUT ROD NUT
SPRING COMPRESSOR
UPPER MOUNT AND BEARING ASSEMBLY

FIGURE 112–36 Removing the strut rod nut. The strut shaft is being held with one wrench while the nut is being removed with the other wrench. Notice that the spring is compressed before the nut is removed.

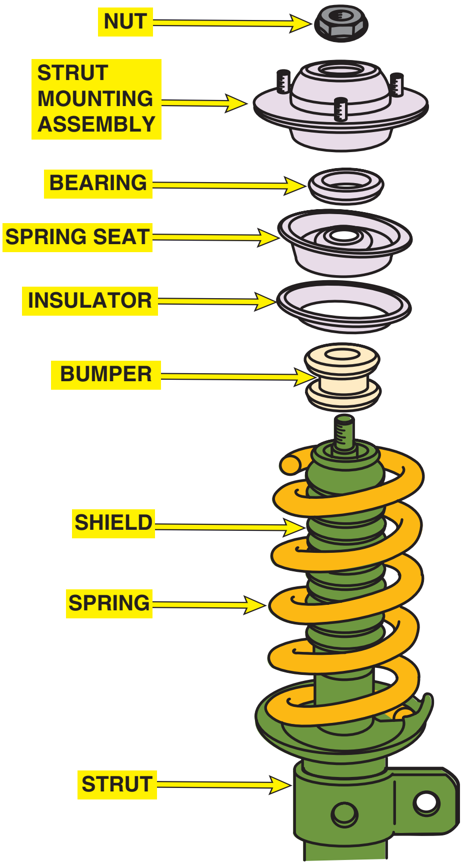

NUT
STRUT MOUNTING ASSEMBLY
BEARING
SPRING SEAT
INSULATOR
BUMPER
SHIELD
SPRING
STRUT

FIGURE 112–37 Typical MacPherson strut showing the various components.

CAUTION: Many GM front-wheel-drive vehicles use a MacPherson strut with a large-diameter spring seat area. GM chassis engineers call this a cow catcher design. If the coil spring breaks, the extra-large cow catcher will prevent the end of the broken spring from moving outward where it could puncture a tire and possibly cause an accident. Always use a replacement strut that has this feature.

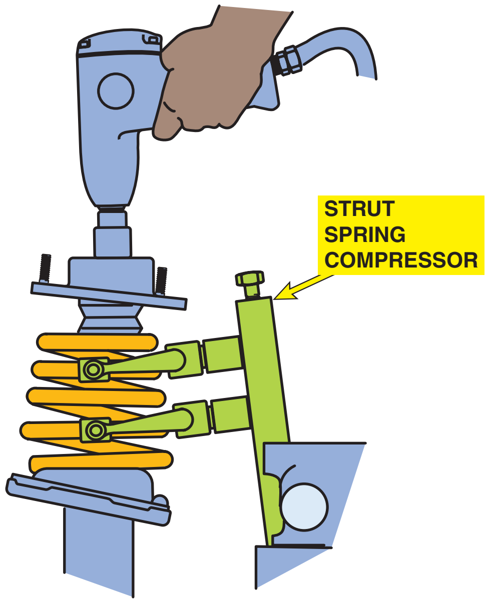

STRUT SPRING COMPRESSOR

FIGURE 112–38 After installing the replacement strut cartridge, reinstall the spring and upper bearing assembly after compressing the spring. Notice that the strut is being held in a strut spring compressor fixture.

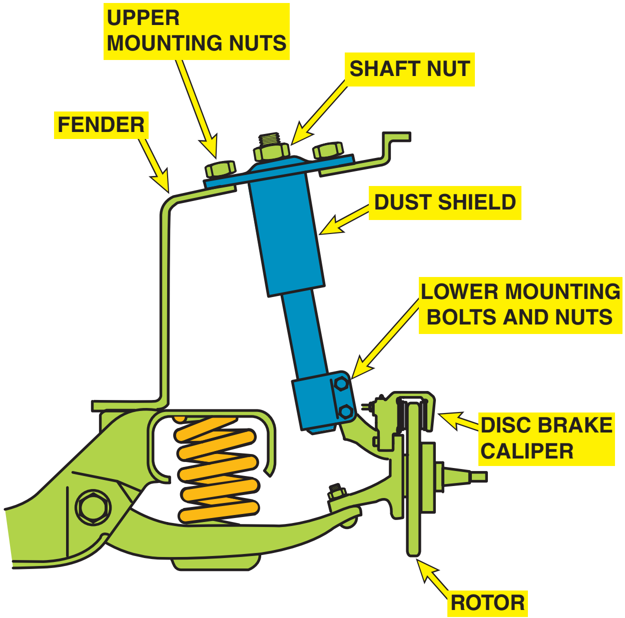

UPPER MOUNTING NUTS
SHAFT NUT
FENDER
DUST SHIELD
LOWER MOUNTING BOLTS AND NUTS
DISC BRAKE CALIPER
ROTOR

FIGURE 112–40 The strut on a modified MacPherson strut assembly can be replaced by removing the upper mounting nuts.

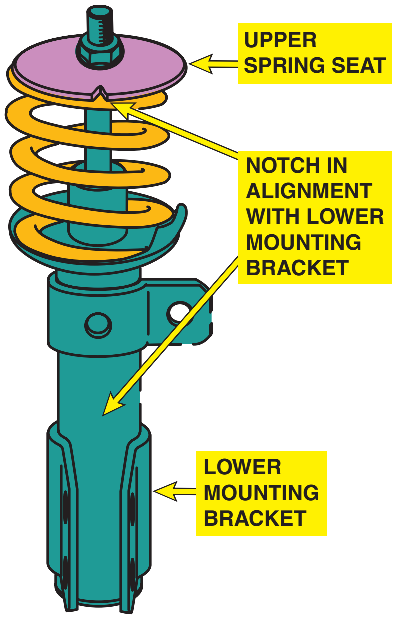

UPPER SPRING SEAT
NOTCH IN ALIGNMENT WITH LOWER MOUNTING BRACKET
LOWER MOUNTING BRACKET

FIGURE 112–39 Before final assembly, make sure the marks you made are aligned. Some struts are manufactured with marks to ensure proper reassembly.

STABILIZER BAR LINKS AND BUSHINGS

DIAGNOSIS Stabilizer bars twist whenever a vehicle turns a corner or whenever one side of the vehicle rises or lowers. The more the body of the vehicle leans, the more the bar twists, and the more the bar counteracts the roll of the body. A great deal of force is transferred from the stabilizer bar to the body or frame of the vehicle through the stabilizer links at the control arm and the stabilizer bar mounting bushings on the body or frame. *The most common symptom of defective stabilizer bar links or bushings is noise while turning, especially over curbs.* When driving up and over a curb at an angle, one wheel is pushed upward. Since the stabilizer bar connects both wheels, the bar tends to resist this motion by twisting. If one or both links are broken, a loud knock or clanking sound is heard as the bar contacts the control arm. Any sound heard when driving should be investigated and the cause determined by a thorough visual inspection.

REPLACEMENT Stabilizer links are usually purchased as a kit consisting of replacement rubber bushings, retainers, a long bolt, and spacer with a nut and lock nut. General Motors recommends that stabilizer links be replaced in pairs and two kits purchased so that the links on both the left and the right can be replaced at the same time. ● **SEE FIGURE 112–41**.

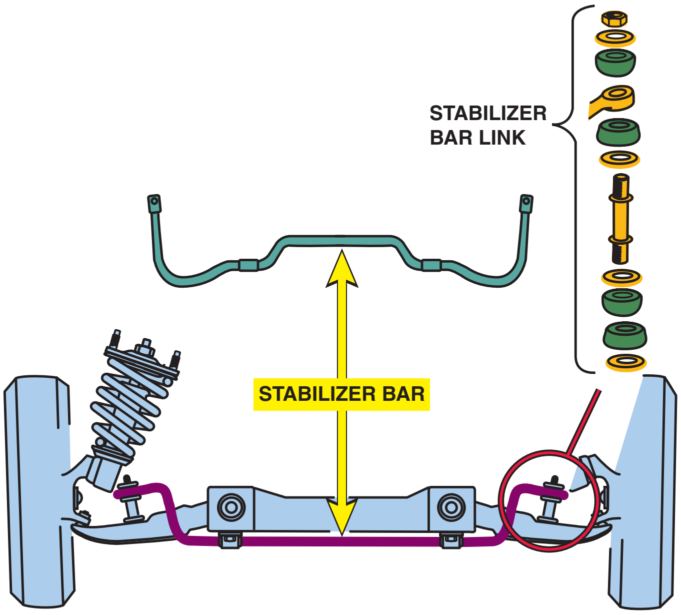

STABILIZER BAR LINK
STABILIZER BAR

FIGURE 112–41 Stabilizer bar links should be replaced as a pair.

Stabilizer links are replaced by unbolting the old parts and installing replacement parts. Special precautions are usually not necessary, but, as always, consult a service manual for the exact recommended procedure and fastener torque.

If the mounting bushings (also called isolator bushings) on the body or frame are worn or defective, a loud squeaking or knocking sound is usually heard.

Stabilizer bar bushings often fail because the rubber has deteriorated from engine oil or other fluid leaks. Before replacing defective bushings, make certain that all other fluid leaks are stopped. Stabilizer bar bushing replacement involves the removal (unbolting) of the bushing retainers that surround the bushing and attach to the vehicle body or frame. The bushings are usually split so that they can be easily removed and replaced on the stabilizer bar and can slide into proper position. Reinstall the bushing retainer bolts and tighten to the specified torque.

STRUT ROD BUSHINGS

DIAGNOSIS Strut rods are used on the front suspension of many front-wheel-drive and rear-wheel-drive vehicles. As with any rubber suspension component, strut rod bushings can deteriorate and crack. When strut rod bushings fail, the lower control arm can move forward and backward during braking or when hitting bumps in the road.

Since the lower control arm position is important to vehicle control, when the bushing fails, a pulling or drifting of the vehicle often occurs. *A common symptom of a defective strut rod bushing is noise and a pull toward one side while braking*.

REPLACEMENT To replace a strut rod bushing, the nut on the end of the strut rod has to be removed. ● **SEE FIGURE 112–42.** As the nut is being removed, the lower control arm is likely to move forward or backward, depending on the location of the strut rod frame mount. After removing the strut rod nut, remove the one or two fasteners that retain the strut rod to the lower control arm. The strut rod can now be removed from the vehicle and the replacement rubber bushings can be installed. Install the strut rod in the reverse order of installation. Most bushings use a serrated spacer to maintain the proper force on the rubber bushings; this prevents the technician from compressing the rubber bushing when the strut rod nut is tightened. ● **SEE FIGURE 112–43.**

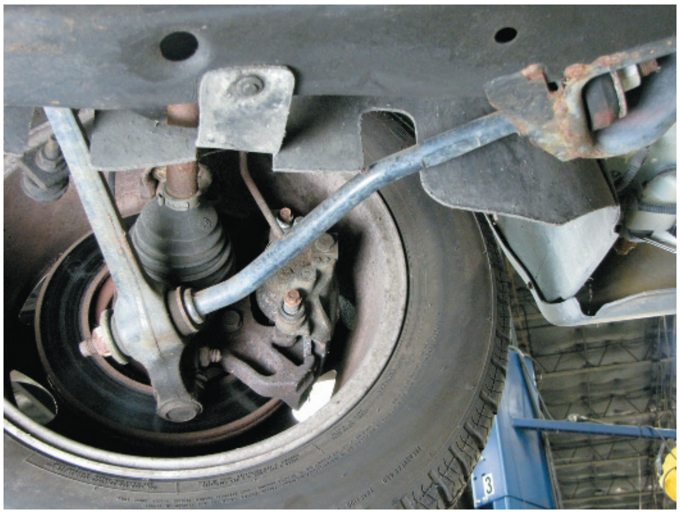


FIGURE 112–42 A strut rod as viewed from the front of the vehicle.

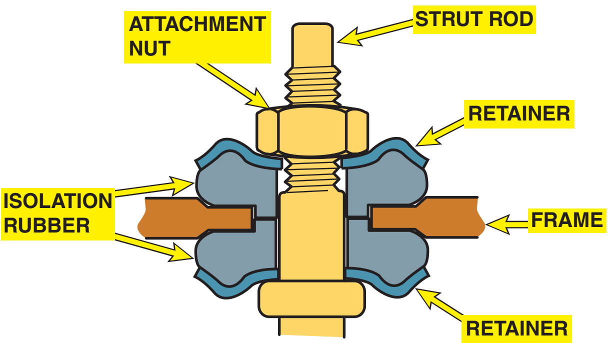


FIGURE 112–43 Typical strut rod bushing with rubber on both sides of the frame to help isolate noise, vibration, and harshness from being transferred to the passengers.

CAUTION: Some suspension bushings are directional and must be installed according to the vehicle manufacturer's instructions. For example, on some vehicles, the bushings have a slit or void, which must face the front of the vehicle. Always check service information when installing new bushings.

FRONT COIL SPRINGS

DIAGNOSIS Coil springs should be replaced in pairs if the vehicle ride height is lower than specifications. Sagging springs can cause the tires to slide laterally (side to side) across the pavement, causing excessive tire wear. ● **SEE FIGURE 112–44.** Sagging springs can also cause the vehicle to bottom out against the suspension bumpers when traveling over normal bumps and dips in the road.

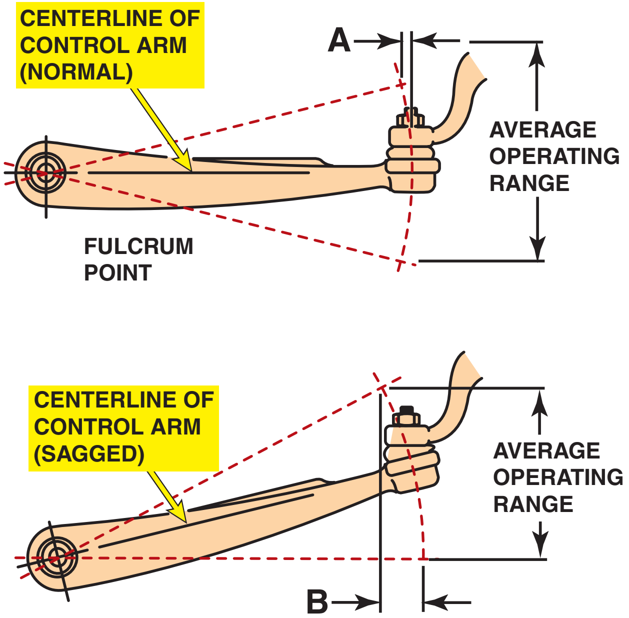

CENTERLINE OF CONTROL ARM (NORMAL)
A
AVERAGE OPERATING RANGE
FULCRUM POINT
CENTERLINE OF CONTROL ARM (SAGGED)
AVERAGE OPERATING RANGE
B

FIGURE 112–44 Notice that if the front coil springs are sagging, the resulting angle of the lower control arm causes the wheels to move from side to side as the suspension moves up and down. Note the difference between the distance at "A" with good springs and the distance at "B" with sagging springs.

If a vehicle is overloaded, the springs of the vehicle can *take a set* and not recover to the proper ride height. This commonly occurs with all types of vehicles whenever a heavy load is carried, even on a short trip.

It is normal for the rear of a vehicle to sag when a heavy load is carried, but it can permanently damage the spring by exceeding the yield point of the steel spring material.

REPLACEMENT The only solution recommended by the vehicle manufacturer is to replace the damaged springs in pairs (both front and both rear, or all four). Several aftermarket alternatives include the following:

- **Helper or auxiliary left springs.** These helper springs are usually designed to increase the load-carrying capacity of leaf springs or to restore the original ride height to sagging springs.
- **Spring inserts for coil springs.** Hard rubber or metal spacers are *not recommended* because they create concentrated pressure points on the coils that can cause the spring to break. Hard rubber stabilizers that bridge the gap between two coils without raising the ride height stiffen the ride by locking two coils together. With two coils connected, the spring rate increases and the spring becomes stiffer.
- **Air shocks or airbag devices.** Air shocks or airbags are generally used to restore or increase the load-carrying capacity to the rear of the vehicle. While these devices do allow the ride height to be maintained, the extra load is still being supported by the tires and rear axle bearings. Caution should be used not to overload the basic chassis or power train of the vehicle.

There are two designs for vehicles that use coil springs. The most commonly used design places the coil spring between the vehicle frame and the lower control arm.

Both front-suspension designs require that the front shock absorbers be removed in order to replace the coil springs. This first step in the coil spring removal procedure can be performed on the ground or on any type of hoist. After removing the shock absorber, use a coil spring compressor and install it through the center of the coil spring. ● **SEE FIGURE 112–45**. Hook the arms of the coil spring compressor over the rungs of the coil spring and rotate the adjusting nut on the spring compressor with a wrench to shorten the spring. Coil spring clips can also be used to retain the coil spring.

CAUTION: When compressed, all springs contain a great deal of stored energy. If a compressed spring were to become disconnected from its spring compressor or clips, it could be projected outward with enough force to cause injury or death.

After the coil spring is retained, the control arm can be separated from the steering knuckle and the coil spring can be removed as shown in ● **FIGURES 112–46 AND 112–47**.

Replacement springs should be compressed and installed using the reverse procedure.

NOTE: Many automotive experts recommend that new coil insulators be installed every time the coil springs are replaced.

Make sure that the spring is positioned correctly in the control arm and that the spring insulators are installed correctly. ● **SEE FIGURE 112–48**. Most control arms use two holes for the

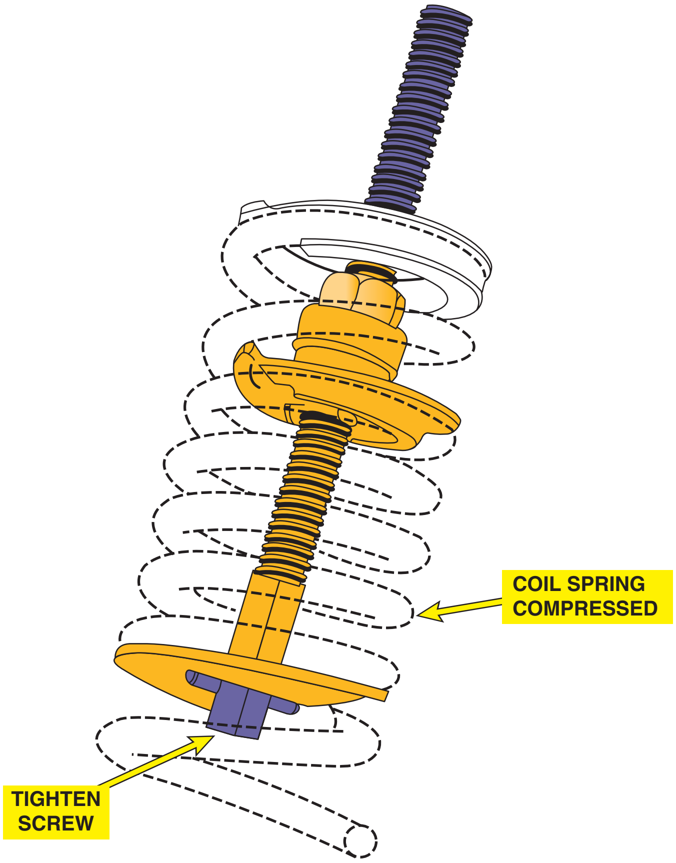


FIGURE 112–45 A spring compressor is required by most vehicle manufacturers to be used whenever disassembling a coil spring suspension system.

CASE STUDY

The Rock-Hard Problem

The owner of a six-month-old full-size pickup truck complained that occasionally when the truck was driven up into a driveway, a loud grinding sound was heard. Several service technicians worked on the truck, trying to find the cause for the noise. After the left front shock absorber was replaced, the noise did not occur for two weeks and then started again. Finally, the service manager told the technician to replace anything and everything in the front suspension in an attempt to solve the customer's intermittent problem. Five minutes later, a technician handed the service manager a small, deformed rock. This technician had taken a few minutes to carefully inspect the entire front suspension. Around the bottom coil spring seat, the technician found the rock. Apparently, when the truck made a turn over a bump, the rock was forced between the coils of the coil spring, making a very loud grinding noise. But the rock did not always get between the coils. Therefore, the problem occurred only once in a while. The technician handed the rock to the very happy customer.

Summary:

Complaint—Vehicle owner complained of loud grinding sound from the front suspension at times.
Cause—A rock was found at the bottom of the coil spring seat.
Correction—The rock was removed.

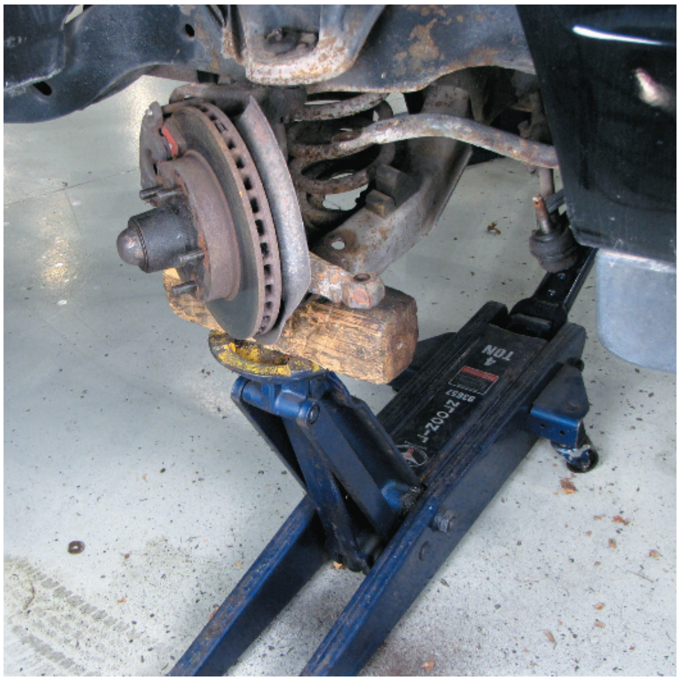


FIGURE 112–46 The steering knuckle has been disconnected from the lower ball joint. The lower control arm and the coil spring are being held up by a floor jack.

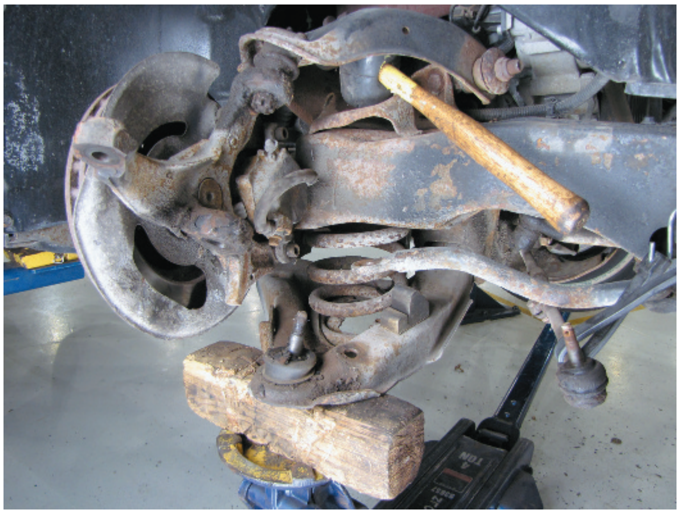


FIGURE 112–47 A rubber mallet is being used to support the upper control arm as the lower control is being lowered using a floor jack. After all of the tension has been removed from the coil spring, it can be removed and the replacement installed.

purpose of coil spring seating. The end of the spring should cover one hole completely and partially cover the second hole. ● **SEE FIGURE 112–49**.

STEERING KNUCKLES

DIAGNOSIS Most steering knuckles are constructed of cast or forged cast iron. The steering knuckle usually incorporates the wheel spindle and steering arm. The steering knuckle/steering arm can become bent if the vehicle is in an accident or hits a curb sideways. Often this type of damage is not apparent until vehicle handling or excessive tire wear is noticed. Unless a thorough inspection is performed during a wheel alignment, a bent steering knuckle is often overlooked.

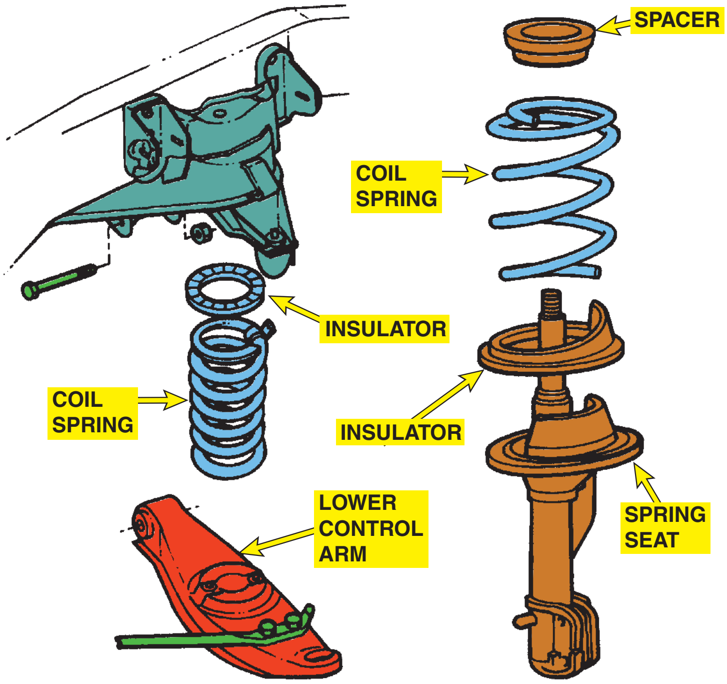


FIGURE 112–48 Spring insulators are installed between the spring seat and the coil spring to reduce noise.

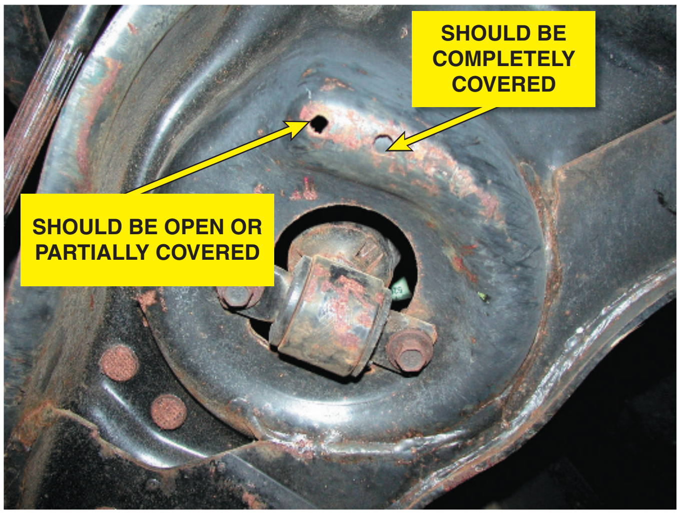

SHOULD BE COMPLETELY COVERED
SHOULD BE OPEN OR PARTIALLY COVERED

FIGURE 112–49 The holes in the lower arm are not only used to allow water to drain from the spring seat, but also used as a gauge to show the service technician that the coil spring is correctly seated.

REPLACEMENT If the steering knuckle is bent or damaged, it must be replaced. It should *not* be bent back into shape or repaired. To replace the steering knuckle, both ball joints must be disconnected from the knuckle and the brake components removed. Be sure to support the control arm and spring properly during the procedure. See a factory service manual for the exact procedure and fastener torque for the vehicle you are servicing.

TORSION BARS

ADJUSTMENT Most torsion bar suspensions are designed with an adjustable bolt to permit the tension on the torsion bar to be increased or decreased to change the ride height. Unequal side-to-side ride height can be corrected by adjusting (turning) the torsion bar tension bolt. ● **SEE FIGURE 112–50**.

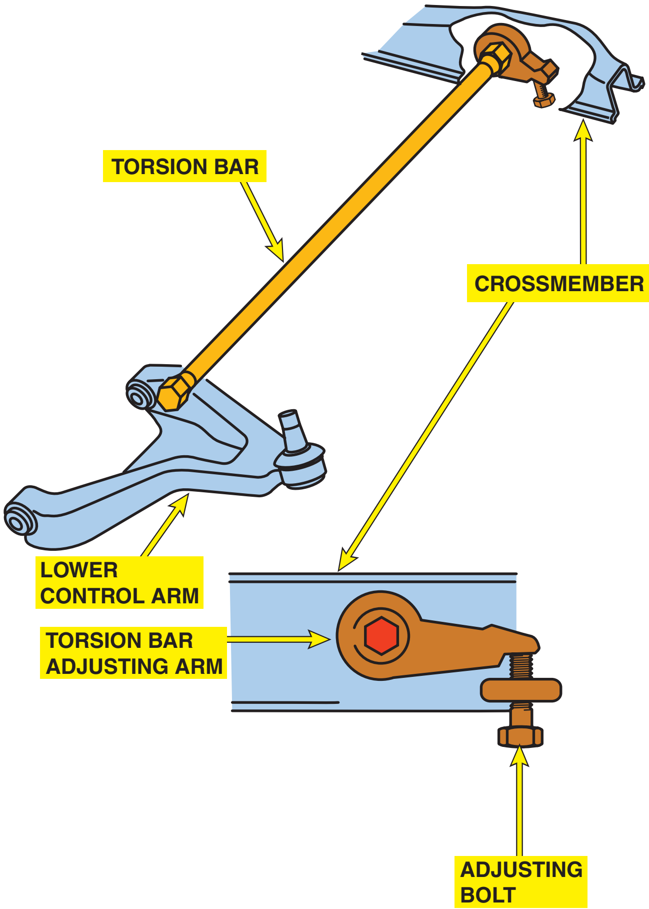


FIGURE 112–50 By rotating the adjusting bolt, the vehicle can be raised or lowered.

Torsion bar adjustment should be made if the difference in ride height from one side to another exceeds 1/8 inch (0.125 inch or 3.2 mm). If the ride height difference side to side is greater than 1/8 inch, the vehicle will tend to wander or be unstable, with constant steering wheel movements required to maintain a straight-ahead direction.

NOTE: Torsion bars should never be switched from one side of the vehicle to the other as they are twisted and work hardened in one direction and can break if installed on the opposite side of the vehicle.

CONTROL ARM BUSHINGS

DIAGNOSIS Defective control arm bushings are a common source of vehicle handling and suspension noise problems. Most suspension control arm bushings are constructed of three parts: an inner metal sleeve, the rubber bushing itself, and an outer steel sleeve. (Some vehicles use a two-piece bushing that does not use an outer sleeve.)

REPLACEMENT To remove an old bushing from a control arm, the control arm must first be separated from the suspension and/or frame of the vehicle. Several methods can be used to remove the bushing from the control arm, but all methods apply force to the *outer* sleeve. While an air chisel is frequently used to force the steel sleeve out of the suspension member, a puller tool is most often recommended by General Motors. ● **SEE FIGURE 112–51**. The puller can be used to remove the old bushing and install the replacement bushing without harming the control arm or the new bushing. All bushings should be tightened with the vehicle on the ground and the wheels in a straight-ahead position; this prevents the rubber bushing from exerting a pulling force on the suspension.

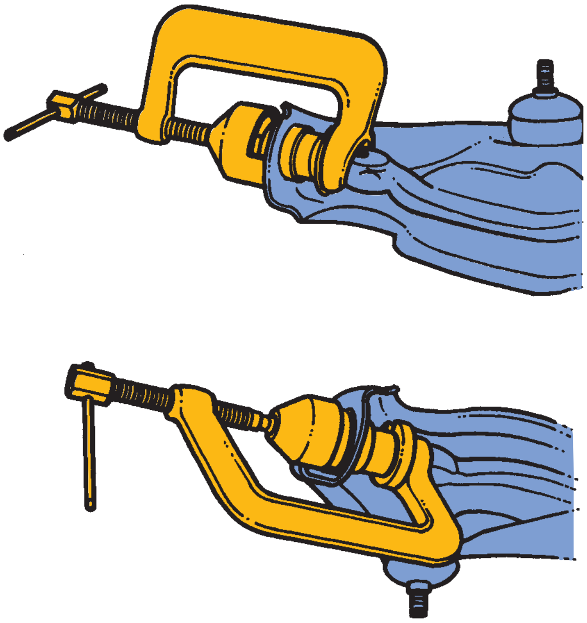


FIGURE 112–51 An adapter and a press or large clamp are used to remove the old bushing from the control arm and to install a new bushing.

NOTE: Some replacement control arm bushings have a higher durometer, or hardness, rating than the original. Urethane bushings are often used in sporty or race-type vehicles and deflect less than standard replacement bushings. These harder bushings also transfer more road noise, vibration, and harshness to the body.

The upper control arm bushings can be replaced in most vehicles that use a short-/long-arm-type suspension by following just four easy steps:

STEP 1 Raise the vehicle and support the lower control arm with a safety stand or floor jack.

STEP 2 Disconnect the upper control arm from the frame by removing the frame-attaching nuts or bolts.

STEP 3 Using the upper ball joint as a pivot, rotate the upper control arm outward into the wheel well area. With the control arm accessible, it is much easier to remove and replace the upper control arm pivot shaft and rubber bushings.

STEP 4 After replacing the bushings, simply rotate the upper control arm back into location and reattach the upper control arm pivot shaft to the vehicle frame.

NOTE: An alignment should always be performed after making any suspension-related repairs.

STRUT REPLACEMENT

STEP BY STEP

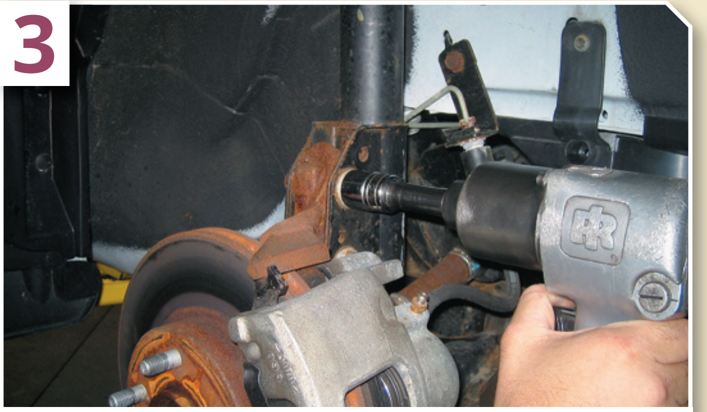
1

The tools needed to replace a front strut assembly include several sockets and a ball-peen hammer, plus a strut compressor.

2

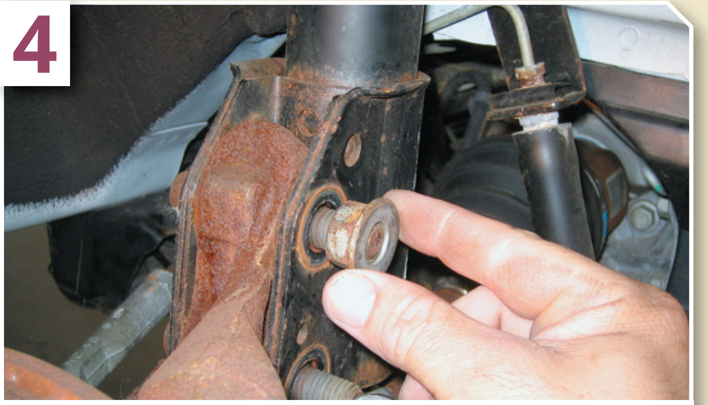
After safely hoisting the vehicle to elbow height and removing the wheel covers, remove the front tire/wheel assembly.

3



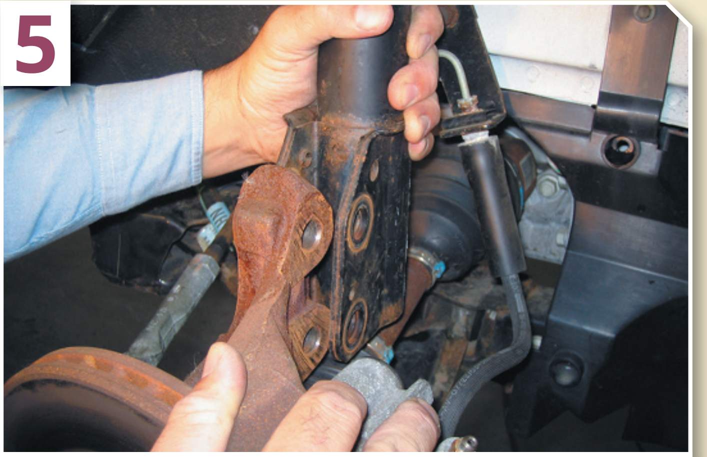
Remove the two strut retaining nuts.

4



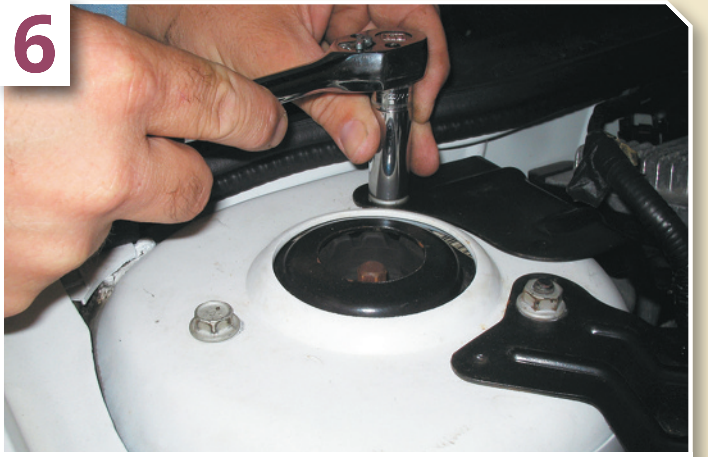
Before using a hammer to drive the retaining bolts from the steering knuckle, thread the nut into the bolt backward to prevent causing damage to the threads.

5



Remove the retaining bolts and separate the strut from the steering knuckle.

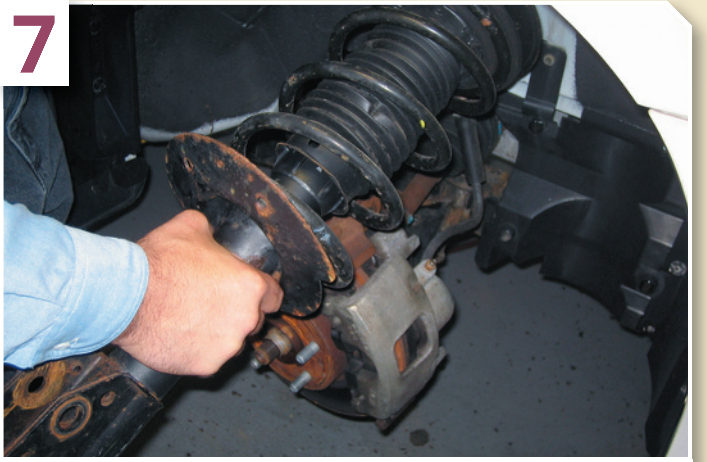
6



Lower the vehicle and remove the upper strut retaining fasteners.

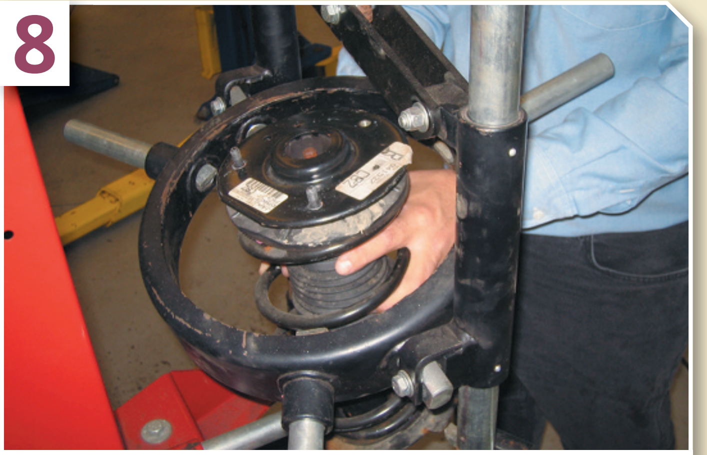
STRUT REPLACEMENT

7



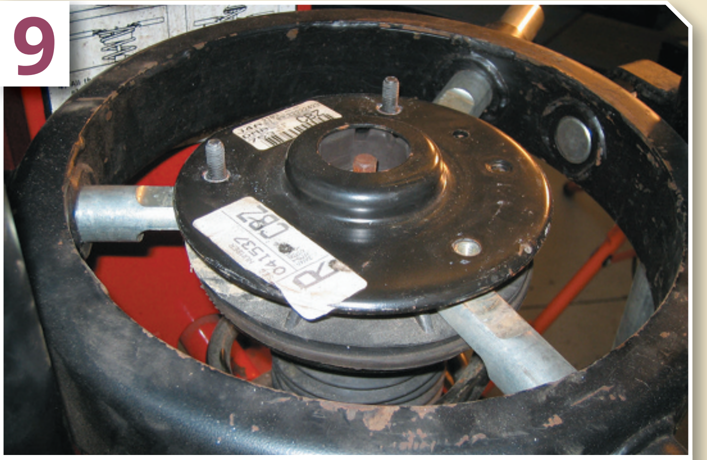
Hold the strut while removing the last upper retaining nut and then remove the strut assembly.

8



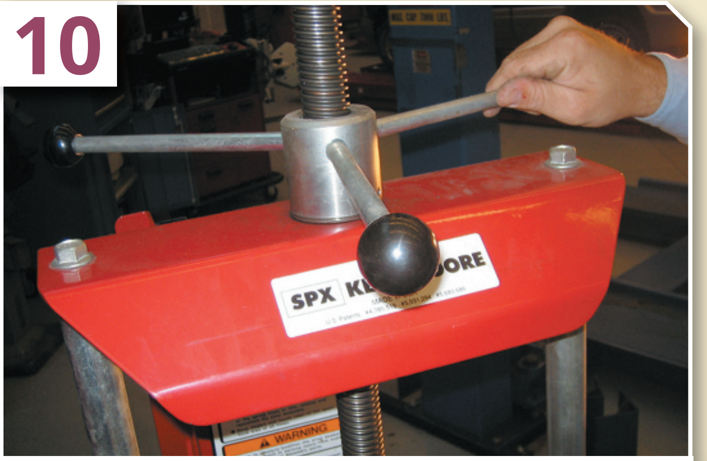
After the strut has been removed from the vehicle, install the assembly into a strut compressor.

9



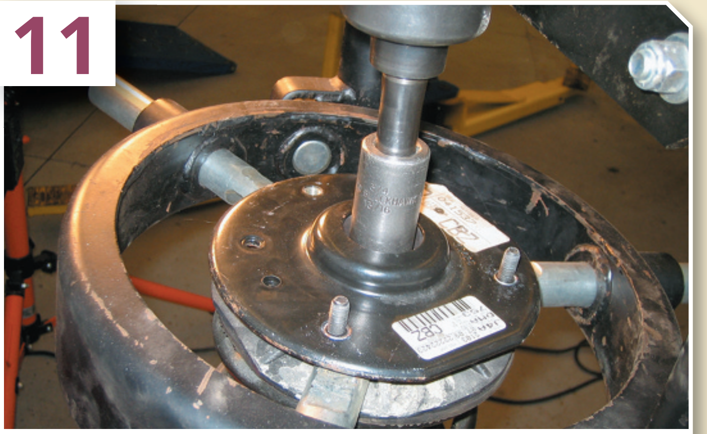
Position the jaws of the compressor under the bearing assembly as per the vehicle manufacturer's instructions.

10



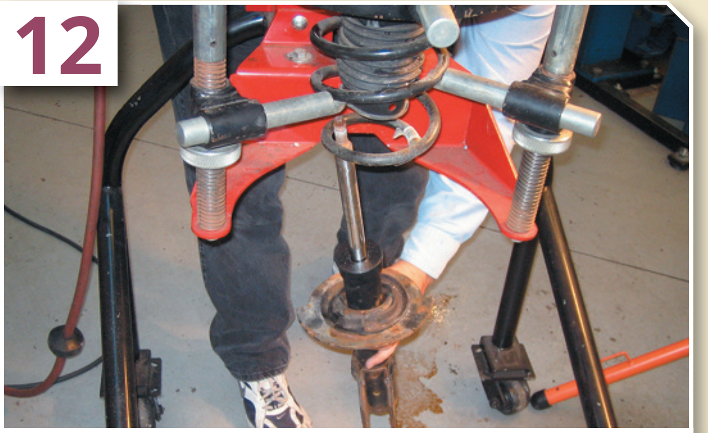
Turn the compressor wheel until all tension of the spring has been relieved from the upper bearing assembly.

11



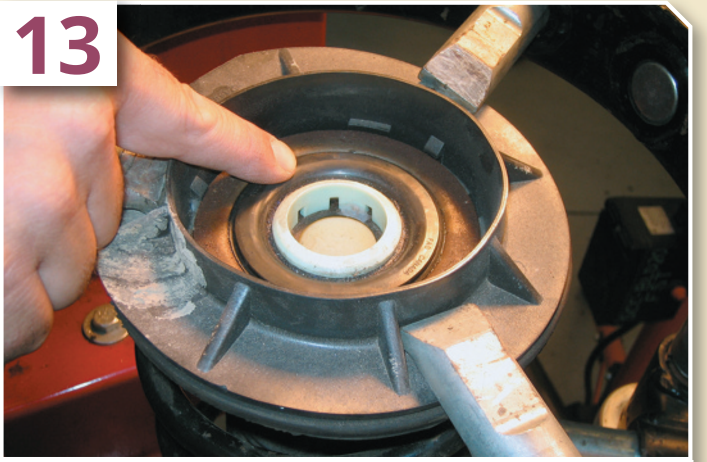
Remove the strut retaining nut.

12



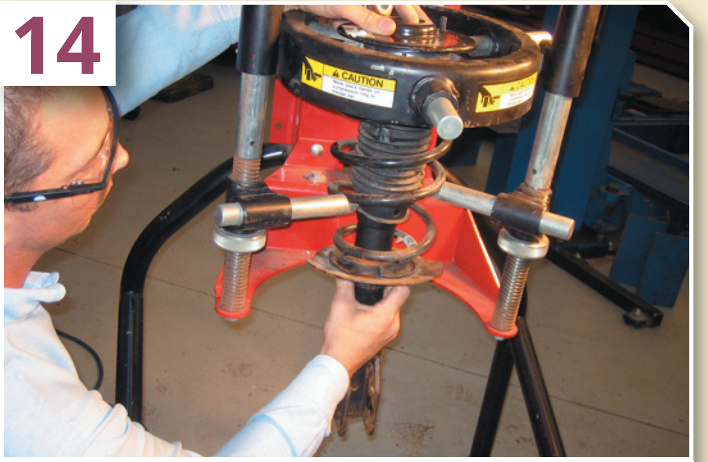
Remove the strut assembly.

13



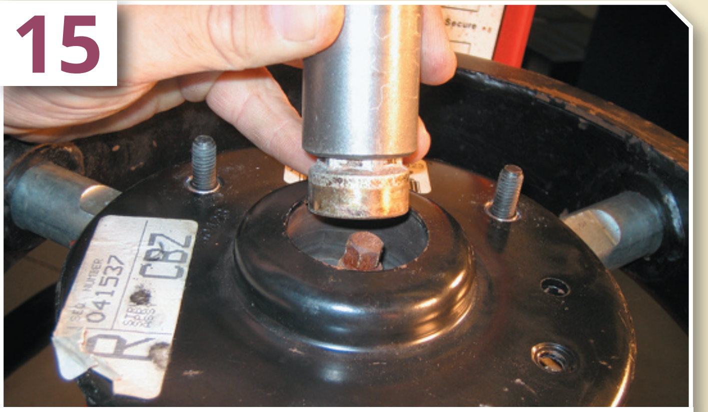
Before installing the replacement strut, check the upper bearing by exerting a downward force on the bearing while rotating and check for roughness. Replace if necessary.

14



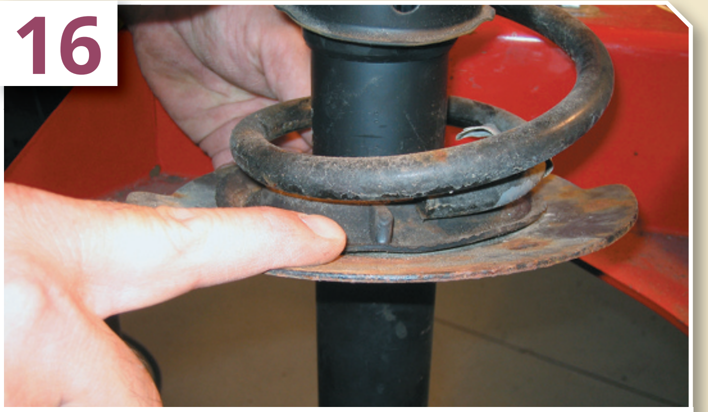
Install the strut from underneath the spring compressor fixture.

15



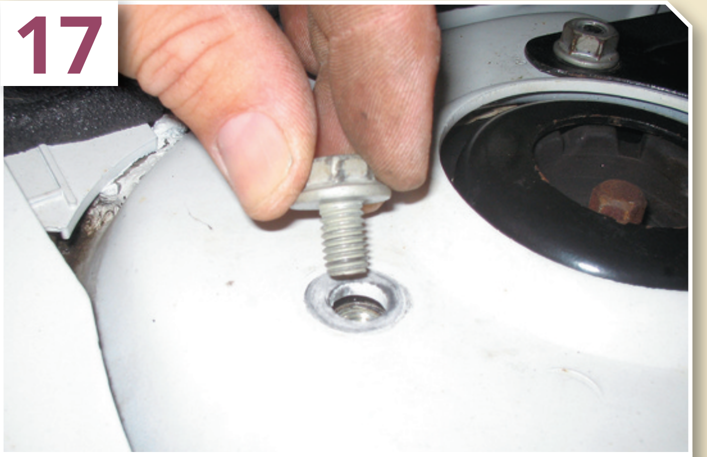
Install the strut retaining nut. Most vehicle manufacturers specify that the strut retaining nut be replaced and the old one discarded.

16



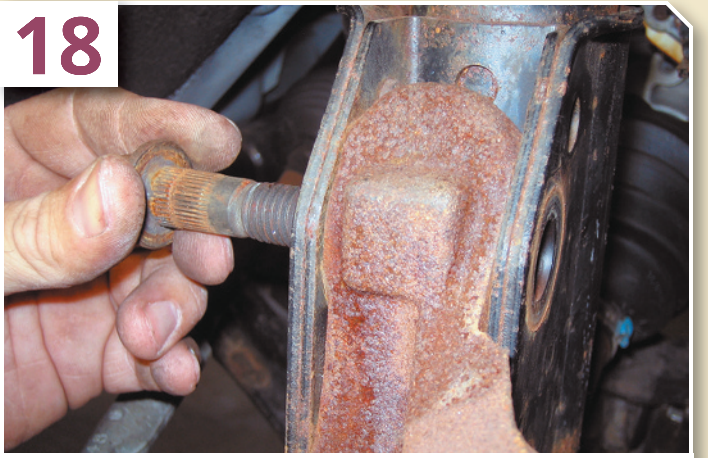
Before loosening the tension, check that the coil spring is correctly located at both the top and the bottom, then release the tension on the spring.

17



Remove the strut assembly from the compressor and back of the vehicle and install the upper fasteners. Do not torque to specifications until the lower fasteners have been installed.

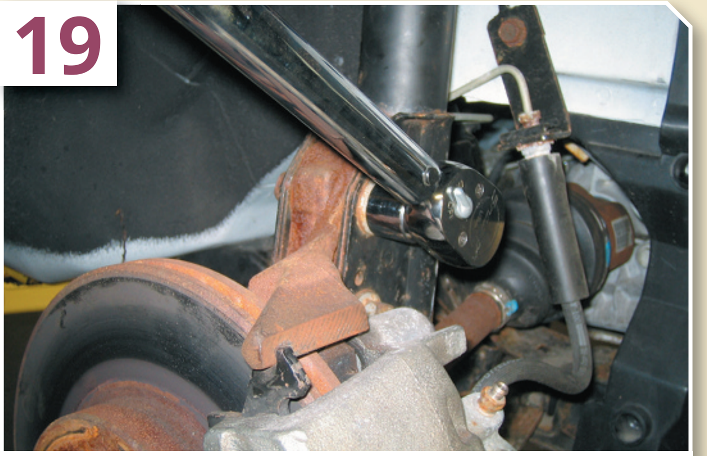
18



Attach the lower strut to the steering knuckle using the original hardened bolts and nuts.

STRUT REPLACEMENT

19



Using a torque wrench, torque all fasteners to factory specifications.

20

Install the tire/wheel assembly, lower the vehicle, and torque the lug nuts to factory specifications. Align the vehicle before returning it to the customer.

REVIEW QUESTIONS

1. How should a proper road test be performed to diagnosis of suspension-related problems?
2. What are the four symptoms of worn or defective shock absorbers?
3. What is the procedure for replacing front shock absorbers on an SLA-type suspension vehicle?
4. What is the testing procedure for ball joints?
5. How should tapered suspension components be removed?

CHAPTER QUIZ

1. A disadvantage of a solid front axle on a vehicle is _____________.
   - **a.** the wheels cannot be turned
   - **b.** lack of ride quality
   - **c.** poor load capacity
   - **d.** All of these
2. A vehicle is equipped with a SLA front suspension. What do the letters mean?
   - **a.** Single long arm
   - **b.** Side-lateral angle
   - **c.** Short-long arm
   - **d.** Solid link assembly
3. Unusual noise during a test-drive can be caused by _____________.
   - **a.** defective wheel bearings or stabilizer bar links
   - **b.** defective or worn control arm bushings or ball joints
   - **c.** worn or defective CV joints
   - **d.** All of the above
4. A noise and a pull toward one side during braking is a common symptom of a worn or defective _____________.
   - **a.** shock absorber
   - **b.** strut rod bushing
   - **c.** stabilizer bar link
   - **d.** track rod bushing
5. To replace the steering knuckle, what component has to be removed or disconnected?
   - **a.** Coil spring or torsion bar
   - **b.** Upper and lower ball joints
   - **c.** Disc brake caliper
   - **d.** All of the above
6. Most manufacturers specify a maximum axial play for ball joints of about _____________.
   - **a.** 0.003 inch (0.076 mm)
   - **b.** 0.010 inch (0.25 mm)
   - **c.** 0.030 inch (0.76 mm)
   - **d.** 0.050 inch (1.27 mm)
7. A light film of oil is observed on the upper area of a shock absorber. Technician A says that this condition should be considered normal. Technician B says that a rod seal may bleed fluid during cold weather, causing the oil film. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Before the strut insert can be removed from a typical MacPherson strut assembly, which operation is necessary to prevent possible personal injury?
   - **a.** The brake caliper and/or brake hose should be removed from the strut housing.
   - **b.** The coil spring should be compressed.
   - **c.** The upper strut mounting bolts should be removed.
   - **d.** The lower attaching bolts should be removed.
9. What should the technician do when replacing stabilizer bar links?
   - **a.** The stabilizer bar should be removed from the vehicle before replacing the links.
   - **b.** The links can be replaced individually, yet the manufacturer often recommends that the links at both ends be replaced together.
   - **c.** The stabilizer bar must be compressed using a special tool before removing or installing stabilizer bar links.
   - **d.** Both b and c are correct.
10. Two technicians are discussing suspension bushings. Technician A says that replacing control arm bushings usually requires special tools. Technician B says using high-performance urethane bushings may cause excessive noise to be transferred to the passenger compartment. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter

113

REAR SUSPENSION AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe solid rear axles.
- Describe leaf spring rear suspensions.
- Distinguish between trailing arm and semi-trailing arm rear suspensions.
- Distinguish between independent and semi-independent rear suspensions.
- Explain rear suspension service.
- Describe replacement of rear shocks.
- Describe replacement of rear springs.

KEY TERMS:

Axle windup 1393 • Chapman strut 1395 • Hotchkiss drive 1393 • IRS 1395 • Live axle 1393 • Panhard rod 1394 • Semi-independent suspension 1395 • Semi-trailing arm 1395 • Solid axle 1392 • Torque arm 1394 • Track rod 1394 • Trailing arm 1393 • Watts linkage 1395

SOLID REAR AXLES

All suspensions have two basic jobs: keeping the tires on the ground and providing a smooth ride. A **solid axle** can be used at the rear of either a rear-wheel-drive or front-wheel-drive vehicle. ● **SEE FIGURE 113–1**. On a rear-wheel-drive vehicle, a solid rear axle consists of the differential gears and axle shafts inside a solid housing. On a front-wheel-drive vehicle, a solid axle is usually a simple U-shaped or tubular beam that may contain a torsion bar, rod, or tube to allow some twisting action.

Certain characteristics apply to any solid rear axle, while other characteristics vary by the type of suspension used to attach the axle to the frame.

Solid axles have some handling characteristics that are inferior to those of an independent suspension. Disadvantages of a solid axle include the following:

- Increased proportion of unsprung weight
- Side-to-side road shock transference
- Poorer tire adhesion

Increasing the proportion of unsprung weight decreases ride quality. Transferring road shock from side to side causes wheel tramp and shimmy, and poor tire adhesion accelerates tire wear. ● **SEE FIGURE 113–2**.

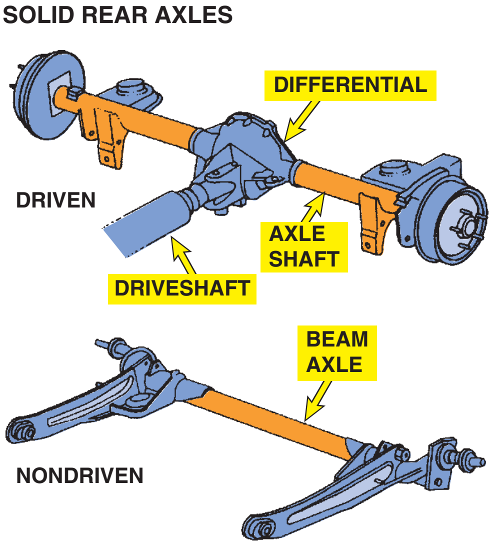


FIGURE 113–1 Solid axles are used on rear-wheel-drive vehicles as well as on front-wheel-drive vehicles.

The sprung weight of the frame and body must be heavy to oppose the unsprung weight of a solid axle, especially on a driven axle. Unsprung weight, wheel tramp, and shimmy all reduce tire adhesion. The effects of these problems are more

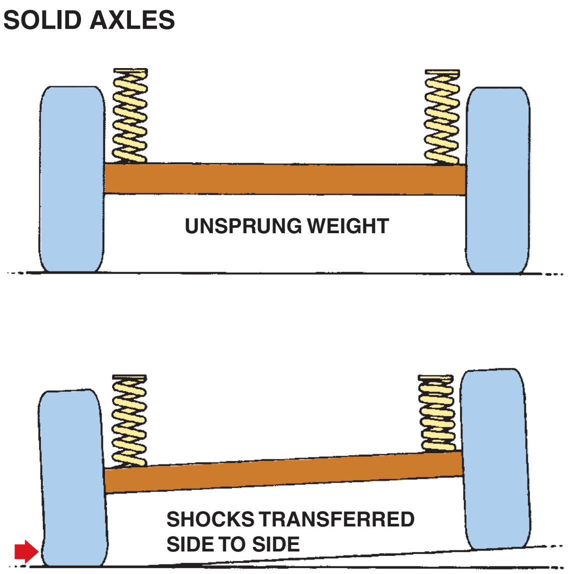


FIGURE 113–2 A solid axle supports the springs, so the axle and suspension components are unsprung weight. When one wheel rides over a bump, the force of impact transfers through the solid axle to the opposite side, leading to unstable handling.

noticeable in rear-wheel-drive vehicles due to the weight of the rear axle and differential assembly. On a typical front-wheel-drive vehicle, the simple axle beam is not heavy enough to decrease ride quality or cause extreme tire wear. In fact, the rear tires of a front-wheel-drive model always wear more slowly than the front tires because the rear axle is so much lighter than the power train.

If engine torque is applied to the rear axle to drive the vehicle, the axle is referred to as a **live axle**.

LEAF SPRING REAR SUSPENSIONS

A leaf spring suspension is a simple system because it does not require control arms to brace and position the axle. The leaf springs link the axle to the frame and effectively serve two purposes:

- Absorbing road shock
- Locating the axle under the vehicle

FREQUENTLY ASKED QUESTION

What Is Axle Windup?

Axle windup is a product of the law of physics, which states that every action produces an equal and opposite reaction. As the axle shafts rotate in one direction to drive the wheels, the axle housing attempts to rotate in the opposite direction. The force of this reaction tends to lift the front end of the vehicle during acceleration. ● **SEE FIGURE 113–3**. Axle windup is a particular problem with a solid, driven rear axle because the axle housing concentrates the reacting force. Under extreme acceleration, the reacting force can actually tilt the drive shaft upward and lift the front wheels off the ground. Leaf springs, control arms, pinion snubbers, and torque arms all are means of controlling axle windup.

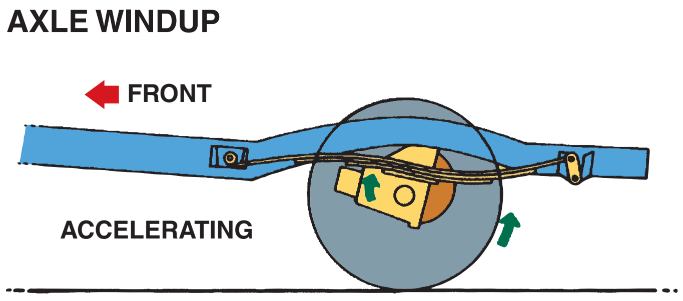


FIGURE 113–3 When the axle housing reacts against the force of axle shaft rotation, the front of the differential tilts upward, creating axle windup.

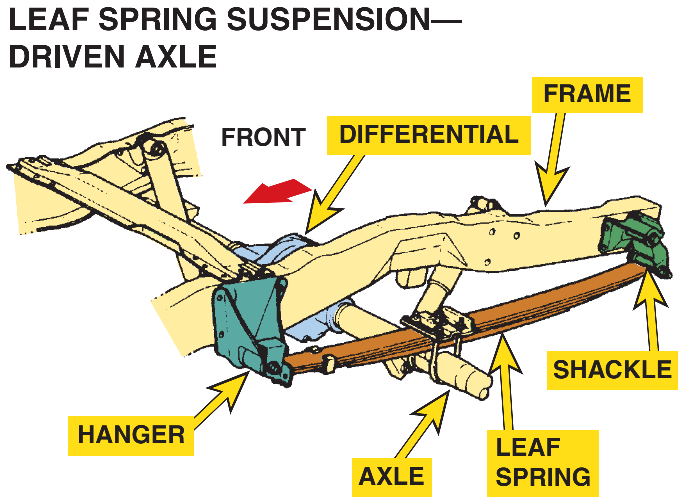


FIGURE 113–4 A typical rear-wheel-drive pickup truck rear suspension equipped with leaf springs. This type of arrangement is called a Hotchkiss drive and the drivetrain forces are controlled by the rear suspension components.

Most rear-wheel-drive trucks use a solid rear axle with leaf springs in an arrangement called a **Hotchkiss drive**. ● **SEE FIGURE 113–4**. Leaf springs on a driven axle control axle windup by transferring force from the axle housing to the frame. The front portion of the leaf spring, from the axle housing to the frame mount, acts like a trailing control arm. However, if the front section of the leaf spring is too flexible, it may not control axle windup as well. To compensate, some manufacturers make the front section of the spring shorter, and therefore less flexible, than the rear section.

Leaf springs are used on the rear of many light- and medium-duty trucks and vans. ● **SEE FIGURE 113–5**. The wheel spindles bolt to the flanges, the centers of the leaf springs rest on the seats, and U-bolts secure the springs to the axle. A shackle attaches the rear of each spring to the unit-body frame, while the front of each spring pivots through a bolt and bushing connected to a hanger that bolts to the body.

TRAILING ARM AND SEMI-TRAILING ARM REAR SUSPENSIONS

TRAILING ARM REAR SUSPENSIONS A **trailing arm** extends from a frame crossmember located ahead of the rear axle back to the axle housing or a wheel knuckle. Trailing arms run parallel

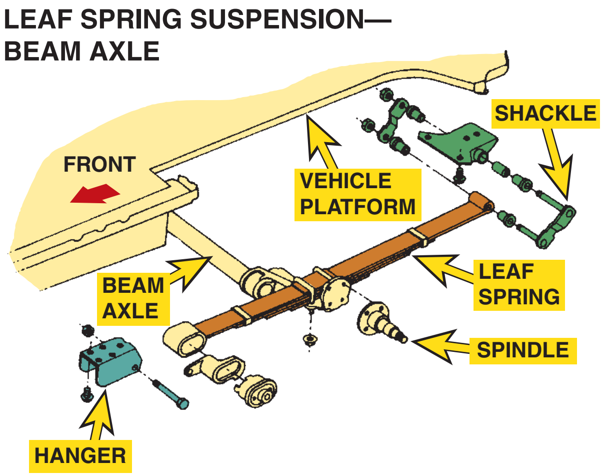

LEAF SPRING SUSPENSION—
BEAM AXLE
FRONT
SHACKLE
VEHICLE PLATFORM
LEAF SPRING
BEAM AXLE
SPINDLE
HANGER

FIGURE 113–5 An exploded view of a beam axle with multileaf springs.

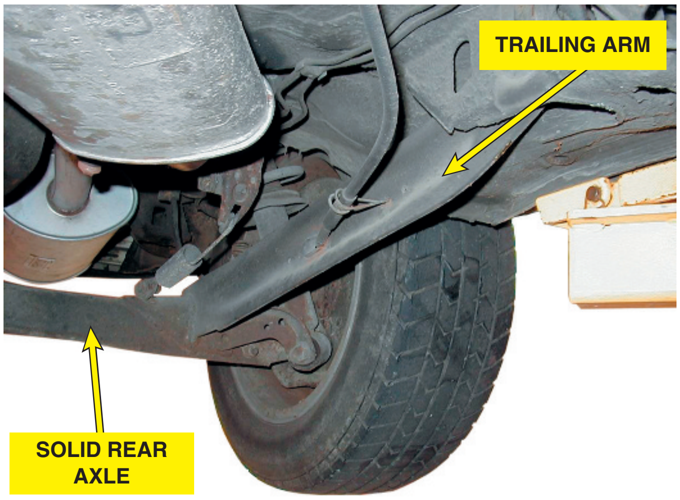

TRAILING ARM
SOLID REAR AXLE

FIGURE 113–6 A trailing arm rear suspension with a solid axle used on a front-wheel-drive vehicle.

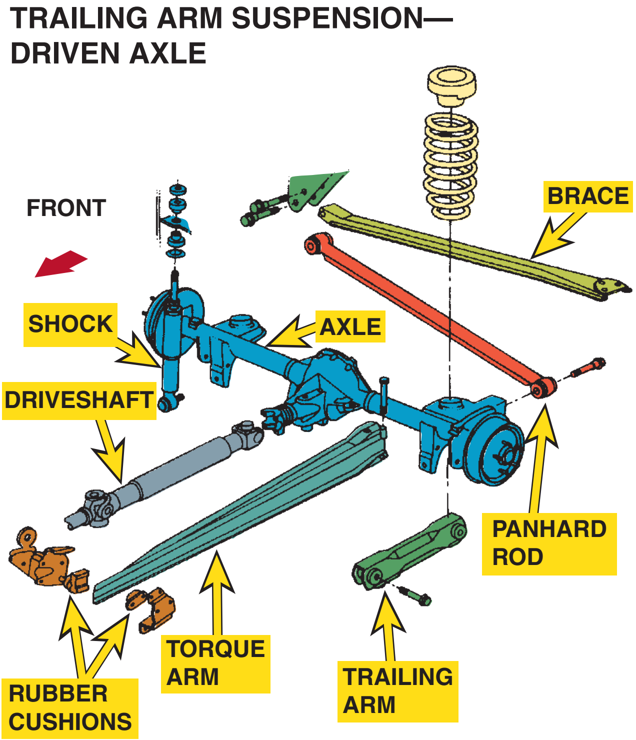

TRAILING ARM SUSPENSION—
DRIVEN AXLE
FRONT
BRACE
SHOCK
AXLE
DRIVESHAFT
PANHARD ROD
TORQUE ARM
RUBBER CUSHIONS
TRAILING ARM

FIGURE 113–7 This rear suspension systems use a torque arm to control axle windup. If the rubber torque arm bushings (cushions) are worn, a loud "bang" could be heard and felt when accelerating suddenly.

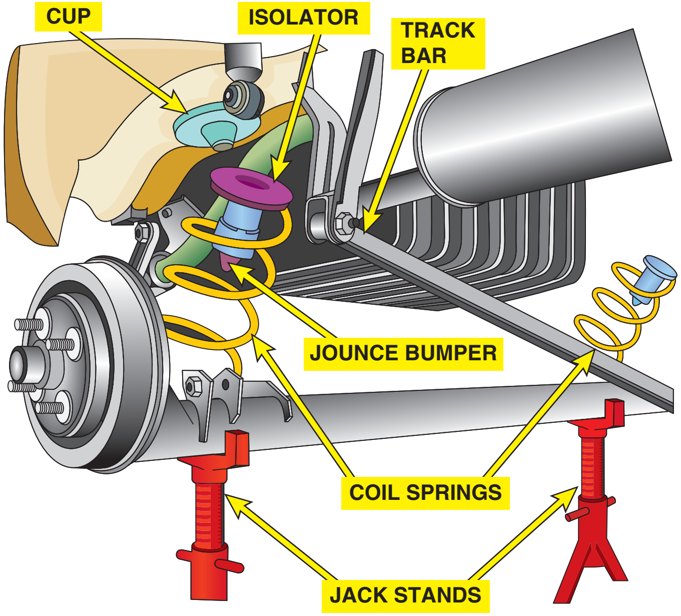

CUP
ISOLATOR
TRACK BAR
JOUNCE BUMPER
COIL SPRINGS
JACK STANDS

FIGURE 113–8 A typical beam axle rear suspension, which uses trailing arms and coil springs along with a track rod, also called a Panhard rod, to control side-to-side axle movement.

to the centerline of the chassis. ● **SEE FIGURE 113–6**. A trailing arm mounts to the frame with bushings, which allow the arm to pivot as the wheel rides over bumps. Some rear suspensions use two sets of trailing arms, one set positioned higher in the chassis than the other. Although the arms in this type of arrangement are commonly referred to as the *upper control arms* and *lower control arms*, they are usually called trailing arms. The word *trailing* applies to any link where the supported member trails the arm. Trailing arms may be used to brace either a driven or nondriven solid rear axle against front-to-rear forces, but they do not provide much resistance to side-to-side, or lateral, forces. The axle itself is one means of locating the wheels side-to-side, and solid rear suspensions frequently use another rod to provide additional support. Trailing arms transfer axle windup force to the frame and control front-to-rear axle movement. On a few models, especially those with a high-performance suspension, a **torque arm** provides additional resistance to axle windup. ● **SEE FIGURE 113–7**. The torque arm extends parallel to the drive shaft between the rear axle and the transmission. One end of the torque arm is rigidly bolted to the differential housing, while the other end attaches to the transmission through a cushioned bracket to allow some flex.

A trailing arm rear suspension on a nondriven solid axle virtually always includes a **track rod**, also called a **Panhard rod**. A track rod is a rod attached to the body or frame on one end and the rear axle on the other. The purpose of the track rod is to keep the rear axle centered under the vehicle. The suspension may use either coil springs or struts.

The rear axle is a U-shaped steel beam that is open on the bottom. ● **SEE FIGURE 113–8**. Flat metal axle end plates, to which the wheel spindles bolt, are attached to each end of the beam. A torsion tube or rod fits inside the beam and is welded to the axle end plates.

The trailing arms, which are welded to the outboard ends of the axle, extend forward and attach to the frame with pivot

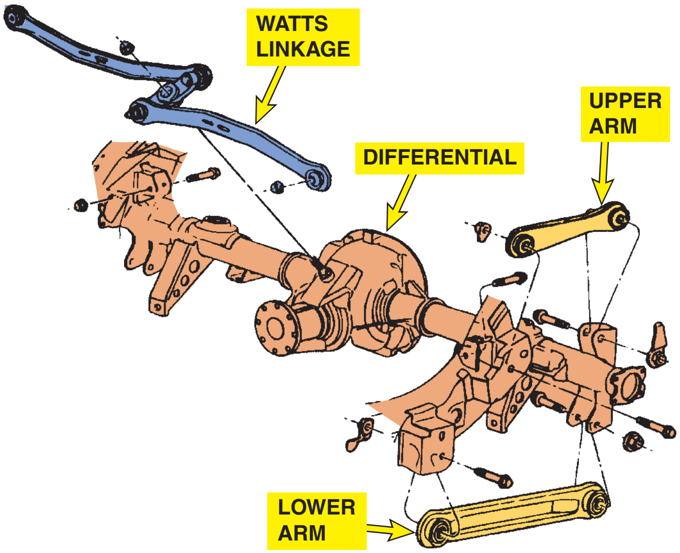


FIGURE 113–9 This Ford rear suspension uses upper and lower semi-trailing arms to mount the rear axle and a watts linkage to control side-to-side movement.

bushing mounts. A bracket on top of the beam axle locates the ring-type lower strut mount, and the upper strut mount attaches to a reinforced area of the wheel well.

SEMI-TRAILING ARM REAR SUSPENSIONS A **semi-trailing arm** is similar to a trailing arm in that it extends back from a frame member to the axle. However, a trailing arm is parallel to the vehicle centerline whereas a semi-trailing arm pivots at an angle to the vehicle centerline. Semi-trailing arms have an advantage over trailing arms because they control both side-to-side and front-to-rear motion. Typically, a semi-trailing arm suspension uses coil springs, air springs, or pivot-base struts.

A semi-trailing arm suspension may be used with either a solid axle or an independent suspension.

The Ford suspension uses two pairs, upper and lower, of semi-trailing arms and a center pivot arrangement to locate the driven rear axle. This axle centering pivot bracket and linkage is called a **watts linkage**. ● **SEE FIGURE 113–9**.

INDEPENDENT AND SEMI-INDEPENDENT REAR SUSPENSIONS

INDEPENDENT REAR SUSPENSIONS The use of **independent rear suspension**, called **IRS**, has grown dramatically over the past several decades to the point where such systems are now fairly common, especially on front-wheel-drive vehicles and some rear-wheel-drive vehicles. Although rarely used on trucks, a number of rear-wheel-drive vehicles do feature an independent rear suspension.

The reduction in unsprung weight is particularly noticeable for driven axles, which are constructed to transfer the weight of the differential and axles to the frame. ● **SEE FIGURE 113–10**. A vehicle with an independent rear suspension rides and handles better than a similar vehicle equipped with a solid rear axle. An SLA-type of independent suspension may be used at the rear of a rear-wheel-drive vehicle. ● **SEE FIGURE 113–11**.

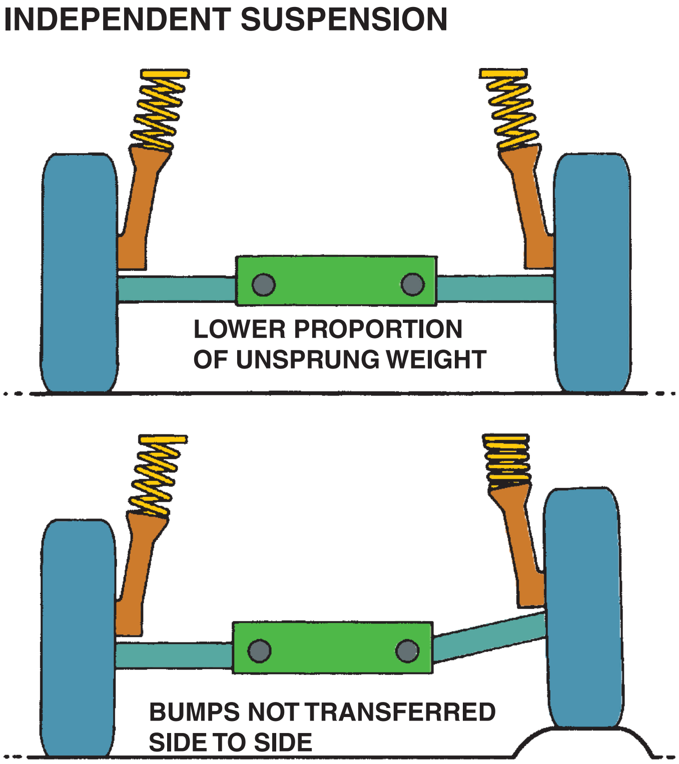

INDEPENDENT SUSPENSION
LOWER PROPORTION OF UNSPRUNG WEIGHT
BUMPS NOT TRANSFERRED SIDE TO SIDE

FIGURE 113–10 An independent rear suspension provides a better ride because less weight is unsprung and the suspension is able to react quickly to bumps in the road without affecting the opposite side.

The differential carrier bolts to the rear subframe, which bears the weight of the axle. Equal-length axle shafts with constant-velocity (CV) joints at either end connect the differential to the rear wheels and allow the wheels to move independently of each other.

The main benefit of an SLA suspension is that it reduces tire scrub and improves traction. The positioning of the control arms determines the suspension roll center location. In general, the lower the roll center, the less body roll.

Unit-body front-wheel-drive vehicles frequently use strut suspensions at the rear axle. Typically, the strut mounts to the knuckle and replaces the upper control arm. The first designer to put MacPherson-type struts in a rear suspension was an Englishman, Colin Chapman. For this reason, a rear strut suspension is often referred to as a **Chapman strut** suspension by European manufacturers and engineers.

The MacPherson strut system is the most popular independent rear suspension for late-model front-wheel-drive vehicles. ● **SEE FIGURE 113–12**. Modified strut rear suspensions are found on a variety of front-wheel-drive models from different manufacturers. ● **SEE FIGURE 113–13**.

General Motors produced two different rear modified strut systems with transverse leaf springs. ● **SEE FIGURE 113–14**. A transverse leaf spring is also used on the Chevrolet Corvette and the Cadillac XLR.

SEMI-INDEPENDENT REAR SUSPENSIONS A **semi-independent suspension** is used only at a nondriven rear axle. The semi-independent design is based on a crossbeam that is similar to the beam axle of a solid, nondriven rear suspension. However, on a semi-independent design, the crossbeam is placed ahead, rather than at the centerline, of the wheels. ● **SEE FIGURE 113–15**. Trailing arms extend rearward from the

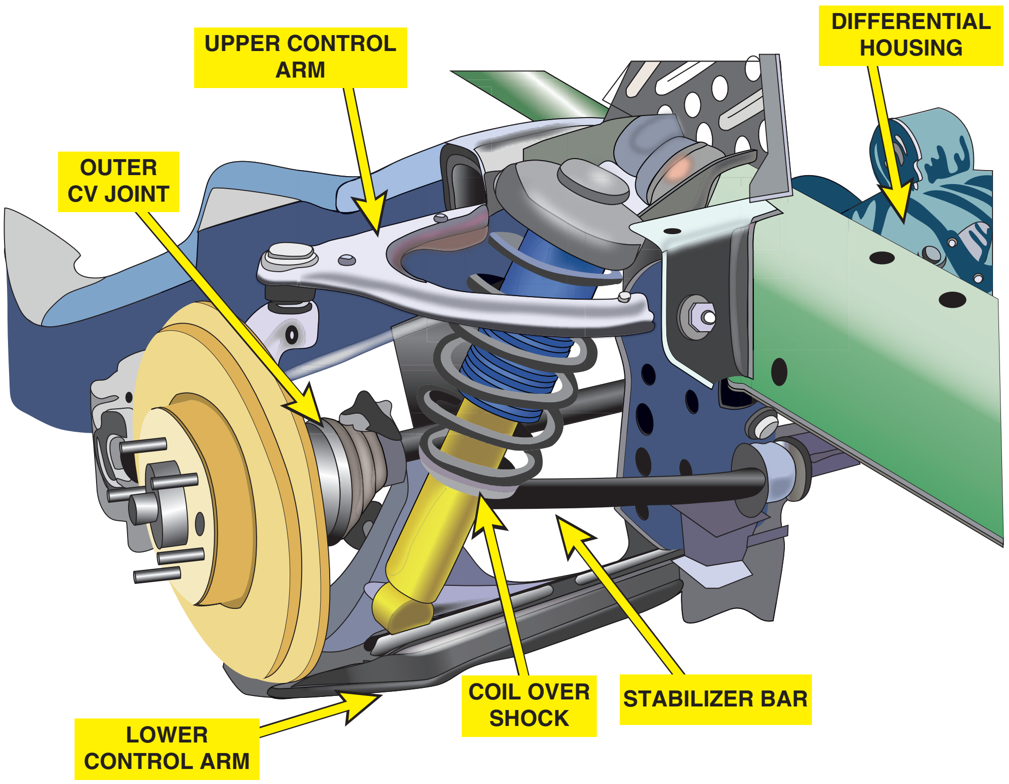

UPPER CONTROL ARM
DIFFERENTIAL HOUSING
OUTER CV JOINT
LOWER CONTROL ARM
COIL OVER SHOCK
STABILIZER BAR

FIGURE 113–11 A typical short-/long-arm independent rear suspension.

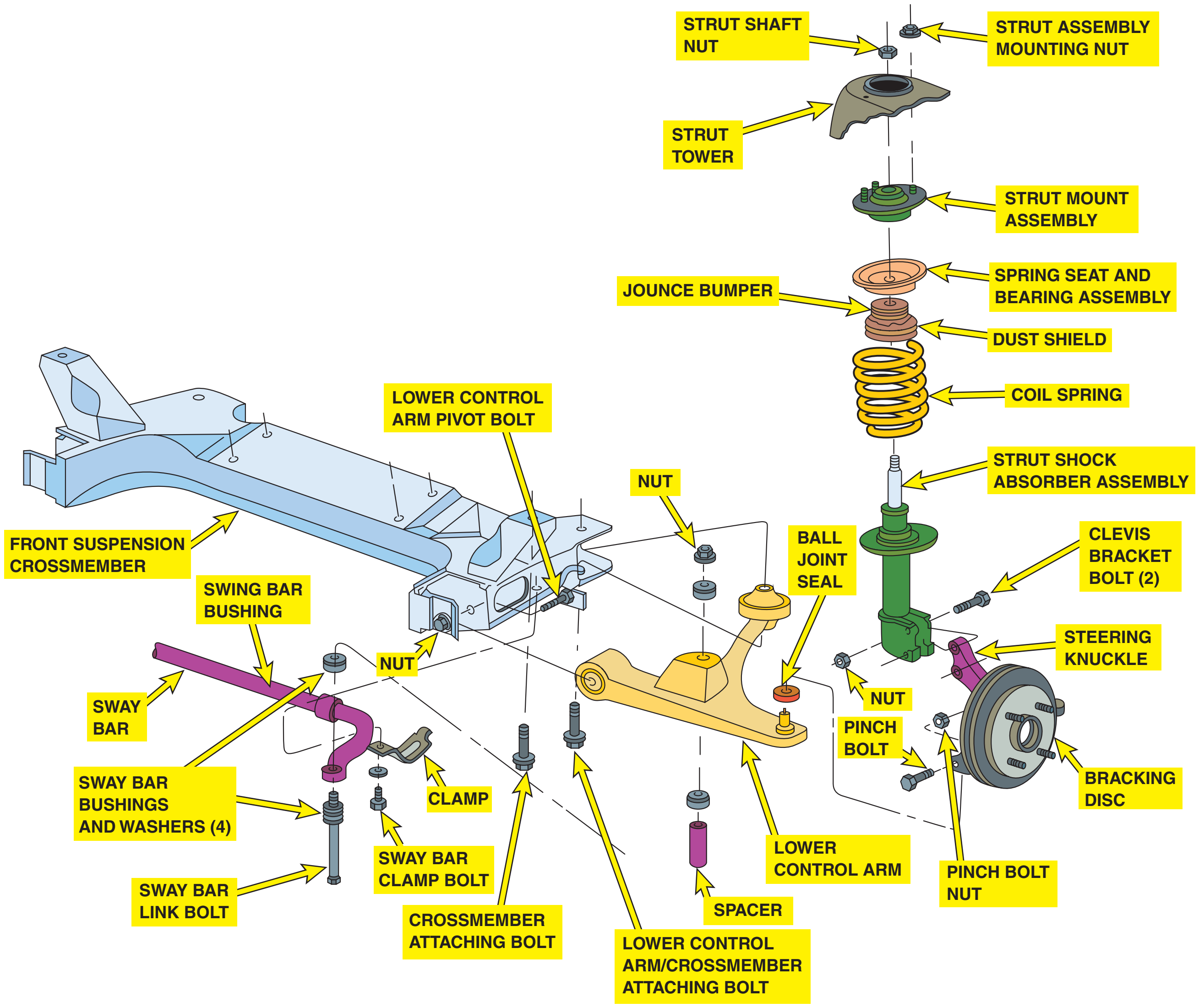

STRUT SHAFT NUT
STRUT ASSEMBLY MOUNTING NUT
STRUT TOWER
STRUT MOUNT ASSEMBLY
JOUNCE BUMPER
SPRING SEAT AND BEARING ASSEMBLY
DUST SHIELD
COIL SPRING
LOWER CONTROL ARM PIVOT BOLT
STRUT SHOCK ABSORBER ASSEMBLY
NUT
BALL JOINT SEAL
CLEVIS BRACKET BOLT (2)
FRONT SUSPENSION CROSSMEMBER
SWING BAR BUSHING
NUT
STEERING KNUCKLE
SWAY BAR
NUT
PINCH BOLT
BRACKING DISC
SWAY BAR BUSHINGS AND WASHERS (4)
CLAMP
LOWER CONTROL ARM
SWAY BAR CLAMP BOLT
PINCH BOLT NUT
SWAY BAR LINK BOLT
SPACER
CROSSMEMBER ATTACHING BOLT
LOWER CONTROL ARM/CROSSMEMBER ATTACHING BOLT

FIGURE 113–12 This independent rear suspension uses a MacPherson strut, with a lower control arm and an anti-sway bar.

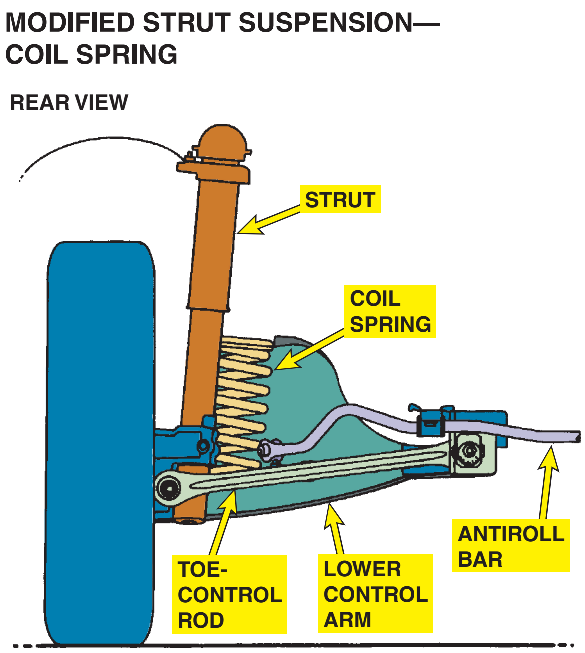

MODIFIED STRUT SUSPENSION—COIL SPRING
REAR VIEW
STRUT
COIL SPRING
ANTIROLL BAR
TOE-CONTROL ROD
LOWER CONTROL ARM

FIGURE 113–13 The toe-control rod provides an extra brace to keep the rear wheels straight ahead during braking and acceleration on this modified-strut-type independent rear suspension.

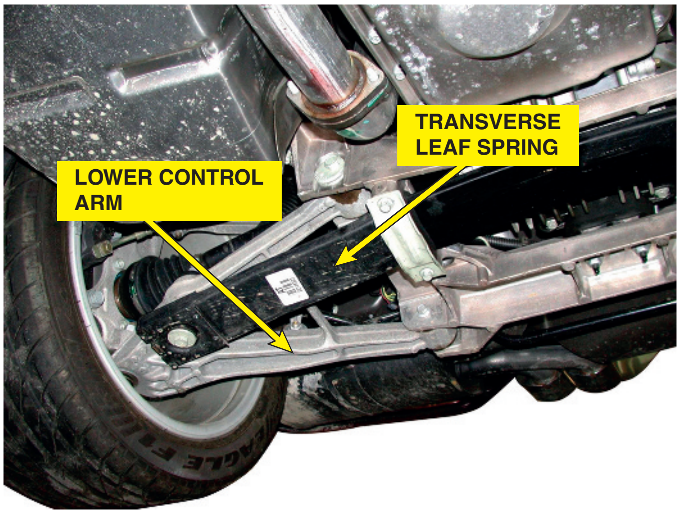

TRANSVERSE LEAF SPRING
LOWER CONTROL ARM

FIGURE 113–14 A transverse mono-type leaf spring used on the rear suspension of a Chevrolet Corvette.

crossbeam to the wheels. The name *semi-independent* indicates that although an axle does not directly link the wheels, the wheels are not completely independent of each other because they are indirectly connected through the crossbeam.

Some semi-independent rear suspensions use struts. ● **SEE FIGURE 113–16**.

REAR SUSPENSION SERVICE

Rear suspension service starts with a thorough test-drive, to observe any unusual noises or vibrations that may be caused by a fault with a rear suspension component.

After a test-drive, safely hoist the vehicle and perform a thorough visual inspection. Use an appropriate prybar and move all of the bushings and joints, checking for deterioration or freeplay. ● **SEE FIGURE 113–17**.

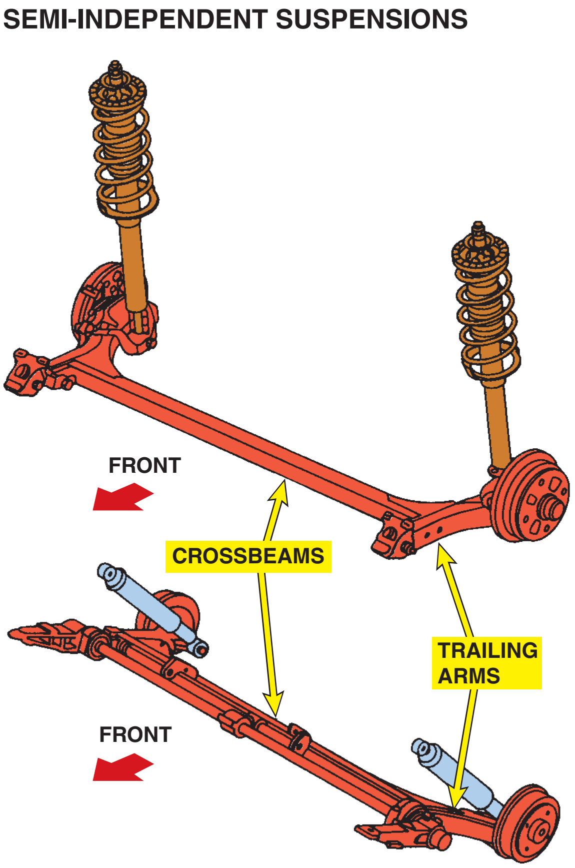

SEMI-INDEPENDENT SUSPENSIONS
FRONT
CROSSBEAMS
FRONT
TRAILING ARMS

FIGURE 113–15 The crossbeam is placed toward the front of the vehicle rather than the centerline of the rear wheels on a semi-independent-type rear suspension.

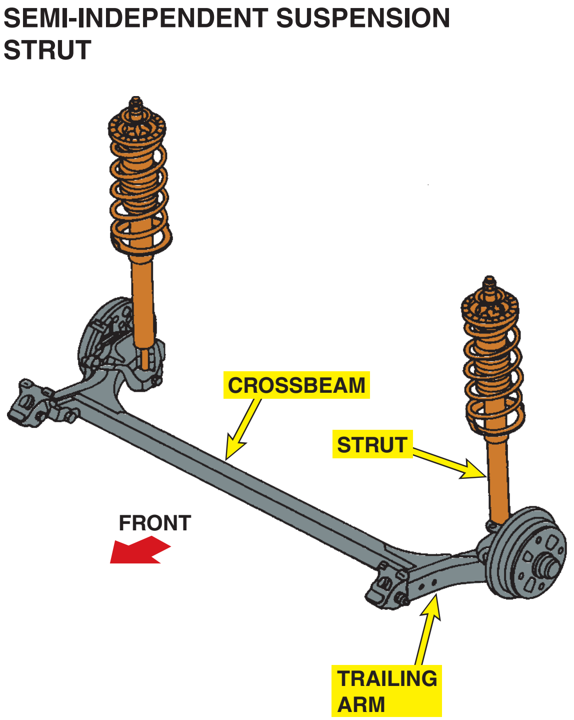

SEMI-INDEPENDENT SUSPENSION STRUT
CROSSBEAM
STRUT
FRONT
TRAILING ARM

FIGURE 113–16 A semi-independent rear suspension with MacPherson struts.

Inspect the shock absorber or struts for leakage or damage. Inspect the bump stops for damage. ● **SEE FIGURE 113–18**. If the bump stops are damaged, this may indicate that the springs are fatigued and the vehicle is at lower-than-normal ride height, or that the shocks or studs are unable to control the springs. ● **SEE FIGURE 113–19**.

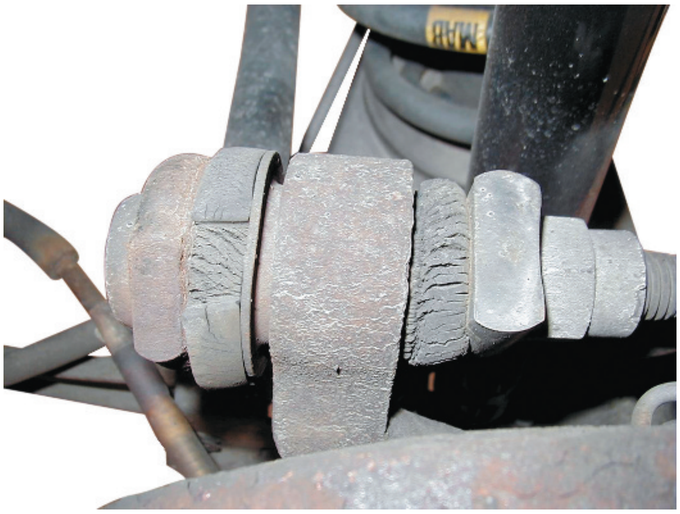


FIGURE 113–17 Check all rubber bushings for excessive cracking.

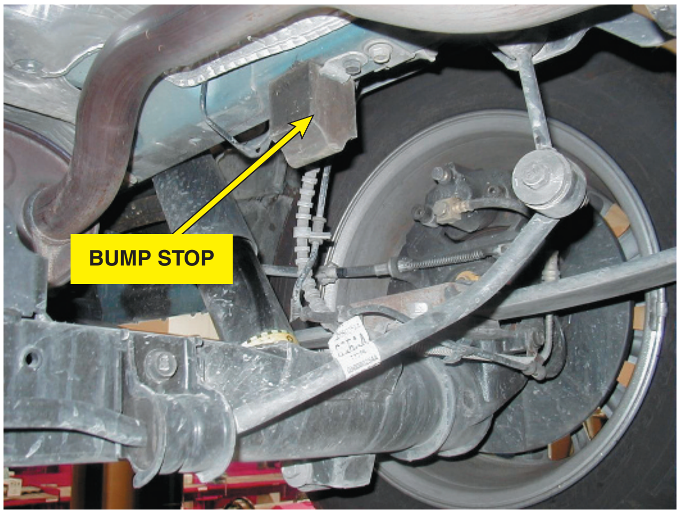


FIGURE 113–18 Carefully inspect the bump stops for damage during a thorough visual inspection.

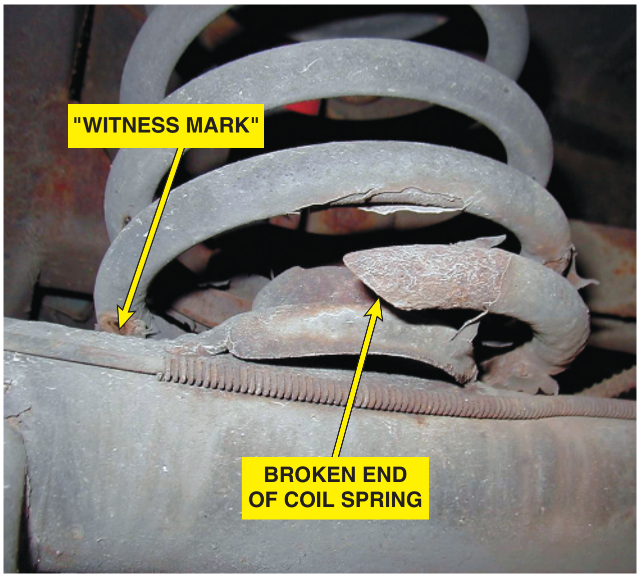


FIGURE 113–19 A broken spring was discovered during a routine under-vehicle visual inspection. Notice the witness marks that show that the spring coils have been hitting each other.

REAR SHOCK REPLACEMENT

PRECAUTIONS Before removing the rear shock absorbers, the rear axle must be supported to prevent stretching of the rear brake flexible hose. Shocks are attached to the frame or body of the vehicle at the top and to a bracket on the rear axle housing at the bottom. Often, the top of the rear shock absorber is fastened *inside* the vehicle. Consult the vehicle manufacturer's service information for exact procedures and fastener torque values.

NOTE: Shock absorbers and/or struts should always be replaced as a pair.

AIR SHOCK INSTALLATION Air-adjustable shock absorbers are a popular replacement for conventional rear shock absorbers. Air shocks can be used to level the vehicle while towing a trailer or when heavily loaded. When the trailer or load is removed, air can be released from the air shocks to return the vehicle height to normal.

Most replacement air shocks are directional and are labeled *left* and *right*. This ensures that the plastic air hose line exits the shock absorber toward the center or rear of the vehicle and is kept away from the wheels.

The plastic air shock line attaches to the shock absorber with an O-ring or brass ferrule and nut. An air leak can result if this O-ring or ferrule is not installed according to the manufacturer's recommendations. Route the plastic air line along the body, keeping it away from the exhaust and any other body parts where the line could be damaged. Attach the line to both shocks to a junction at a convenient location for adding or releasing air.

REAR SPRING REPLACEMENT

REAR COIL SPRINGS

REPLACEMENT Coil springs in the rear are easily replaced on both front-wheel-drive and rear-wheel-drive vehicles. The procedure includes the following steps:

1. Raise the vehicle safely on a hoist.
2. Remove both rear wheels.
3. Support the rear axle assembly with tall safety stands.
4. Remove the lower shock absorber mounting bolts/nuts and disconnect the shock absorber from the rear axle assembly.
5. Slowly lower the rear axle assembly by either lowering the height of the adjustable safety stands or raising the height of the vehicle on the hoist.
6. Lower the rear axle just enough to remove the coil springs. ● **SEE FIGURE 113–21.**

CAUTION: The shock absorber is usually the only component that limits the downward movement of the rear axle to allow removal of the rear coil springs. Some vehicles may be equipped with rear suspension height sensors for the adjustable suspension system or an adjustable rear proportioning valve for the rear brakes. Some vehicles also require that the rear stabilizer bar or track rod be disconnected or removed before lowering the rear axle assembly. Always consult service information for the exact procedure and torque specifications for the vehicle being serviced.

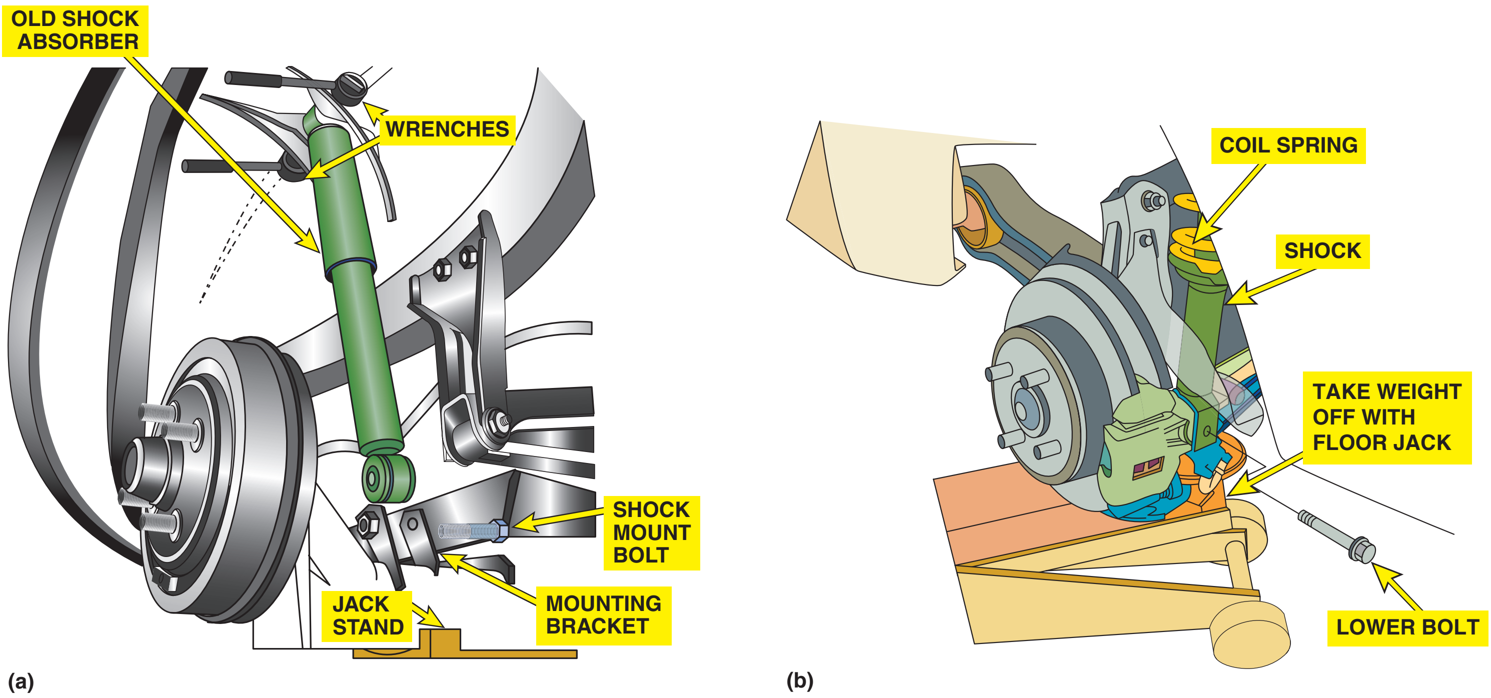


FIGURE 113–20 (a) The rear axle has to be supported before the rear shock absorber is removed. (b) Before removing a rear strut assembly, the rear axle has to be supported. Always follow the vehicle manufacturer's specified procedures.

CASE STUDY

The Harsh Riding Buick

The owner requested that all of the shock absorbers be replaced on a ten-year-old Buick. The rear was equipped with air shocks as part of the ride leveling system. During a test-drive after installing all four shocks, the service technician noticed that it seemed to ride much harsher than normal for a Buick. The technician asked the owner to ride along to verify that it was not usual to ride as harsh as it was. Puzzled as to why this occurred, the technician contacted the parts store, which then asked their supplier about the issue. It was discovered that the air shocks were not cycled before they were installed. Installing air shocks/struts requires cycling the shock/strut to spread lubricant inside the diaphragm to avoid binding. The installing technician should inflate the air diaphragm through the air fitting until the shock/strut fully extends. Then the shock can be kept fully extended to make it easier to install. After removing the rear shocks and inflating them as instructed, and reinstalling, the Buick rode normally.

Summary:

Complaint—The service technician was concerned that the Buick rode harsher than normal after new shock absorbers were installed.

Cause—The proper installation procedure was not followed prior to installing the air shock on the rear.

Correction—The air shocks were removed and cycled and then inflated before being reinstalled, which solved the harsh ride concern.

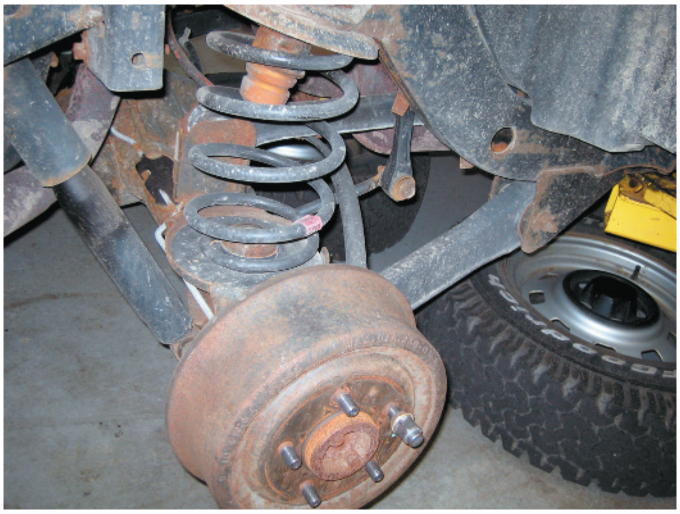


FIGURE 113–21 The shock absorber needs to be disconnected before removing the coil spring. Installation is the reverse of removal procedure.

REAR LEAF SPRINGS

REPLACEMENT Rear leaf springs often need replacement due to one of the following common causes:

1. Individual leaves of a leaf spring often crack, then break. When a leaf spring breaks, the load-carrying capacity of the vehicle decreases and it often sags on the side with the broken spring. Metal fatigue, corrosion, and overloading are three of the most common causes of leaf spring breakage. ● **SEE FIGURE 113–22.**

NOTE: When one rear spring on one side sags, the opposite front end of the vehicle tends to *rise.* For example, if the right-rear spring breaks or sags down, the left front of the vehicle tends to rise higher than the right front. This unequal vehicle height can make the vehicle difficult to handle, especially around corners or curves.

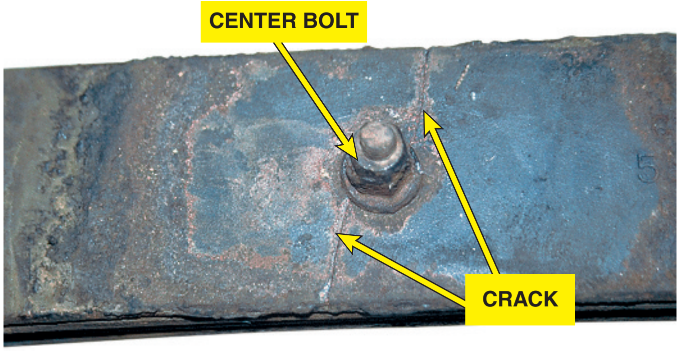


FIGURE 113–22 The center bolt is used to hold the leaves of the leaf spring together. However, the hole for the center bolt also weakens the leaf spring. The crack shown is what a technician discovered when the leaf spring was removed during the diagnosis of a sagging rear suspension.

CASE STUDY

Strange Leakage

The owner of a small business drove the company pickup truck into the shop to get it ready to load for the day's delivery. It was a very cold day in northern Ohio with the temperature well below freezing (32°F [0°C]). After about 15 minutes, the business owner noticed that "something" was leaking from underneath the rear of the truck. ● **SEE FIGURE 113–23**.

Not sure what it was, the owner called a local automotive repair shop and asked for help. The shop sent a technician to look at the truck. The service technician noticed that one of the rear shock absorbers had leaked all of the hydraulic fluid out of the bottom of the shock. ● **SEE FIGURE 113–24**.

Obviously, both rear shock absorbers would require replacement because shocks should always be replaced in pairs. The service technician recommended that all four (both front and both rear) shocks be replaced to restore proper handling. Knowing that the front shock absorbers were operating under the same conditions as the rear and were the same age, the truck owner approved the replacement of all four shock absorbers.

Summary:

Complaint—A liquid was found leaking from underneath a truck.
Cause—Hydraulic fluid had leaked from a rusty shock absorber.
Correction—Based on the owner's approval, all four shocks were replaced.

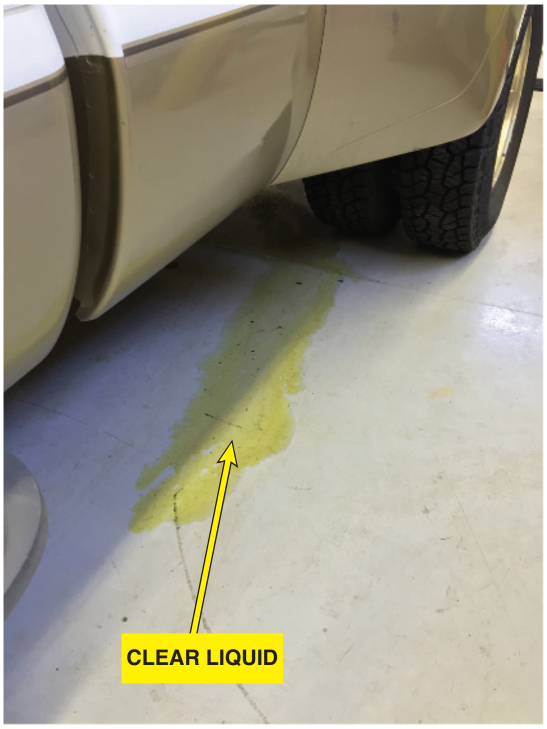


FIGURE 113–23 Whatever was leaking appeared to be a clear liquid but it did not smell like gasoline. What could it be from the rear of the truck?

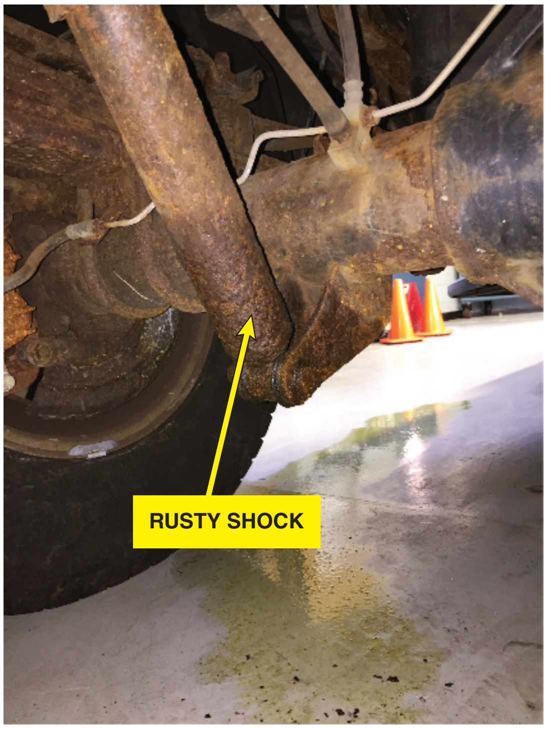


FIGURE 113–24 The source of the leak was discovered to be hydraulic shock fluid that had leaked from the bottom of the shock and not from around the shaft seal, which is the most likely location for shocks to leak. Apparently, rust had eaten through the housing of the shock.

2. If the center bolt breaks, the individual leaves can move and the rear axle is no longer held in the correct location. When one side of the rear axle is behind the other side, the vehicle will *dog track*. Dog tracking refers to the sideways angle of the vehicle while traveling straight. It is commonly caused by the rear axle steering the vehicle toward one side, while the driver controls the direction of the vehicle with the front wheels.

NOTE: Leaf springs should be replaced in pairs.

To replace leaf springs in the rear of a rear-wheel-drive vehicle, follow these steps:

1. Raise the vehicle safely on a hoist.
2. Support the rear axle with safety stands.
3. Remove the rear shackle bolts and forward mounting bolt or mounting bracket.
4. Remove the U-bolts.
5. Remove the spring, being careful of any nearby brake line.
6. Install the new spring, being careful to position the center bolt correctly into the hole on the axle pedestal.

REVIEW QUESTIONS

1. What are the disadvantages of a solid rear axle?
2. What is the purpose of a torque arm?
3. What must be done to ensure safety when replacing the rear shock absorbers?
4. What is meant by "dog tracking"?
5. What is the purpose of a track rod?

CHAPTER QUIZ

1. Some light-duty trucks use a solid rear axle that is attached to ______________ with U-bolts.
   - **a.** struts
   - **b.** coil springs
   - **c.** torsion bars
   - **d.** leaf springs
2. When axle windup is controlled by the rear leaf spring during acceleration, this system is called ______________.
   - **a.** trailing arm
   - **b.** semi-trailing arm
   - **c.** torque arm
   - **d.** Hotchkiss drive
3. Independent rear suspension (IRS) is being discussed. Technician A says that most trucks use this system. Technician B says IRS is used on many front-wheel-drive vehicles. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. A track rod is also called a ______________.
   - **a.** Panhard rod
   - **b.** control rod
   - **c.** handing link
   - **d.** semi-independent rod
5. A semi-trailing arm rear suspension uses ______________.
   - **a.** coil springs
   - **b.** air springs
   - **c.** struts
   - **d.** Any of the above
6. During a visual inspection of the rear suspension, the service technician should check for ______________.
   - **a.** witness marks
   - **b.** cracked rubber bushings
   - **c.** damaged bump stops
   - **d.** All of the above
7. A vehicle equipped with a coil spring front suspension and a leaf spring rear suspension "dog tracks" while driving on a straight, level road. Technician A says that a broken center bolt could be the cause. Technician B says defective rear shock absorbers could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Two technicians are discussing rear shock absorbers. Technician A says that if one shock is leaking, then both rear shock absorbers should be replaced. Technician B says that the rear axle should be supported before removing rear shock absorbers. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. The left front of the vehicle is higher than the right front and the right rear is lower than the left rear. What is the most likely cause of this problem?
   - **a.** A weak right-rear shock absorber
   - **b.** A broken track rod
   - **c.** A broken left-front shock absorber
   - **d.** A sagging right-rear spring
10. One rear leaf spring is broken. Technician A says that both rear leaf springs should be replaced. Technician B says the rear axle should be removed from the vehicle to replace a leaf spring. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B

Chapter 114

ELECTRONIC SUSPENSION SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the need for electronic suspension systems.
- Explain the characteristics of the various sensors used for electronic suspension control.
- Describe electronic suspension system actuators.
- List the types of electronic suspension systems.
- Describe the parts and operation of the automatic level control system.
- Describe how to troubleshoot rear electronic leveling systems.
- Explain how magneto-rheological shocks work.

KEY TERMS:

Actuator 1402 • Air suspension 1404 • Armature 1408 • Automatic level control (ALC) 1409 • Desiccant 1415 • Driver selector switch 1407 • Electronic brake control module (EBCM) 1404 • Electronic control unit (ECU) 1402 • Electromagnet 1407 • Handwheel position sensor 1404 • Height sensor 1402 • Input 1402 • Lateral accelerometer sensor 1405 • Light-emitting diode (LED) 1402 • Magneto-rheological (MR) 1415 • Mode select switch 1409 • Phototransistor 1402 • Pulse width 1408 • Pulse-width modulation 1408 • Real-time dampening (RTD) 1404 • RPO (regular production option) 1412 • Selectable ride (SR) 1407 • Solenoid 1408 • Solenoid controlled damper 1413 • Stabilitrak 1413 • Steering wheel position sensor 1404 • Vehicle stability enhancement system (VSES) 1405 • Vehicle speed (VS) sensor 1405 • Yaw rate sensor 1405

THE NEED FOR ELECTRONIC SUSPENSIONS

Since the mid-1980s, many vehicle manufacturers have been introducing models with electronic suspension controls that provide a variable shock stiffness or spring rate. The main advantage of electronic controls is that the suspension can react to different conditions. The system provides a firm suspension feel for fast cornering and quick acceleration and braking, with a soft ride for cruising. ● **SEE FIGURE 114–1**.

ELECTRONIC SUSPENSION CONTROLS AND SENSORS

INPUTS AND OUTPUTS Sensors and switches provide **input** to the electronic control module (ECM), or system computer. The ECM, which may also be referred to as the **electronic control unit (ECU)**, is a small computer that receives input in the form of electrical signals from the sensors and switches and provides output electrical signals to the system actuators. ● **SEE FIGURE 114–2**. The electrical signal causes an **actuator** to perform some type of mechanical action.

HEIGHT SENSORS Sensors, which are the input devices that transmit signals to the ECM, monitor operating conditions and component functions. A **height sensor** senses the vertical relationship between the suspension component and the body. Its signal indicates to the ECM how high the frame or body is, or how compressed the suspension is. A number of sensor designs are used to determine ride height, including a photocell type of sensor. ● **SEE FIGURE 114–3**.

Four height sensors, one at each wheel, deliver an input signal to the ECM. All four sensors are similar and use a control link, lever, slotted disc, and four photo interrupters to transmit a signal. Each photo interrupter consists of a **light-emitting diode (LED)** and a **phototransistor**, which reacts to the LED.

Inside the sensor, the LEDs and phototransistors are positioned opposite each other on each side of the slotted disc. ● **SEE FIGURE 114–4**. When the system is activated, the ECM applies voltage to the LEDs, which causes them to illuminate. Light from an LED shining on the phototransistor causes the transistor to generate a voltage signal. Signals generated by the phototransistors are delivered to the ECM as an input that reflects ride height.

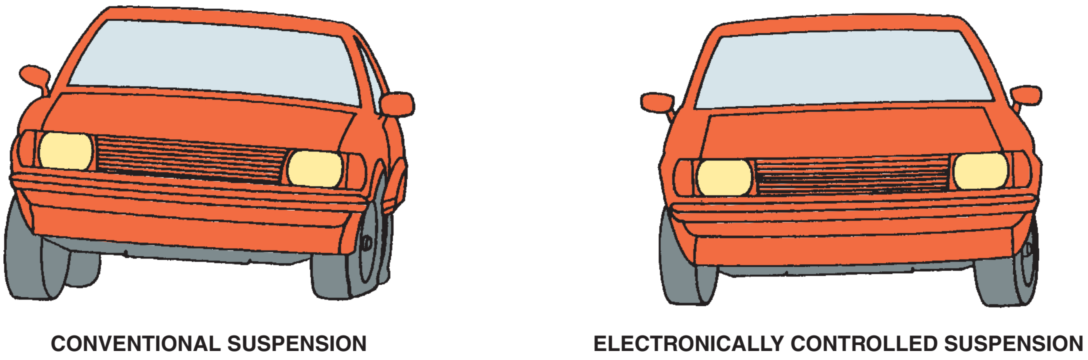

CONVENTIONAL SUSPENSION
ELECTRONICALLY CONTROLLED SUSPENSION

FIGURE 114–1 An electronically controlled suspension system can help reduce body roll and other reactions better than most conventional suspension systems.

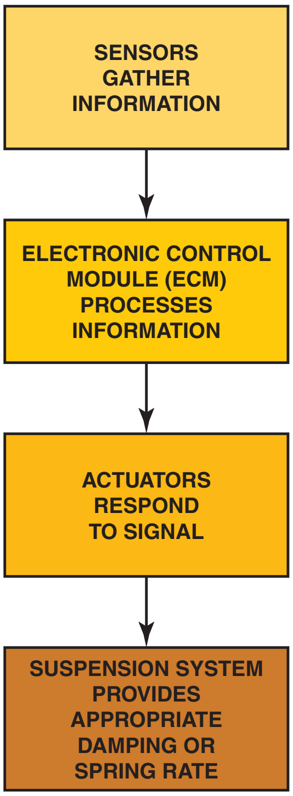

SENSORS GATHER INFORMATION
ELECTRONIC CONTROL MODULE (ECM) PROCESSES INFORMATION
ACTUATORS RESPOND TO SIGNAL
SUSPENSION SYSTEM PROVIDES APPROPRIATE DAMPING OR SPRING RATE

FIGURE 114–2 Input devices monitor conditions and provide information to the electronic control module, which processes the information and operates the actuators to control the movement of the suspension.

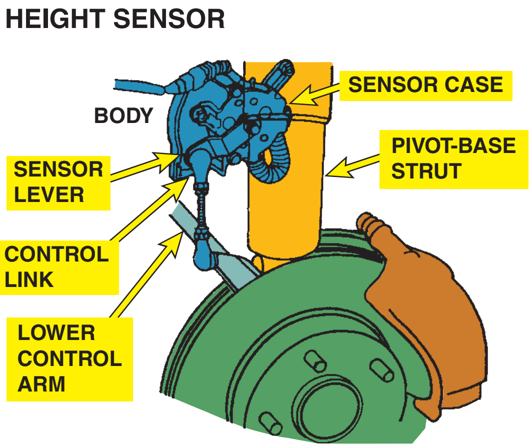

HEIGHT SENSOR
SENSOR CASE
BODY
PIVOT-BASE STRUT
SENSOR LEVER
CONTROL LINK
LOWER CONTROL ARM

FIGURE 114–3 A typical electronic suspension height sensor, which bolts to the body and connects to the lower control arm through a control link and lever.

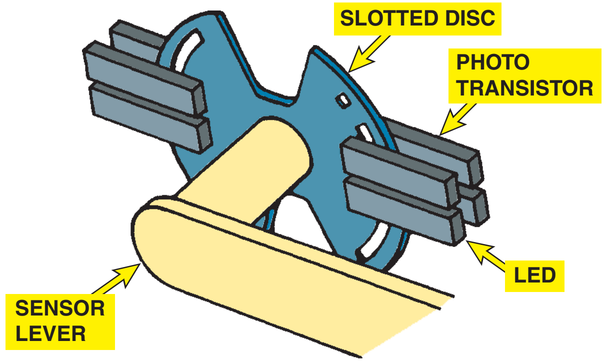

SLOTTED DISC
PHOTO TRANSISTOR
LED
SENSOR LEVER

FIGURE 114–4 When suspension action moves the lever, it rotates the slotted disc and varies how much of the photo transistor is exposed to the LEDs, which vary the input signal.

As suspension movement rotates the disc, the slots or windows on the disc either allow light from the LEDs to shine on the phototransistors or prevent it. The windows are positioned in such a manner that, in combination with the four LEDs and transistors, the sensor is capable of generating 16 different levels of voltage. This variable voltage, which is transmitted to the ECM as an input signal, directly corresponds to 1 of 16 possible positions of the suspension. This input signal tells the ECM the position of the suspension in relation to the body. Whether the input voltage signal is increasing or decreasing allows the ECM to determine if the suspension is compressing or extending.

The ECM can also determine the relative position of the body to the suspension, or the attitude of the vehicle, from the four height sensors. Comparing front-wheel input signals to those of the rear wheels determines the amount of pitch caused by forces of acceleration or deceleration. A side-to-side comparison allows the ECM to determine the amount of body roll generated by cornering force.

GENERAL MOTORS ELECTRONIC SUSPENSION SENSORS

There are five different sensors found on electronic suspension systems, and GM vehicles can have between one and four of these sensors, depending on the system.

Depending on the vehicle, the *suspension position sensor* may be called by a different name. It can be called

- An automatic level control sensor
- An electronic suspension position sensor
- A position sensor
- An air suspension sensor

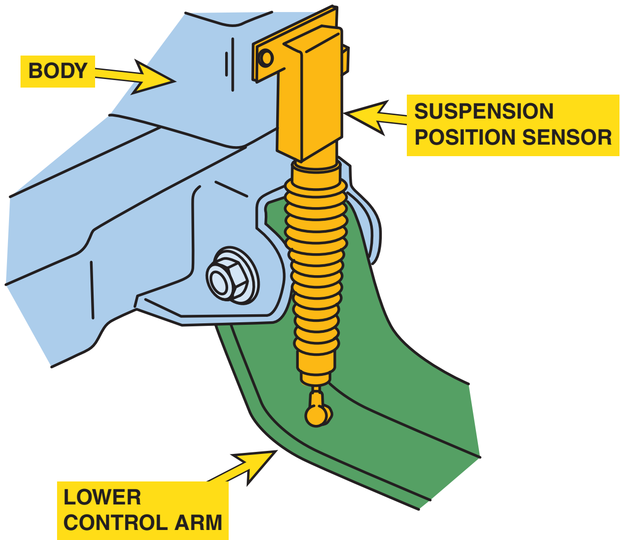


FIGURE 114–5 Typical suspension position sensor.

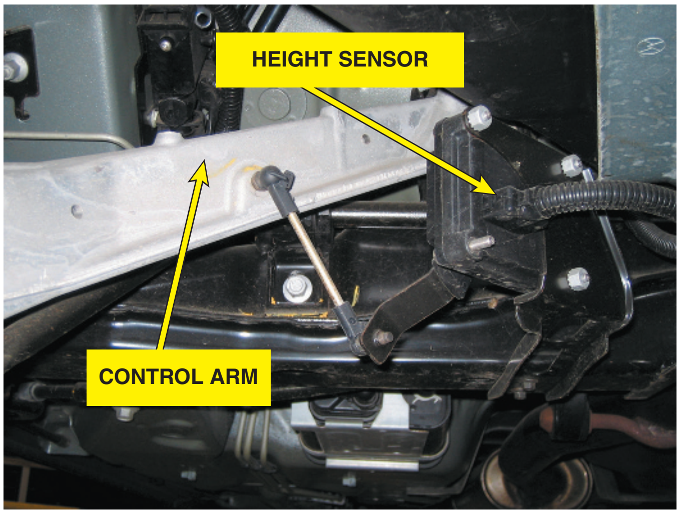


FIGURE 114–7 A suspension height sensor.

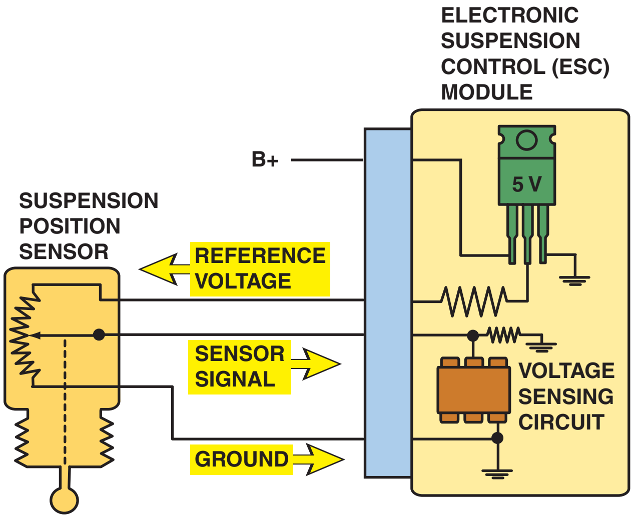

ELECTRONIC SUSPENSION CONTROL (ESC) MODULE
B+
SUSPENSION POSITION SENSOR
REFERENCE VOLTAGE
5 V
SENSOR SIGNAL
VOLTAGE SENSING CIRCUIT
GROUND

FIGURE 114–6 A three-wire suspension position sensor schematic.

The sensor provides the control module with information regarding the relative position and movement of suspension components. The common mounting location is between the vehicle body and the suspension control arm. ● **SEE FIGURE 114–5**.

The operation of the sensor is either an air suspension sensor two-wire type or a potentiometer three-wire type. The **air suspension** sensor is also known as a *linear Hall-effect* sensor. The air suspension sensor operation consists of a moveable iron core linked to the components. As the core moves, it varies the inductance of the internal sensor coil relative to suspension position.

The suspension control module energizes and de-energizes the coil approximately 20 times a second, thereby measuring sensor inductance as it relates to suspension position. The potentiometer three-wire sensor requires reference and ground voltage. Similar to the throttle position (TP) sensor, it produces a variable analog voltage signal. ● **SEE FIGURE 114–6**.

As the suspension moves up or down, an arm moves on the suspension position sensor through a ball-and-cup link. ● **SEE FIGURE 114–7**.

Suspension position sensor voltage changes relative to this movement. The sensor receives a 5 volt reference signal from the control module. The position sensor returns a voltage signal between 0 and 5 volts depending on suspension arm position.

NOTE: Some systems may require sensor learning or "reprogramming" after replacement. For instance, the sensor used on the Tahoe or Suburban needs to be programmed if replaced. Always check service information for the details and procedures to follow when replacing a sensor on the suspension.

STEERING WHEEL POSITION SENSOR Depending on the vehicle, the **steering wheel position sensor** may also be called a **handwheel position sensor**. The function of this sensor is to provide the control module with signals relating to steering wheel position, the speed, and direction of handwheel position.

The sensor is found on most **real-time dampening (RTD)** and road-sensing suspension (RSS) applications. The sensor is typically located at the base of the steering column. Always refer to service information for vehicle-specific information. ● **SEE FIGURES 114–8 AND 114–9**.

The handwheel sensor produces two digital signals, which are used by the **electronic brake control module (EBCM)**. These signals are produced as the steering wheel is rotated. The sensor can also produce more than two signals. As an example, the Cadillac Escalade handwheel sensor produces one analog and three digital signals.

The sensor uses a 5 volt signal reference. Analog signal voltage values increase or decrease, between 0 and 5 volts, as the steering wheel is moved left and right of center. The digital signal is also a standard power-to-ground circuit as shown in the schematic.

There are three possible digital signals:

- Phase A
- Phase B
- Index pulse

These signals provide the suspension control module with steering wheel speed and direction information. Digital signals are either high or low, 5 volts or 0 volts. ● **SEE FIGURE 114–10**.

A scan tool provides DTC (diagnostic trouble code) faults for this sensor. If there is an intermittent concern with a steering wheel position sensor, select snapshot and slowly turn the steering wheel lock to lock. After the snapshot is complete, plot

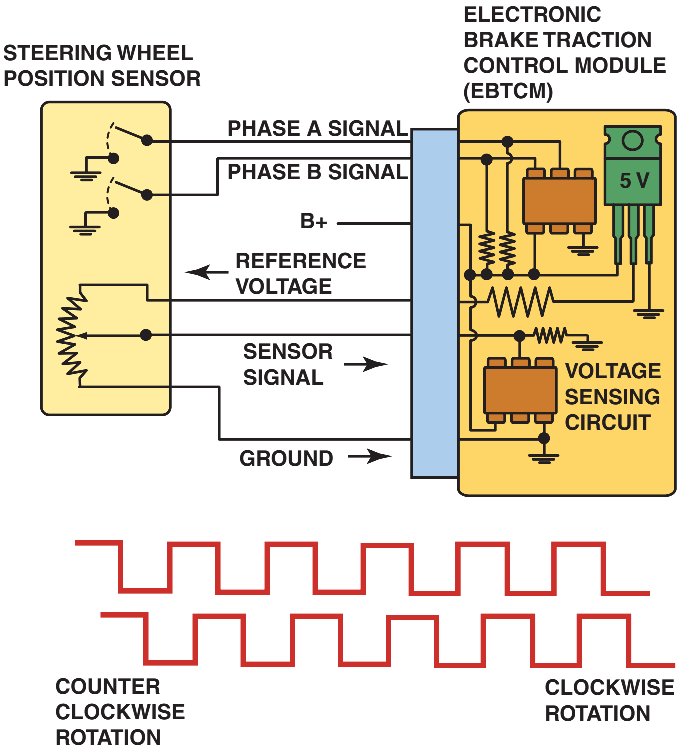

STEERING WHEEL POSITION SENSOR
ELECTRONIC BRAKE TRACTION CONTROL MODULE (EBTCM)
PHASE A SIGNAL
PHASE B SIGNAL
B+
REFERENCE VOLTAGE
SENSOR SIGNAL
GROUND
5 V
VOLTAGE SENSING CIRCUIT
COUNTER CLOCKWISE ROTATION
CLOCKWISE ROTATION

FIGURE 114–8 The steering wheel position (handwheel position) sensor wiring schematic and how the signal varies with the direction that the steering wheel is turned.

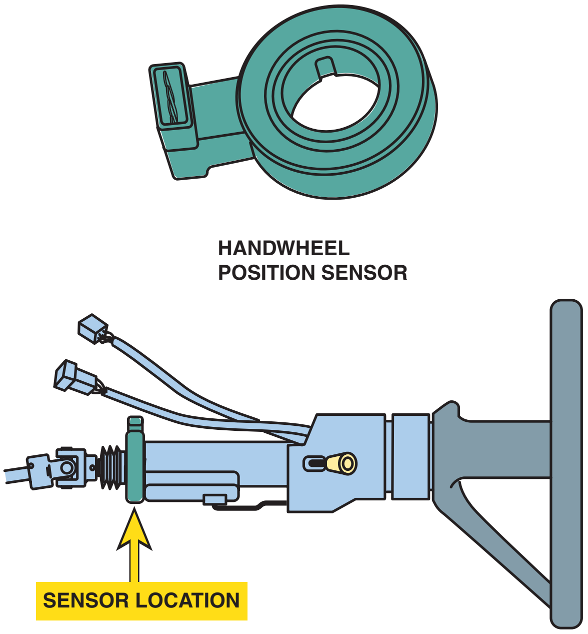

HANDWHEEL POSITION SENSOR
SENSOR LOCATION

FIGURE 114–9 The handwheel position sensor is located at the base of the steering column.

the analog sensor voltage to see if the signal dropped out. Any dropout is an indication of an intermittent problem.

VEHICLE SPEED SENSOR The **vehicle speed (VS) sensor** is used by the EBCM to help control the suspension system. The vehicle speed sensor is a magnetic sensor and generates an analog signal whose frequency increases as the speed increases. The ride is made firmer at high speeds and during braking and acceleration and less firm at cruise speeds. ● **SEE FIGURE 114–11**.

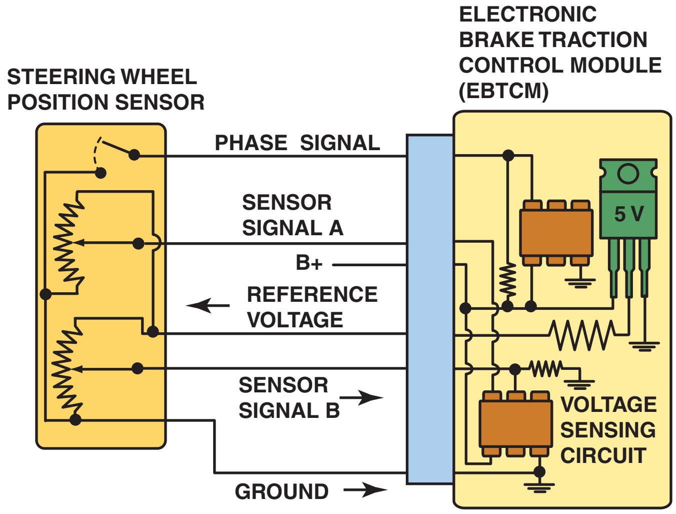

STEERING WHEEL POSITION SENSOR
ELECTRONIC BRAKE TRACTION CONTROL MODULE (EBTCM)
PHASE SIGNAL
SENSOR SIGNAL A
B+
REFERENCE VOLTAGE
SENSOR SIGNAL B
GROUND
5 V
VOLTAGE SENSING CIRCUIT

FIGURE 114–10 Steering wheel (handwheel) position sensor schematic.

PRESSURE SENSOR A pressure transducer (sensor) is typically mounted on the compressor assembly. This sensor is typically found on systems such as air suspension, real-time damping, and road-sensing suspension that use a compressor assembly. The main function of the pressure sensor is to provide feedback to the suspension control module about the operation of the compressor. The sensor assures both that a minimum air pressure is maintained in the system and that a maximum value is not exceeded. ● **SEE FIGURE 114–12**.

The operation of the pressure sensor requires a 5 volt reference, a ground, and a signal wire to provide feedback to the control module. The voltage output on the signal wire will vary from 0 to 5 volts based upon pressure in the system. A high voltage indicates high pressure and low voltage indicates a low pressure.

LATERAL ACCELEROMETER SENSOR The function of the **lateral accelerometer sensor** is to provide the suspension control module with feedback regarding vehicle cornering forces. This type of sensor is also called a G-sensor, with the letter "G" representing the force of gravity. For example, when a vehicle enters a turn, the sensor provides information as to how hard the vehicle is cornering. This information is processed by the suspension control module to provide appropriate damping on the inboard and outboard dampers during cornering events. The lateral accelerometer sensor is found on the more complex suspensions systems, such as RTD and RSS systems that incorporate the **vehicle stability enhancement system (VSES)**.

This sensor can be either a stand-alone unit or combined with the yaw rate sensor. Typically, the sensor is mounted in the passenger compartment under a front seat, center console, or package shelf.

The sensor produces a voltage signal of 0 to 5 volts as the vehicle maneuvers left or right through a curve. The signal is an input to the EBCM. If the lateral acceleration is zero, the sensor input is 2.5 volts. Check service information for specific codes that can be set.

If driving the vehicle and the voltage values increase or decrease during cornering events, this indicates proper operation. ● **SEE FIGURE 114–13**.

YAW RATE SENSOR The **yaw rate sensor** provides information to the suspension control module and the EBCM. This

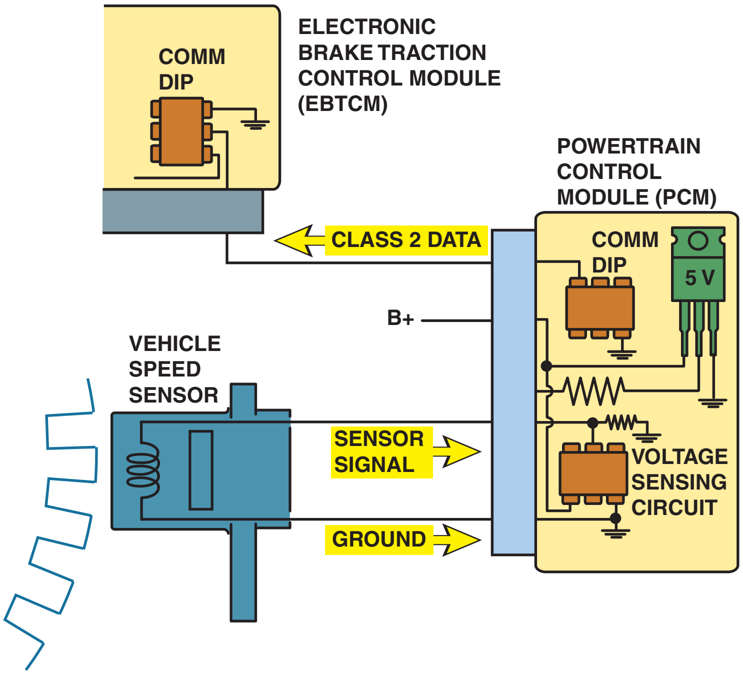

COMM
DIP
ELECTRONIC
BRAKE TRACTION
CONTROL MODULE
(EBTCM)
POWERTRAIN
CONTROL
MODULE (PCM)
CLASS 2 DATA
COMM
DIP
5 V
B+
VEHICLE
SPEED
SENSOR
SENSOR
SIGNAL
VOLTAGE
SENSING
CIRCUIT
GROUND

FIGURE 114–11 The VS sensor information is transmitted to the EBCM by Class 2 serial data.

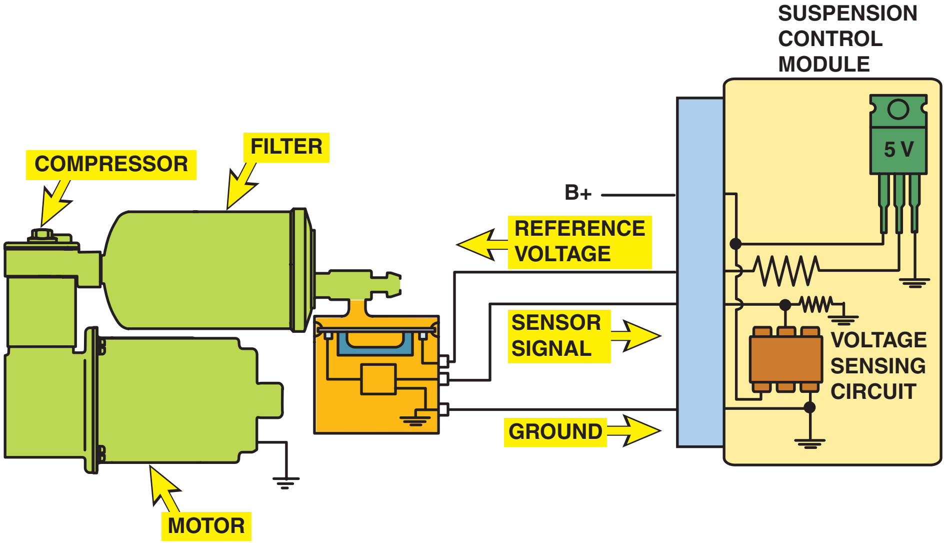

SUSPENSION
CONTROL
MODULE
COMPRESSOR
FILTER
5 V
B+
REFERENCE
VOLTAGE
SENSOR
SIGNAL
VOLTAGE
SENSING
CIRCUIT
GROUND
MOTOR

FIGURE 114–12 An air pressure sensor.

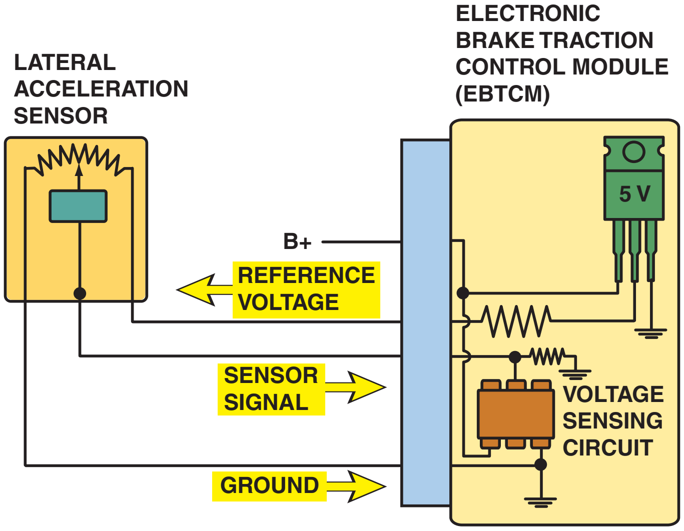

LATERAL
ACCELERATION
SENSOR
ELECTRONIC
BRAKE TRACTION
CONTROL MODULE
(EBTCM)
5 V
B+
REFERENCE
VOLTAGE
SENSOR
SIGNAL
VOLTAGE
SENSING
CIRCUIT
GROUND

FIGURE 114–13 A schematic showing the lateral acceleration sensor and the EBCM.

TECH TIP

The Lateral Acceleration Sensor Needed to Control the Electronic Suspension

The lateral acceleration sensor is one part of the group of sensors that provides the information needed for the suspension to be able to react to driver commands and road conditions. Using just the steering wheel position sensor would not be enough information for the suspension controller to determine the cornering loads. ● **SEE FIGURE 114–14**.

information is used to determine how far the vehicle has deviated from the driver's intended direction. The yaw sensor is used on vehicles equipped with Electronic Stability Control (ESC).

This sensor can be either a stand-alone unit or combined with the lateral accelerometer sensor. Typically, the sensor is

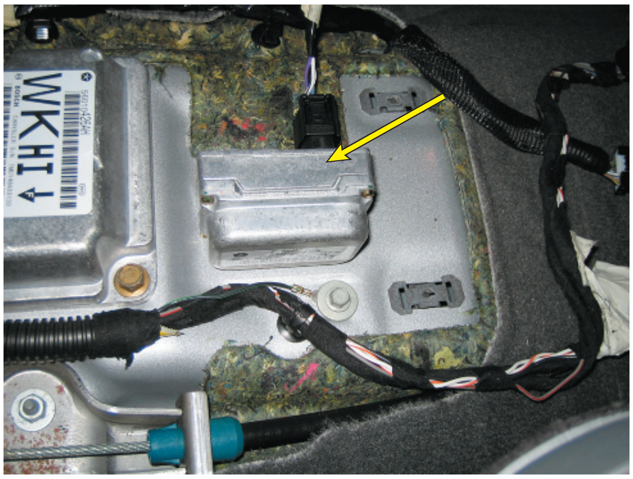


FIGURE 114–14 The lateral accelerometer sensor (G-sensor) is usually located under the center console. This sensor can be tested by unbolting the sensor, turning it on its side with the key on, engine off (KOEO), and looking at the scan tool data to verify that it reads 1 G.

mounted in the passenger compartment under the front seat, center console, or on the rear package shelf.

The sensor produces a voltage signal of 0 to 5 volts as the vehicle yaw rate changes. The voltage signal is an input to the EBCM. The yaw rate input to the EBCM indicates the number of degrees that the vehicle deviates from its intended direction.

For example, with a 0 degree yaw rate, the sensor output is 2.5 volts. During an emergency maneuver, the signal will vary above or below 2.5 volts. This sensor does set DTC codes. These codes can be found in service information. ● **SEE FIGURE 114–15.**

DRIVER SELECTOR SWITCH The **driver selector switch** is a two- or three-mode switch, usually located in the center console, and is an input to the suspension control module.

The switch that is used to select either touring (soft) or performance (firm) ride is found on the **selectable ride (SR)** and the computer command ride (CCR) systems. The mode select switch status is generally displayed on a scan tool. The three-position switch is used on the Corvette RTD system and allows the driver to select three modes of operation:

- Tour
- Sport
- Performance

ELECTRONIC SUSPENSION SYSTEM ACTUATORS

TERMINOLOGY Each actuator in an electronically controlled suspension system receives output signals from the ECM and responds to these signals, or commands, by performing a mechanical action. Actuators are usually inductive devices that operate using an electromagnetic field. A simple **electromagnet** consists of a soft iron core with a coil of wire, usually copper, wrapped around it. ● **SEE FIGURE 114–16.**

Electrical current traveling through the coiled wire creates a magnetic field around the core. All magnets are polarized; that is, they have a north, or positive, and a south, or negative, pole. When the opposite poles of two magnets are placed near each other—positive to negative—the magnets attract each other. Place the same poles together, positive to positive or negative to negative, and the magnets repel each other. ● **SEE FIGURE 114–17.** Magnets also attract and are attracted to certain types of metals, especially iron and steel.

When an electromagnet has more than one coil, the stronger primary coil can induce voltage into the weaker secondary coil.

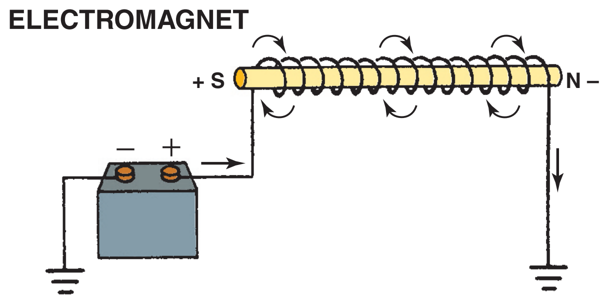


FIGURE 114–16 A magnetic field is created whenever an electrical current flows through a coil of wire wrapped around an iron core.

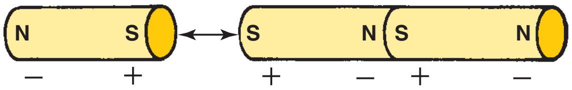


FIGURE 114–17 When magnets are near each other, like poles repel and opposite poles attract.

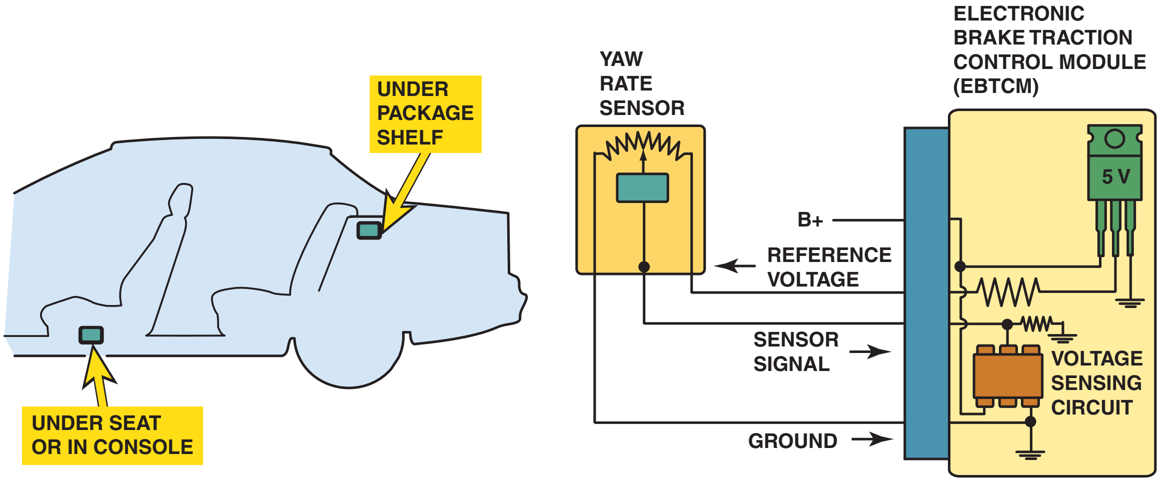


FIGURE 114–15 Yaw rate sensor showing the typical location and schematic.

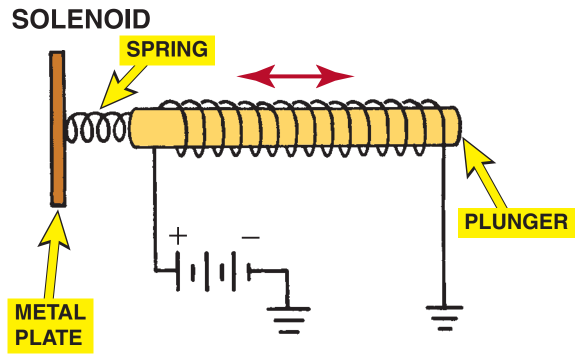


FIGURE 114–18 When electrical current magnetizes the plunger in a solenoid, the magnetic field moves the plunger against spring force. With no current, the spring pushes the plunger back to its original position.

This inductive transfer occurs even though there is no physical connection between the two coils.

SOLENOIDS In a **solenoid**, the core of the electromagnet also acts as a plunger to open and close a passage or to move a linkage. Solenoids are cylindrically shaped with a metal plate at one end and open at the other end to allow the plunger to move in and out. The electromagnetic coils are placed along the sides of the cylinder. A preload spring forces the plunger toward one end of the device when the solenoid is de-energized, or there is no current in the coil.

When the solenoid is energized, current passes through the coil and magnetizes the core. The magnetized core is attracted to the metal plate and the strength of the magnetic field overcomes spring force to pull the plunger inward. ● **SEE FIGURE 114–18**. When the electrical current switches off, the solenoid de-energizes and spring force returns the plunger to its rest position.

An airflow control valve is an example of a solenoid used in an electronically controlled suspension. ● **SEE FIGURE 114–19**. As the solenoid plunger extends and retracts, it opens and closes air passages between the system air-pressure tank and the air springs. The position of the plunger determines whether the springs receive more pressure or whether pressure bleeds out of them. Increasing the pressure in the air springs lifts the body higher, and decreasing the pressure by bleeding air from the springs lowers the body.

Solenoids are digital devices that are either on or off. However, the ECM can vary the amount a solenoid opens by pulsing the output signal to the coil. If the signal is rapidly switched on and off, spring and magnetic forces do not have enough time to react and effectively move the plunger between the signal changes. The amount of time the current is on compared to the amount of time it is off is called **pulse width**, and the control of a solenoid using this pulsing-on-and-off method is called **pulse-width modulation**.

ACTUATOR MOTORS If a current-carrying conductor is placed in a magnetic field, it tends to move from the stronger field area to the weaker field area. A motor uses this principle to convert electrical energy into mechanical movement. Electrical current is directed through the field coils on the motor frame to create a magnetic field within the frame. By applying an electrical current to the **armature**, which is inside the motor frame, the armature rotates from a strong field area to a weaker field area. Armature movement can in turn move another part, such as a gear, pulley, or shaft, attached to it.

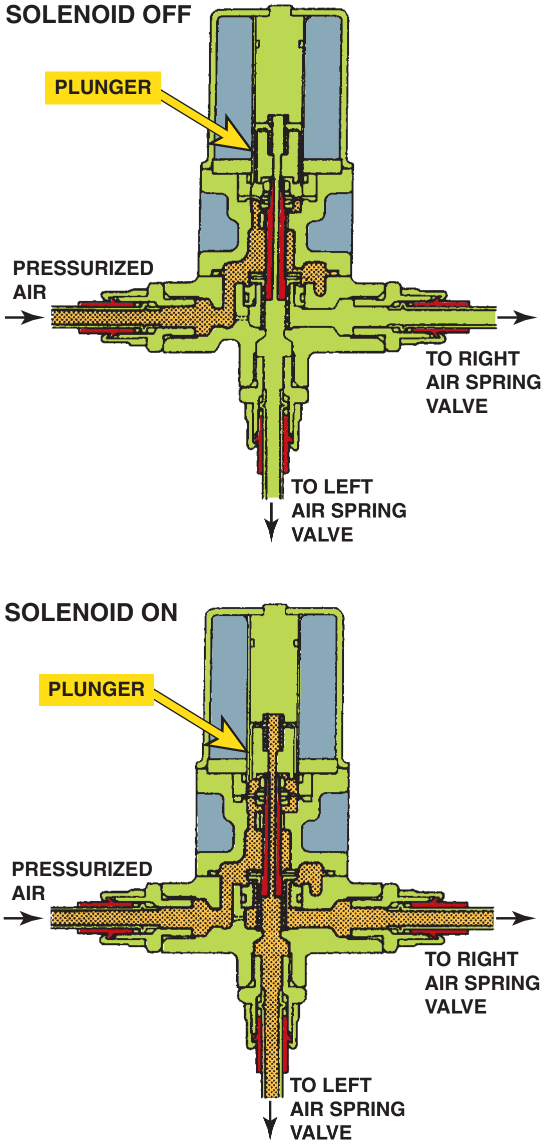


FIGURE 114–19 This air supply solenoid blocks pressurized air from the air spring valves when off. The plunger pulls upward to allow airflow to the air spring valves when the solenoid is energized.

Located at the top mount of the air spring variable shock assembly of each wheel, the suspension control actuator moves a control rod that regulates air pressure to the spring, which determines ride height. The actuator is an electromagnetic device consisting of four stator coils and a permanent magnet core. ● **SEE FIGURE 114–20**.

The ECM applies current to two stator coils at a time to create opposing magnetic fields around the core, which causes the core to rotate into a new position. Which coils are energized determines how far and in which direction the core rotates. ● **SEE FIGURE 114–21**. By switching current from one pair of coils to the other, the ECM moves the core into a new position, and a third position is available by reversing the polarity of the coils.

A gear at the base of the permanent magnet connects to a rod that operates the air valve to the air spring. The gear also drives another gear, which operates the control rod of the variable shock absorber. Therefore, the three positions of the suspension control actuator motor provide three shock absorber stiffness settings in addition to a variable air spring.

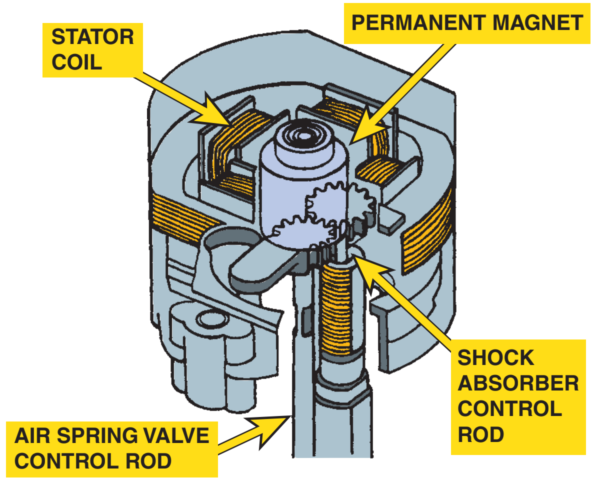

STATOR COIL
PERMANENT MAGNET
SHOCK ABSORBER CONTROL ROD
AIR SPRING VALVE CONTROL ROD

FIGURE 114–20 An actuator motor uses a permanent magnet and four stator coils to drive the air spring control rod.

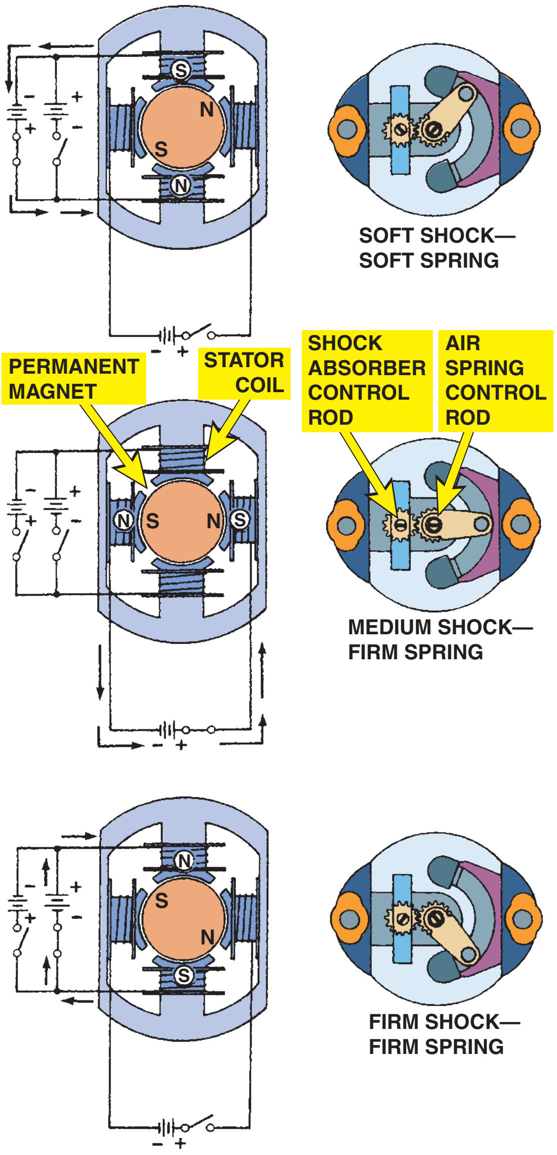

S
N
S
N
SOFT SHOCK—SOFT SPRING
PERMANENT MAGNET
STATOR COIL
SHOCK ABSORBER CONTROL ROD
AIR SPRING CONTROL ROD
N
S
N
S
MEDIUM SHOCK—FIRM SPRING
N
S
N
S
FIRM SHOCK—FIRM SPRING

FIGURE 114–21 The stator coils of the actuator are energized in three ways to provide soft, medium, or firm ride from the air springs and shock absorbers.

TYPES OF ELECTRONIC SUSPENSION

The types of electronic suspension systems used on General Motors vehicles, as examples, include

1. Selectable Ride
2. Automatic Level Control
3. Air Suspension
4. Computer Command Ride
5. Real-Time Dampening/Road-Sensing Suspension
6. Vehicle Stability Enhancement System
7. Magneto-Rheological Suspension (F55)

SELECTABLE RIDE The selectable ride (SR) system is the most basic of the electronic systems offered by General Motors. Selectable ride allows the driver to choose between two distinct damping levels:

- Firm
- Normal

SR is found on Chevrolet and GMC full-size pickup trucks. ● **SEE FIGURE 114–22**.

A switch is used to control four electronically controlled gas-charged dampers. The **mode select switch** activates the bi-state (two settings) dampers at all four corners of the vehicle, allowing the driver to select vehicle ride characteristics. The system is either energizing or de-energizing the bi-state dampers to provide a firm or normal ride.

AUTOMATIC LEVEL CONTROL The **automatic level control (ALC)** system automatically adjusts the rear height of the vehicle in response to changes in vehicle loading and unloading. ALC is found on many General Motors vehicles. ALC controls rear leveling by monitoring the rear suspension position sensor and energizing the compressor to raise the vehicle or energizing the exhaust valve to lower the vehicle. ALC has several variations across the different platforms. ● **SEE FIGURE 114–23**.

AIR SUSPENSION Air suspension (AS) is a system very similar to the ALC system. The purpose of the AS system is to

1. Keep the vehicle visually level.
2. Provide optimal headlight aiming.
3. Maintain optimal ride height.

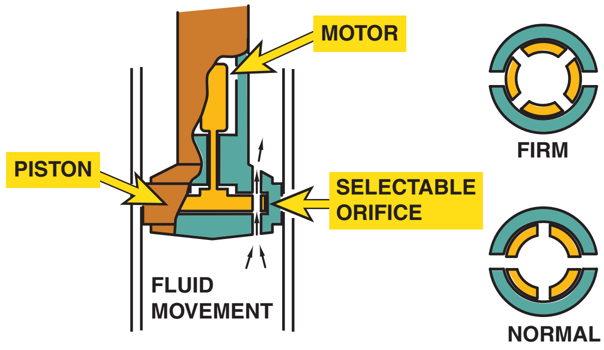

MOTOR
PISTON
SELECTABLE ORIFICE
FLUID MOVEMENT
FIRM
NORMAL

FIGURE 114–22 Selectable ride as used on Chevrolet and GMC pickup trucks.

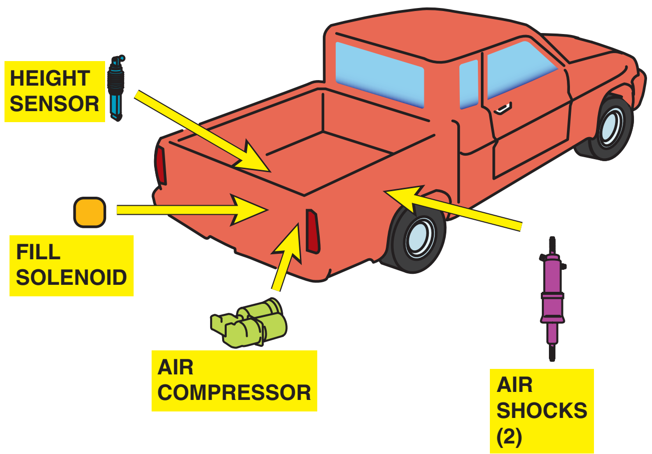

HEIGHT SENSOR
FILL SOLENOID
AIR COMPRESSOR
AIR SHOCKS (2)

FIGURE 114–23 ALC maintains the same ride height either loaded or unloaded by increasing or decreasing the air pressure in the rear air shocks.

The AS system includes the following components:

- An air suspension compressor assembly
- Rear air springs
- Air suspension sensors

The AS system is designed to maintain rear trim height within 3/16 inch (4 mm) in all loading conditions, and the leveling function will deactivate if the vehicle is overloaded.

The AS system also includes an accessory air inflator found in the rear cargo area. ● **SEE FIGURE 114–24**.

VARIABLE-RATE AIR SPRINGS In an air spring system with ordinary shock absorbers, the ECM uses the air springs to control trim height and is used on many Ford, Mercury, and Lincoln vehicles.

The three height sensors transmit a signal to the ECM that reflects trim height at each axle. ● **SEE FIGURE 114–25**. The ignition and brake light switches tell the ECM whether the ignition switch is on or off, and if the brake pedal is depressed. The dome light switch indicates whether any doors are open. The on/off switch disables the air spring system to avoid unexpected movement while towing or servicing the vehicle.

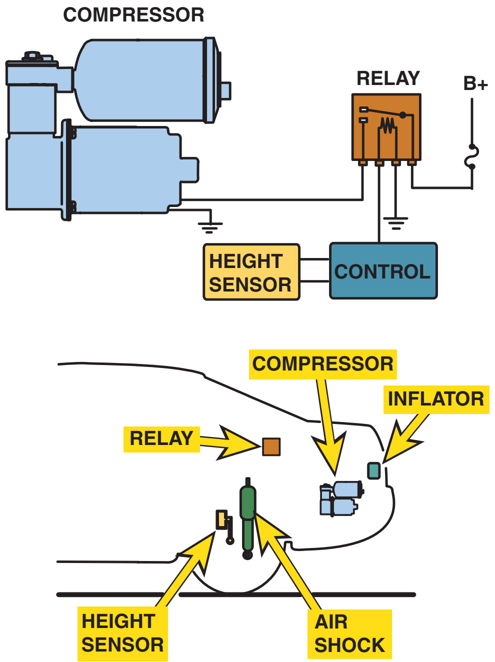

COMPRESSOR
RELAY
B+
HEIGHT SENSOR
CONTROL
COMPRESSOR
INFLATOR
RELAY
HEIGHT SENSOR
AIR SHOCK

FIGURE 114–24 A typical schematic showing the air suspension compressor assembly and sensor.

CAUTION: Failure to turn off the system will cause the air springs to be vented when the vehicle is hoisted. This will cause the vehicle to drop almost to the ground when the vehicle is lowered. This can cause damage to the air springs and/or to the vehicle. The shut-off switch is usually located in the trunk.

The ECM receives information from the height sensors indicating that the trim height is too high or too low, and it energizes the actuators to add or bleed air from the air springs. The system actuators can still operate for up to an hour after the ignition is switched off.

Any time the ignition is switched to the “run” position, the ECM raises the vehicle, if necessary, within the first 45 seconds. If trim height is too high and the vehicle must be lowered, the ECM delays doing so for 45 seconds after the ignition is switched on.

An air compressor with a regenerative dryer provides the air change required to inflate the air springs on the air suspension

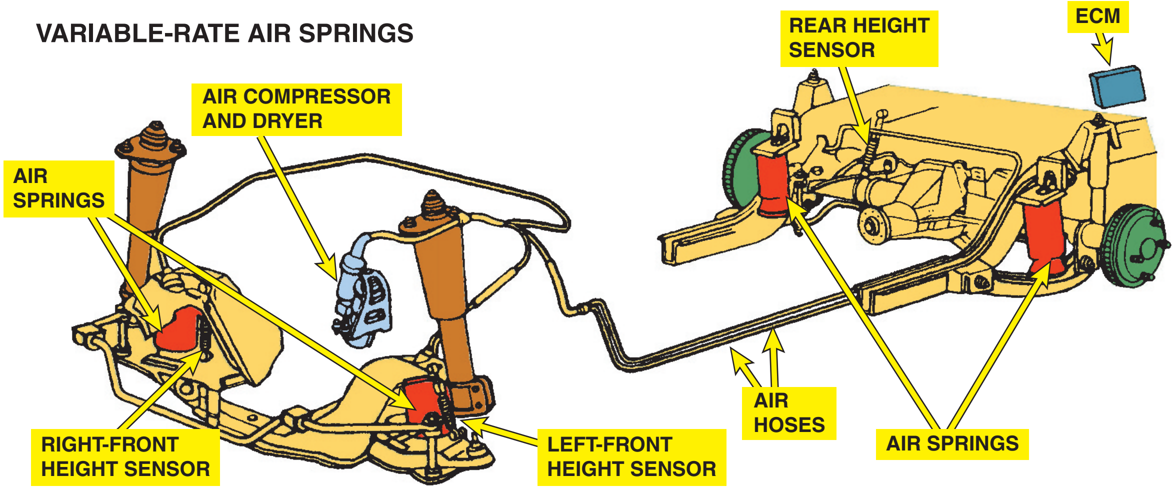

VARIABLE-RATE AIR SPRINGS
AIR COMPRESSOR AND DRYER
AIR SPRINGS
RIGHT-FRONT HEIGHT SENSOR
LEFT-FRONT HEIGHT SENSOR
AIR HOSES
AIR SPRINGS
REAR HEIGHT SENSOR
ECM

FIGURE 114–25 The typical variable-rate air spring system uses three height sensors, two in the front and one in the rear, to monitor trim height and to provide input signals to the ECM.

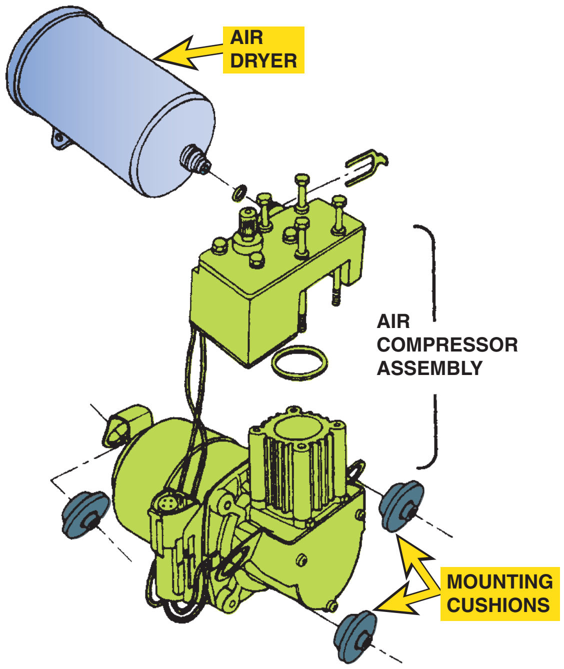


FIGURE 114–26 The air spring compressor assembly is usually mounted on rubber cushions to help isolate it from the body of the vehicle. All of the air entering or leaving the air springs flows through the regenerative air dryer.

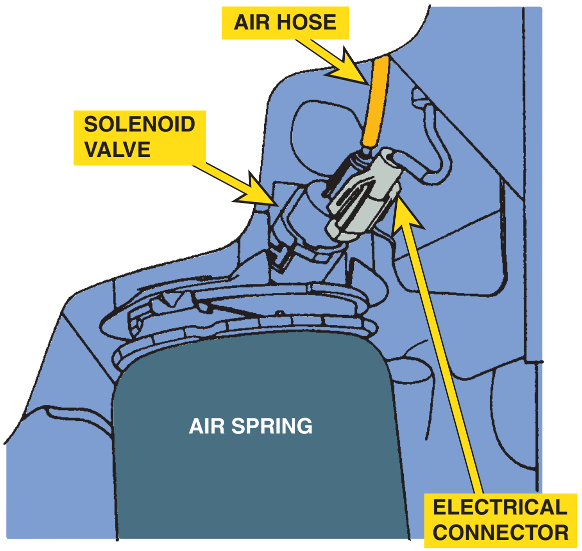


FIGURE 114–27 A solenoid valve at the top of each spring regulates airflow into and out of the air spring.

system, and a vent solenoid is used to relieve air pressure and deflate the springs. ● **SEE FIGURE 114–26**.

By energizing the compressor relay, the ECM directs current to turn on the compressor motor when trim height needs to be raised. The ECM command to lower the vehicle is an electrical signal that opens the vent solenoid to bleed air pressure out of the system. ● **SEE FIGURE 114–27**.

GENERAL MOTORS COMPUTER COMMAND RIDE The General Motors computer command ride (CCR) system controls ride firmness by automatically controlling an actuator in each of the four struts to increase ride firmness as speed increases.

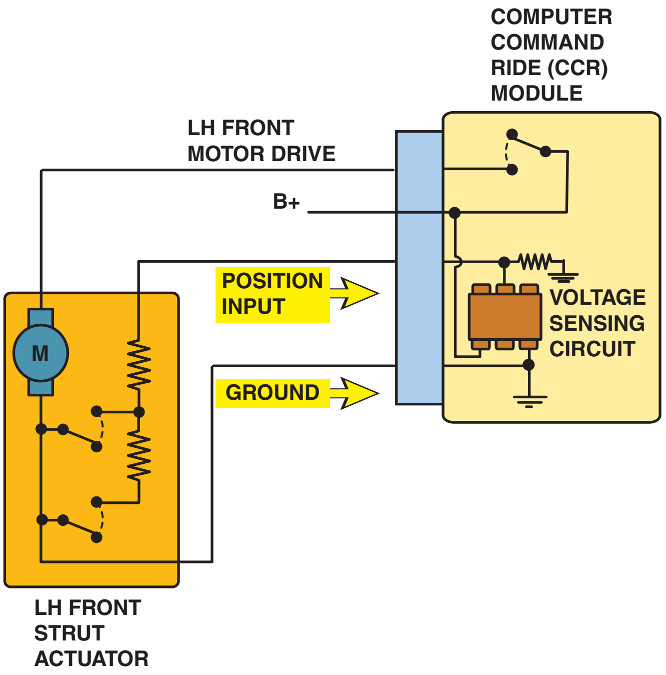


FIGURE 114–28 Schematic showing computer command ride system.

The three damping modes are

- Comfort
- Normal
- Sport

Damping mode selection is controlled by the CCR control module according to vehicle speed conditions, driver select switch position, and any error conditions that may exist.

In the perform ride mode, the system will place the damping level in the firm mode regardless of vehicle speed.

In the touring ride mode, the damping level depends on vehicle speed. ● **SEE FIGURE 114–28**.

REAL-TIME DAMPENING AND ROAD-SENSING SUSPENSION

Real-time dampening (RTD) independently controls a solenoid in each of the four shock absorbers in order to control the vehicle ride characteristics and is capable of making changes within milliseconds (0.001 second).

Road-sensing suspension (RSS), along with ALC, controls damping forces in the front struts and rear shock absorbers in response to various road and driving conditions.

Real-time damping suspension systems use inputs from the steering wheel position sensor, vehicle speed sensor (VSS), and a sensor cluster containing a lateral accelerometer and yaw rate sensor. These components may be indirect or direct inputs. ● **SEE FIGURE 114–29**.

RTD and RSS incorporate the following components:

- An electronic suspension control module
- Front and rear suspension position sensors
- Bi state dampers
- A ride select switch
- An air compressor is used on some models.

● **SEE FIGURES 114–30 AND 114–31**.

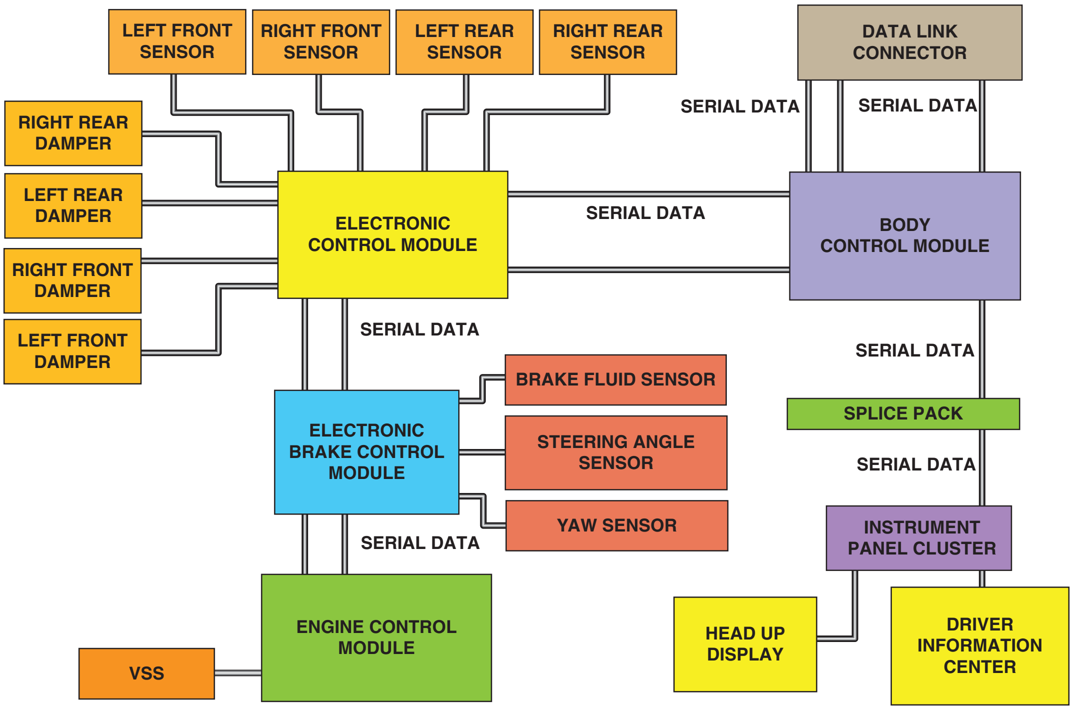

LEFT FRONT SENSOR
RIGHT FRONT SENSOR
LEFT REAR SENSOR
RIGHT REAR SENSOR
DATA LINK CONNECTOR
SERIAL DATA
SERIAL DATA
RIGHT REAR DAMPER
LEFT REAR DAMPER
RIGHT FRONT DAMPER
LEFT FRONT DAMPER
ELECTRONIC CONTROL MODULE
SERIAL DATA
BODY CONTROL MODULE
SERIAL DATA
SERIAL DATA
BRAKE FLUID SENSOR
ELECTRONIC BRAKE CONTROL MODULE
STEERING ANGLE SENSOR
YAW SENSOR
SPLICE PACK
SERIAL DATA
SERIAL DATA
INSTRUMENT PANEL CLUSTER
ENGINE CONTROL MODULE
VSS
HEAD UP DISPLAY
DRIVER INFORMATION CENTER

FIGURE 114–29 Diagram of the components and connections of the real-time damping and road-sensing suspension system.

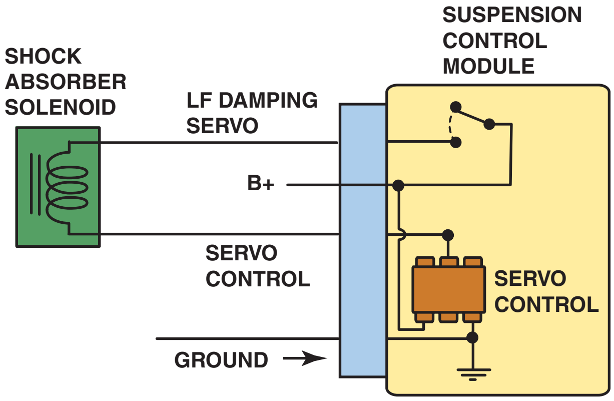

SUSPENSION CONTROL MODULE
SHOCK ABSORBER SOLENOID
LF DAMPING SERVO
B+
SERVO CONTROL
SERVO CONTROL
GROUND

FIGURE 114–30 Schematic showing the shock control used in the RSS system.

TECH TIP

Check the RPO Code

Whenever working on the suspension system, check the **RPO (regular production option)** code for the type of suspension used. For example, the F55 RPO may be called by a different name depending on the make and model of vehicle. Also, service procedures will be different on the same vehicle depending on whether it is equipped with an F45 or an F55 system. The General Motors vehicle RPO codes are on a sticker on the spare tire cover in the trunk or in the glove compartment.

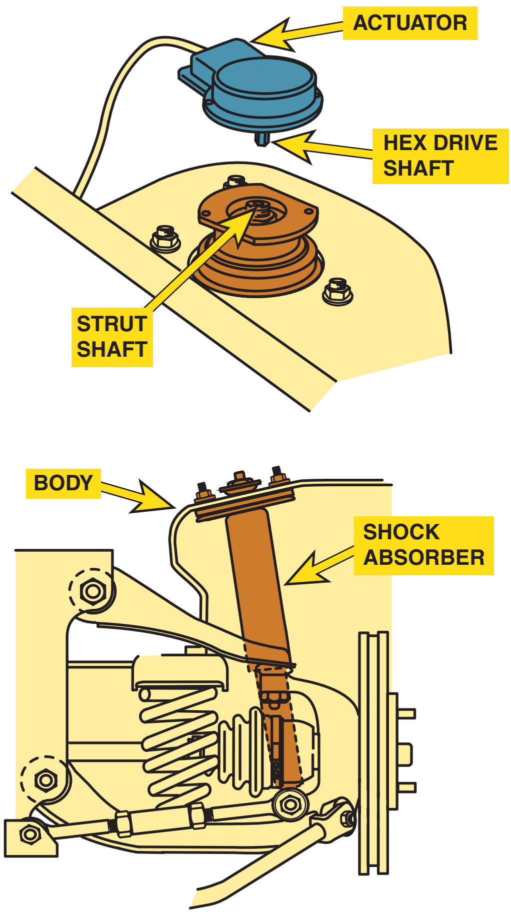

ACTUATOR
HEX DRIVE SHAFT
STRUT SHAFT
BODY
SHOCK ABSORBER

FIGURE 114–31 Bi-state dampers (shocks) use a solenoid to control fluid flow in the unit to control compression and rebound actions.

BI-STATE AND TRI-STATE DAMPERS The bi-state damper is also known as a **solenoid controlled damper**. Bi-state dampers are found on the RTD, RSS, and SR systems. Each of the suspension dampers used in these systems have an integral solenoid. The solenoid valve provides various amounts of damping by directing hydraulic damping fluid in the suspension shock absorber or strut.

The General Motors version of ESC is called the vehicle stability enhancement system (VSES) and includes an additional level of vehicle control to the EBCM. VSES is also known as **Stabilitrak**.

The purpose of the vehicle stability enhancement system along with the antilock brake system (ABS) is to provide vehicle stability enhancement during oversteer or understeer conditions.

The pulse-width modulation (PWM) voltage signal from the suspension control module controls the amount of current flow through each of the damper solenoids. With a low PWM signal de-energized, more hydraulic damping fluid is allowed to bypass the main suspension damper passage, resulting in a softer damping mode.

As the PWM signal increases, or is energized, the damping mode becomes more firm. ● **SEE FIGURE 114–32**.

NOTE: If the suspension module does not control the shock absorber solenoid, a full soft damping mode results. In some system malfunctions, the module may command one or all of the damper solenoids to a full soft damping.

The main difference between a tri-state damper and a bi-state damper is that the tri-state damper uses an electrical actuator, whereas the bi-state damper is solenoid controlled.

The three damping modes include

- Comfort
- Normal
- Sport

A tri-state damper has an integral electrical strut actuator that rotates a selector valve to change the flow of hydraulic damping fluid. ● **SEE FIGURE 114–33**.

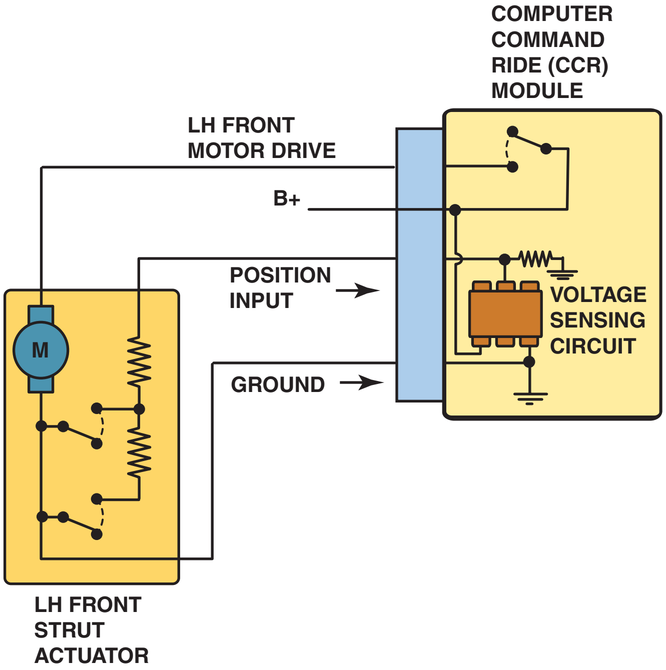


FIGURE 114–32 A typical CCR module schematic.

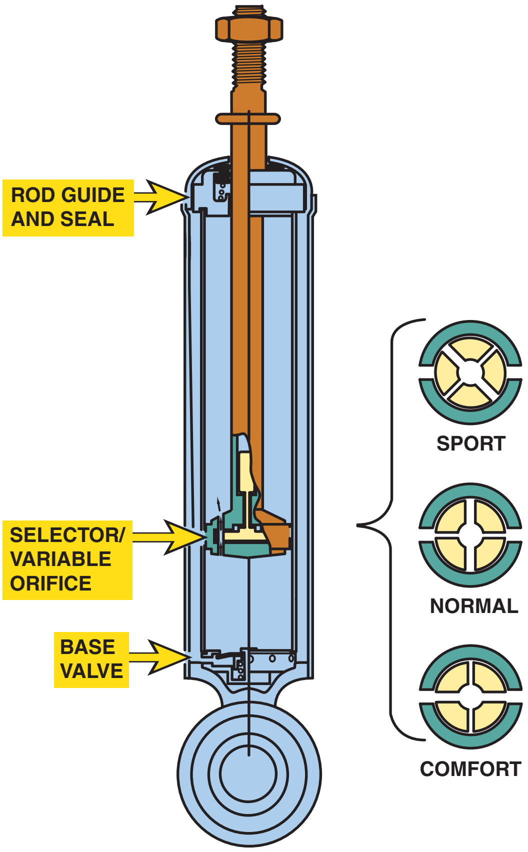


FIGURE 114–33 The three dampening modes of a CCR shock absorber.

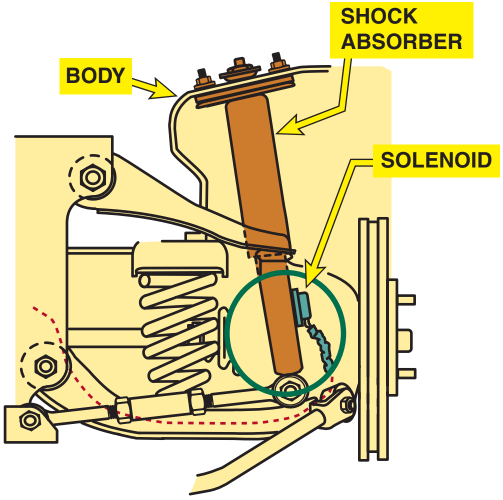


FIGURE 114–34 Integral shock solenoid.

The CCR module controls the operation of the strut actuators to provide the three damping modes.

The strut position input provides feedback to the CCR module. The strut position input is compared to the commanded actuator position to monitor system operation. ● **SEE FIGURE 114–34**.

AUTOMATIC LEVEL CONTROL (ALC)

PARTS AND OPERATION Vehicles that have an air inflator system as part of the ALC system also have an air inflator switch. The air inflator switch is an input to the ALC and AS system.

FREQUENTLY ASKED QUESTION

What Are Self-Leveling Shocks?

A German company, ZF Sachs, supplies a self-leveling shock absorber to several vehicle manufacturers, such as Chrysler for use on the rear of minivans, plus BMW, Saab, and Volvo. The self-leveling shocks are entirely self-contained and do not require the use of height sensors or an external air pump. ● **SEE FIGURE 114–35**.

The shock looks like a conventional shock absorber but contains the following components:

- Two reservoirs in the outer tube
- An oil reservoir (low-pressure reservoir)
- A high-pressure chamber

Inside the piston rod is the pump chamber containing an inlet and an outlet valve. When a load is placed in the rear of the vehicle, it compresses the suspension and the shock absorber. When the vehicle starts to move, the internal pump is activated by the movement of the body. Extension of the piston rod causes oil to be drawn through the inlet valve into the pump. When the shock compresses, the oil is forced through the outlet valve into the high-pressure chamber. The pressure in the oil reserve decreases as the pressure in the high-pressure chamber increases. The increasing pressure is applied to the piston rod, which raises the height of the vehicle.

When the vehicle's normal height is reached, no oil is drawn into the chamber. Because the shock is mechanical, the vehicle needs to be moving before the pump starts to work. It requires about 2 miles of driving for the shock to reach the normal ride height. The vehicle also needs to be driven about 2 miles after a load has been removed from the vehicle for it to return to normal ride height.

The inflator switch is used to control the air inflator system operation and provides a signal to the ALC or AS module to initiate compressor activation.

With the ignition on, the driver can turn the system to ON. The switch will command the compressor to run for up to 10 minutes, allowing time to inflate a tire or other items requiring air.

NOTE: There are no DTCs associated with compressor assembly.

INFLATOR OR COMPRESSOR RELAY The suspension control module energizes the relay to activate the compressor motor. This adjusts the rear trim height as needed. The suspension control module controls the compressor relay for normal operation or for the accessory air inflator.

To avoid compressor overheating, the timer within the suspension control module limits the compressor run time to 10 minutes. ● **SEE FIGURE 114–36**.

On RTD or RSS systems with a compressor, the scan tool may display DTCs associated with compressor relay operation. On some vehicle applications, the scan tool will display data relating to relay operation and can be used to command the relay to verify proper operation.

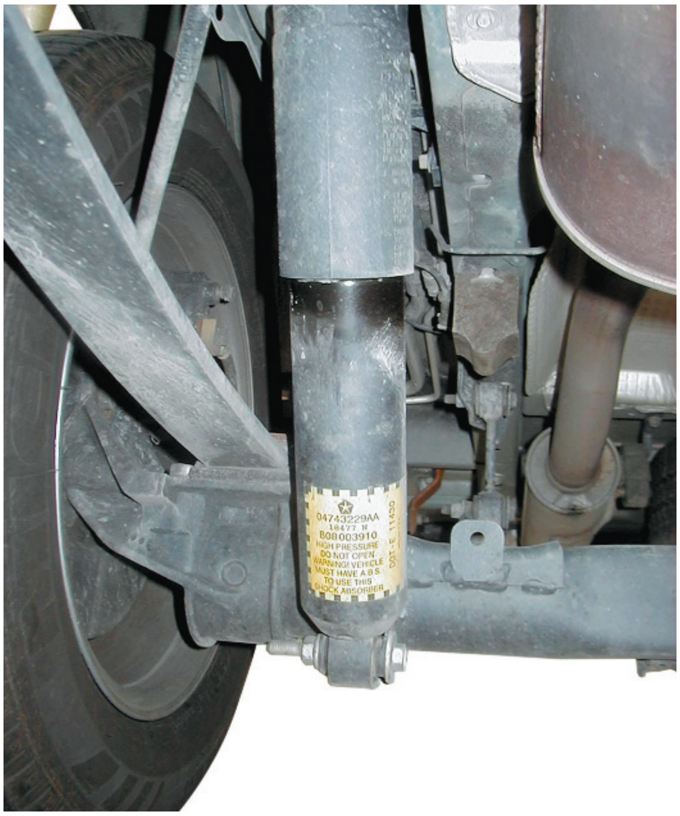


FIGURE 114–35 A typical ZF Sachs self-leveling shock, as used on the rear of a Chrysler minivan.

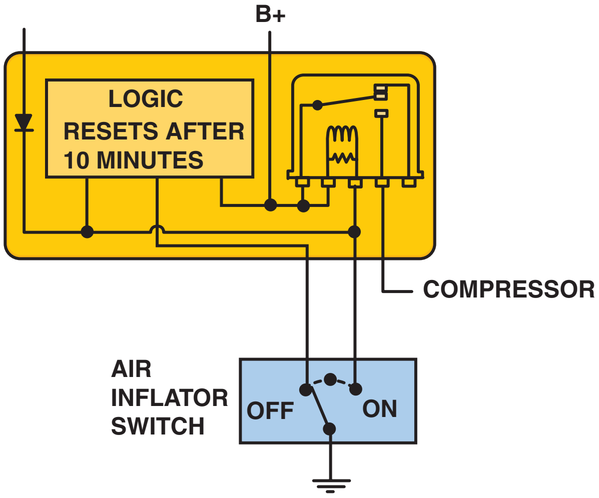


FIGURE 114–36 Schematic of the ALC system.

COMPRESSOR The compressor is a positive-displacement air pump and can generate up to 150 pounds of pressure per square inch (PSI). The compressor is found on the ALC, AS, RTD, and RSS systems. A 12 volt permanent magnet motor drives the compressor. The compressor supplies compressed air to the rear air shock absorbers or struts to raise the vehicle. ● **SEE FIGURE 114–37**.

AIR DRYER Within the compressor is an air dryer. The air dryer is responsible for removing moisture from the compressor system. Improper air dryer operation can cause a premature failure

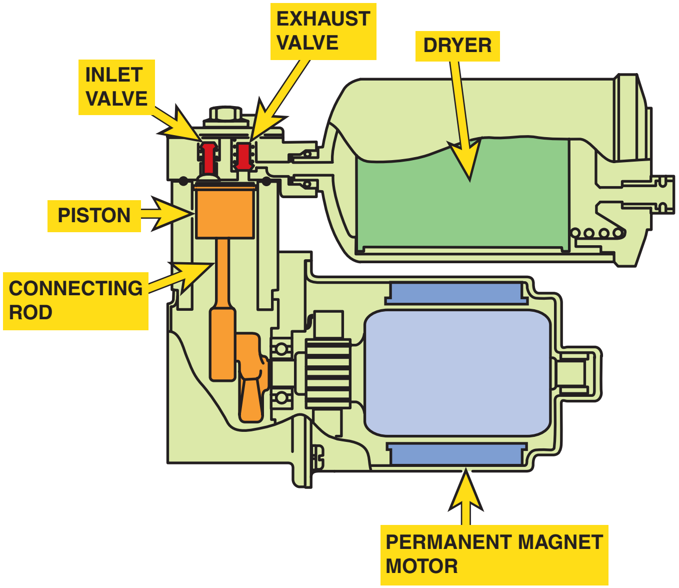


FIGURE 114–37 Air compressor assembly can be located at various locations depending on the vehicle.

in the system if an air line restriction occurs due to excessive moisture buildup. A dryer on the output side of the compressor contains silica gel **desiccant**, which removes moisture from the discharge air before it travels through the nylon air hoses to the air chamber of the rear shocks.

EXHAUST SOLENOID The exhaust solenoid, which is located on the compressor, relieves pressure in the system. The ground-side switched exhaust solenoid has three main functions:

1. It releases compressed air from the shock absorbers or air springs to lower the vehicle body.
2. It relieves compressor head pressure. By exhausting air, it protects compressor start-up from high head pressure, which can possibly cause fuse failure.
3. The solenoid acts as a pressure relief valve, which limits overall system pressure.

The special functions on many scan tools can be used to command the solenoid and to verify its operation. ● **SEE FIGURE 114–38**.

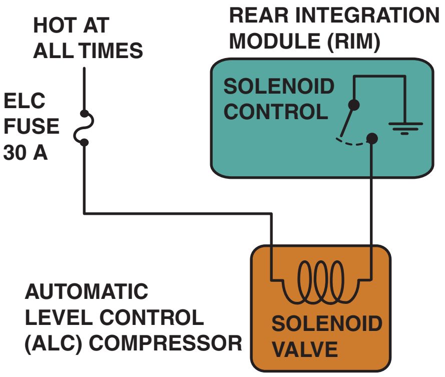

HOT AT ALL TIMES
REAR INTEGRATION MODULE (RIM)
ELC FUSE 30 A
SOLENOID CONTROL
AUTOMATIC LEVEL CONTROL (ALC) COMPRESSOR
SOLENOID VALVE

FIGURE 114–38 The exhaust solenoid is controlled by the rear integration module.

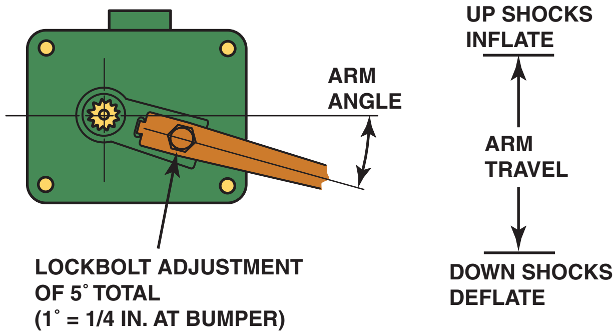


FIGURE 114–39 Most electronic level-control sensors can be adjusted, such as this General Motors unit.

TROUBLESHOOTING REAR ELECTRONIC LEVELING SYSTEMS

The first step with any troubleshooting procedure is to check for normal operation. Some leveling systems require that the ignition key be on (run), while other systems operate all the time. Begin troubleshooting by placing approximately 300 pounds (135 kg) on the rear of the vehicle. If the compressor does not operate, check to see if the sensor is connected to a rear suspension member and that the electrical connections are not corroded.

Also check the condition of the compressor ground wire. It must be tight and free of rust and corrosion where it attaches to the vehicle body. If the compressor still does not run, check to see if 12 volts are available at the power lead to the compressor. If necessary, use a fused jumper wire directly from the positive (+) of the battery to the power lead of the compressor. If the compressor does not operate, it must be replaced.

If the ride height compressor runs excessively, check the air compressor, the air lines, and the air shocks (or struts) with soapy water for air leaks. Most air shocks or air struts are not repairable and must be replaced. Most electronic leveling systems provide some adjustments of the rear ride height by adjusting the linkage between the height sensor and the rear suspension. ● **SEE FIGURE 114–39**.

MAGNETO-RHEOLOGICAL (MR) SUSPENSION

TERMINOLOGY MR fluid shocks use a working fluid inside the shock that can change viscosity rapidly depending on electric current sent to an electromagnetic coil in each device. The fluid is called **magneto-rheological (MR)** and is used in monotube-type shock absorbers. This type of shock and suspension system is called the magneto-rheological real-time damping (MRRTD) or chassis continuously variable real-time dampening magneto-rheological suspension (CCVRTMR).

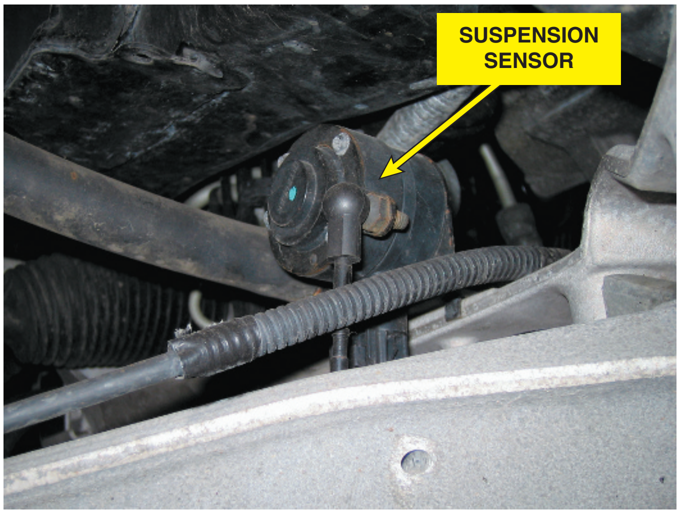


FIGURE 114–40 Vehicles that use magneto-rheological shock absorbers have a sensor located near each wheel, as shown on this C6 Corvette.

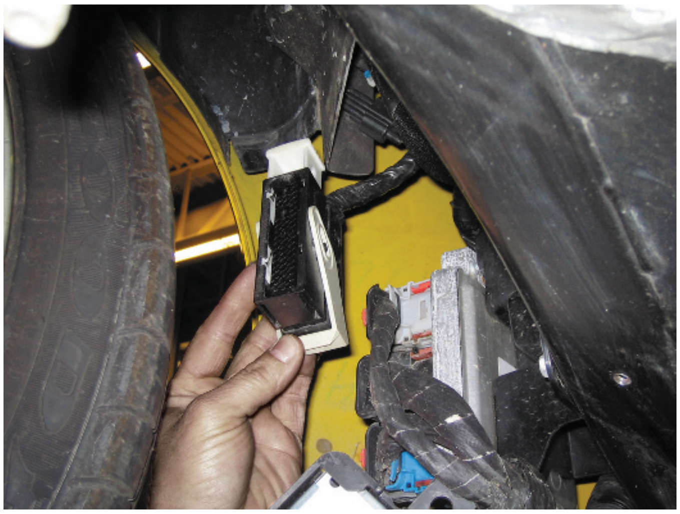


FIGURE 114–41 The controller for the magneto-rheological suspension system on a C6 Corvette is located behind the right front wheel.

Under normal operating conditions, the fluid flows easily through orifices in the shock and provides little dampening. When a large or high-frequency bump is detected, a small electrical current is sent from the chassis controller to an electromagnetic coil in each shock and the iron particles in the fluid respond within 3 milliseconds (ms), aligning themselves in fiber like strands. ● **SEE FIGURES 114–40 AND 114–41**.

This causes the MR fluid to become thick like peanut butter and increases the firmness of the shock. This type of shock absorber is used to control squat during acceleration and brake dive as well as to reduce body roll during cornering by the chassis controller. ● **SEE FIGURE 114–42**.

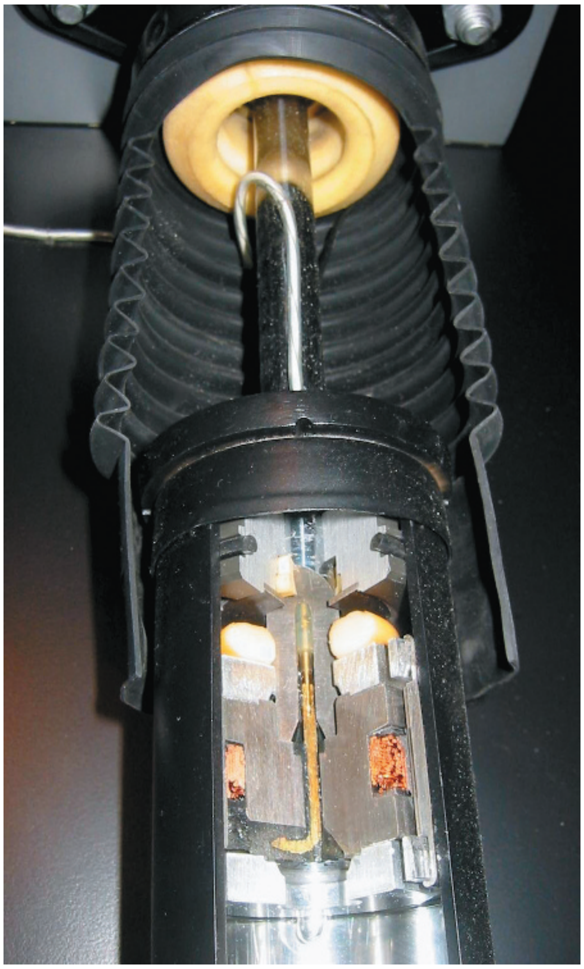


FIGURE 114–42 A cutaway of a magneto-rheological shock absorber as displayed at the Corvette Museum in Bowling Green, Kentucky.

FREQUENTLY ASKED QUESTION

Can Computer-Controlled Shock Absorbers and Struts Be Replaced with Conventional Units?

Maybe. If the vehicle was manufactured with or without electronic or variable shock absorbers, it may be possible to replace the originals with the standard replacement units. The electrical connector must be disconnected, and this may cause the control system to store a diagnostic trouble code (DTC) and/or turn on a suspension fault warning light on the dash. Some service technicians have used a resistor equal in resistance value of the solenoid or motor across the terminals of the wiring connector to keep the controller from setting a DTC. All repairs to a suspension system should be done to restore the vehicle to like-new condition, so care should be exercised if replacing electronic shocks with nonelectronic versions.

REVIEW QUESTIONS

1. What type of sensor is usually used on electronically controlled suspensions to sense the height of the vehicle?
2. Why is the vehicle speed sensor used as input for many electronic suspension systems?
3. What is a lateral accelerometer sensor and why is it used?
4. Why does the output side of the suspension air compressor contain a desiccant?
5. How does a magneto-rheological suspension system work?

CHAPTER QUIZ

1. What is the purpose of an electronically controlled suspension system?
    - **a.** Adjusts shock stiffness depending on conditions
    - **b.** Changes settings to firm for cornering
    - **c.** Selects soft for cruising
    - **d.** Any of the above
2. What type of sensor is used as a height sensor on vehicles equipped with an electronically controlled suspension?
    - **a.** Hall-effect
    - **b.** Photo cell
    - **c.** Potentiometer
    - **d.** Any of the above
3. Which sensors do most vehicles use if equipped with electronic suspension?
    - **a.** Height sensors
    - **b.** Steering wheel position sensors
    - **c.** Lateral accelerometer sensors
    - **d.** All of the above
4. A lateral acceleration sensor is used to provide the suspension control module with feedback regarding ___________ force.
    - **a.** cornering
    - **b.** acceleration
    - **c.** braking
    - **d.** All of the above
5. A steering wheel position sensor is being discussed. Technician A says that the sensor is used to determine the direction the steering wheel is turned. Technician B says that the sensor detects how fast the steering wheel is turned. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B
6. What type of electronically controlled suspensions is commonly used?
    - **a.** Automatic level control
    - **b.** Air suspension
    - **c.** Magneto-rheological suspension
    - **d.** Any of the above
7. The *firm* setting is usually selected by the electronic suspension control module whenever which of the following occurs?
    - **a.** High speed
    - **b.** Rapid braking
    - **c.** Rapid acceleration
    - **d.** Any of the above
8. What is/are commonly used as actuators in electronic suspension systems?
    - **a.** Solenoids
    - **b.** Actuator motor
    - **c.** Stepper motor
    - **d.** Either a or b
9. A ride height compressor that runs excessively indicates ___________.
    - **a.** low tire pressure
    - **b.** an air leak in the system
    - **c.** a vacuum leak in the system
    - **d.** Any of the above
10. Some vehicles have shocks that use magneto-rheological fluid. This MR fluid changes viscosity when ___________ is applied to the fluid.
    - **a.** a vacuum
    - **b.** an electrical current
    - **c.** shock force
    - **d.** heat

Chapter 115

STEERING COLUMNS AND GEARS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the purpose and function of a steering wheel.
- Explain how to remove a steering wheel.
- Discuss steering columns and intermediate shafts.
- Explain the purpose and function of conventional steering gears.
- Explain how a recirculating ball steering gear works.
- Describe how a rack-and-pinion steering gear works.

KEY TERMS:

Collapsible column 1422 • Flexible coupling 1421 • Inflator module 1418 • Kickback 1429 • Lock plate 1423 • Pitman arm 1425 • Pitman shaft 1425 • Rack-and-pinion 1426 • Rack support 1427 • Sector gear 1425 • Sector shaft 1425 • Steering shaft 1420 • Stub shaft 1423 • Tilt steering column 1422 • Universal joint 1421 • Variable ratio 1425 • Worm gear 1425

STEERING WHEELS

PURPOSE AND FUNCTION The steering wheel, which consists of a rigid rim and a number of spokes connecting the rim to a center hub, attaches to the top of the steering shaft at its center. Most steering wheel hubs have internal splines that fit over external splines on the steering shaft. A bolt or nut at the center of the hub secures the wheel to the shaft. The steering wheel may also contain controls for the cruise control and audio controls, as well as the driver's airbag.

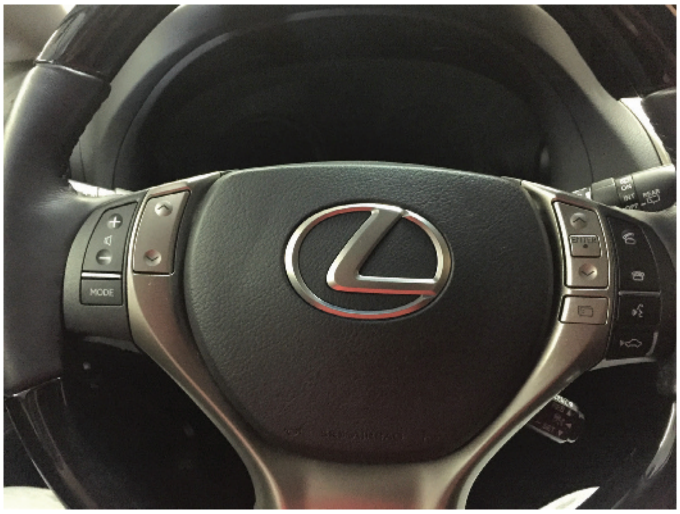


FIGURE 115–1 A steering wheel assembly includes a driver's side air bag module plus many also include steering wheel controls.

AIRBAGS An airbag is a device made of nylon cloth that is covered with neoprene. The airbag is folded and stored in the front center of the steering wheel. In a front-end collision, the airbag inflates in a fraction of a second to provide a cushion between the driver and the steering wheel and dashboard. ● **SEE FIGURES 115–1 AND 115–2**. The part of the steering wheel where the airbag is stored is called the **inflator module**. The module also contains an igniter, a canister of flammable gas, and a number of sodium azide pellets. The sodium azide pellets burn quickly and rapidly release nitrogen gas while they burn. The nitrogen gas fills the airbag. As it inflates, the airbag tears open the module cover and spreads out across the steering wheel, windshield, and dashboard. The entire process, from sensor reaction to full airbag deployment, takes 30 to 65 milliseconds. Within a second of inflating, the bag deflates partially as the nitrogen gas escapes through exhaust vents in the side of the airbag. Once deployed, an airbag cannot be reused.

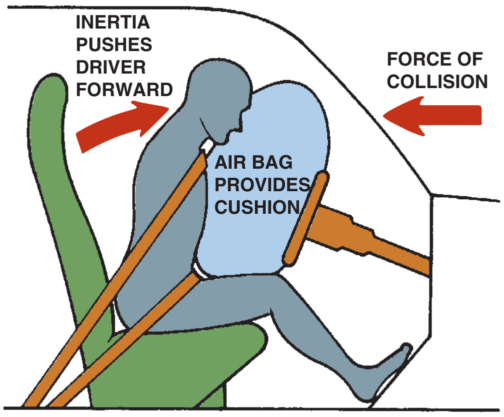


FIGURE 115–2 The airbag inflates at the same time the driver moves toward the steering wheel during a front-end collision and supplements the protection of the safety belt.

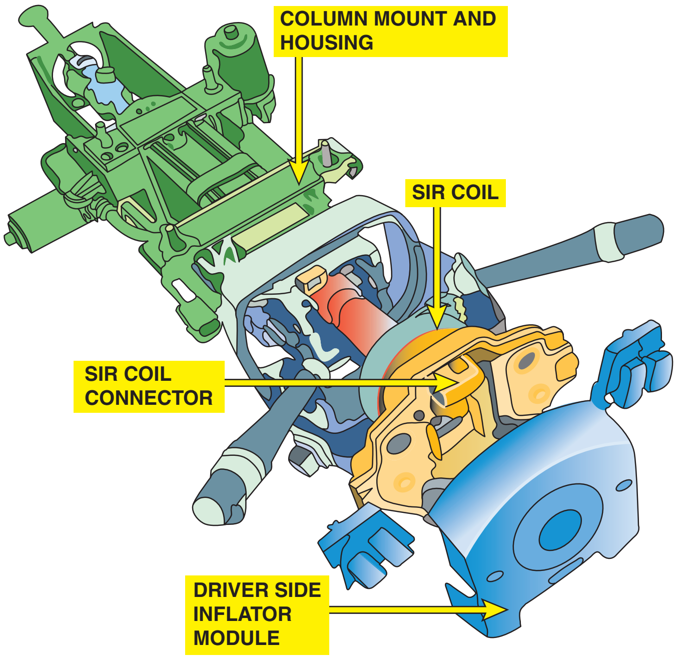


FIGURE 115–3 The airbag module attaches to the steering wheel and is removed as an assembly to service the steering wheel and column.

The module fits in front of the nut that secures the steering wheel to the steering shaft. Bolts at the back of the steering wheel fasten the airbag module to the steering wheel. Electrical current is provided to the airbag through the spiral cable, which is also known as a clockspring or coil. The spiral cable connects to the airbag module with two wire leads. The spiral cable is a coiled metal strip that allows steering wheel rotation while maintaining electrical continuity. ● **SEE FIGURE 115–3.**

CAUTION: Whenever working on the steering column, consult service information for the recommended airbag disabling procedure.

STEERING WHEEL REMOVAL

If the steering wheel must be removed, first disconnect the airbag wire connector at the base of the steering column. This reduces the chance of personal injury and prevents accidental airbag deployment.

TECH TIP

Locking Pliers to the Rescue

Many vehicles use a jam nut on the tie rod end. This jam nut must be loosened to adjust the toe. Because the end of the tie rod is attached to a tie rod end that is movable, loosening the nut is often difficult. Every time force is applied to the nut, the tie rod end socket moves and prevents the full force of the wrench from being applied to the nut. To prevent this movement, simply attach locking pliers (Vise Grips®) to hold the tie rod. Wedge the pliers against the control arm to prevent any movement of the tie rod. By preventing the tie rod from moving, full force can be put on a wrench to loosen the jam nut without doing any harm to the tie rod end.

CAUTION: Always follow the manufacturer's recommended procedures whenever working on or around the steering column.

Remove the center section of the steering column by removing the retaining screws, including the inflator module on vehicles equipped with an airbag.

After removal of the airbag inflator module, remove the steering wheel retaining nut. Note the locating marks on the steering wheel and steering shaft. ● **SEE FIGURE 115–4.** These marks indicate the proper position of the steering wheel for centerline steering. This means that the steering wheel spoke angle is straight and in line with the centerline position of the steering gear or rack-and-pinion steering unit.

Most steering wheels are attached to the steering shaft with a spline and a taper. After removing the steering wheel nut, use a steering wheel puller to remove the steering wheel from the steering shaft. ● **SEE FIGURE 115–5.**

To reinstall the steering wheel, align the steering wheel in the desired straight-ahead position and slip it down over the splines. Install and tighten the retaining nut to specifications.

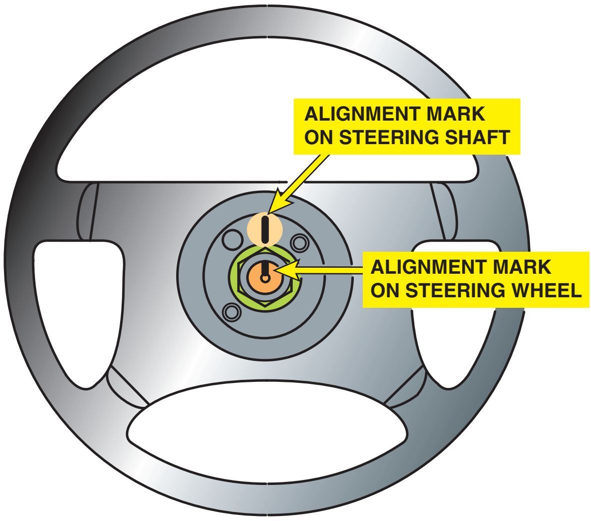

ALIGNMENT MARK ON STEERING SHAFT
ALIGNMENT MARK ON STEERING WHEEL

FIGURE 115–4 Most vehicles have alignment marks made at the factory on the steering shaft and steering wheel to help the service technician keep the steering wheel in the center position.

STEERING COLUMNS

PURPOSE AND FUNCTION The steering shaft transmits rotary motion from the steering wheel to the steering gear, while the column jacket that encases it attaches to the vehicle body and offers a stationary mounting point for a number of switches and mechanisms. ● **SEE FIGURE 115–6**.

STEERING SHAFT The **steering shaft** extends from the steering wheel to the steering gear. A bolt or nut secures the shaft to the steering wheel, and a flexible coupling joins it to the steering gear input shaft. The coupling can be a simple rubber or fabric insert, a universal joint (U-joint), or a pot joint.

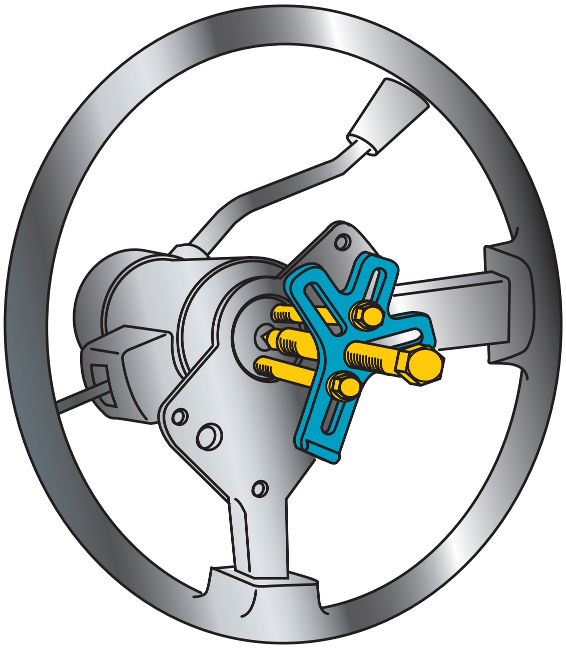
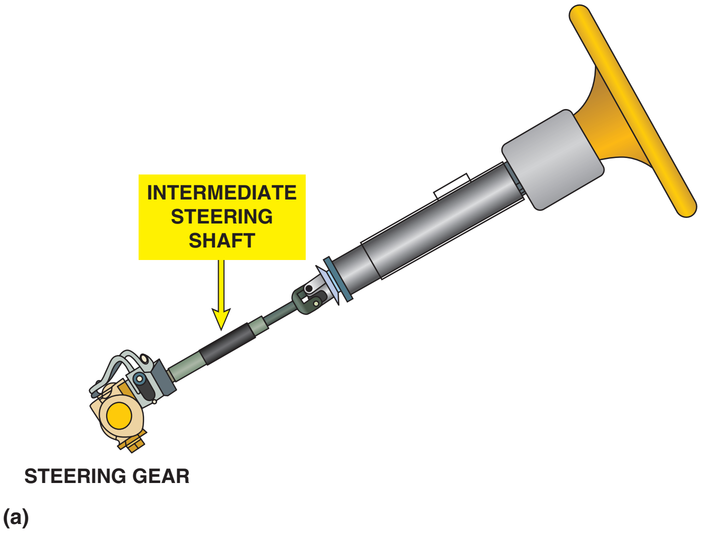


FIGURE 115–5 A puller being used to remove a steering wheel after the steering wheel retaining nut has been removed.


INTERMEDIATE STEERING SHAFT
STEERING GEAR
(a)

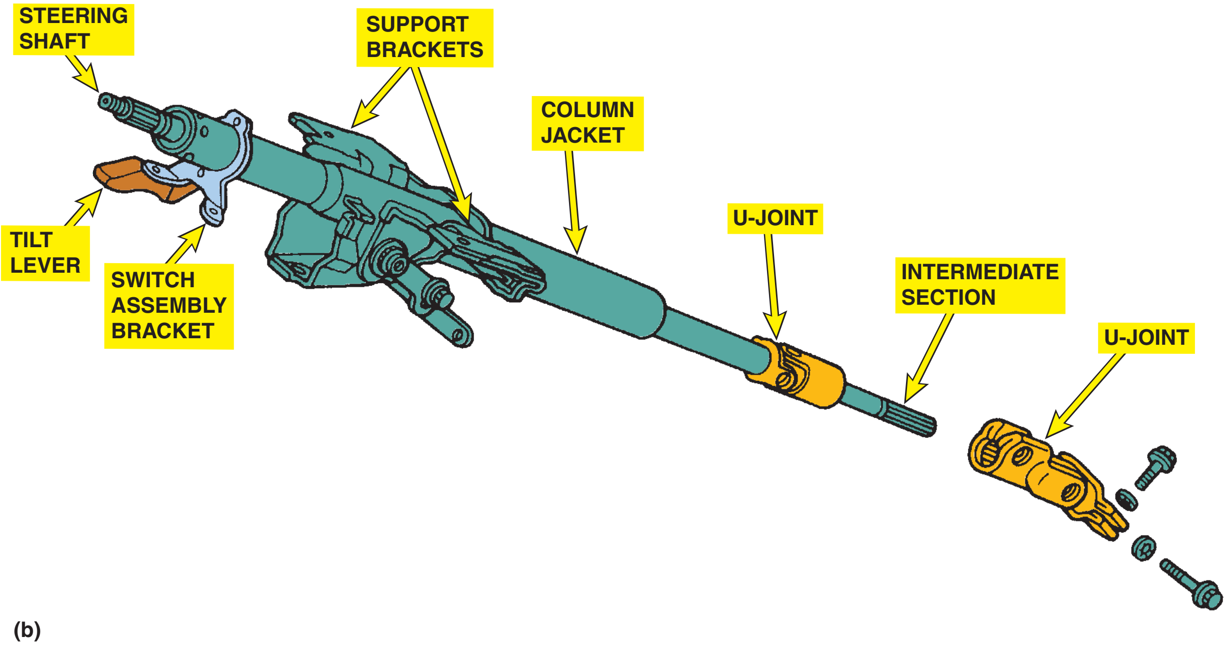

STEERING SHAFT
SUPPORT BRACKETS
COLUMN JACKET
TILT LEVER
SWITCH ASSEMBLY BRACKET
U-JOINT
INTERMEDIATE SECTION
U-JOINT
(b)

FIGURE 115–6 (a) The intermediate steering shaft is located forward of the bulkhead and between the steering column and the steering gear. (b) The steering shaft links the steering wheel to the steering gear while the column jacket, which surrounds part of the shaft, holds support brackets and switches. This steering shaft has a small intermediate section between the main section and the steering gear.

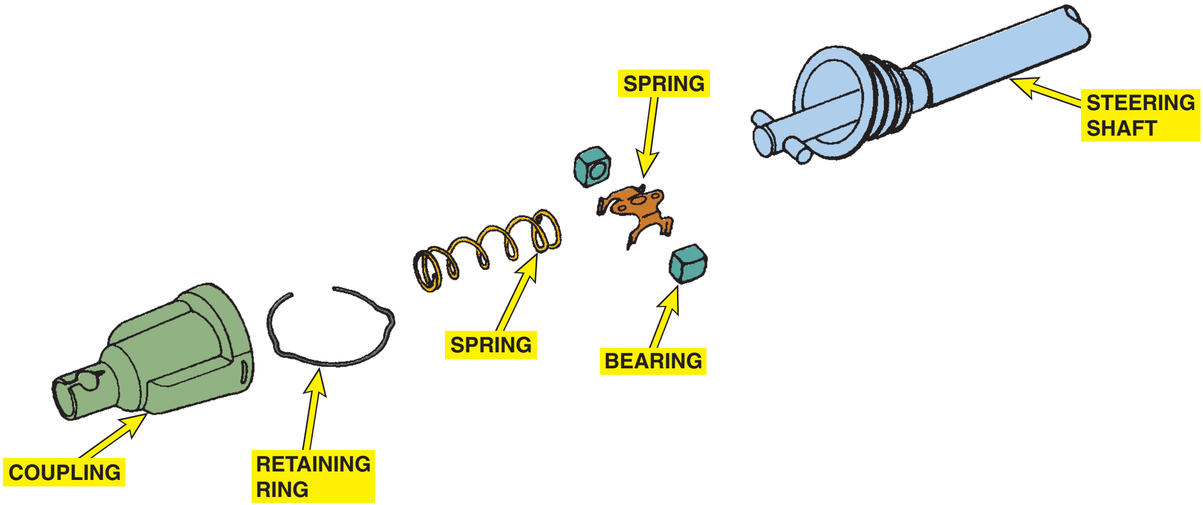

SPRING
STEERING SHAFT
SPRING
BEARING
COUPLING
RETAINING RING

FIGURE 115–7 A pot joint is a flexible coupling used to join two shafts that allow plunging motion.

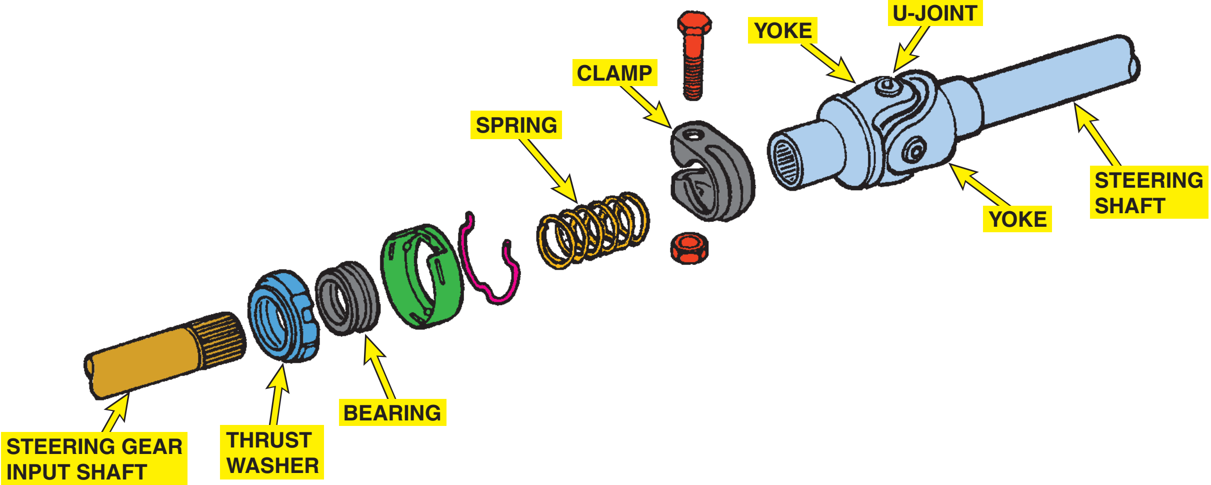

U-JOINT
YOKE
CLAMP
SPRING
STEERING SHAFT
YOKE
BEARING
THRUST WASHER
STEERING GEAR INPUT SHAFT

FIGURE 115–8 A typical intermediate steering shaft assembly showing a U-joint and related components.

In addition to allowing a directional change of the shaft, a pot joint permits a limited amount of plunging motion. ● **SEE FIGURE 115–7**.

UNIVERSAL JOINT A **universal joint**, or U-joint, consists of two yokes with a steel crosspiece joining them together. ● **SEE FIGURE 115–8**. Universal joints allow changes in the angle between two rotating shafts. In a steering shaft, U-joints allow rotary motion transfer between the steering wheel and the steering gear even though the steering shaft meets the steering gear input shaft at an angle. On some models the steering shaft itself is assembled in sections that are connected by U-joints. This permits the steering shaft to bend around obstacles between the steering wheel and the steering gear.

FLEXIBLE COUPLING A **flexible coupling** is a simple device made of rubber, or rubber reinforced with fabric, that is placed between two shafts to allow for a change in angle between them. ● **SEE FIGURE 115–9**. The rubber in a steering shaft flexible coupling absorbs vibrations and helps keep the steering wheel from shaking. A fail-safe connection between the steering shaft and the steering gear input shaft keeps the two shafts linked should the rubber coupling wear out or break. This allows the driver to maintain steering control, although the steering feels loose when this happens.

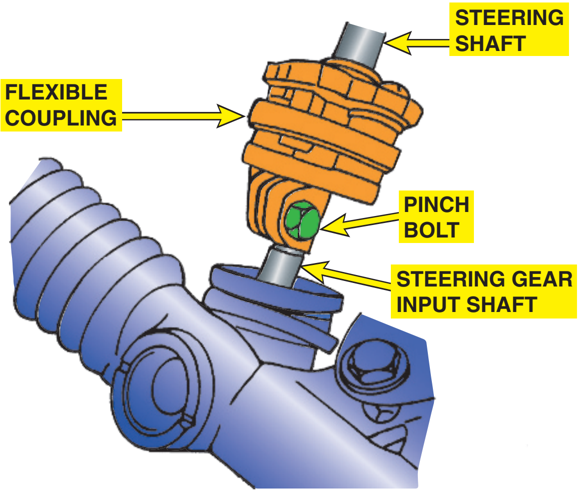

STEERING SHAFT
FLEXIBLE COUPLING
PINCH BOLT
STEERING GEAR INPUT SHAFT

FIGURE 115–9 A flexible coupling is used to isolate road noise and vibration from the steering shaft.

COLUMN COVER To keep the wiring from the jacket-mounted switches out of sight, the part of the steering column that extends into the passenger compartment is shrouded by the column cover. ● **SEE FIGURE 115–10**. The column cover is usually at least two separate pieces, top and bottom. A knee

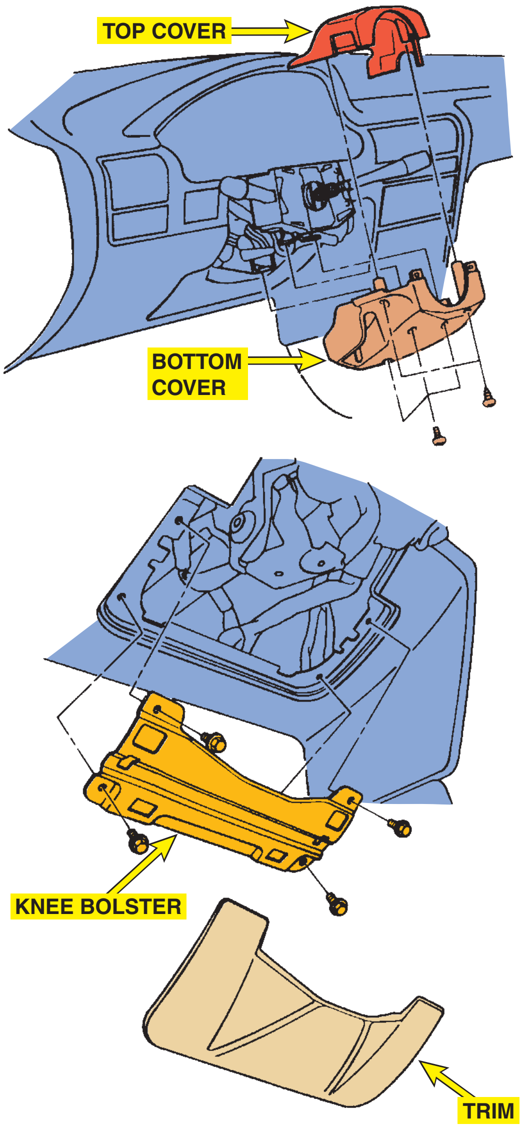


FIGURE 115–10 Steering column covers are often part of the interior trim.

bolster that mounts under the steering column is a safety feature designed to keep the driver from sliding forward during a collision. Knee bolsters are part of the passive restraint system required to meet U.S. federal safety standards on certain vehicles.

COLLAPSIBLE COLUMN Federal law requires that all vehicles sold in the United States have steering columns and shafts that collapse, **collapsible columns**, during a head-on collision to absorb some of the energy of the crash and lessen the danger of injury to the driver. ● **SEE FIGURE 115–11**. One early method used a section of the steering column constructed out of mesh, which would collapse easily during a crash. Another method is to use a two-piece column. One section of the column has a smaller diameter so that it fits inside the other and rides on a roller bearing. During a collision, the smaller section slides down into the larger one to collapse like a telescope.

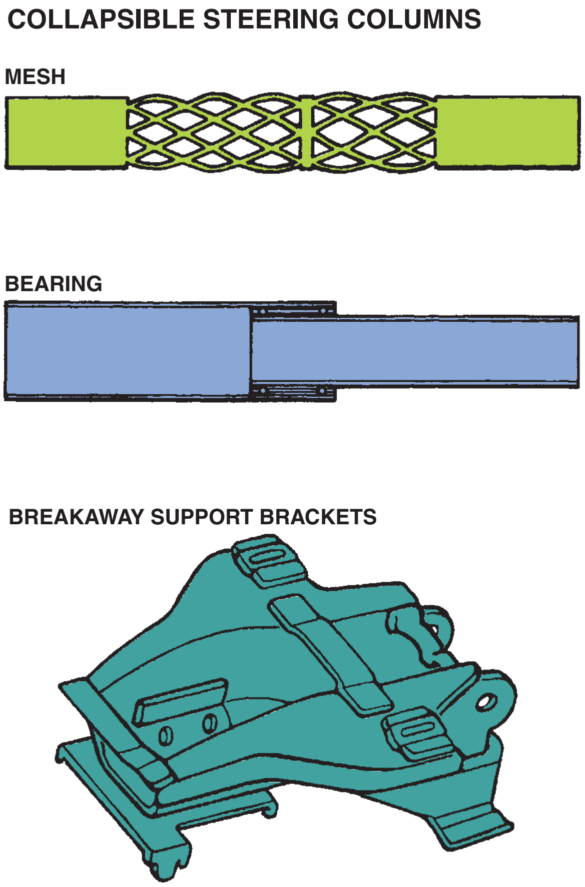


FIGURE 115–11 Collapsible steering columns include a mesh design that crushes easily, a bearing design that allows one section of the column to slide into the other, and a breakaway device that separates the steering column from the body of the vehicle in the event of a front-end collision.

TILT MECHANISMS Many steering columns have tilt mechanisms, which allow the driver to adjust the angle of the steering wheel relative to the steering column. In a typical **tilt steering column**, the steering shaft has a short section at the top joined to the rest of the steering shaft either by a U-joint or gears. Most tilt mechanisms are some sort of ratchet device that enables the driver to lift the steering wheel and the top section of the shaft and place them in the desired position. ● **SEE FIGURE 115–12**. Usually, spring tension locks the steering wheel in place on the ratchet, and a release lever compresses the spring to allow tilt adjustment.

TELESCOPING STEERING COLUMNS Some steering columns are designed to telescope, which means that the top of the steering shaft and jacket can be pulled out toward the driver or pushed in toward the dashboard, and then locked into the new position.

TECH TIP

Do Not Pound on the Steering Column

Always use a steering wheel puller and/or the special tools recommended by the vehicle manufacturer when servicing the steering column. If a hammer is used on the steering shaft in an attempt to remove a steering wheel, the shaft could collapse, requiring the replacement of the entire steering column assembly.

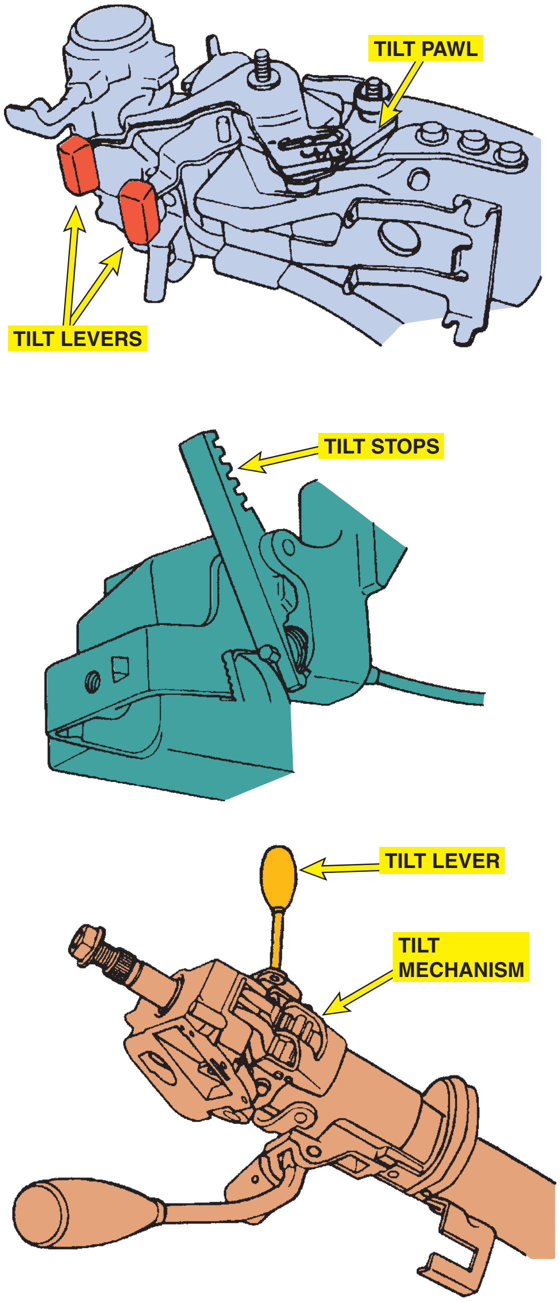


FIGURE 115–12 Tilt mechanisms vary by design and vehicle manufacturer, although most use a ratchet to position the top portion of the steering column.

STEERING COLUMN CONSTRUCTION The steering shaft is at the center of the steering column. ● **SEE FIGURES 115–13 AND 115–14**. The top end of the steering shaft splines to the center of the steering wheel, and a large nut fastens the steering wheel to the shaft. The lock housing, which contains the ignition lock cylinder, encases the top part of the steering shaft. The steering column jacket covers the shaft under the ignition lock housing, and the gear selector lever housing fits over a portion of the column jacket.

A U-joint connects the lower end of the steering shaft to a small intermediate shaft, often called a **stub shaft**. Because this steering column includes a gear selector lever, the lower end of the column also incorporates an attachment point that connects the shift tube to the gear shift rod. The intermediate shaft extends through a hole in the floor where it is coupled to the steering gear input shaft by a U-joint.

A toe plate bolts to the floor of the passenger compartment to cover the shaft opening and to protect the interior from noise, drafts, and dirt. ● **SEE FIGURE 115–15**. The toe plate has a tube for the intermediate shaft, and a seal and silencer fit on top of the tube.

Two sections at the upper end of the steering column house the column-mounted controls. ● **SEE FIGURE 115–16**. The lock housing, seated on top of the column jacket, is the topmost piece and contains the turn signal lever, hazard light control, and ignition lock. The gear selector lever and its housing are just below the lock housing, and the housing encases the top of the steering column jacket.

The lock housing contains the ignition lock cylinder, several electrical switches, and a steering shaft bearing. Some of the switches have driver-operated controls on the outside of the lock housing.

A multifunction switch operates the turn signals, the windshield wiper and washer switch, and the dimmer switch.

Most steering shafts ride on at least two bearings, one near the top and one near the bottom of the shaft, to allow the shaft to rotate freely without affecting other parts of the steering column. ● **SEE FIGURE 115–17**. A snap ring at the center of the bearing housing rests in a groove on the steering shaft to secure the bearing, and an O-ring on the steering shaft keeps lubricant in the bearing.

Underneath the bearing and housing is a **lock plate** and coil spring that lock the steering shaft into position when the driver removes the ignition key. ● **SEE FIGURE 115–18**. The ignition lock

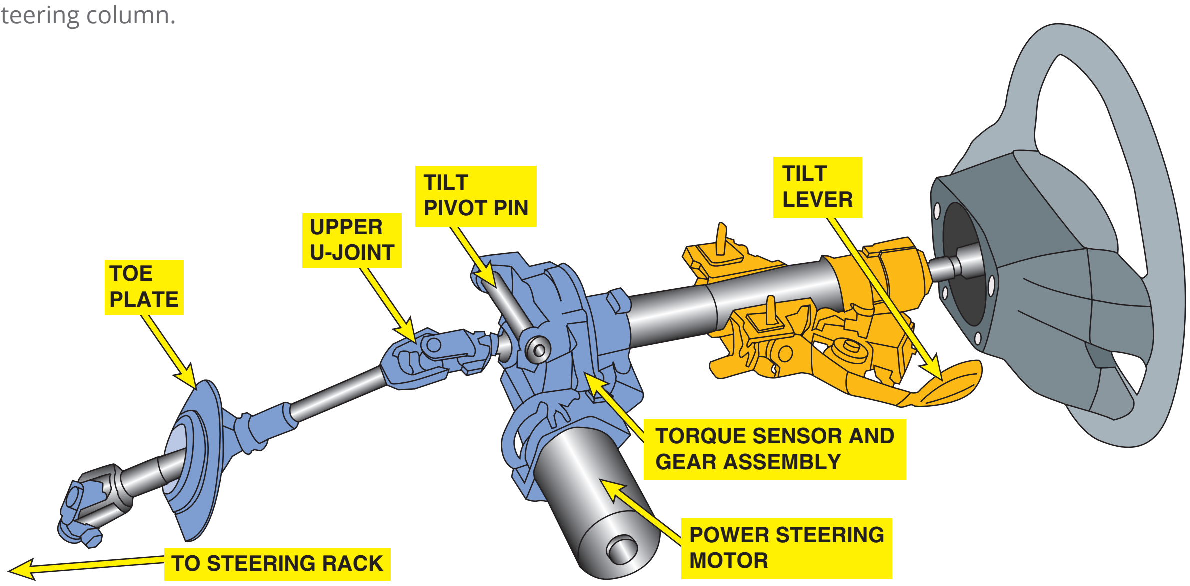


FIGURE 115–13 Typical steering column showing all of the components from the steering wheel to the steering gear. Note that this column uses a column-type electric power steering system (EPS) and a tilt wheel.

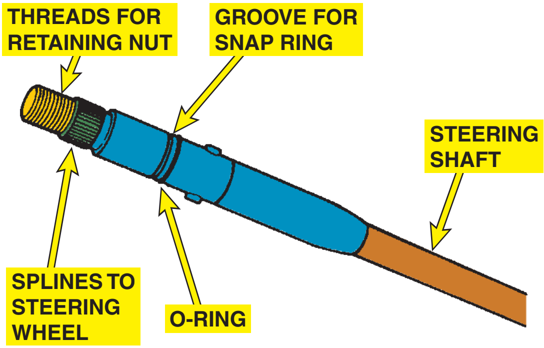

THREADS FOR RETAINING NUT
GROOVE FOR SNAP RING
STEERING SHAFT
SPLINES TO STEERING WHEEL
O-RING

FIGURE 115–14 The steering shaft splines onto the steering wheel.

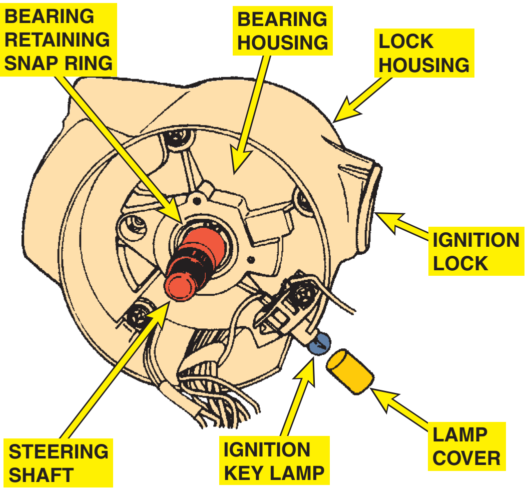

BEARING RETAINING SNAP RING
BEARING HOUSING
LOCK HOUSING
IGNITION LOCK
STEERING SHAFT
IGNITION KEY LAMP
LAMP COVER

FIGURE 115–17 The upper section of the steering column contains the steering shaft bearing.

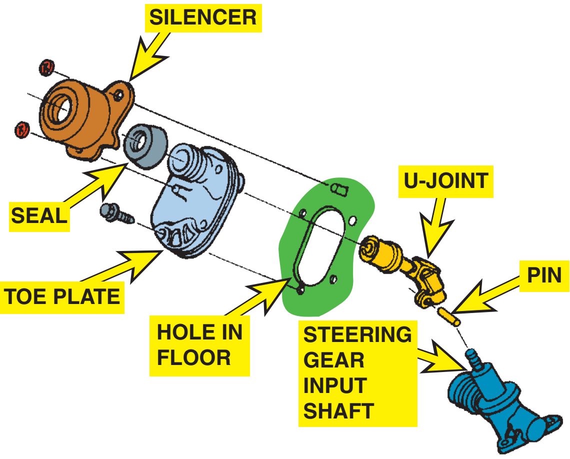

SILENCER
SEAL
U-JOINT
PIN
TOE PLATE
HOLE IN FLOOR
STEERING GEAR INPUT SHAFT

FIGURE 115–15 The toe plate seals the hole from the steering shaft and helps seal out noise and moisture.

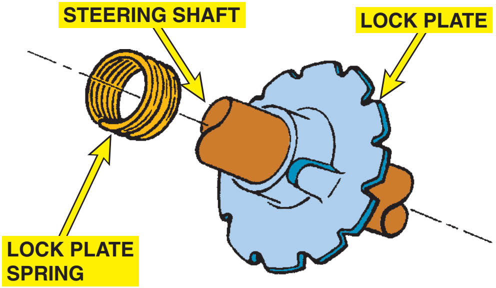

STEERING SHAFT
LOCK PLATE
LOCK PLATE SPRING

FIGURE 115–18 The lock plate engages an ignition lock pawl to keep the steering wheel in one position when the ignition is off.

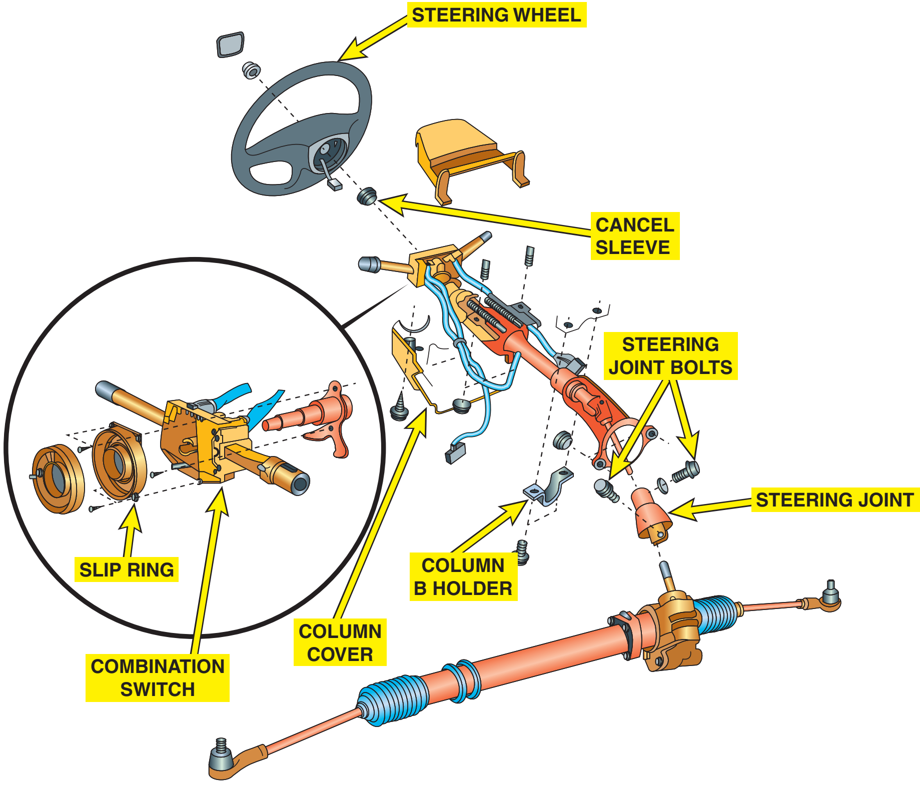

STEERING WHEEL
CANCEL SLEEVE
STEERING JOINT BOLTS
STEERING JOINT
COLUMN B HOLDER
COLUMN COVER
SLIP RING
COMBINATION SWITCH

FIGURE 115–16 The upper portion of the steering column contains the combination switch, often called the multi-function switch used to control many functions.

cylinder, which is under the lock plate, moves a bellcrank that in turn operates a spring and lever assembly linked to the ignition switch actuating rod.

CONVENTIONAL STEERING GEARS

PURPOSE AND FUNCTION All steering gears have an input gear, which transmits rotary movement from the steering wheel into the steering gear, and an output gear, which causes the steering linkage to move laterally. The rotation of the steering wheel is transferred to the front wheels through a steering gear and linkage. The intermediate shaft is splined to a **worm gear** inside a conventional steering gear. Around the worm gear is a nut with gear teeth that meshes with the teeth on a section of a gear called a **sector gear**. The sector gear is part of a **pitman shaft**, also known as a **sector shaft**, as shown in ● **FIGURE 115–19**.

Ball, roller, or needle bearings support the sector shaft and the worm gear shaft, depending on the make and model of the gear assembly.

As the steering wheel is turned, the movement is transmitted through the steering gear to an arm attached to the bottom end of the pitman shaft. This arm is called the **pitman arm**. Whenever the steering wheel is turned, the pitman arm moves.

STEERING GEAR RATIO When the steering wheel is turned, the front wheels turn on their steering axis. If the steering wheel is rotated 20 degrees and results in the front wheels rotating 1 degree, then the steering gear ratio is 20:1 (read as "20 to 1"). ● **SEE FIGURE 115–20**. The front wheels usually are able to rotate through 60 to 80 degrees of rotation. The steering wheel, therefore, has to rotate 20 times the number of degrees that the wheels move.

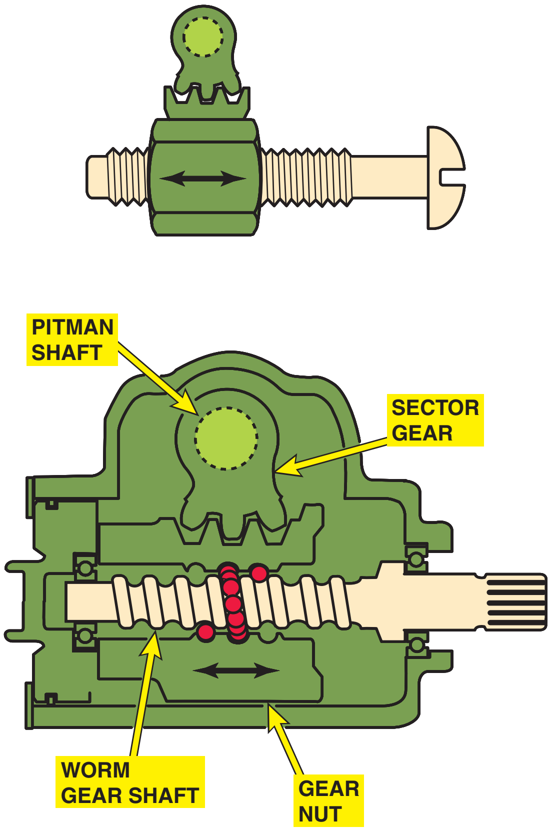


FIGURE 115–19 As the steering wheel is turned, the nut moves up or down on the threads, shown using a bolt to represent the worm gear and the nut representing the gear nut that meshes with the teeth of the sector gear.

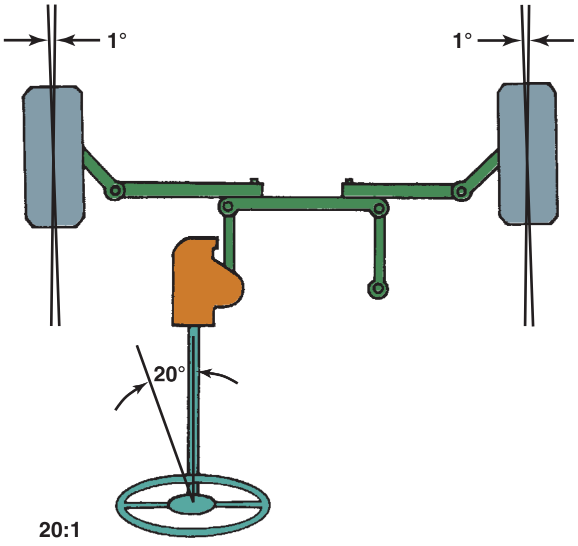


FIGURE 115–20 Steering gear ratio is the ratio between the number of degrees the steering wheel is rotated to the number of degrees the front wheel turns.

20 × 60 degrees = 1,200 degrees, or about three full revolutions (360 degrees = 1 full turn) of the steering wheel

20 × 80 degrees = 1,600 degrees, or over four revolutions of the steering wheel

A vehicle that turns three complete revolutions from full left to full right is said to have three turns "lock to lock."

A high ratio, such as 22 to 1 (22:1), means that the steering wheel must be rotated 22 degrees to move the front wheels 1 degree. This high ratio means that the steering wheel is easier to turn than a steering wheel with a lower ratio such as 14:1. The 14:1 ratio is considered to be "faster" than the 22:1 ratio. This fast ratio allows the front wheels to be turned with less movement of the steering wheel, yet more force may be required to turn the wheel. This is considered by some to be more "sporty."

Most steering gears and some rack-and-pinion steering gears feature a **variable ratio**. This feature causes the steering ratio to decrease as the steering wheel is turned from the on-center position. The high on-center ratio (such as 16:1) provides good steering feel at highway speeds while the reduced off-center ratio (13:1) provides fewer steering wheel turns during turning and parking. The ratio is accomplished by changing the length of the gear teeth on the sector gear. ● **SEE FIGURE 115–21** for an example of the teeth of a constant-ratio sector gear.

● **SEE FIGURE 115–22** for an example of the teeth on a variable-ratio sector gear.

The sector gear meshes with the ball nut inside the steering gear, as shown in ● **FIGURE 115–23**.

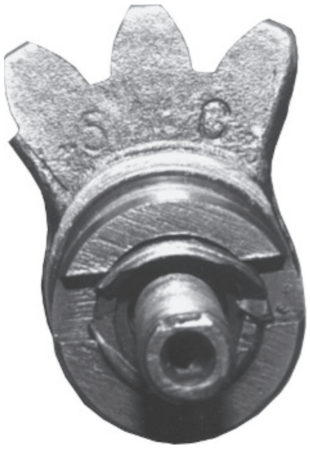


FIGURE 115–21 Constant-ratio steering gear sector shaft. Notice that all three gear teeth are the same size.

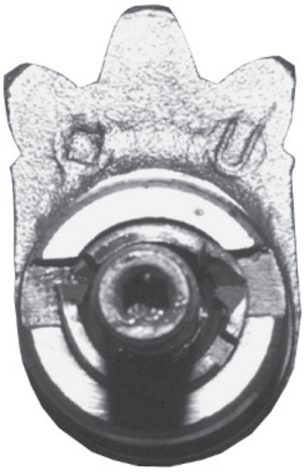


FIGURE 115–22 Variable-ratio steering gear sector shaft. Notice the larger center gear tooth.

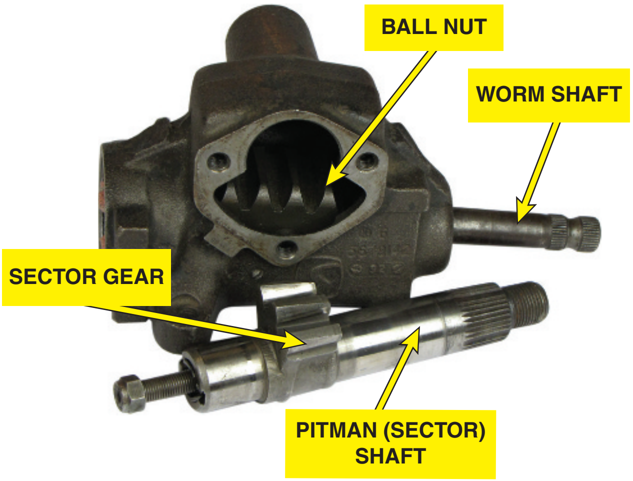


FIGURE 115–23 The sector gear meshes with the gear teeth on the ball nut.

RECIRCULATING BALL STEERING GEAR

PARTS AND OPERATION A recirculating ball steering gear is the most commonly used conventional steering gear. ● **SEE FIGURE 115–24**.

The end of the steering gear input shaft, or worm shaft, splines to the steering shaft U-joint and provides rotary input to the steering gear. An oil seal prevents fluid leakage where the input shaft enters the steering gear housing. At the top and the bottom of the worm gear are the upper and lower thrust bearings. The upper bearing cup seats in the housing, and the lower bearing cup seats in the adjuster plug. The thrust bearings reduce friction between the worm gear and the steering gear housing and control worm endplay.

The adjuster plug at the lower end of the worm gear holds the worm gear, shaft, and bearings inside the steering gear housing.

The ball nut, which has internal grooves that match the worm gear thread, fits over the worm gear. Steel balls roll through the tunnels formed by the ball nut grooves and the worm gear thread. Crescent-shaped ball-return guides link the ends of the ball-nut tunnels together, so the balls continuously circulate through the ball nut and worm gear, into the ball-return guides, and back again. A clamp secured by screws holds the return guides in place on one side of the ball nut. Gear teeth mesh with the teeth of the sector gear machined into the outside of the ball nut on the side opposite the ball-return guides.

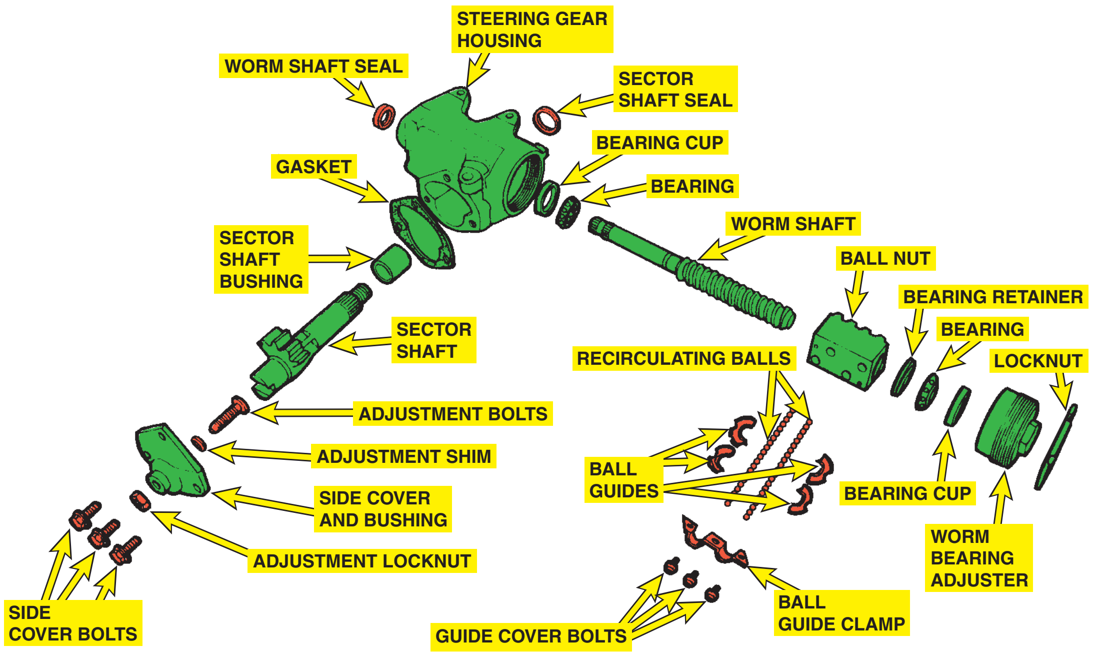
The sector gear is an integral part of the sector shaft, which runs through the center of the sector gear, and forms the axis of the gear. One end of the sector shaft extends out of the steering gear housing and splines to the pitman arm. An oil seal prevents lubricant leakage where the sector shaft goes through the opening in the housing. To reduce friction, the sector shaft rides on two bushings. One bushing fits inside the housing and the other is part of the housing side cover. ● **SEE FIGURE 115–25**.

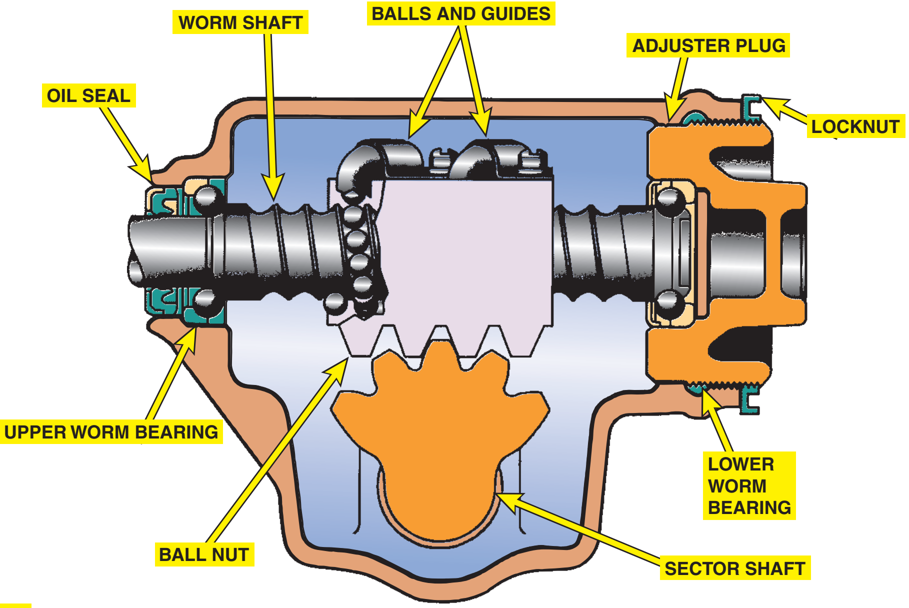
RACK-AND-PINION STEERING GEAR

PARTS AND OPERATION The term *rack and pinion* is simply a description of the basic design of this type of steering gear. The **rack-and-pinion** steering gear is widely used because it is light in weight and takes less space than a conventional steering gear. The input gear of a rack-and-pinion steering gear is a pinion gear that receives rotary input from the steering shaft. The rack is a rod with gear teeth machined into one side. The pinion gear teeth mesh with the teeth on the rack so that when the pinion gear turns, it pushes the rack from side to side. ● **SEE FIGURE 115–26**. The rack connects directly to the tie rod in the steering linkage to move the linkage back and forth in a straight line.

The steering gear input shaft is splined to the steering shaft U-joint. ● **SEE FIGURE 115–27**. At the end of the steering gear input shaft, which extends into the rack housing, is the pinion gear. Two ball bearings reduce friction between the shaft and the steering gear housing. The upper bearing is a press-fit on the input shaft, and the lower bearing installs inside the housing at the bottom of the pinion gear. A cover, which fits around the shaft and threads into the housing, seats on top of the upper ball bearing to preload it and close the top of the steering gear housing. An oil seal between the top cover and the input shaft keeps lubricant from leaking out of the housing. A lock nut holds the top cover in position.

FIGURE 115–24 A typical manual recirculating ball steering gear.


STEERING GEAR HOUSING
WORM SHAFT SEAL
SECTOR SHAFT SEAL
BEARING CUP
GASKET
BEARING
WORM SHAFT
SECTOR SHAFT BUSHING
BALL NUT
BEARING RETAINER
SECTOR SHAFT
BEARING
RECIRCULATING BALLS
LOCKNUT
ADJUSTMENT BOLTS
ADJUSTMENT SHIM
BALL GUIDES
SIDE COVER AND BUSHING
BEARING CUP
WORM BEARING ADJUSTER
ADJUSTMENT LOCKNUT
BALL GUIDE CLAMP
SIDE COVER BOLTS
GUIDE COVER BOLTS


WORM SHAFT
BALLS AND GUIDES
ADJUSTER PLUG
OIL SEAL
LOCKNUT
UPPER WORM BEARING
LOWER WORM BEARING
BALL NUT
SECTOR SHAFT

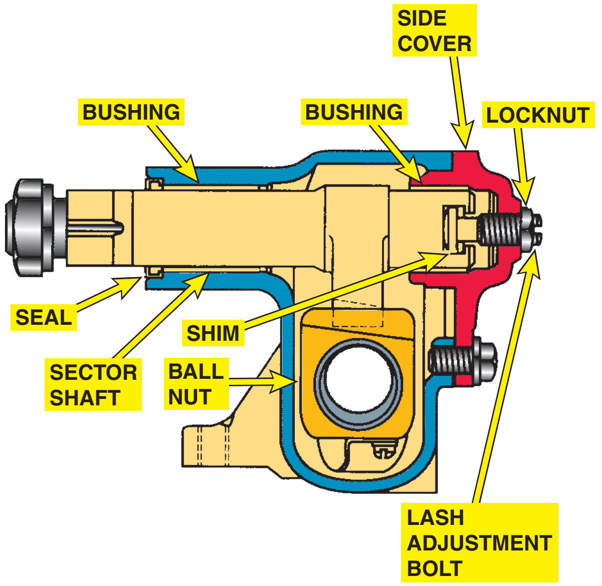

SIDE COVER
BUSHING
BUSHING
LOCKNUT
SEAL
SHIM
SECTOR SHAFT
BALL NUT
LASH ADJUSTMENT BOLT

FIGURE 115–25 The sector shaft is supported by bushings, one in the housing and one in the side cover.

The teeth of the pinion gear mesh with the teeth of the rack. The teeth are at one end of the rack and the pinion is offset at one side of the housing.

The rack is encased in the long, tubular steering gear housing with a mounting flange on the pinion end. Rubber bushings fit into the mounting flange bolt holes to absorb vibration and isolate the assembly from the frame.

A spring-loaded **rack support** and related hardware install through a hole at the back of the steering gear housing to position the rack. ● **SEE FIGURE 115–28**. The face of the rack support curves to match the back of the rack, which rests on it and slides back and forth across it. A spring behind the rack support cushions the rack from vibration and shocks. While the rack support provides a sliding surface to reduce friction at the pinion end of the rack, the rack rides in a bushing pressed into the steering gear housing at the opposite end to reduce friction.

Most rack-and-pinion units use a small metal tube running along the outside of the housing to connect the two boots and transfer air from one to the other. ● **SEE FIGURE 115–29**. If there

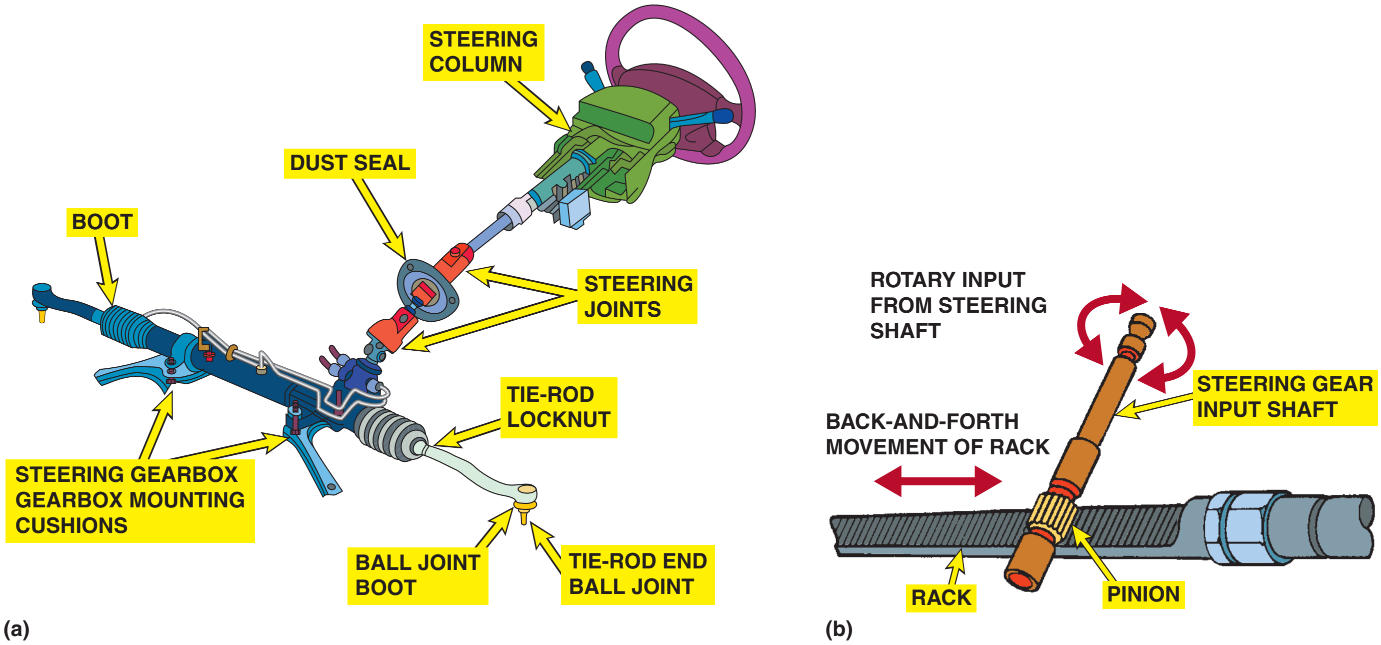

STEERING COLUMN
DUST SEAL
BOOT
STEERING JOINTS
TIE-ROD LOCKNUT
STEERING GEARBOX
GEARBOX MOUNTING CUSHIONS
BALL JOINT BOOT
TIE-ROD END BALL JOINT
(a)
ROTARY INPUT FROM STEERING SHAFT
STEERING GEAR INPUT SHAFT
BACK-AND-FORTH MOVEMENT OF RACK
RACK
PINION
(b)

FIGURE 115–26 (a) An overall view of a rack and pinion steering system showing its relationship to the other front-end components. (b) Rack-and-pinion steering gear operation is simple, direct, and the rack is in a straight line to the front wheels.

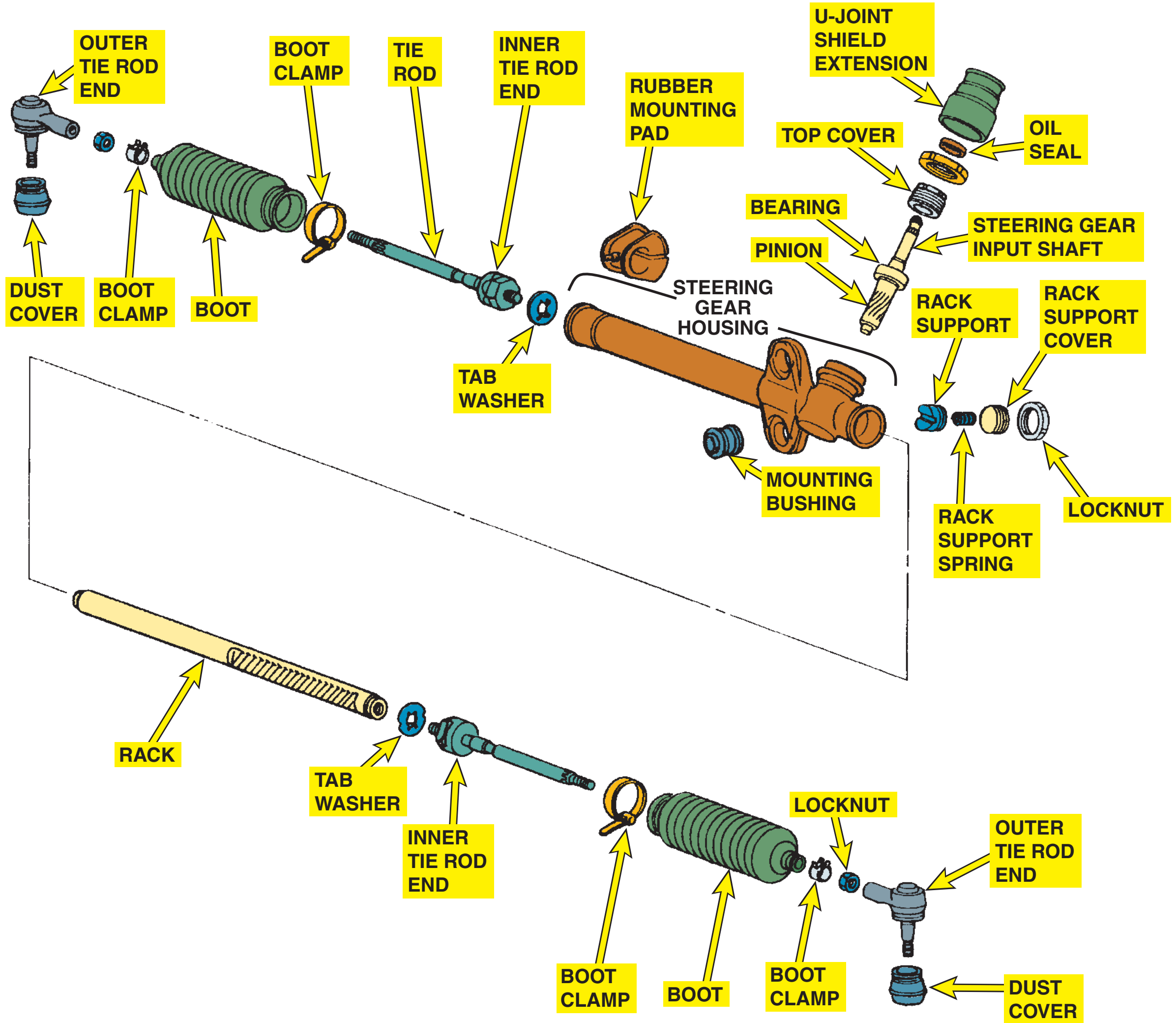

OUTER TIE ROD END
BOOT CLAMP
TIE ROD
INNER TIE ROD END
RUBBER MOUNTING PAD
U-JOINT SHIELD EXTENSION
TOP COVER
OIL SEAL
BEARING
STEERING GEAR INPUT SHAFT
PINION
DUST COVER
BOOT CLAMP
BOOT
STEERING GEAR HOUSING
RACK SUPPORT
RACK SUPPORT COVER
TAB WASHER
MOUNTING BUSHING
LOCKNUT
RACK SUPPORT SPRING
RACK
TAB WASHER
INNER TIE ROD END
LOCKNUT
OUTER TIE ROD END
BOOT CLAMP
BOOT
BOOT CLAMP
DUST COVER

FIGURE 115–27 A typical manual rack-and-pinion steering gear used in a small front-wheel-drive vehicle.

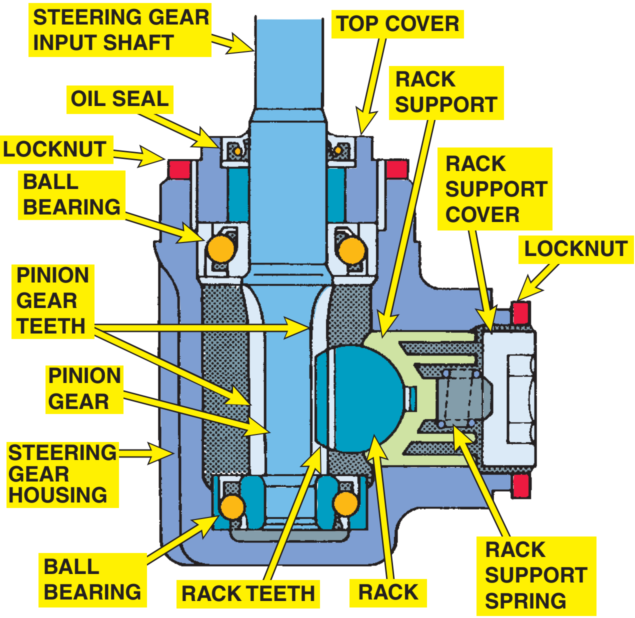

STEERING GEAR INPUT SHAFT
TOP COVER
OIL SEAL
RACK SUPPORT
LOCKNUT
BALL BEARING
RACK SUPPORT COVER
LOCKNUT
PINION GEAR TEETH
PINION GEAR
STEERING GEAR HOUSING
BALL BEARING
RACK TEETH
RACK
RACK SUPPORT SPRING

FIGURE 115–28 The spring-loaded rack support positions the rack to keep it from rubbing against the housing and establishes the pinion torque.

were no means for air displacement between the boots, they might collapse as they expanded or explode as they compressed.

Internal threads on each end of the rack allow attachment of the externally threaded tie rods.

A rubber boot at each side of the steering gear housing covers the end of the rack and the inner tie rod end to prevent dirt, water, and other contaminants from entering the assembly. Band clamps fasten the ends of the boots to the housing and tie rods.

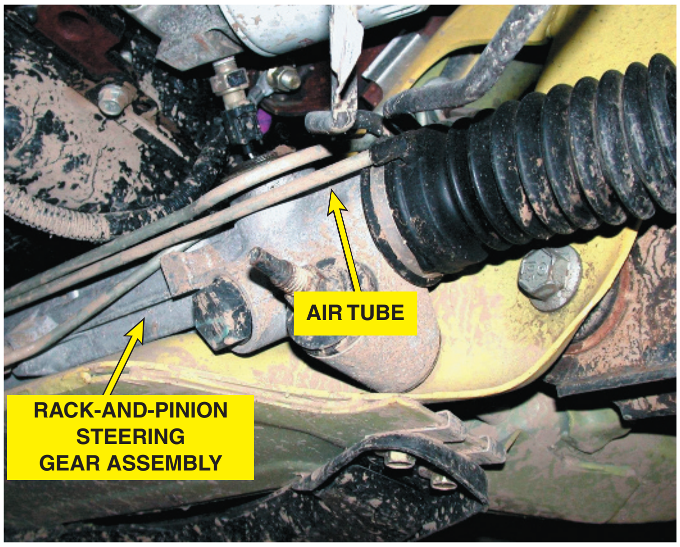

AIR TUBE
RACK-AND-PINION STEERING GEAR ASSEMBLY

FIGURE 115–29 A small air tube is used to transfer air between the boots as they extend and compress during turns.

The tie rods move back and forth with the rack and connect it to the wheels through the steering linkage.

The housing generally bolts to either a flange on the firewall or to the subframe or engine cradle. ● **SEE FIGURE 115–30**. The mounting points have rubber cushions to isolate the steering gear from shock and vibration. If the driver can feel vibration and road shocks through the steering wheel, the condition is called **kickback**. Kickback is most noticeable when driving into a curbed driveway.

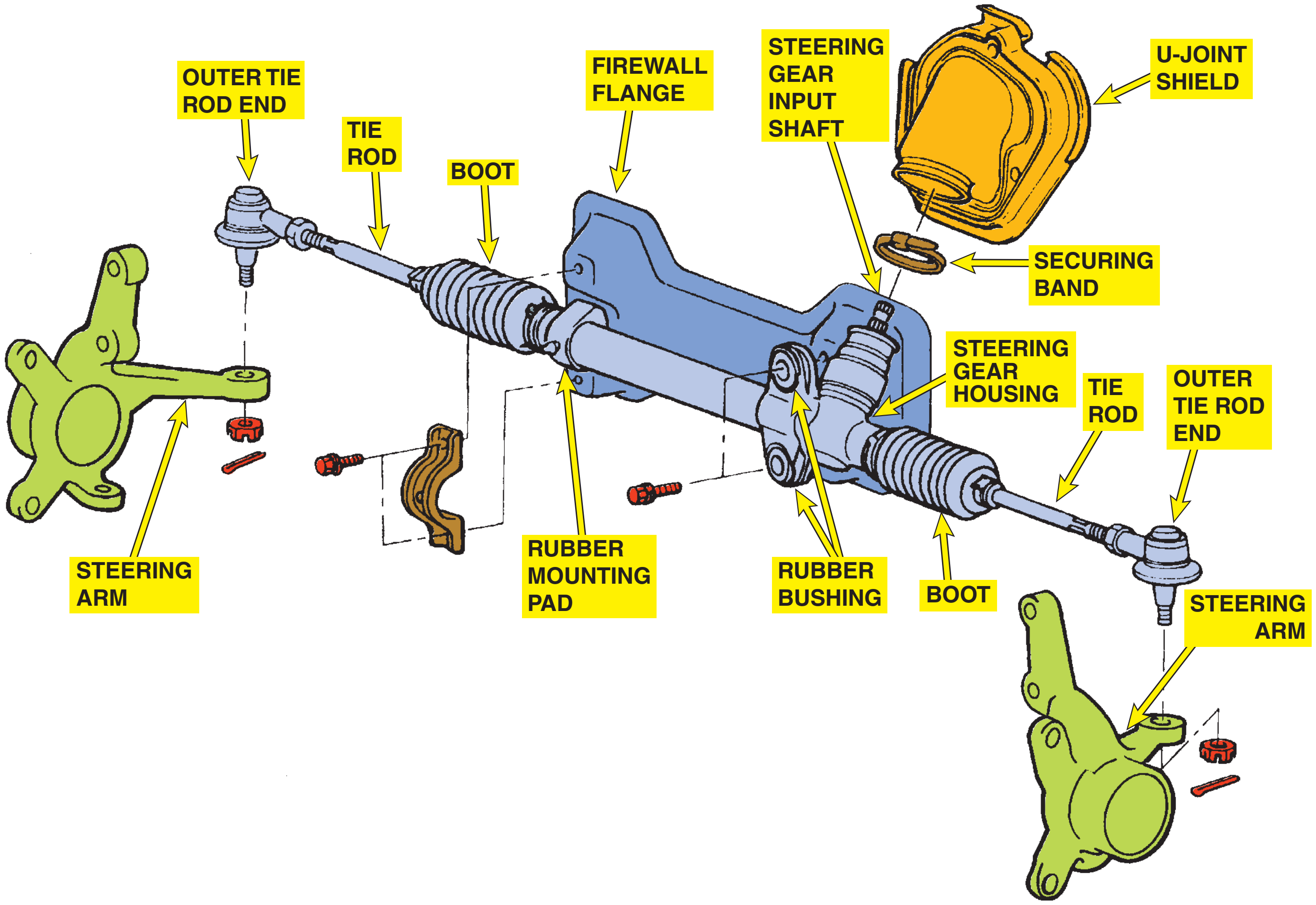

OUTER TIE ROD END
TIE ROD
BOOT
FIREWALL FLANGE
STEERING GEAR INPUT SHAFT
U-JOINT SHIELD
SECURING BAND
STEERING GEAR HOUSING
TIE ROD
OUTER TIE ROD END
STEERING ARM
RUBBER MOUNTING PAD
RUBBER BUSHING
BOOT
STEERING ARM

FIGURE 115–30 This manual rack-and-pinion steering gear mounts to the bulkhead (firewall), whereas others mount to the engine cradle or frame of the vehicle.

REVIEW QUESTIONS

1. What components are included in a typical steering column assembly?
2. When the driver turns the steering wheel, how is the motion transferred to the front wheels through a conventional steering gear?
3. What is the purpose and function of a pitman arm?
4. What are some features of a rack and pinion steering system?
5. What is the purpose of a collapsible steering column?

CHAPTER QUIZ

1. The circuit to the airbag inflation module is connected from the steering column to the steering wheel through which component?
   - **a.** Slip ring and carbon brushes
   - **b.** Clockspring (coil)
   - **c.** Magnetic field sensor
   - **d.** Hall-effect switch
2. After removing the center nut, use a _______________ to remove the steering wheel from the steering shaft.
   - **a.** puller
   - **b.** hammer
   - **c.** shaft depressor
   - **d.** snap ring plier
3. Which part in the steering column allows for changes in the angle between the upper and lower shafts?
   - **a.** Flexible coupling
   - **b.** Column cover
   - **c.** Universal joint
   - **d.** Collapsible section
4. The rotation of the steering wheel causes which part to move the actual steering linkage in a conventional steering gear?
   - **a.** Sector shaft
   - **b.** Pitman arm
   - **c.** Worm gear
   - **d.** Gear nut
5. The driver rotates the steering wheel one-half of one revolution (180 degrees) on a vehicle equipped with a steering gear with a 20:1 gear ratio. How many degrees will the front wheels be rotated?
   - **a.** 9 degrees
   - **b.** 0.1 degree
   - **c.** 90 degrees
   - **d.** 11.1 degrees
6. What causes a variable-ratio steering gear to be able to change the ratio as the steering wheel is turned?
   - **a.** Using two or three different sector gears depending on design
   - **b.** Using a variable-length pitman arm
   - **c.** Changing the number of teeth on the worm gear
   - **d.** Changing the length of the teeth on the sector gear
7. The sector shaft used in most conventional steering gears rides on two bushings in order to _______________.
   - **a.** provide for a variable ratio
   - **b.** keep the steering wheel centered
   - **c.** reduce friction
   - **d.** help provide feedback to the driver regarding the road surface
8. The steering wheel is attached to the steering shaft using a _______________.
   - **a.** bolt and clamp
   - **b.** bolt or nut
   - **c.** clockspring
   - **d.** snap-ring
9. On a rack-and-pinion steering gear, the inner tie rods are protected by _______________.
   - **a.** boots
   - **b.** gaskets
   - **c.** O-rings
   - **d.** flanges
10. What is the purpose and function of the air tube connecting the two end boots?
    - **a.** To transfer air from one boot to the other when the wheels are turned
    - **b.** To move grease from one boot to the other to equalize the amount of grease in each boot
    - **c.** To prevent water from entering the boots
    - **d.** To keep any fluid from escaping

Chapter 116

STEERING LINKAGE AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Identify steering linkage components.
- Describe rack-and-pinion inner tie rod ends.
- Describe four-wheel steering systems.
- Discuss steering linkage lubrication.
- Describe the purpose and procedure for performing a dry park test.
- Describe the steps for under-vehicle inspection of steering systems.
- Explain how to replace steering linkage parts.

KEY TERMS:

Articulation test 1440 • Ball socket assembly 1433 • Center link 1431 • Center take-off rack 1434 • Cross-steer linkage 1431 • Dry park test 1435 • Front steer 1434 • Grease fitting 1433 • Opposite-phase steering 1434 • Parallelogram linkage 1431 • Pitman arm 1431 • Rubber-bonded socket (RBS) 1433 • Rear steer 1434 • Same-phase steering 1434 • Steering dampener 1431 • Steering stops 1435 • Tie rods 1431 • Zerk fitting 1433

STEERING LINKAGE

PURPOSE AND FUNCTION The steering linkage relays steering forces from the steering gear to the front wheels. Most conventional steering linkages use the **parallelogram-type** design. A parallelogram is a geometric box shape where opposite sides are parallel and equal distance. A parallelogram-type linkage uses four **tie rods**, two inner and two outer (left and right), a **center link** (between the tie rods), and an idler arm on the passenger side and a **pitman arm** attached to the steering gear output shaft (pitman shaft). ● **SEE FIGURE 116–1**.

As the steering wheel is rotated, the pitman arm is moved. The pitman arm attaches to a center link. At either end of the center link are inboard (inner) tie rods, adjusting sleeves, and outboard (outer) tie rods connected to the steering arm, which moves the front wheels. The passenger side of all these parts is supported and held horizontal by an idler arm that is bolted to the frame. The center link may be known by several names, including the following:

- Center link
- Connecting link
- Connecting rod
- Relay rod
- Intermediate rod
- Drag link (usually a truck term only)

Other types of steering linkages often used on light trucks and vans include the **cross-steer linkage**. ● **SEE FIGURE 116–2** for a comparison of parallelogram and cross-steer-type steering linkage arrangements.

NOTE: Many light trucks, vans, and some luxury cars use a steering dampener attached to the linkage. A steering dampener is similar to a shock absorber, and it absorbs and dampens sudden motions in the steering linkage. ● SEE FIGURE 116–3.

FREQUENTLY ASKED QUESTION

Why Is a Grease Fitting Sometimes Called a Zerk Fitting?

In 1922, the *zerk* fitting was developed by Oscar U, Zerk, an employee of the Alemite Corporation, a manufacturer of pressure lubrication equipment. A zerk or grease fitting is also known as an *Alemite fitting.*

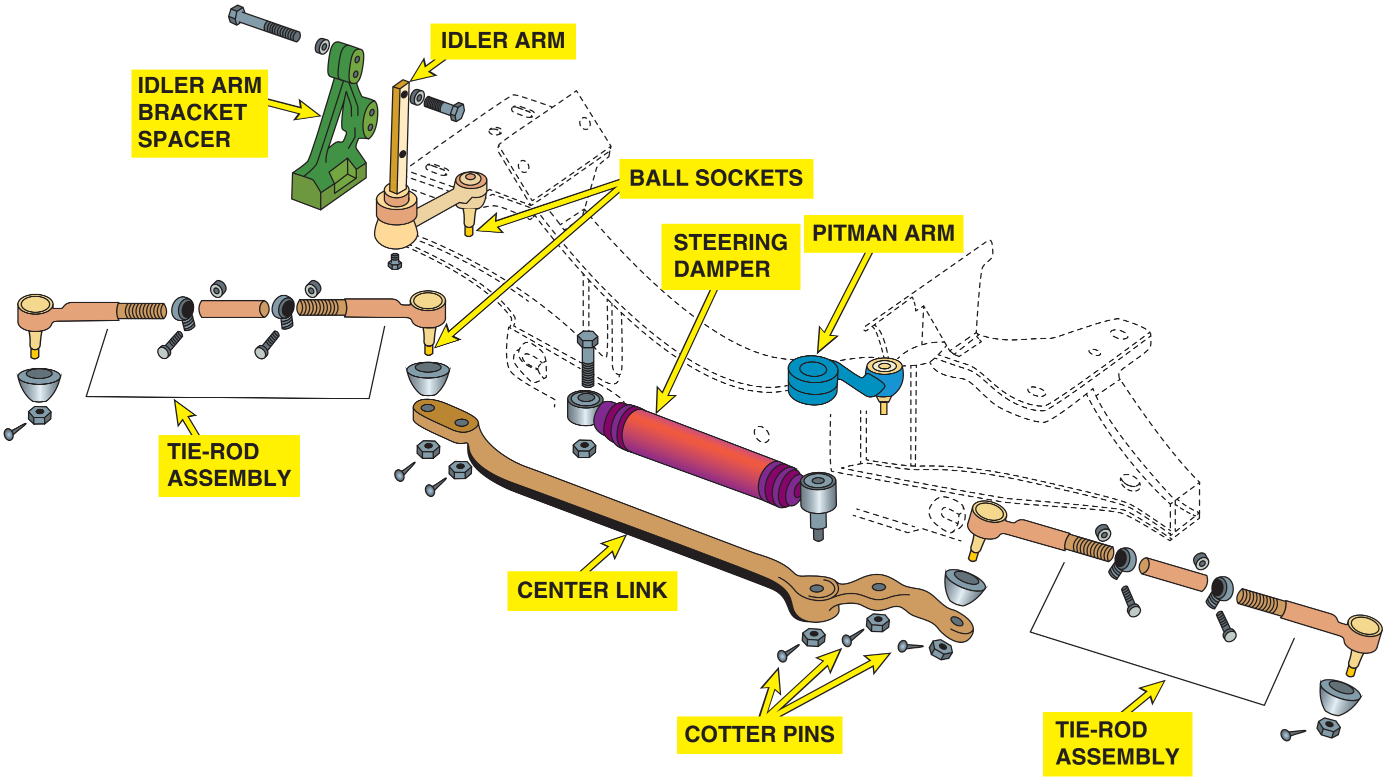

IDLER ARM
IDLER ARM BRACKET SPACER
BALL SOCKETS
STEERING DAMPER
PITMAN ARM
TIE-ROD ASSEMBLY
CENTER LINK
COTTER PINS
TIE-ROD ASSEMBLY

FIGURE 116–1 Steering movement is transferred from the pitman arm that is splined to the sector shaft (pitman shaft), through the center link and tie rods, to the steering knuckle at each front wheel. The idler arm supports the passenger side of the center link and keeps the steering linkage level with the road. This type of linkage is called a parallelogram-type design.

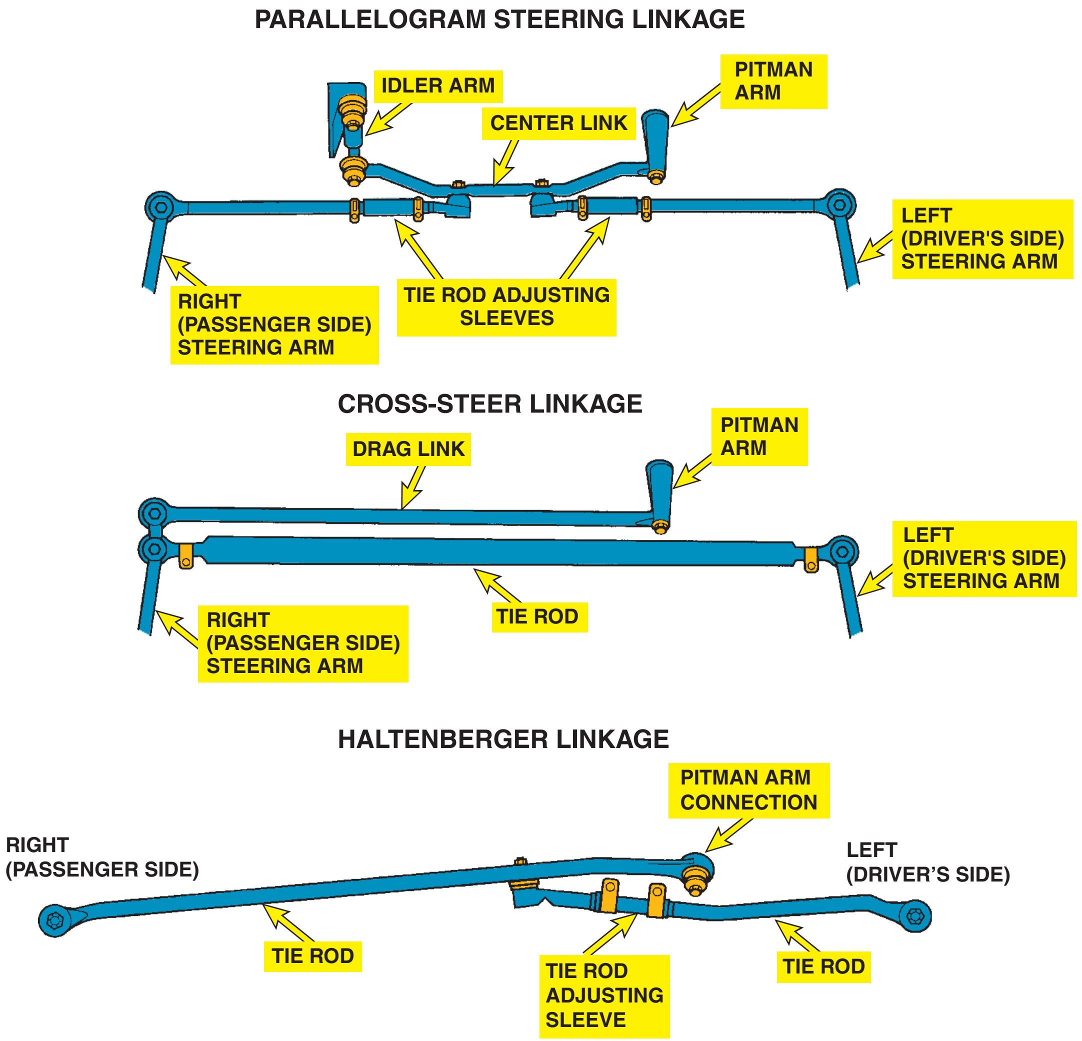

PARALLELOGRAM STEERING LINKAGE
IDLER ARM
PITMAN ARM
CENTER LINK
LEFT (DRIVER'S SIDE) STEERING ARM
RIGHT (PASSENGER SIDE) STEERING ARM
TIE ROD ADJUSTING SLEEVES
CROSS-STEER LINKAGE
DRAG LINK
PITMAN ARM
LEFT (DRIVER'S SIDE) STEERING ARM
TIE ROD
RIGHT (PASSENGER SIDE) STEERING ARM
HALTENBERGER LINKAGE
PITMAN ARM CONNECTION
RIGHT (PASSENGER SIDE)
LEFT (DRIVER'S SIDE)
TIE ROD
TIE ROD ADJUSTING SLEEVE
TIE ROD

FIGURE 116–2 The most common type of steering is the parallelogram. The cross-steer and Haltenberger linkage designs are used on some trucks and vans.

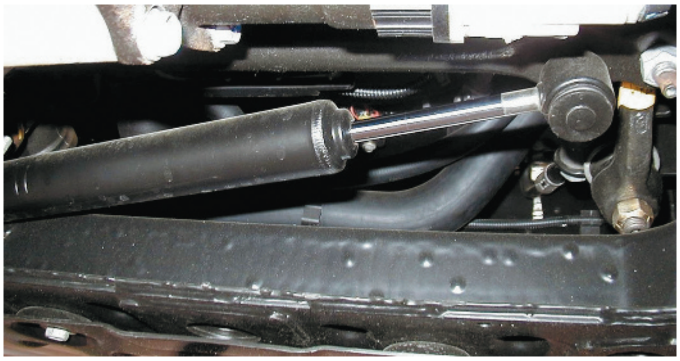


FIGURE 116–3 Typical steering dampener used on a Hummer H2.

Connections between all steering component parts are constructed of small ball-and-socket joints. These joints allow side-to-side movement to provide steering of both front wheels, and allow the joints to move up and down, which is required for normal suspension travel.

It is important that all of these joints be lubricated with chassis grease through a **grease fitting**, also called a **zerk fitting**, at least every six months or per the vehicle manufacturer's specifications.

Some vehicles come equipped with sealed joints and do not require periodic servicing. Some vehicles come from the factory with plugs that need to be removed and replaced with grease fittings and then lubricated.

TIE ROD ENDS Tie rod ends connect the steering linkage to the steering knuckles and to other steering linkage components. Conventional tie rod ends use a hardened steel ball stud assembled into a hardened steel and thermoplastic bearing. An internal preload spring limits the ball stud endplay and helps compensate for ball-and-socket wear. ● **SEE FIGURE 116–4** for two designs of tie rod ends.

For many years, Ford Motor Company used tie rod ends that included a rubber-bonded steel ball stud. Because there is no sliding friction inside the tie rod end, no lubrication was needed. This type of tie rod end is called **RBS (rubber-bonded socket)**. ● **SEE FIGURE 116–5**.

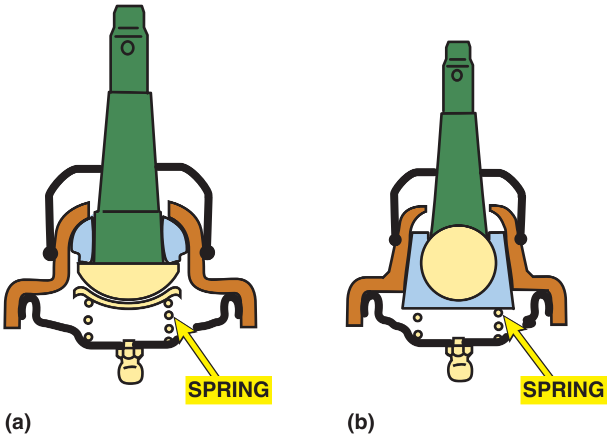


FIGURE 116–4 (a) A dual bearing design with a preload spring. The use of two bearing surfaces allows one surface for rotation (for steering) and another surface for pivoting (to allow for suspension up-and-down movement). (b) The nylon wedge bearing type allows for extended lube intervals. Wear is automatically compensated for by the tapered design and spring-loaded bearing.

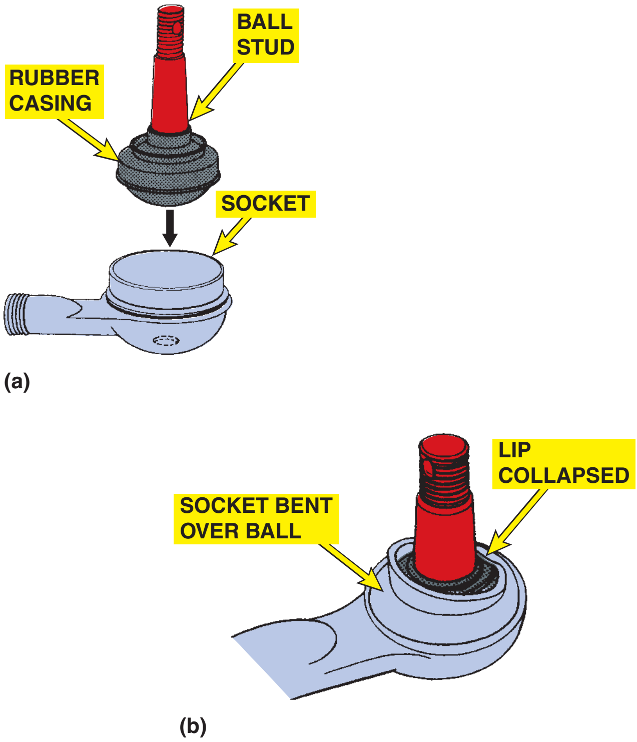


FIGURE 116–5 (a) A rubber-bonded socket is constructed of a rubber casing surrounding the ball stud, which is then inserted into the socket of the tie rod end. The hole in the socket allows air to escape as the ball stud is installed and there is not a place for a grease fitting. (b) The socket is crimped over the ball so that part of the socket lip retains the stud.

RACK-AND-PINION INNER TIE ROD ENDS

TERMINOLOGY Inner tie rod end assemblies used on rack-and-pinion steering units require special consideration and often special tools. The inner tie rod end is also called a **ball socket assembly**.

The inner tie rod assemblies are attached to the end of the steering rack by one of several methods. ● **SEE FIGURE 116–6**.

STAKED This method is common on Saginaw-style rack-and-pinion steering units found on General Motors vehicles.

The flange around the outer tie rod must be restaked to the flat on the end of the rack.

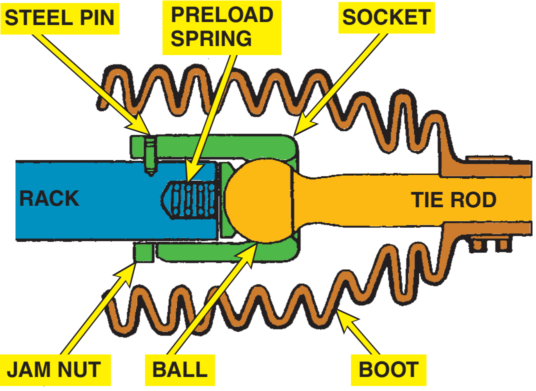


FIGURE 116–6 Rack-and-pinion steering systems use a ball-and-socket-type inner tie rod end.

RIVETED OR PINNED This method is commonly found on Ford vehicles. Some roll pins require a special puller, or the pin can be drilled out. Many styles use an aluminum rivet. A special, very deep socket or a large open-end wrench can usually be used to shear the aluminum rivet by unscrewing the socket assembly from the end of the rack while the rack-and-pinion unit is still in the vehicle. ● **SEE FIGURE 116–7**.

CENTER TAKE-OFF RACKS For the **center take-off racks**, use bolts to secure the inner tie rods to the rack, as shown in ● **FIGURE 116–8**.

FRONT STEER VERSUS REAR STEER **Front steer**, also called *forward steer*, is the term used to describe a vehicle that has the steering gear in front of the front wheel centerline. Having the steering gear located in this position improves handling and directional stability, especially when the vehicle is heavily loaded.

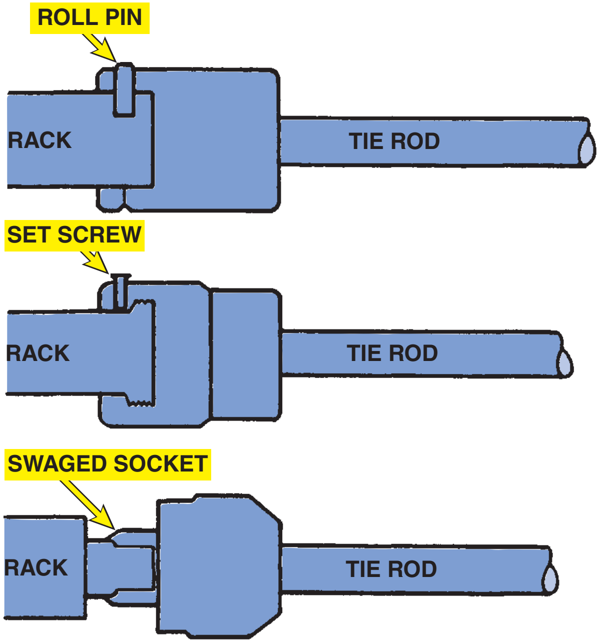


FIGURE 116–7 A variety of methods are used to secure the inner tie rod end socket assembly to the end of the rack.

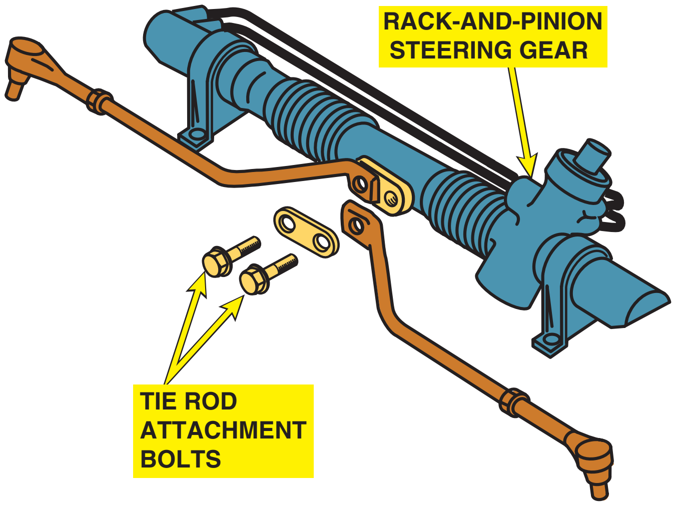


FIGURE 116–8 Exploded view of a center-take-off-style rack-and-pinion steering gear assembly.

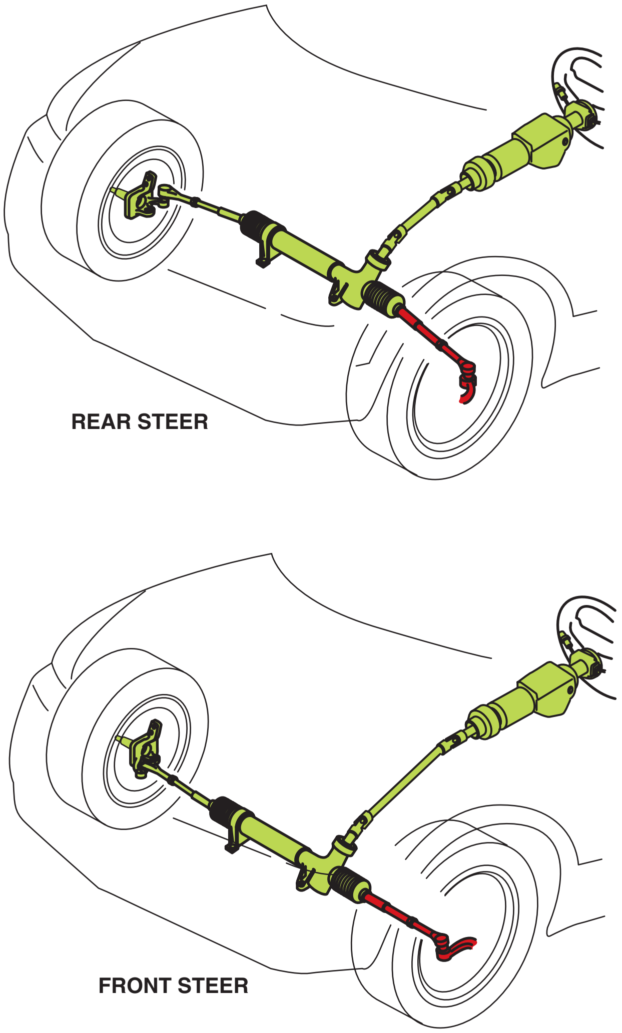


FIGURE 116–9 In a rear-steer vehicle, the steering linkage is behind the centerline of the front wheels, whereas the linkage is in front on a front-steer vehicle.

Front-steer vehicles usually produce an understeer effect that makes the vehicle feel very stable while cornering. If the steering gear linkage is located behind the wheels, it is called **rear steer** and the cornering forces are imposed on the steering in the direction of the turn. This is an oversteer effect. It tends to make the steering easier and makes the vehicle feel less stable.

Most front-wheel-drive vehicles are rear steering, with the rack-and-pinion steering unit attached to the bulkhead or sub-frame behind the engine. ● **SEE FIGURE 116–9**.

FOUR-WHEEL STEERING SYSTEMS

TERMINOLOGY Some vehicles were equipped with a system that steers all four wheels. Two terms are commonly used when discussing four-wheel steering:

1. **Same-phase steering**. **Same-phase steering** means that the front and rear wheels are steered in the same direction. Same-phase steering improves steering response, especially during rapid-lane-change-type maneuvers.
2. **Opposite-phase steering.** Also called *negative-phase mode*, **opposite-phase steering** is when the front wheels

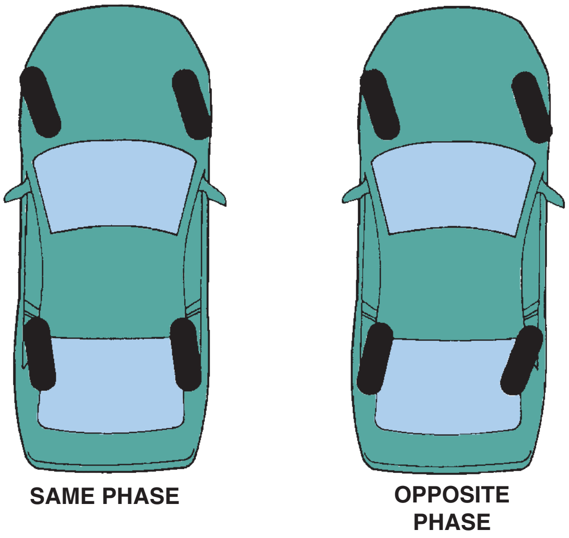


FIGURE 116–10 Opposite-phase four-wheel steer is usually used only at low vehicle speed to help in parking maneuvers. Same-phase steering helps at higher speeds and may not be noticeable by the average driver.

and rear wheels are steered in the opposite direction. ● **SEE FIGURE 116–10**. Opposite-phase steering will quickly change the vehicle's direction, but may cause a feeling of oversteering.

Opposite-phase steering is best at low speeds; same-phase steering is best for higher-speed handling and lane-change maneuvers.

STEERING LINKAGE LUBRICATION

Keeping all joints equipped with a grease fitting properly greased is necessary for long life and ease of steering. ● **SEE FIGURE 116–11**.

During a chassis lubrication, do not forget to put grease on the *steering stop,* if so equipped. **Steering stops** are the projections or built-up areas on the control arms of the front suspension designed to limit the steering movement at full lock. ● **SEE FIGURE 116–12**.

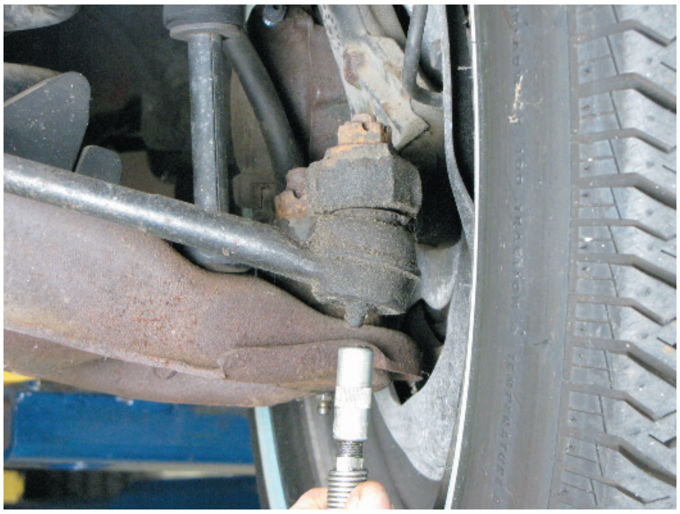


FIGURE 116–11 Greasing a tie rod end. Some joints do not have a hole for excessive grease to escape, and excessive grease can destroy the seal.

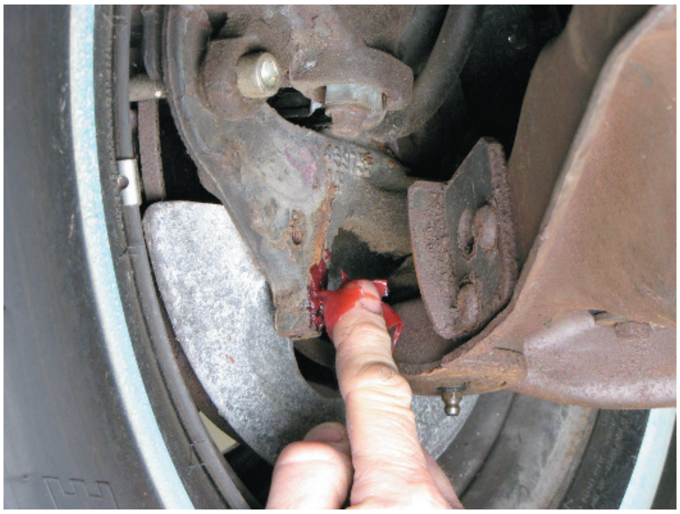


FIGURE 116–12 Part of steering linkage lubrication is applying grease to the steering stops. If these stops are not lubricated, a grinding sound may be heard when the vehicle hits a bump when the wheels are turned all the way one direction or the other. This often occurs when driving into or out of a driveway that has a curb.

When the steering wheel is turned as far as it can go, the steering should *not* stop inside the steering gear. Forces exerted by the power steering system can do serious damage to the steering gear if absorbed by the steering gear rather than the steering stop.

NOTE: Many rack-and-pinion steering units are designed with a rack-travel-limit internal stop and do not use an external stop on the steering knuckle or control arm.

Most steering stops are designed so that the lower control arm hits a small section of the body or frame when the steering wheel is turned to the full "lock" position. Steering stops should be lubricated to prevent a loud grinding noise when turning while the vehicle is going over a bump. This noise is usually noticeable when turning into or out of a driveway.

DRY PARK TEST

PURPOSE Since many steering (and suspension) components do *not* have exact specifications for replacement purposes, it is extremely important that the beginning service technician work closely with an experienced veteran technician. While most technicians can determine when a steering component such as a tie rod end is definitely in need of replacement, marginally worn parts are often hard to spot and can lead to handling problems. One of the most effective, yet easy to perform, steering component inspection methods is called the **dry park test**.

Excessive play in the steering wheel can be caused by worn or damaged steering components. Looseness in the steering components usually causes freeplay in the steering wheel. Freeplay refers to the amount of movement of the steering wheel required to cause movement of the front wheels. The exact cause of freeplay in the steering should be determined if the freeplay exceeds 2 inch (5 cm) for parallelogram-type steering

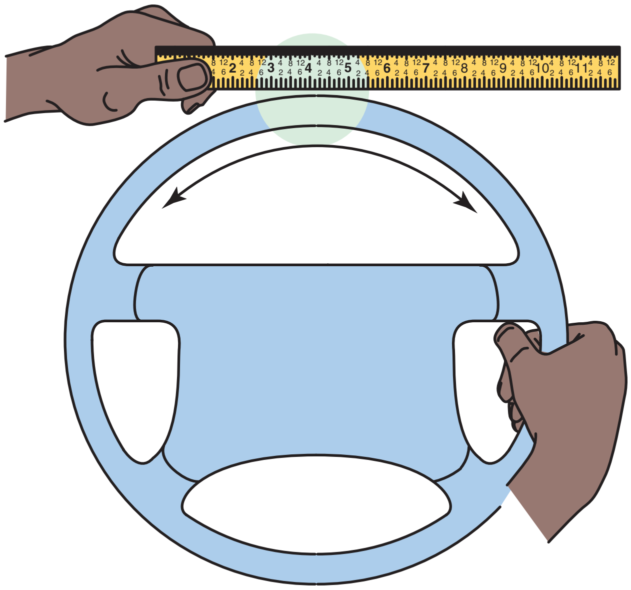


FIGURE 116–13 Checking for freeplay in the steering.

linkages, or 3/8 inch (1 cm) for rack-and-pinion steering. ● **SEE FIGURE 116–13**.

This simple test is performed with the vehicle on the ground or on a drive-on ramp-type hoist, moving the steering wheel back and forth *slightly* while an assistant feels for movement at each section of the steering system. The technician can start checking for any looseness in the steering linkage starting either at the outer tie rod ends and working toward the steering column, or from the steering column toward the outer tie rod ends. It is important to check each and every joint and component of the steering system, including the following:

1. The intermediate shaft and flexible coupling.
2. All steering linkage joints, including the inner tie rod end ball socket. ● **SEE FIGURE 116–14**.
3. Steering gear mounting and rack-and-pinion mounting bushings.

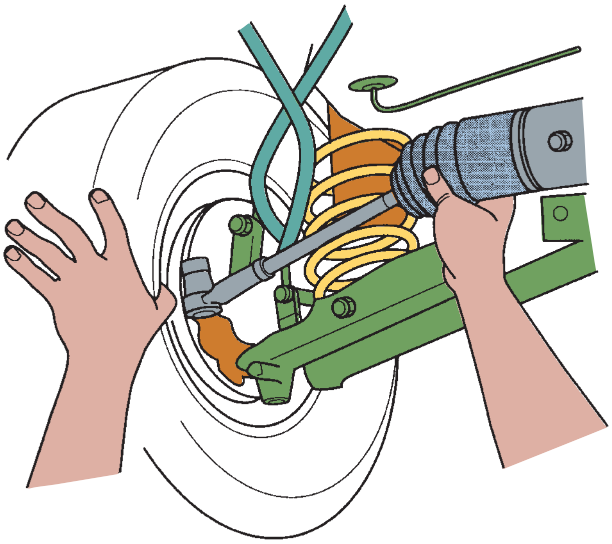


FIGURE 116–14 All joints should be felt during a dry park test. Even inner tie rod ends (ball socket assemblies) can be felt through the rubber bellows on many rack-and-pinion steering units.

FREQUENTLY ASKED QUESTION

Why Do Only a Few Vehicles Use Grease Fittings?

Many years ago, all vehicles were equipped with grease fittings, while today very few vehicles are so equipped. The reasons for this, as given by engineers, include the following:

- It has been determined that the use of the wrong type of grease can cause more harm than good.
- If a grease fitting is used to allow grease to enter the suspension or steering joint, then water can also get inside the joint.
- Grease fittings are often ignored or the greasing of the joint is not performed by the service technician.
- Low-friction joints do not require routine service like the older metal-to-metal joints required.

TECH TIP

Jounce/Rebound Test

All steering linkage should be level and "work" at the same angle as the suspension arms, as shown in ● **FIGURE 116–15**. A simple test to check these items is performed as follows:

1. Park on a hard, level surface with the wheels straight ahead and the steering wheel in the *unlocked* position.
2. Bounce (jounce) the vehicle up and down at the front bumper while watching the steering wheel.

The steering wheel should *not* move during this test. If the steering wheel moves while the vehicle is being bounced, look for a possible bent steering linkage, suspension arm, or steering rack. ● **SEE FIGURE 116–16**.

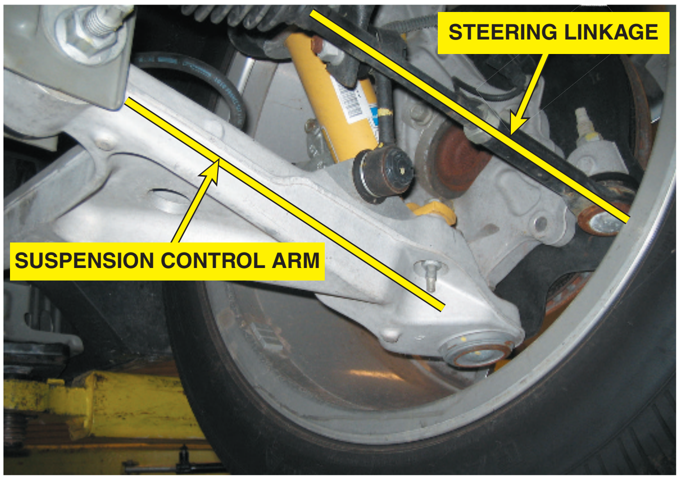


FIGURE 116–15 The steering and suspension arms must remain parallel to prevent the up-and-down motion of the suspension from causing the front wheels to turn inward or outward.

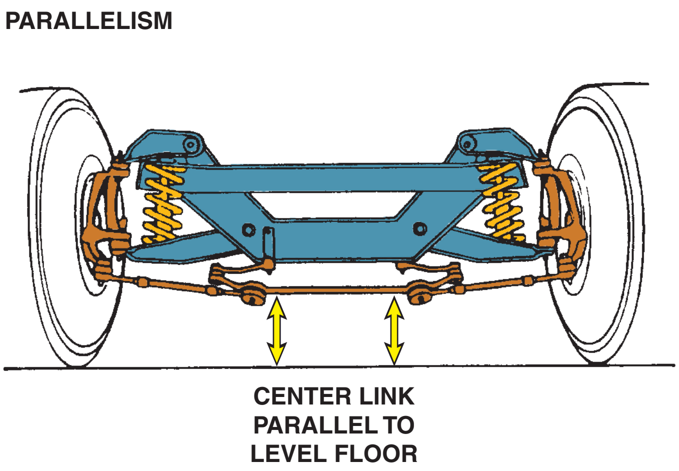


FIGURE 116–16 The center link should be parallel to the ground.

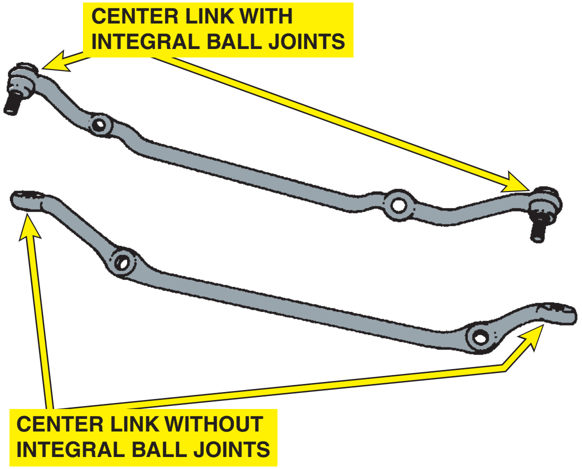


FIGURE 116–17 Some center links have ball joints while others have tapered socket holes to accept ball joints on the pitman arm, idler arm, and inner tie rod ends.

TECH TIP

Wear and Nonwear Center Links

Some center links are equipped with ball-and-socket joints, which can wear. Other center links are manufactured with holes for ball-joint studs only. ● **SEE FIGURE 116–17**. Generally, the center links that do not use joints are unlikely to need replacement unless a joint becomes loose and wears the tapered stud hole. Knowing which style of center link is used will help determine the most likely location to check for excessive steering linkage play.

UNDER-VEHICLE INSPECTION

After checking the steering system components as part of a dry park test, hoist the vehicle and perform a thorough part-by-part inspection:

1. Inspect each part for damage due to an accident or bent parts due to the vehicle hitting an object in the roadway.

CAUTION: Never straighten a bent steering linkage; always replace with new parts.

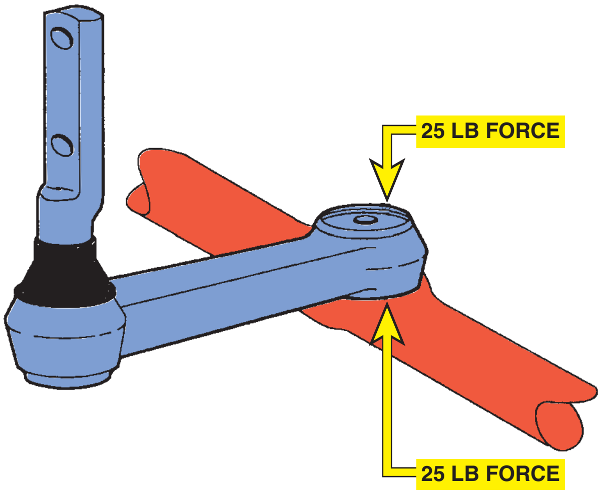


FIGURE 116–18 To check an idler arm, most vehicle manufacturers specify that 25 pounds of force be applied by hand up and down to the idler arm. The idler arm should be replaced if the total movement (up and down) exceeds 1/4 inch (6 mm).

2. Idler arm inspection is performed by using *hand* force of 25 pounds (110 N-m) up and down on the arm. If the *total* movement exceeds 1/4 inch (6 mm), the idler arm should be replaced. ● **SEE FIGURE 116–18**.
3. All other steering linkage should be tested *by hand* for any vertical or side-to-side looseness. Tie rod ends use ball-and-socket joints to allow for freedom of movement for suspension travel and to transmit steering forces to the front wheels. It is therefore normal for tie rods to rotate in their sockets when the tie rod sleeve is rocked. **Endplay in any tie rod should be zero**. Many tie rods are spring loaded to help keep the ball-and-socket joint free of play as the joint wears. Eventually, the preloaded spring cannot compensate for the wear, and endplay occurs in the joint. ● **SEE FIGURES 116–19 AND 116–20**.
4. All steering components should be tested with the wheels in the straight-ahead position. If the wheels are turned, some apparent looseness may be noticed due to the angle of the steering linkage.

CAUTION: Do not turn the front wheels of the vehicle while suspended on a lift to check for looseness in the steering linkage. The extra leverage of the wheel and tire assembly can cause a much greater force to be applied to the steering components than can be exerted by hand alone. This extra force may cause some apparent movement in good components that may not need replacement.

TECH TIP

The Killer Bs

The "three Bs" that can cause steering and suspension problems are bent, broken, or binding components. Always inspect each part under the vehicle for each of the killer Bs.

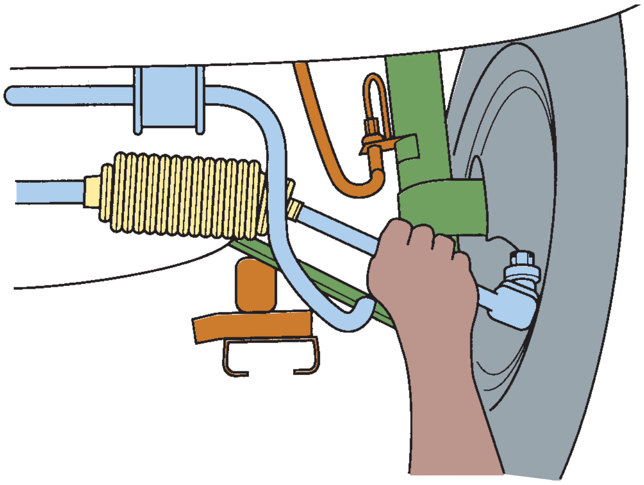


FIGURE 116–19 Steering system component(s) should be replaced if any noticeable looseness is detected when moved by hand.

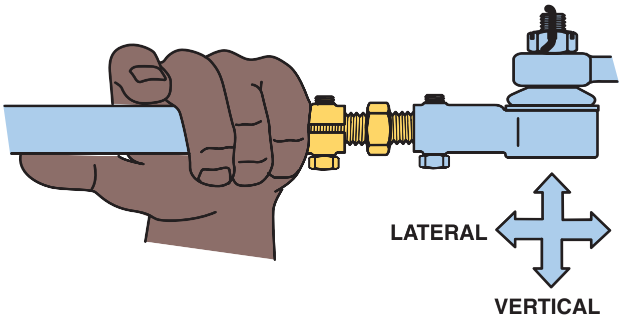


FIGURE 116–20 All joints should be checked by hand for any lateral or vertical play.

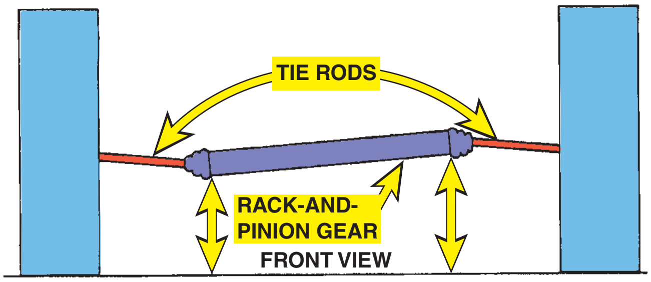


FIGURE 116–21 If a rack-and-pinion or any other steering linkage system is not level, the front tires will be moved inward and/or outward whenever the wheels of the vehicle move up or down.

STEERING LINKAGE REPLACEMENT

PARALLELOGRAM TYPE When replacing any steering system component, it is best to replace all defective and marginally good components at the same time. Use the following guidelines.

Parts that can be replaced *individually* include the following:

Idler arm
Center link
Pitman arm
Intermediate shaft
Intermediate shaft U-joint

CASE STUDY

Bump Steer

Bump steer, or orbital steer, is used to describe what happens when the steering linkage is not level. The front tires turn inward or outward as the wheels and suspension move up and down. (Automotive chassis engineers call it roll steer.) The vehicle's direction is changed without moving the steering wheel whenever the tires move up and down over bumps, dips in the pavement, or even over gentle rises!

This author experienced bump steer once and will never forget the horrible feeling of not having control of the vehicle. After replacing an idler arm and aligning the front wheels, everything was normal until about 40 MPH (65 km/h); then the vehicle started darting from one lane of the freeway to another. Because there were no "bumps" as such, bump steer was not considered as a cause. Even when holding the steering wheel perfectly still and straight ahead, the vehicle would go left, then right. Did a tie rod break? It certainly felt exactly like that's what happened. I slowed down to below 30 MPH and returned to the shop.

After several hours of checking everything, including the alignment, I discovered that the idler arm was not level with the pitman arm. This caused a pull on the steering linkage whenever the suspension moved up and down. As the suspension compressed, the steering linkage pulled inward on the tie rod on that side of the vehicle. As the wheel moved inward (toed in), it created a pull just as if the wheel were turned by the driver.

This is why all steering linkages must be parallel with the lower control. The reason for the bump steer was that the idler arm was bolted to the frame, which was slotted vertically. I didn't pay any attention to the location of the original idler arm and simply bolted the replacement to the frame. After raising the idler arm back up where it belonged (about 1/2 inch [13 mm]), the steering problem was corrected.

Other common causes of bump steer are worn or deteriorated rack mounting bushings, a noncentered steering linkage, or a bent steering linkage. If the steering components are not level, any bump or dip in the road will cause the vehicle to steer one direction or the other. ● **SEE FIGURE 116–21**.

Summary:

Complaint—Driver complained that the vehicle pulled to one lane and then the other when driving over a rough section of road.

Cause—The idler arm was not installed in the correct location to prevent bump steer.

Correction—The idler arm was installed correctly and the bump steer was corrected.

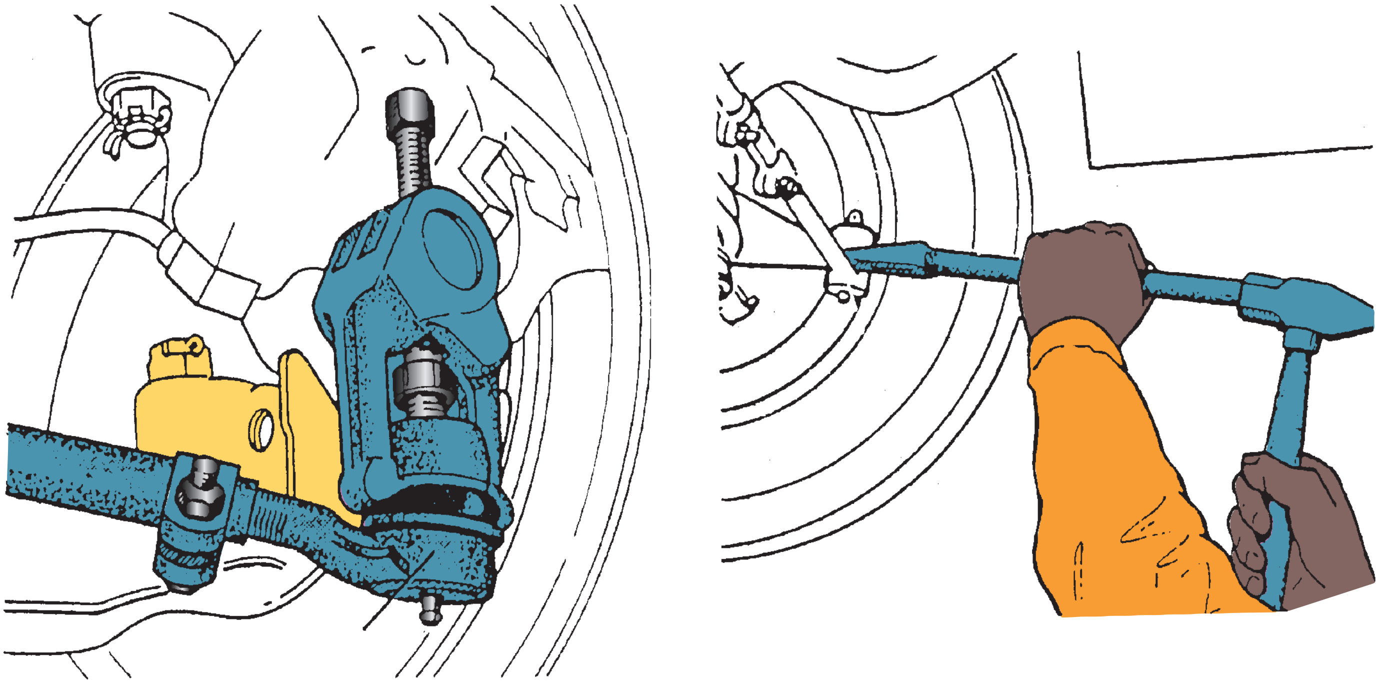


FIGURE 116–22 The preferred method for separating the tie rod end from the steering knuckle is to use a puller such as the one shown. A pickle-fork-type tool should only be used if the tie rod end is going to be replaced. A pickle-fork-type tool can damage or tear the rubber grease boot.

Parts that should be replaced in *pairs only* include the following:

Outer tie rod ends

Inner tie rod ends

Idler arm (if there are two on the same vehicle, such as GM's Astro van)

Replacing steering system components involves these steps:

STEP 1 Hoist the vehicle safely with the wheels in the straight-ahead position. Remove the front wheels, if necessary, to gain access to the components.

STEP 2 Loosen the retainer nut on tapered components, such as tie rod ends. Use a tie rod removal puller (also called a *taper breaker*), as shown in ● **FIGURE 116–22** or use hammers to slightly deform the taper, as shown in ● **FIGURE 116–23**.

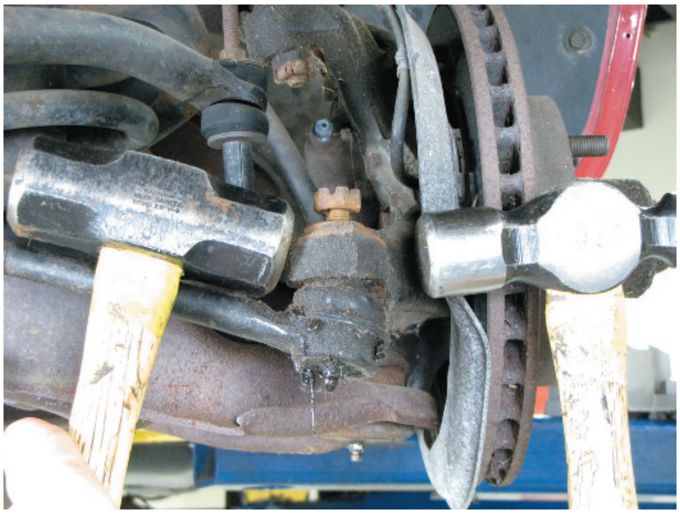


FIGURE 116–23 Two hammers being used to disconnect a tie rod end from the steering knuckle. One hammer is used as a backing for the second hammer. Notice that the attaching nut has been loosened, but not removed. This prevents the tie rod end from falling when the tapered connection is knocked loose.

CAUTION: Vehicle manufacturers often warn not to use a tapered pickle-fork tool to separate tapered parts. The wedge tool can tear the grease seal and damage both the part being removed and the adjoining part.

Pitman arms require a larger puller to remove the pitman arm from the splines of the pitman shaft. ● **SEE FIGURES 116–24 AND 116–25**.

STEP 3 Replace the part using the hardware and fasteners supplied with the replacement part. *Do not reuse the precrimped prevailing torque nuts used at the factory as original equipment on many tie rod ends*.

CAUTION: Whenever tightening the nuts of tapered parts such as tie rods, *DO NOT* loosen after reaching the proper

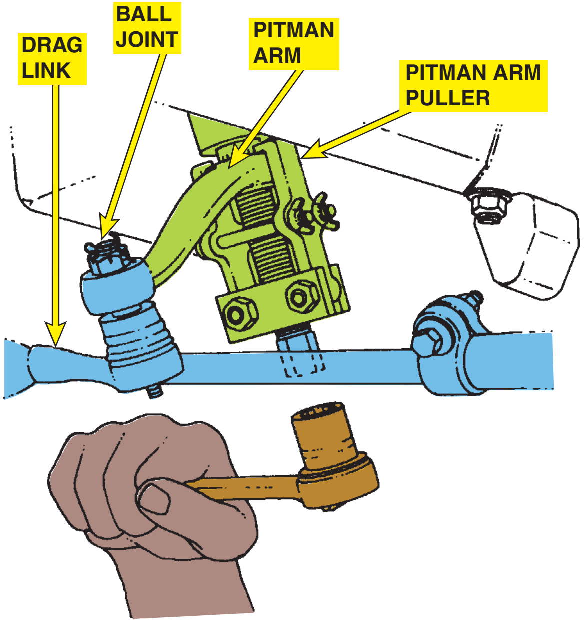


FIGURE 116–24 A pitman arm puller is used to remove the pitman arm from the pitman shaft.

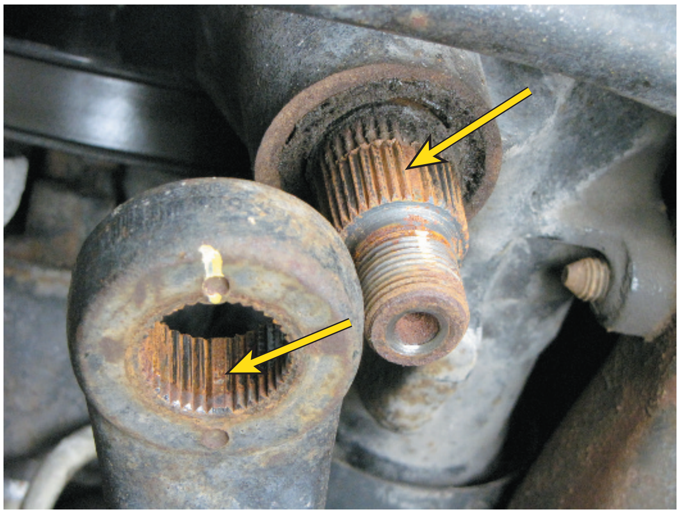


FIGURE 116–25 Pitman arm and pitman shaft indexing splines.

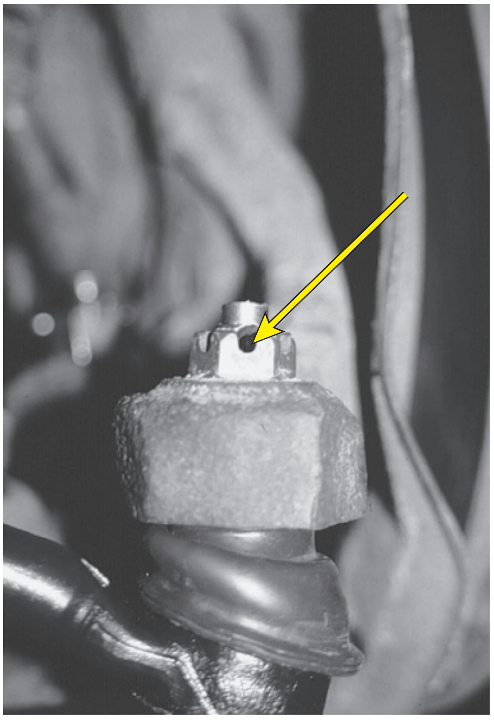


FIGURE 116–26 Align the hole in the tie rod end with the slot in the retaining nut. If the holes do not line up, always tighten the nut farther (never loosen) until the hole lines up.

assembly torque to align the cotter key hole. If the cotter key does not fit, *tighten* the nut farther until the hole lines up for the cotter key. ● SEE FIGURE 116–26. Always use a new cotter key.

When replacing tie rod ends, use the adjusting sleeve to adjust the total length of the tie rod to the same position and length as the original. Measure the original length of the tie rods and assemble the replacement tie rod(s) to the same overall length. ● **SEE FIGURE 116–27**.

When positioning the tie rod end(s), check that the stud is centered in the socket, as shown in ● **FIGURE 116–28**. This permits maximum steering linkage movement without getting into a bind if the steering linkage is pivoted beyond the angle the tie rod end can move in the socket.

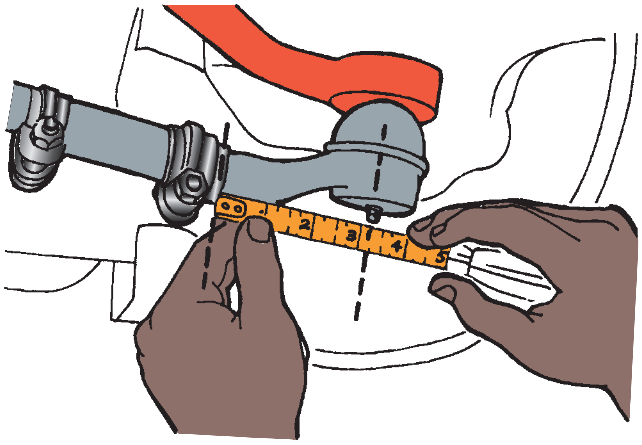


FIGURE 116–27 Replacement tie rods should be of the same overall length as the originals. Measure from the edge of the tie rod sleeve to the center of the grease fitting. When the new tie rod is threaded to this dimension, the toe setting will be close to the original.

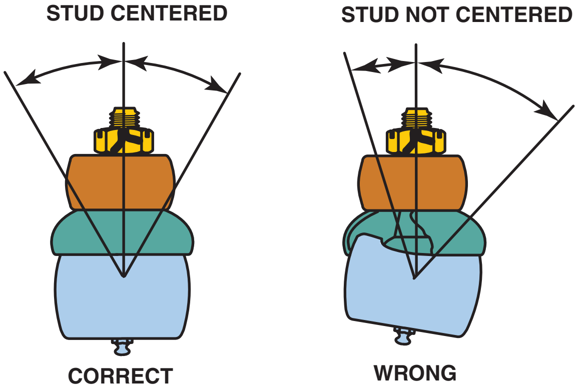


FIGURE 116–28 All tie rod ends should be installed so that the stud is in the center of its operating range, as shown.

NOTE: To ensure proper wheel alignment, install the adjusting sleeve with an equal number of threads showing at each end of the sleeve. Some manufacturers also specify a *minimum* of three threads showing at each end. If the sleeve itself is corroded or bent, it should be replaced along with either or both of the tie rod ends (inner and outer). ● SEE FIGURE 116–29.

SERVICE OF BALL SOCKET ASSEMBLIES Inner tie rod end assemblies used on rack-and-pinion steering units require special consideration and often special tools. The inner tie rod end, also called a ball socket assembly, should be replaced whenever there is any noticeable freeplay in the ball-and-socket joint. Another test of this joint is performed by disconnecting the outer tie rod end and measuring the effort required to move the tie rod in the socket, as shown in ● **FIGURE 116–30**. This is called the **articulation test**.

NOTE: The articulation test is to be used on metal-tometal ball socket assemblies. Low-friction joints (polished ball and plastic liner-type joints) may require less effort to move and still be serviceable.

The inner tie rod assemblies are attached to the end of the steering rack by one of several methods.

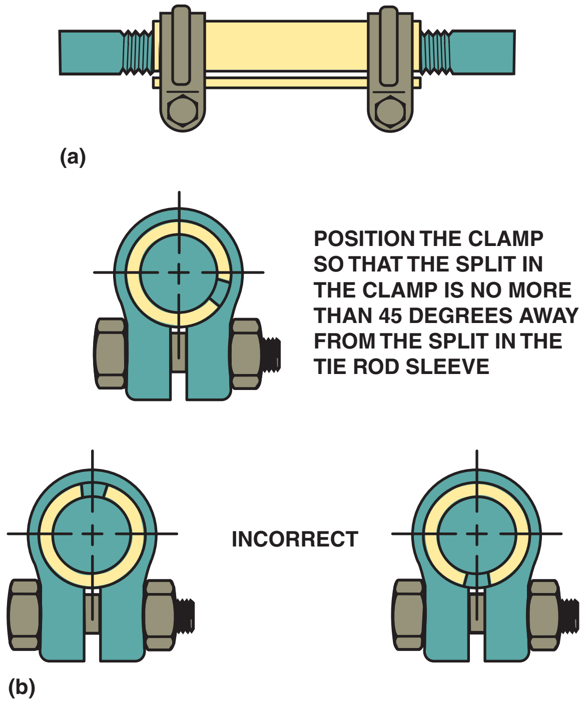

(a)
POSITION THE CLAMP SO THAT THE SPLIT IN THE CLAMP IS NO MORE THAN 45 DEGREES AWAY FROM THE SPLIT IN THE TIE ROD SLEEVE
INCORRECT
(b)

FIGURE 116–29 (a) Tie rod adjusting sleeve. (b) Be sure to position the clamp correctly on the sleeve.

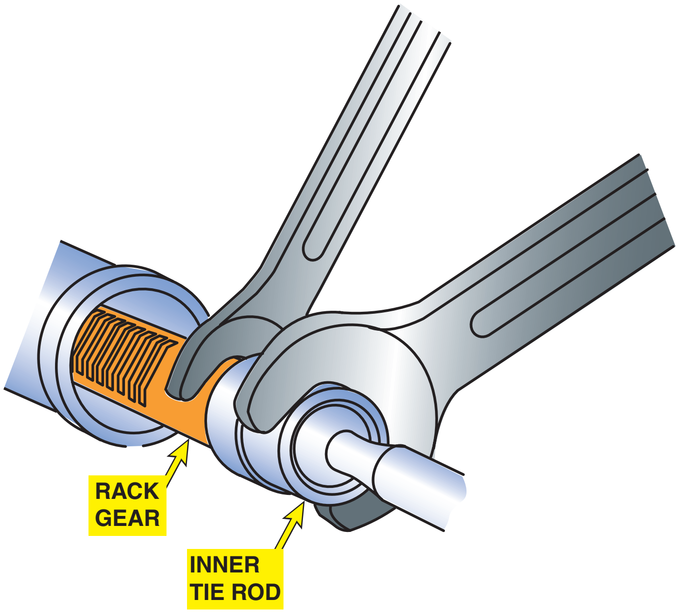

RACK GEAR
INNER TIE ROD

FIGURE 116–31 Removing a staked inner tie rod assembly requires two wrenches—one to hold the rack and the other to unscrew the joint from the end of the steering rack.

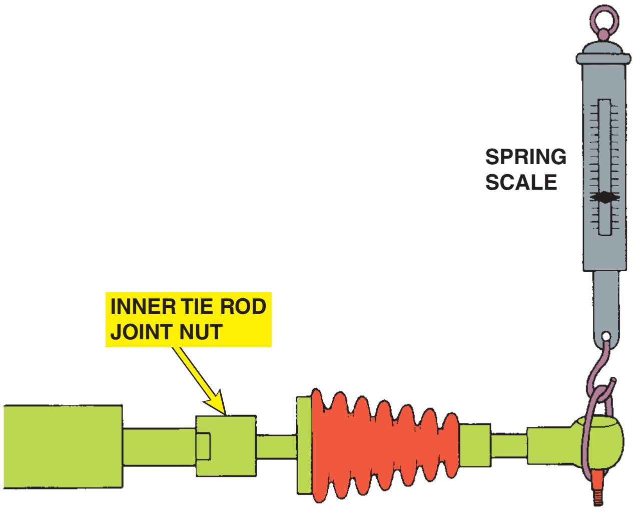

SPRING SCALE
INNER TIE ROD JOINT NUT

FIGURE 116–30 An articulation test uses a spring scale to measure the amount of force needed to move the tie rod in the ball socket assembly. Most manufacturers specify a minimum of 1 pound (4.4 N) of force and a maximum of 6 pounds (26 N).

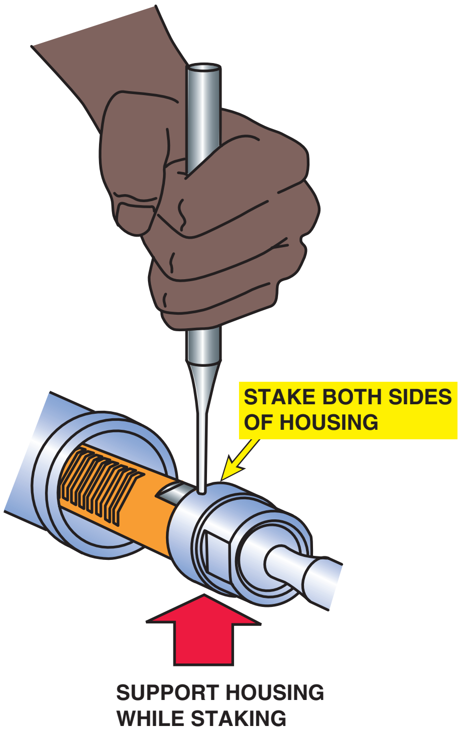

STAKE BOTH SIDES OF HOUSING
SUPPORT HOUSING WHILE STAKING

FIGURE 116–32 When the inner tie rod end is reassembled, both sides of the housing must be staked down onto the flat shoulder of the rack.

Removing a ball socket assembly usually requires the use of two wrenches or a special tool. ● **SEE FIGURE 116–31**.

The flange around the outer tie rod must be restaked to the flat shoulder on the end of the rack, as shown in ● **FIGURE 116–32**.

Always follow the instructions that come with the replacement part(s). ● **SEE FIGURE 116–33**.

NOTE: When replacing a rack-and-pinion assembly, specify an entire replacement rack-and-pinion assembly if possible. A short rack does not include the bellows (boots) or inner tie rod ends (ball socket assemblies). The labor and cost required to exchange or replace these parts usually make it easier and less expensive to replace the entire steering unit.

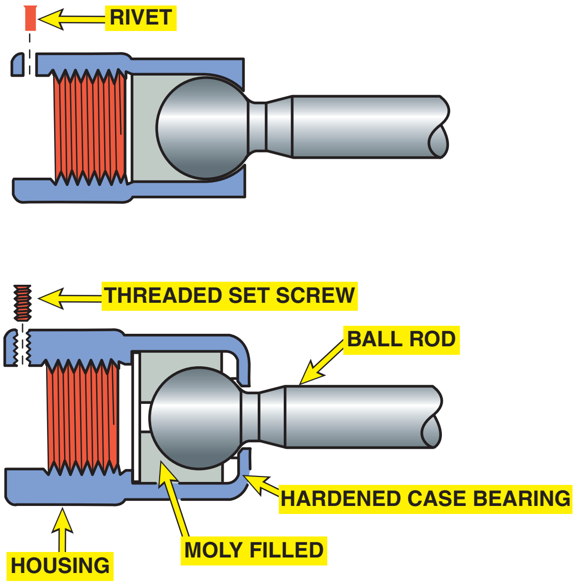


FIGURE 116–33 After replacing an inner tie rod end, the socket assembly should be secured with a rivet or set screw depending on the style of the replacement part.

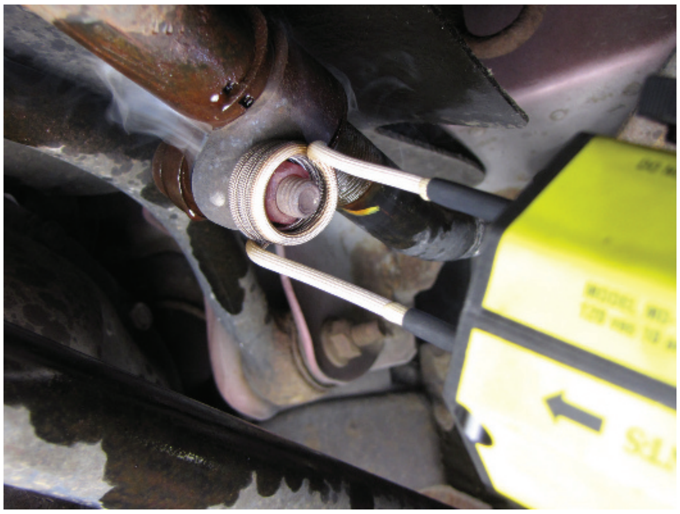


FIGURE 116–34 Using an inductive heater caused this retaining nut to be cherry red in a just a few seconds.

TECH TIP

Inductive Heating Tool

Fasteners are often rusted and difficult to remove especially those that are part of the steering system where they are exposed to road moisture, dirt, and debris. A heating tool, such as the Mini-Ductor, which uses electrical induction to heat a coil at the tip, is the tool that many experts recommend to use when heating of a fastener is needed. Using this tool allows a technician to heat a part quickly without the hazard of using an open flame. ● **SEE FIGURE 116–34**.

DRY PARK TEST

STEP BY STEP

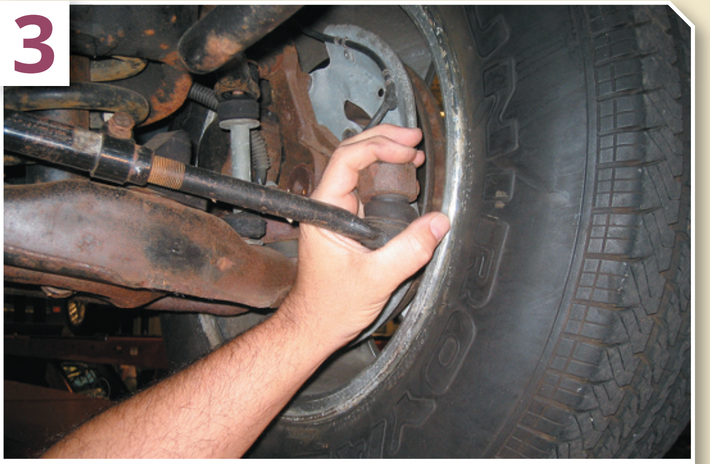
1

Drive the vehicle onto a drive-on-type hoist and have an assistant gently rotate the steering wheel back and forth about 2 inches (50 mm).

2

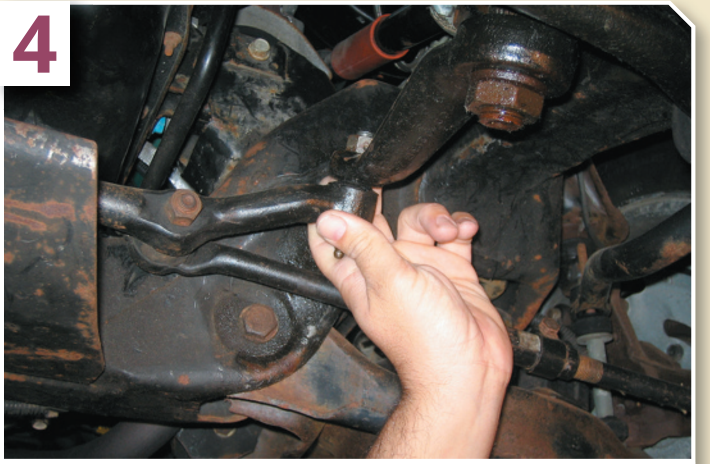
Perform a visual inspection of the steering and suspension system, looking for damage from road debris or other faults.

3



As the assistant wiggles the steering wheel, grasp the joint at the outer tie rod end on the driver's side to check for any movement.

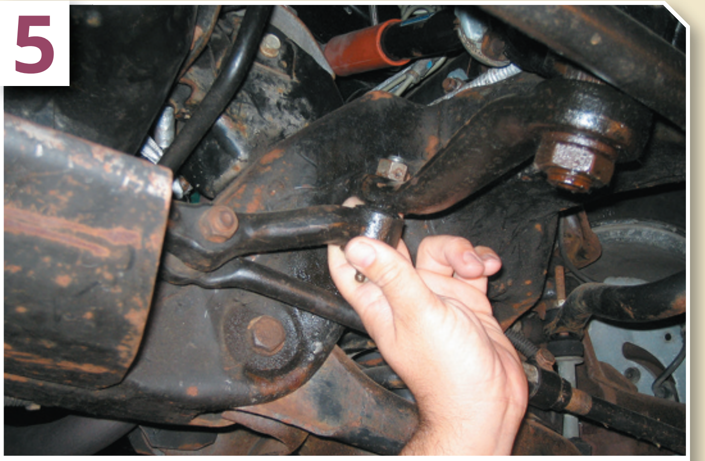
4



Next, check for any freeplay at the pitman arm.

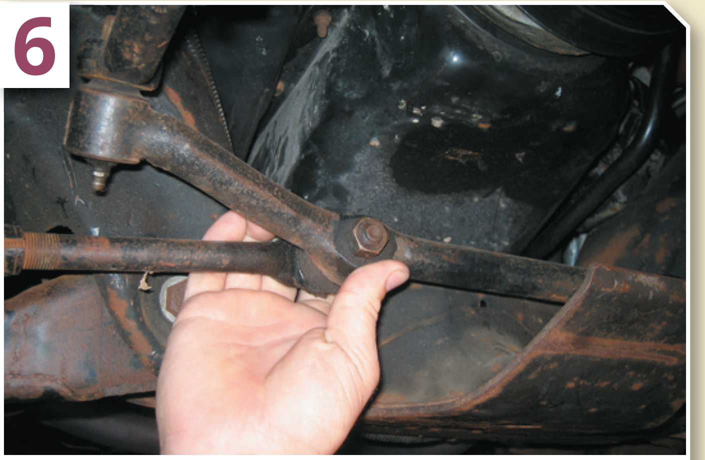
DRY PARK TEST

5



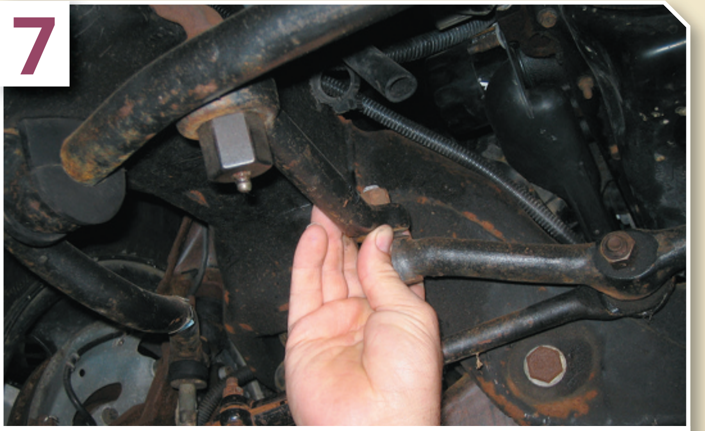
Check the joint between the left inner tie rod end and the center link for play.

6



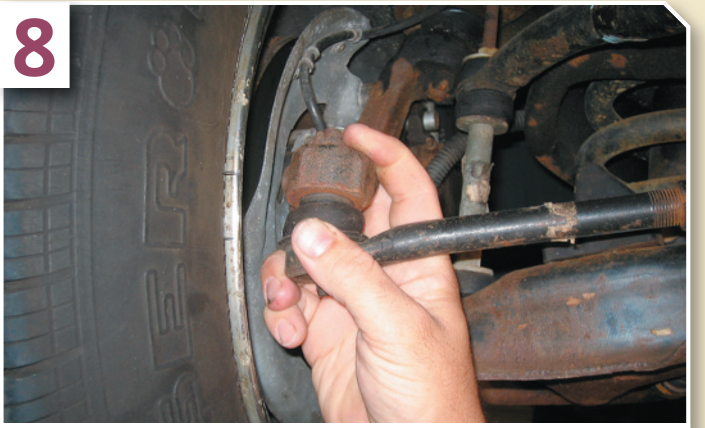
Move to the passenger side and check for any looseness at the joint between the center link and the right-side inner tie rod end.

7



Check for looseness at the idler arm connector to the center link and the idler arm at the frame mount.

8



Check for looseness at the passenger-side outer tie rod end. After the inspection, record the results on the work order.

REVIEW QUESTIONS

1. How is a dry park test performed?
2. What steering parts should be replaced in pairs?
3. What test procedure can be used to check that the steering linkage is straight and level?
4. What is the difference between a wear and nonwear center link?
5. What can cause bump steer?

CHAPTER QUIZ

1. Which of the following is NOT a component of a parallelogram- type steering linkage?
   a. Pitman arm
   b. Drag link
   c. Center link
   d. Idler arm
2. How are the inner tie rods attached to the rack on a center-take-off-type rack-and-pinion steering gear?
   a. Staked
   b. Bolts
   c. Riveted
   d. Pinned
3. A vehicle equipped with four-wheel steering will use ___________ mode when moving at low speeds.
   a. same-phase
   b. single-phase
   c. opposite-phase
   d. right-phase
4. Steering linkage joints should be lubricated with ___________.
   a. brake fluid
   b. 20W-50 engine oil
   c. 80W-90 gear oil
   d. grease
5. A vehicle has an excessive amount of freeplay in the steering wheel. Which of these should be checked during a dry park test?
   a. Intermediate shaft
   b. All steering linkage joints
   c. Rack-and-pinion mounting bushings
   d. All of the above
6. Which of the following steering linkage parts should be replaced in pairs?
   a. Outer tie rod ends
   b. Pitman arm
   c. Inner tie rod ends
   d. All of the above
7. Two technicians are discussing bump steer. Technician A says that an unlevel steering linkage can be its cause. Technician B says that if the steering wheel moves when the vehicle is bounced up and down, the steering linkage may be bent. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. How much endplay is usually acceptable in the tie rod ends during a dry park test?
   a. Zero
   b. 0.010 to 0.030 inch
   c. 0.030 to 0.050 inch
   d. 0.050 to 0.100 inch
9. Technician A says that prevailing torque nuts can be reused unless damaged. Technician B says that a new cotter key should always be used. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. New tie rods are being installed. Technician A says to tighten the retaining nuts to specification and then loosen, if needed, to align the cotter pin hole. Technician B says to tighten farther to align the cotter key hole. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

Chapter

117

HYDRAULIC POWER STEERING SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the operation of hydraulic power steering systems.
- Discuss the components and operation of power steering pumps.
- Explain the purpose and function of integral power steering.
- Discuss the purpose and function of variable effort steering systems.
- Discuss power steering diagnosis and troubleshooting.
- Describe service of power steering components and fluid.

KEY TERMS:

Flow control valve 1448 • Force 1446 • Integral reservoir 1447 • Pascal's law 1446 • Pressure 1446 • Pressure-relief valve 1449 • Power steering pressure (PSP) 1449 • Remote reservoir 1447 • Rotary control valve 1450

HYDRAULIC POWER STEERING SYSTEMS

PURPOSE AND FUNCTION Power-assisted steering hydraulically boosts the mechanical steering gear operation so the driver can turn the steering wheel with less effort for the same response. Hydraulic power steering has been available since the 1950s, and many late-model systems are enhanced by electronic controls.

FUNDAMENTALS Hydraulics is the study of liquids and their use to transmit force and motion. Hydraulic systems transmit force and motion through the use of fluid pressure. The terms used and their meaning include

- **Force—Force** is a push or pull acting on an object and is usually measured in pounds of force or Newtons.
- **Pressure—Pressure** is measured in force per unit of area, such as pounds per square inch (PSI), or kilopascals (kPa). One PSI is equal to 6.9 kPa.

PASCAL'S LAW The Pascal is a unit of measure named after the French scientist Blaise Pascal (1623–1662), who studied the behavior of fluids in closed systems. One of his discoveries, known as **Pascal's law**, states:

> When force is applied to a liquid confined in a container or an enclosure, the pressure is transmitted equally and undiminished in every direction.

Hydraulic systems can transmit force and motion through liquids because, for all practical purposes, a liquid cannot be compressed. No matter how much pressure is placed on a liquid, its volume remains the same. This allows a liquid to transmit force much like a mechanical lever. ● **SEE FIGURE 117–1**.

The advantage of a liquid over a mechanical lever is that a liquid has volume but does not have a fixed shape. Because it assumes the shape of its container, a liquid can transfer force through pipes and passages of any shape. A liquid can also decrease or increase the force it transmits depending on the area of the output surface to which the force is applied. ● **SEE FIGURE 117–2**.

POWER STEERING PUMP AND RESERVOIR

PARTS AND OPERATION The power steering pump draws fluid from the reservoir, pressurizes it, and delivers it to the power steering system. A power steering pump produces a high-pressure stream of fluid, typically in the 1,500 PSI

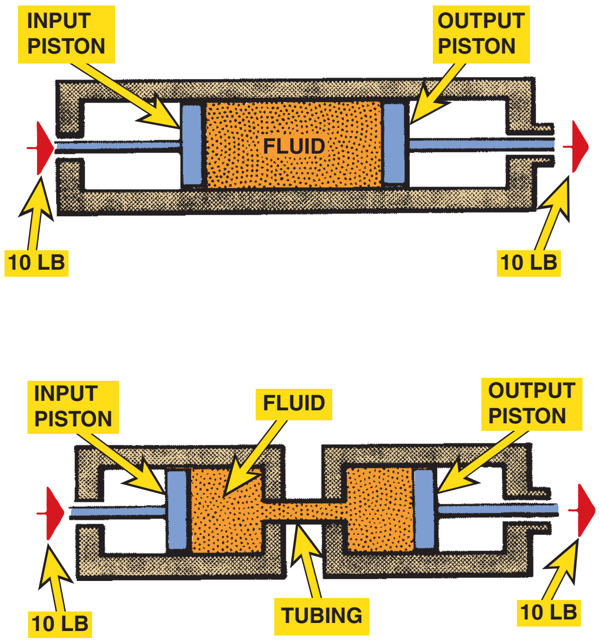


FIGURE 117–1 Hydraulic fluid transmits the same force whether it passes through a single chamber or two chambers connected by a narrow passage.

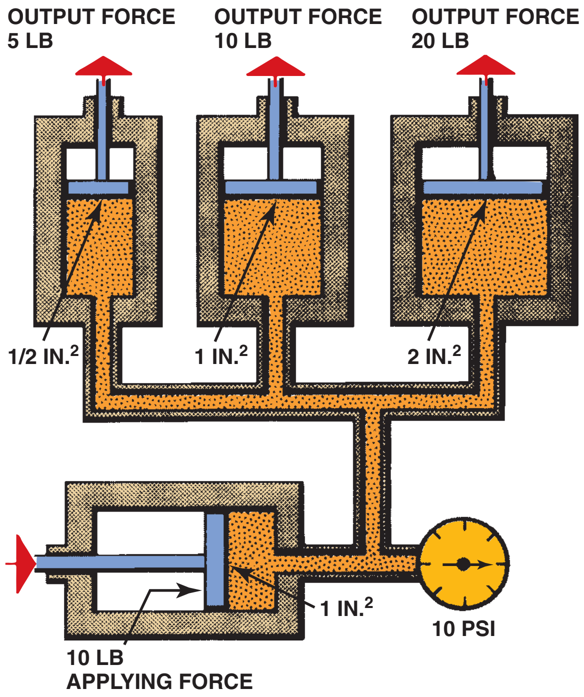


FIGURE 117–2 A fluid applies a force equal to the applied force on a surface that is equal in size to the applying surface. If the surface is half the size, then the fluid exerts half the force; if the surface is twice as large, the fluid exerts twice the force.

10,500 kPa) range. A reservoir stores power steering fluid. The fluid reservoir may be either integral to (built into) the pump or remotely mounted and connected to the pump by a hose. The power steering fluid reservoir is usually made of either plastic or stamped metal, and it includes the fluid filler neck, cap, and dipstick. An **integral reservoir** is part of the pump, and the pump itself operates submerged in power steering fluid. ● **SEE FIGURE 117–3**.

REMOTE RESERVOIRS

Although once common, steering pumps with an integral reservoir have given way to those with a remote reservoir on many current-production vehicles. This is because the remote reservoir allows for a smaller, more compact pump assembly that is better suited to the cramped engine compartment of a modern vehicle. A **remote reservoir** is a separate assembly from the pump and provides fluid to it through a suction hose. ● **SEE FIGURE 117–4**.

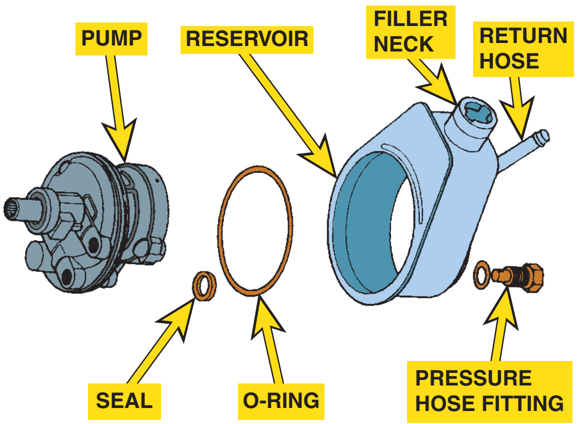


FIGURE 117–3 A typical integral power steering pump when the pump is mounted inside the reservoir.

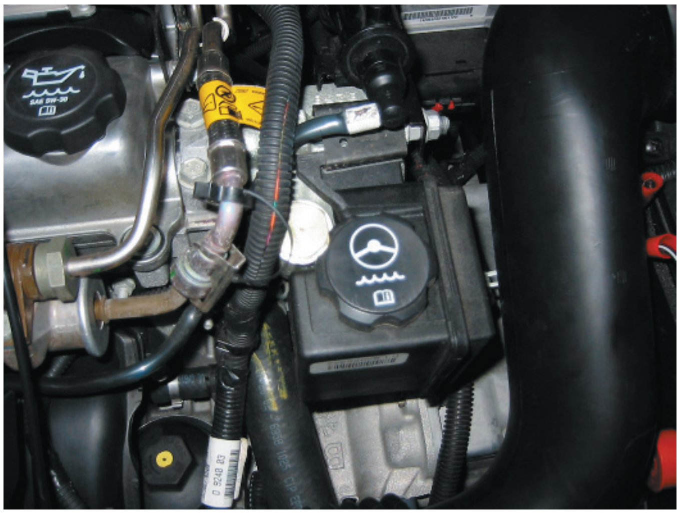


FIGURE 117–4 Typical remote reservoir.

FORCES AND PRESSURES INVOLVED

A typical power steering system requires only 2 to 3.5 pounds (0.9 to 1.6 kg) of driver effort to turn the steering wheel. Most power steering systems use an engine-driven hydraulic pump. Power steering hydraulic pumps are usually belt driven from the front crankshaft pulley of the engine. Pumps come in many sizes and styles. ● **SEE FIGURE 117–5**.

The power steering pump delivers a constant flow of hydraulic fluid to the power steering gear or rack. A typical power steering pump requires less than 1/2 horsepower, which is less than 1% of engine power while driving straight ahead. Even while parking at low speed, the power steering requires only about 3 horsepower while providing high hydraulic pressures. Typical pressures generated by a power steering system include the following:

- *Straight ahead* less than 150 PSI (1,400 kPa)
- *Cornering* about 450 PSI (3,100 kPa)
- *Parking* (maximum) 750–1,400 PSI (5,200–10,000 kPa)

TYPES OF PUMPS

The power steering pump drive pulley is usually fitted to a chrome-plated shaft with a press fit. The shaft

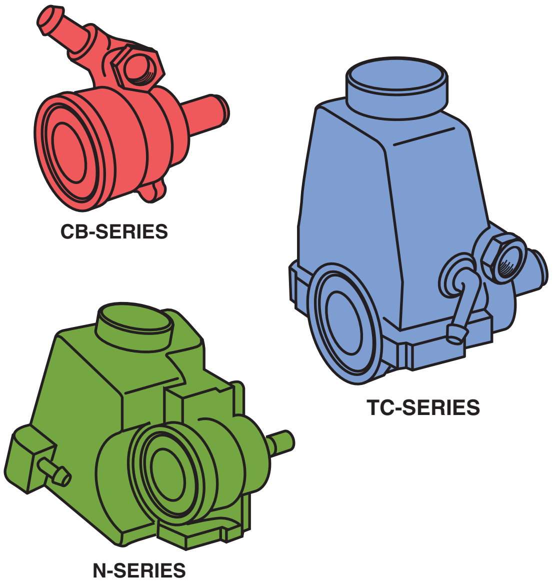


FIGURE 117–5 Typical power steering pump assemblies.

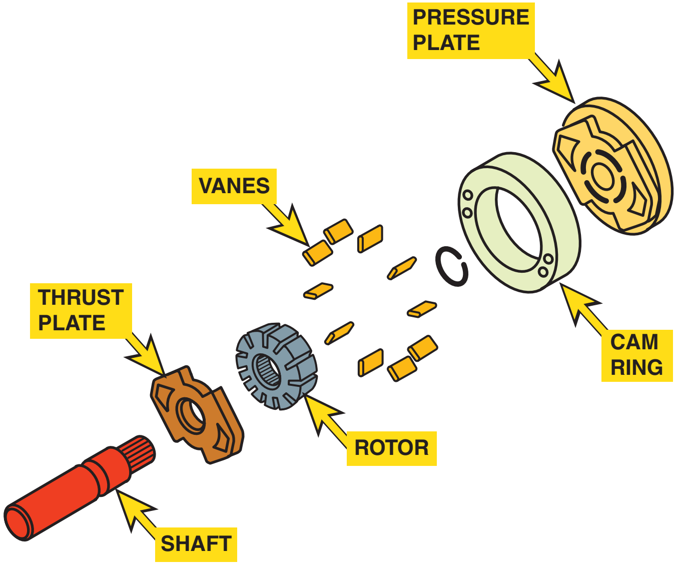


FIGURE 117–6 General Motors vane-type pump.

is applied to a rotor with vanes that rotate between a thrust plate and a pressure plate. ● **SEE FIGURE 117–6**.

- When the engine starts, the drive belt rotates the power steering pump pulley and the rotor assembly inside the power steering pump.
- Centrifugal force and hydraulic pressure push the vanes of the rotor outward into contact with the pump ring.
- The shape of the pump ring causes a change in the volume of fluid between the vanes. As the volume increases, the pressure is decreased in the space between the vanes and draws in fluid from the pump reservoir. When the volume between the vanes decreases, the pressure is increased and flows out the pump discharge port. ● **SEE FIGURES 117–7, 117–8, AND 117–9**.

CONTROL VALVE The pressure outlet hose connects to a fitting that threads into the outlet port of the pump body. A modulator valve, commonly called a **flow control valve**, installs in the same bore as the hose fitting. ● **SEE FIGURE 117–10**.

The modulator valve is a spring-loaded pressure-relief device that bleeds off excess pressure to prevent system damage.

- When pump output is more than what the power steering system requires, the excess pressure overcomes spring force and moves the valve down in its bore.
- This uncovers an orifice through which the fluid can flow back into the inlet passages. An orifice is a small opening that regulates fluid pressure and flow. It can be a restriction in a fluid line or a hole between two fluid chambers. The opening is called a *variable orifice* because the size of the opening varies with the amount of pressure applied to the valve.
- When fluid pressure is not high, spring force keeps the valve seated so that all of the pressurized fluid flows through the outlet port and into the pressure hose. Because the engine drives the pump, the power steering pump places a load on the engine whenever the engine is running.

The pressure increases when the steering wheel is turned to its full stop in either direction. To handle the excess pressure, a

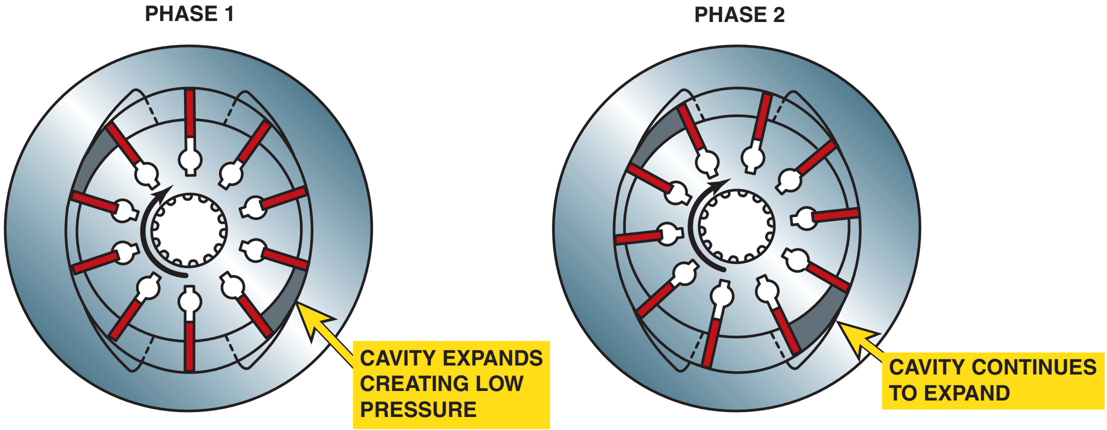

PHASE 1
PHASE 2
CAVITY EXPANDS CREATING LOW PRESSURE
CAVITY CONTINUES TO EXPAND

FIGURE 117–7 Vane pump operation. In phase 1, the rotor moves past the opposed suction ports, and the vanes move out to maintain contact with the ring. This creates a low-pressure area, drawing fluid into the cavities formed by the vanes. As the rotor continues to move during phase 2, the vanes follow the contour of the ring. The contour of the ring forms a larger cavity between the vanes. This increases the suction and draws more fluid into the pump.

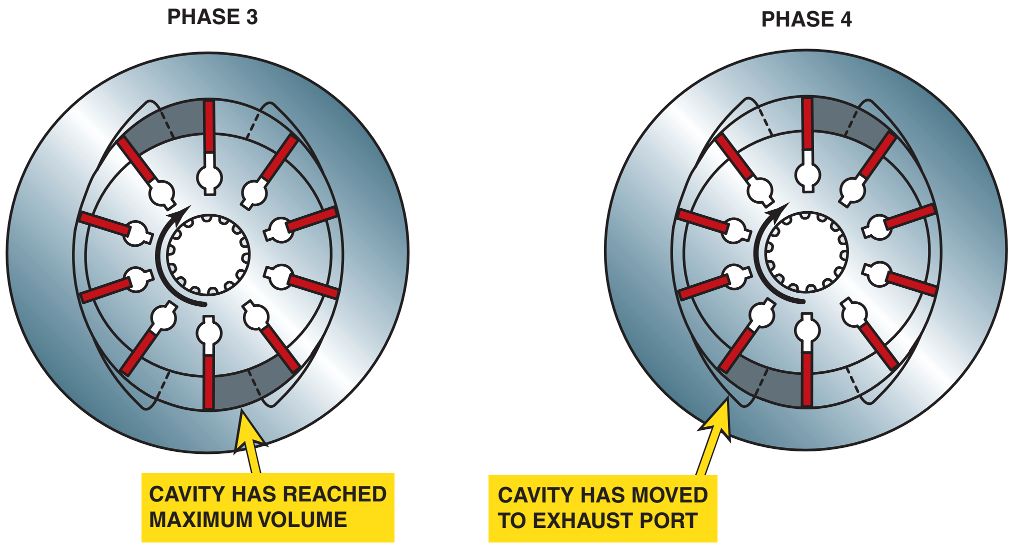

PHASE 3
PHASE 4
CAVITY HAS REACHED MAXIMUM VOLUME
CAVITY HAS MOVED TO EXHAUST PORT

FIGURE 117–8 Vane pump operation—continued. At phase 3, the vanes are at the end of the intake port of the pump and the cavity has reached its maximum volume. In phase 4, the rotor moves into alignment with the opposed discharge ports.

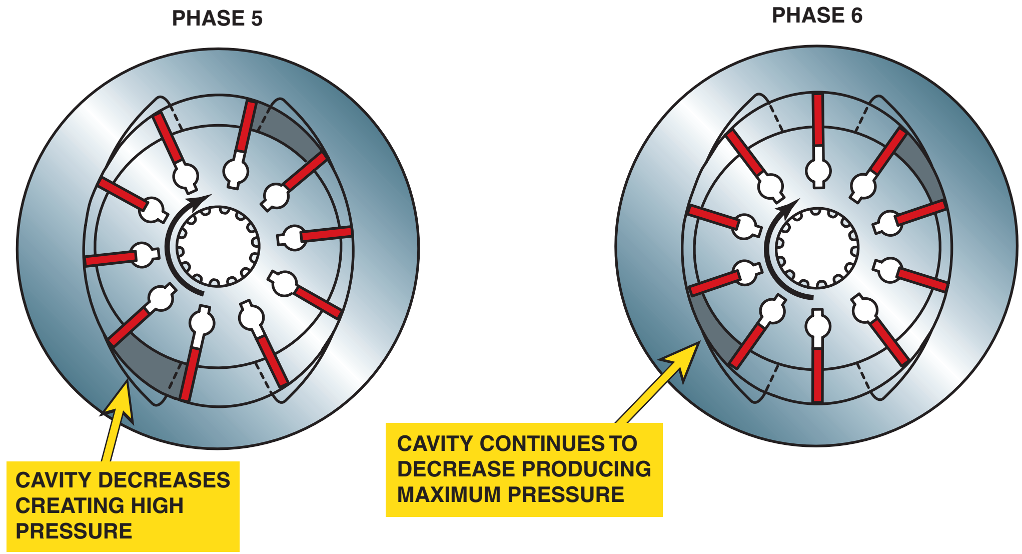

PHASE 5
PHASE 6
CAVITY DECREASES CREATING HIGH PRESSURE
CAVITY CONTINUES TO DECREASE PRODUCING MAXIMUM PRESSURE

FIGURE 117–9 Vane pump operation—continued. As the rotor continues to move during phase 5, the volume of the cavity decreases, which increases the discharge pressure. At phase 6, the last phase, the contour of the ring results in the minimum cavity volume, and the discharge of fluid is completed.

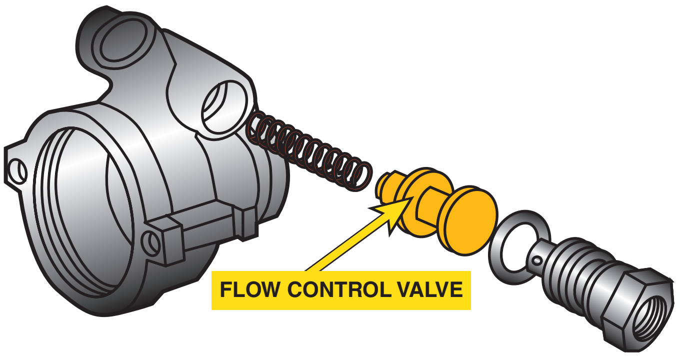

FLOW CONTROL VALVE

FIGURE 117–10 Flow control valve.

pressure-relief passage runs from a point near the pressure hose fitting to the spring end of the modulator valve. Inside the passage is a **pressure-relief valve**. The spring end of the modulator valve forms a seat for the pressure relief check ball. Under normal circumstances, the check ball remains seated.

FREQUENTLY ASKED QUESTION

What Is the Purpose of the PSP Switch in the High-Pressure Line?

Under certain conditions, such as when the steering wheel is turned to or near full stop for more than a few seconds, pressure builds in the system and the pump must work harder to keep up with the demand. As a result, the pump draws more power from the engine. If the engine is running at idle, the extra load can cause it to stall. A pressure switch, known as the **power steering pressure (PSP)** switch, transmits an electronic signal to the powertrain control module (PCM) when the pressure in the system is high enough to increase the load on the engine. In response to the PSP switch signal, the PCM increases the engine idle speed to prevent stalling.

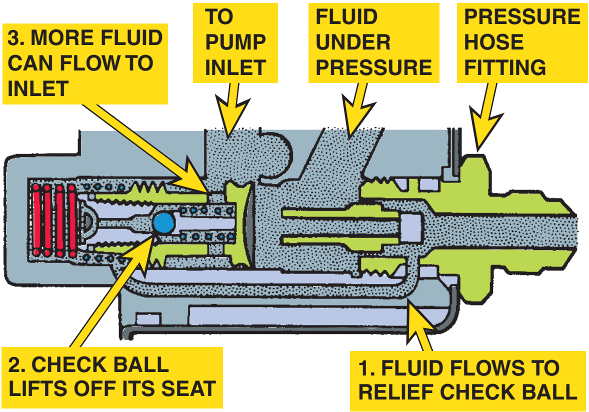

3. MORE FLUID CAN FLOW TO INLET
TO PUMP INLET
FLUID UNDER PRESSURE
PRESSURE HOSE FITTING
2. CHECK BALL LIFTS OFF ITS SEAT
1. FLUID FLOWS TO RELIEF CHECK BALL

FIGURE 117–11 The pressure-relief check ball unseats, allowing fluid to flow back into the pump inlet if the pressure rises above a certain limit.

The parts of the pressure-relief valve include

- Spring
- Valve piston
- Check ball
- Seat

A shim installs on the check ball seat to adjust the pressure at which the check ball unseats to open the pressure-relief valve. Normally, the spring force holds the piston against the check ball to keep it in its seat. When pressure becomes excessive in the pressure-relief passage, the check ball raises off its seat to allow fluid to flow through the relief passage and out through an orifice in the modulator valve. ● **SEE FIGURE 117–11**.

The pressure when this occurs varies from 750 to 1,400 PSI (5,200 to 10,000 kPa) depending on the calibration of the pressure-relief valve. When power steering systems are pushed to the limit, most will make a chattering or squealing noise until the pressure is reduced.

POWER STEERING HOSES Because the power steering pump and the steering gear are not part of the same assembly, the system requires two hoses to connect the power steering pump and gear assembly.

- The pressure hose is connected to the flow control/relief valve. This hose supplies pressurized fluid to the steering gear.
- The second hose is called the *return hose* and it returns the fluid from the steering gear back to the pump.
- Some vehicles will use a cooler in the return path to the pump. The cooler is used to reduce the temperature of the fluid before it enters the pump. The cooler is often a length of metal line that is routed in the air stream under the vehicle so that air flowing past it will cool the fluid inside the line. ● **SEE FIGURE 117–12**.

INTEGRAL POWER STEERING

PURPOSE AND FUNCTION In an integral power steering system, the control valve and a power piston which applies force to the pitman arm are incorporated into the steering gear construction. The control valve regulates the application of pressurized fluid against the power piston, and the power piston helps move the pitman arm when pressure is applied to one side of it.

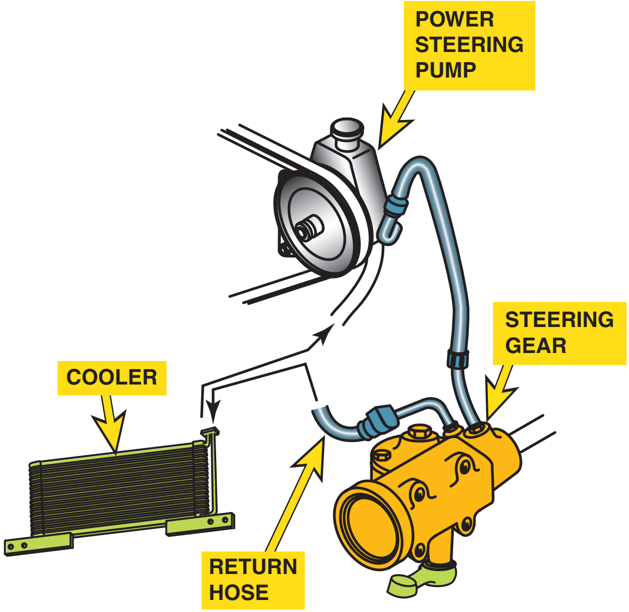


FIGURE 117–12 The power steering fluid cooler, if used, is located in the return hose. Often the "cooler" is simply a length of return metal line that is arranged in a loop and routed near the front of the vehicle. The airflow past the return line helps reduce the temperature of the fluid.

INTEGRAL STANDARD STEERING GEAR Most standard steering gears with power assist are the recirculating-ball type, and the ball nut functions as the power piston. The steering gear is lubricated from the power steering fluid that is flowing through the unit. Hydraulic pressure from the steering gear control valve is applied directly against the ball nut to help move it through the housing. The ball nut in this type of power steering gear is called the power piston because hydraulic pressure moves it as if it were a piston traveling in a cylinder. ● **SEE FIGURE 117–13**.

ROTARY CONTROL VALVE A **rotary control valve** is a two-piece assembly that operates by rotating an inner valve within an outer valve. A steering gear with a rotary control valve is also a torsion bar steering gear, because a small torsion bar is used to control valve movement. The rotary control valve consists of two cylindrical elements:

1. Inner valve element
2. Outer valve element

The inner valve element is secured to the steering gear input shaft and the torsion bar. In the valve, the inner element and the input shaft are one piece, and the torsion bar attaches between them connecting the inner valve element and the input shaft. ● **SEE FIGURE 117–14**.

The inner element assembly fits inside the outer valve element, and is also secured to the torsion bar by a pin. The outer valve element is also the steering worm gear.

- The torsion bar acts as a spring between the two elements to allow movement between them when the steering shaft turns. The spring force of the torsion bar tends to pull the elements back to their neutral positions when the steering wheel is released or returned to center. The strength of the torsion bar determines steering feel.

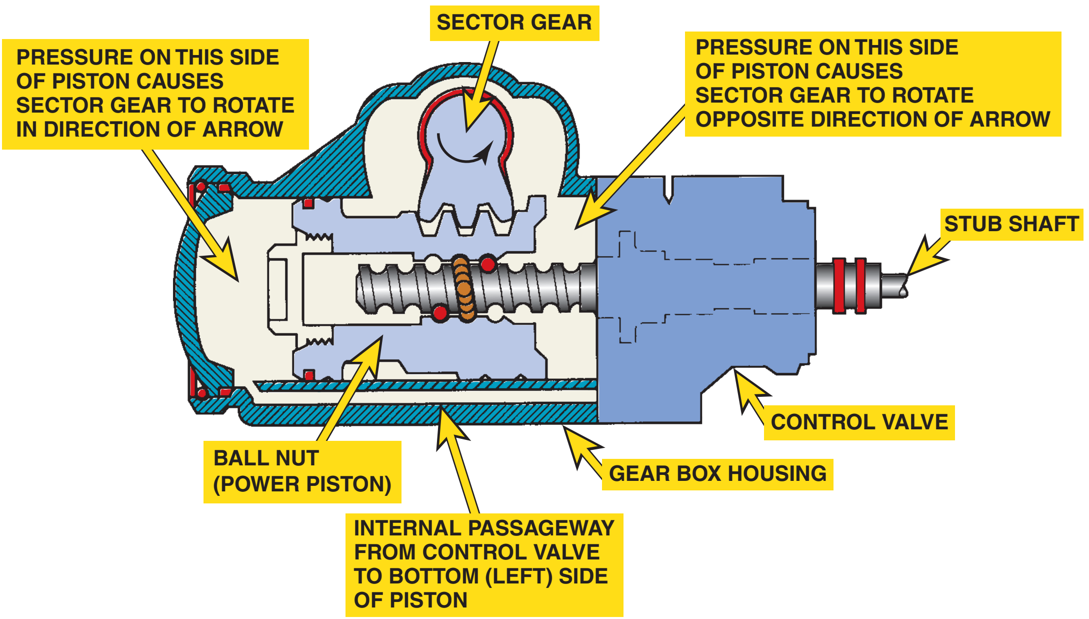

SECTOR GEAR
PRESSURE ON THIS SIDE OF PISTON CAUSES SECTOR GEAR TO ROTATE IN DIRECTION OF ARROW
PRESSURE ON THIS SIDE OF PISTON CAUSES SECTOR GEAR TO ROTATE OPPOSITE DIRECTION OF ARROW
STUB SHAFT
CONTROL VALVE
GEAR BOX HOUSING
BALL NUT (POWER PISTON)
INTERNAL PASSAGEWAY FROM CONTROL VALVE TO BOTTOM (LEFT) SIDE OF PISTON

FIGURE 117–13 Forces acting on the rack piston of an integral power steering gear.

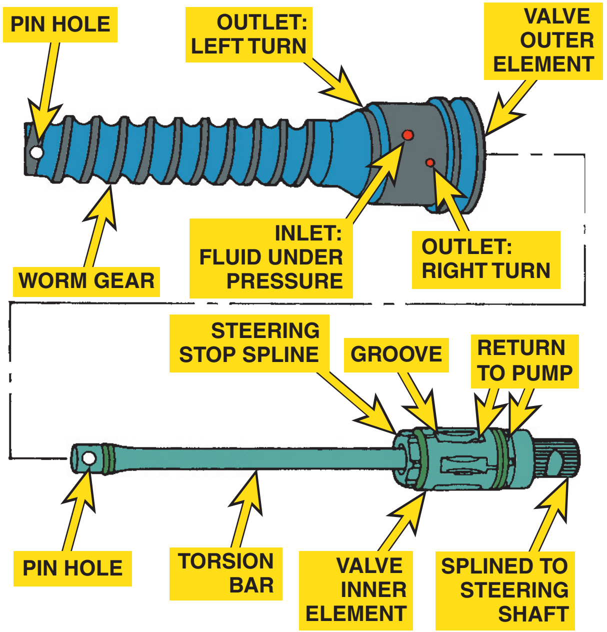

PIN HOLE
OUTLET: LEFT TURN
VALVE OUTER ELEMENT
WORM GEAR
INLET: FLUID UNDER PRESSURE
OUTLET: RIGHT TURN
STEERING STOP SPLINE
GROOVE
RETURN TO PUMP
PIN HOLE
TORSION BAR
VALVE INNER ELEMENT
SPLINED TO STEERING SHAFT

FIGURE 117–14 The rotary valve consists of inner and outer elements. The worm gear is part of the outer element and the torsion bar is part of the inner element. A pin attaches the worm gear to the bottom of the torsion bar to join the two elements together.

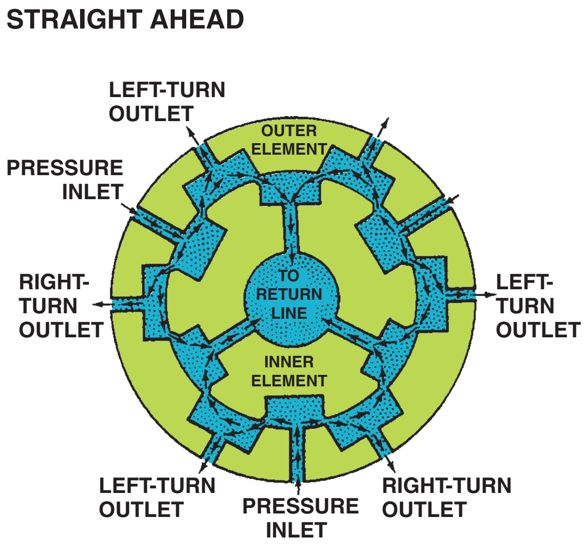

STRAIGHT AHEAD
LEFT-TURN OUTLET
OUTER ELEMENT
PRESSURE INLET
RIGHT-TURN OUTLET
TO RETURN LINE
LEFT-TURN OUTLET
INNER ELEMENT
LEFT-TURN OUTLET
PRESSURE INLET
RIGHT-TURN OUTLET

FIGURE 117–15 When the steering wheel is in the straight-ahead position, all of the ports in a rotary valve are open equally to the pressure and return circuits.

- A weak torsion bar moves easily and provides soft steering, while a strong bar resists movement and makes steering feel firm. Many high-performance vehicles use a steering gear that has a thicker torsion bar to increase the firmness of the steering.

The surfaces of the inner and outer elements have grooves machined into them through which fluid can flow. Passages carry fluid from some of the inner-element grooves to the center of the element where it travels through the return line to the pump reservoir. The outer element has three sets of fluid passages that connect the outside of the element to a groove at the inside. One set of passages carries fluid into the element from the pressure hose fitting, the second set carries fluid to and from the left-turn side of the power piston, and the third carries it to and from the right-turn side. When the steering wheel is aimed straight ahead, the valve is in its neutral position. Fluid enters the valve and flows equally to both sides of the steering gear piston and to the return line. ● **SEE FIGURE 117–15.**

When the steering wheel and steering shaft turn to the left, the inner element twists on the torsion bar and repositions the valve ports. In this left-turn position, pressurized fluid flowing into the valve can only exit through the left-turn ports. ● **SEE FIGURE 117–16.**

Meanwhile, the right-turn ports align with the return ports to bleed off residual pressure from the opposite side of the power piston. Pressurized fluid flowing through the left-turn ports is directed into the steering gear, where it applies force to the power piston and reduces the effort needed to turn the steering linkage to the left. ● **SEE FIGURE 117–17.**

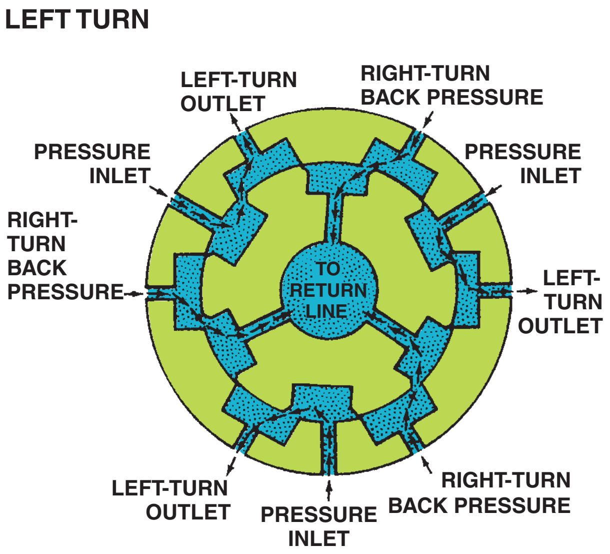

LEFT TURN
LEFT-TURN OUTLET
RIGHT-TURN BACK PRESSURE
PRESSURE INLET
PRESSURE INLET
RIGHT-TURN BACK PRESSURE
TO RETURN LINE
LEFT-TURN OUTLET
LEFT-TURN OUTLET
PRESSURE INLET
RIGHT-TURN BACK PRESSURE

FIGURE 117–16 During a left turn, the inner element turns so that the left-turn circuits are open to pressure and the right-turn circuits are open to the return circuit.

As the piston moves, it forces fluid out of the right-turn side, and that fluid returns through the control valve to the pump reservoir. Exactly the opposite flow occurs during a right-hand turn: The right-turn ports are opened and the left-turn ports exhaust to the return line. ● **SEE FIGURE 117–18**.

Hydraulic pressure moves the piston up the housing bore during a right-hand turn. ● **SEE FIGURE 117–19**.

When the steering wheel is released, the spring force of the torsion bar returns the two elements to their natural positions. Fluid pressure equalizes throughout the steering gear and re-centers the piston in the middle of the steering gear.

POWER RACK-AND-PINION STEERING The rotary control valve on a power rack-and-pinion steering gear is located between the steering gear input shaft and the pinion gear. ● **SEE FIGURE 117–20**.

Fluid discharged by the valve travels through external steel lines to either side of the power piston located in the rack housing. A steel air-transfer tube allows air displacement between the boots as they compress and expand, since the power piston prevents air from passing through the rack housing. The rotary valve in a rack-and-pinion steering unit operates in the same manner as the one previously described for a standard steering gear. During a left-hand turn, the control valve directs fluid flow into the left-turn steel line, which routes it to the right-hand side of the power piston in order to move the rack to the left. As this happens, fluid on the opposite side of the power piston is forced out through the right-turn steel line and back to the control valve, where it is exhausted to the return circuit. When the steering wheel is turned to the right, fluid flow is reversed so the power piston moves to the right and fluid in

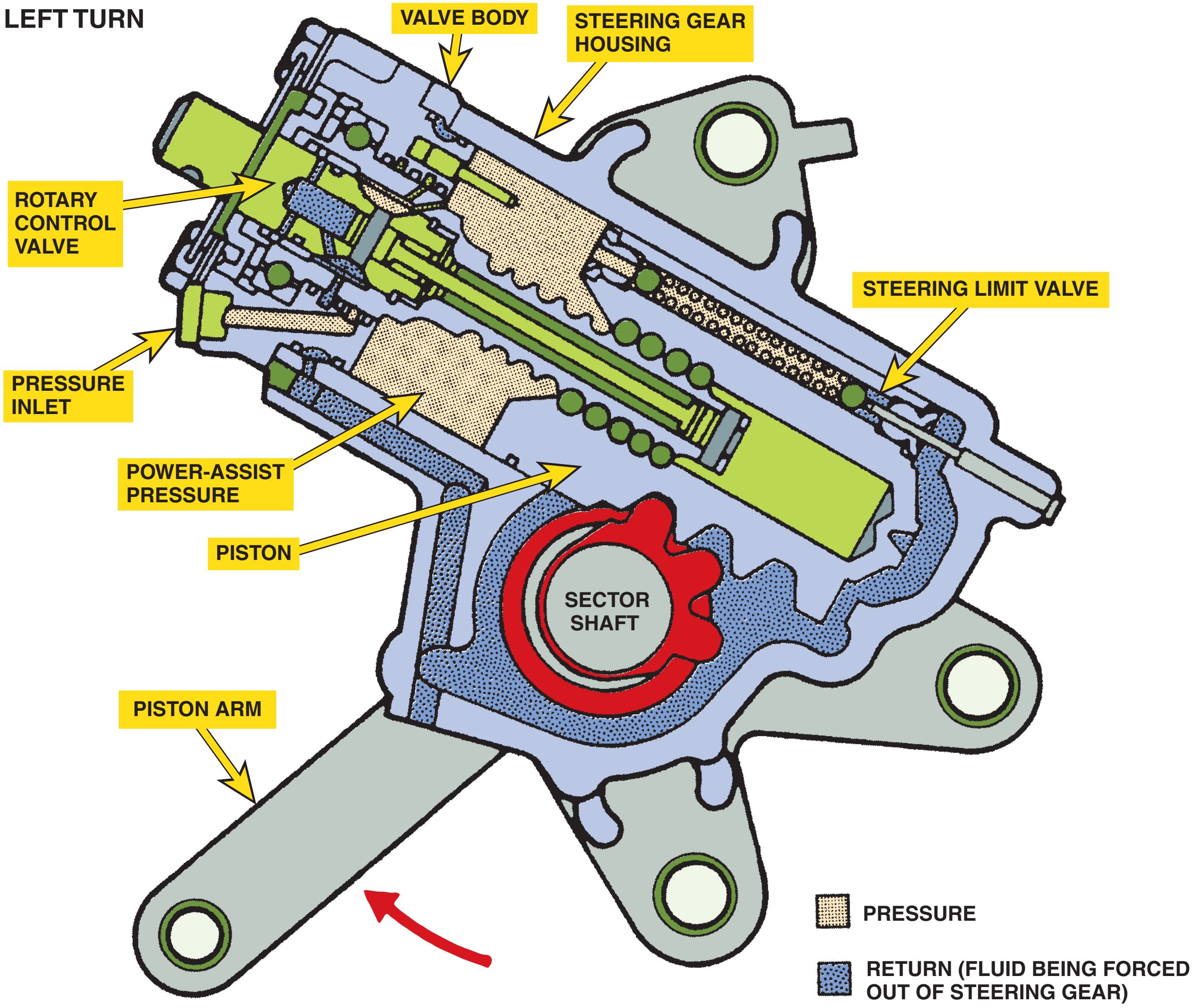

LEFT TURN
VALVE BODY
STEERING GEAR HOUSING
ROTARY CONTROL VALVE
STEERING LIMIT VALVE
PRESSURE INLET
POWER-ASSIST PRESSURE
PISTON
SECTOR SHAFT
PISTON ARM
▨ PRESSURE
▨ RETURN (FLUID BEING FORCED OUT OF STEERING GEAR)

FIGURE 117–17 During a left turn, the high-pressure fluid helps push the piston along the worm gear, thereby reducing the steering effort from the driver.

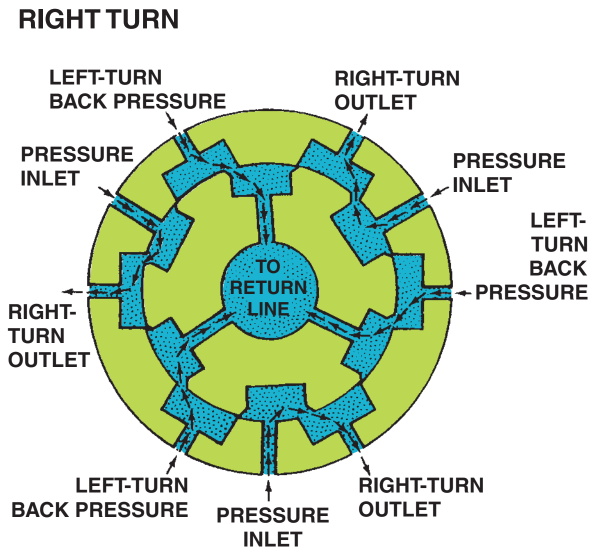

RIGHT TURN
LEFT-TURN BACK PRESSURE
RIGHT-TURN OUTLET
PRESSURE INLET
PRESSURE INLET
LEFT-TURN BACK PRESSURE
TO RETURN LINE
RIGHT-TURN OUTLET
LEFT-TURN BACK PRESSURE
PRESSURE INLET
RIGHT-TURN OUTLET

FIGURE 117–18 During a right turn, the inner element turns so that the right-turn outlets are open to pressure and the left-turn outlets are open to the return circuit.

the left-turn chamber is exhausted to the return circuit. ● **SEE FIGURE 117–21**.

FLOW CONTROL VALVE OPERATION The operation of the flow control valve includes the following stages:

- When the power steering pump begins operation, the fluid from the output of the pump flows into the control valve.
- The fluid then flows through the orifice, where a pressure differential is formed. The pressure differential results in a higher pressure on the pump side than on the system side. The fluid from the orifice flows into the power steering system and through a passage on the backside of the control valve. ● **SEE FIGURE 117–22**.
- The fluid on the backside of the control valve is used to assist the spring force acting on the valve.
- At this point, the combination of the spring force and hydraulic pressure is higher than the output pressure of the pump. This causes the control valve to block the passage to the pump intake. When the output pressure is higher than the spring force, the pressure behind the valve

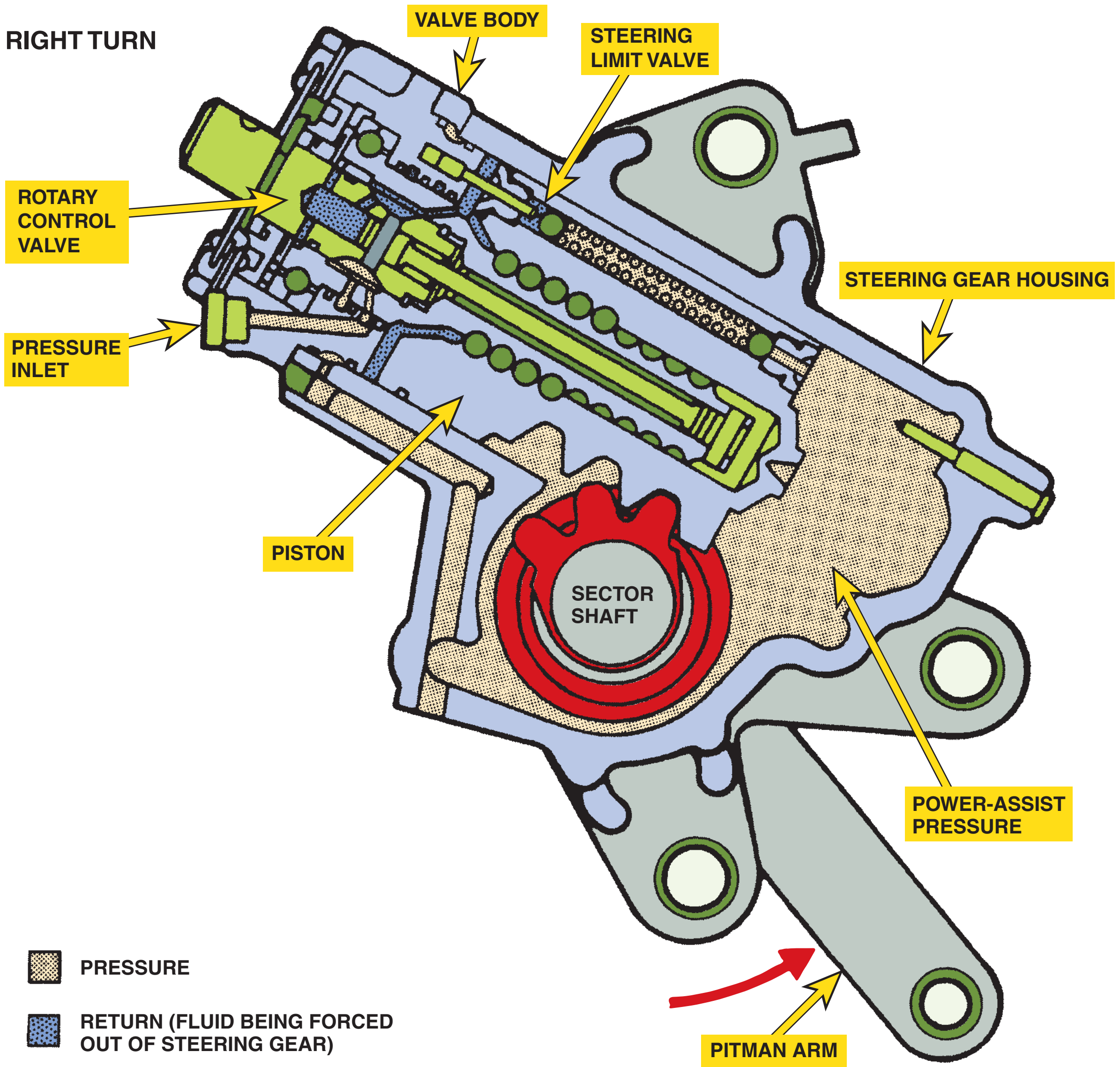

RIGHT TURN
VALVE BODY
STEERING LIMIT VALVE
ROTARY CONTROL VALVE
STEERING GEAR HOUSING
PRESSURE INLET
PISTON
SECTOR SHAFT
POWER-ASSIST PRESSURE
▨ PRESSURE
▨ RETURN (FLUID BEING FORCED OUT OF STEERING GEAR)
PITMAN ARM

FIGURE 117–19 During a right turn, high-pressure fluid pushes the piston up the worm gear, moving the sector shaft and pitman arm to provide assist during a right turn.

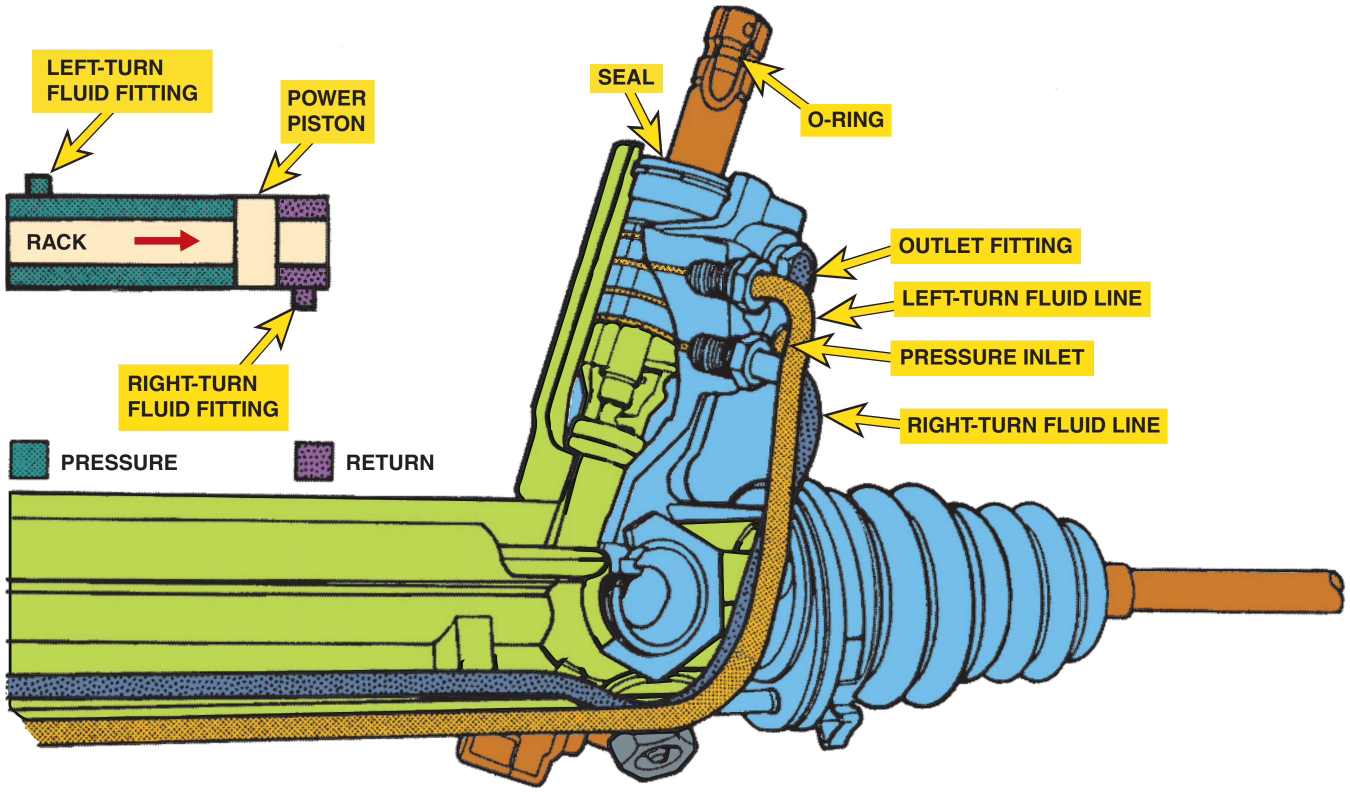

LEFT-TURN FLUID FITTING
POWER PISTON
RACK
RIGHT-TURN FLUID FITTING
PRESSURE
RETURN
SEAL
O-RING
OUTLET FITTING
LEFT-TURN FLUID LINE
PRESSURE INLET
RIGHT-TURN FLUID LINE

FIGURE 117–20 During a left turn, the control valve directs pressure into the left-turn fluid line and the rack moves left (see inset). Fluid pushed out of the right-turn fluid chamber travels back through the right-turn fluid line and control valve to the return circuit.

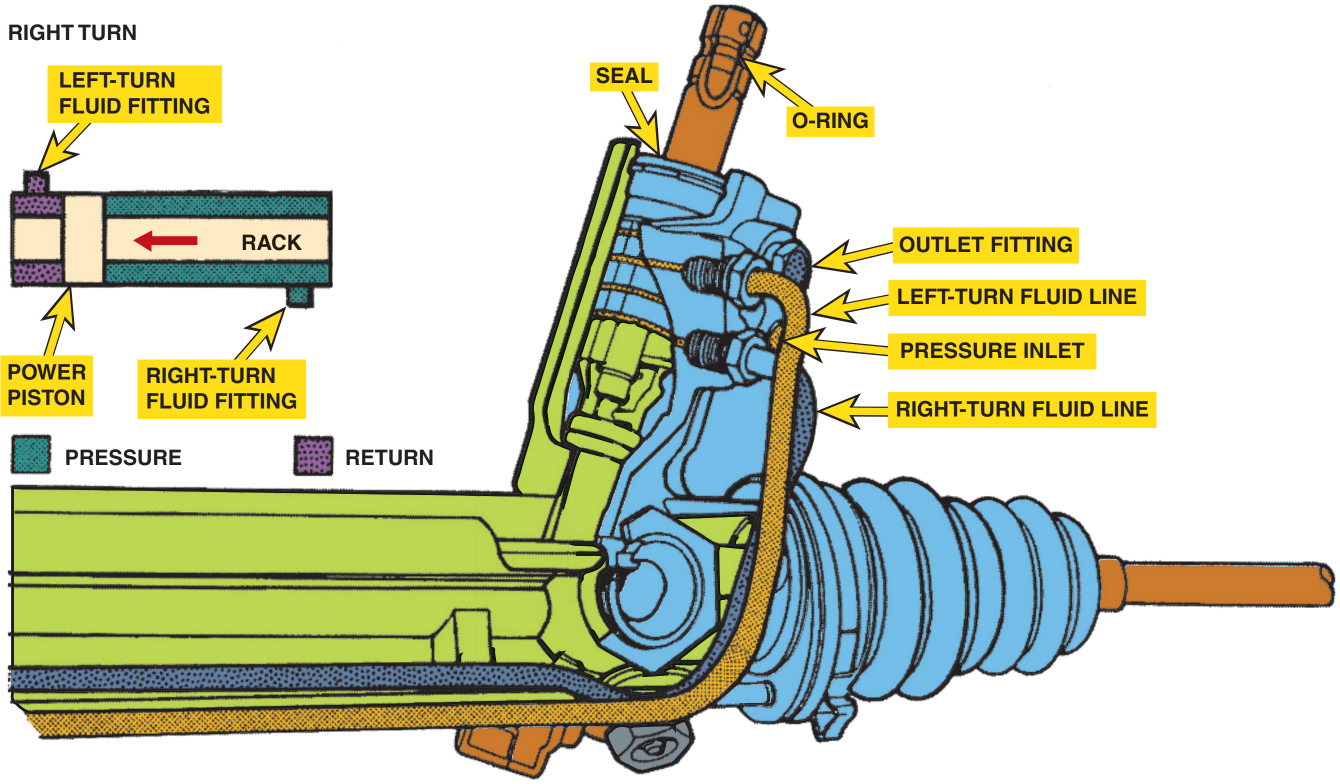

RIGHT TURN
LEFT-TURN FLUID FITTING
RACK
POWER PISTON
RIGHT-TURN FLUID FITTING
PRESSURE
RETURN
SEAL
O-RING
OUTLET FITTING
LEFT-TURN FLUID LINE
PRESSURE INLET
RIGHT-TURN FLUID LINE

FIGURE 117–21 The control valve routes high-pressure fluid to the left-hand side of the power piston, which pushes the piston and assists in moving the rack toward the right when the steering wheel is turned right.

forces the control valve to move. The movement of the valve opens the passage to the intake side of the pump. This allows some of the fluid to flow into the passage.

- As the pump speed continues to increase, the valve moves more to compensate for the higher pressure and flow. The pressure and flow in the power steering system must remain in the correct range or the steering system components can be damaged. Failure of the control valve to regulate the pressure in the power steering system can result in excessive pressure and temperature. As long as fluid can flow through the system, the control valve can regulate the pressure. ● **SEE FIGURE 117–23**.

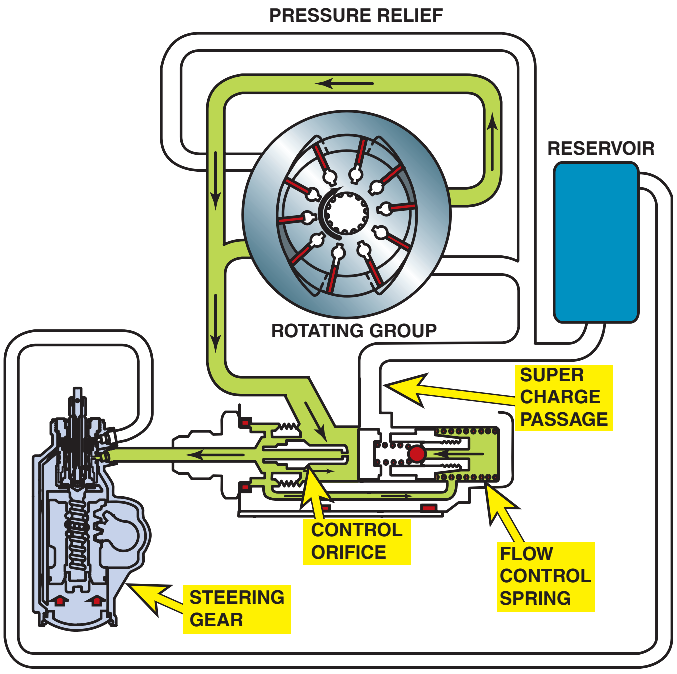

PRESSURE RELIEF
RESERVOIR
ROTATING GROUP
SUPER CHARGE PASSAGE
CONTROL ORIFICE
FLOW CONTROL SPRING
STEERING GEAR

FIGURE 117–22 Low-speed flow control.

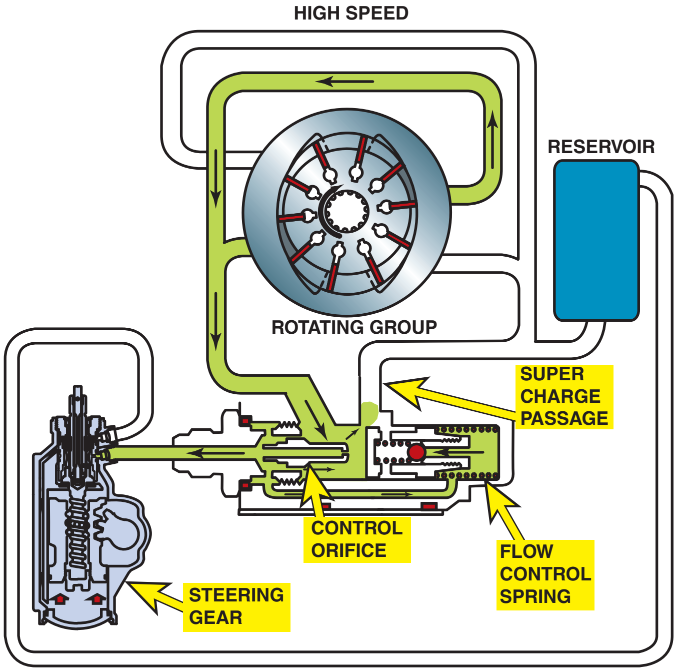

HIGH SPEED
RESERVOIR
ROTATING GROUP
SUPER CHARGE PASSAGE
CONTROL ORIFICE
FLOW CONTROL SPRING
STEERING GEAR

FIGURE 117–23 High-speed flow control operation.

However, there are times during normal operation when the flow in the system will stop. Fluid flow can stop during parking maneuvers and when the steering wheel is turned to the extreme right and left positions. When the fluid flow through the system stops, the pressure equalizes on both sides of the orifice. This creates equal pressure on both sides of the control valve. Because the backside of the valve has a spring, the combination of the hydraulic pressure and spring force positions the control valve to prevent flow into the pump intake passage. As the pump continues to operate, the pressure in the system builds. If the pressure is not relieved, the system can be damaged. To prevent this, the control valve has a check valve inside it. At a specific pressure, the check valve opens to relieve the pressure on the backside of the control valve. This creates a pressure differential and allows the control valve to move. With the control valve moved, the high pressure is allowed into the pump intake passage. ● **SEE FIGURE 117–24**.

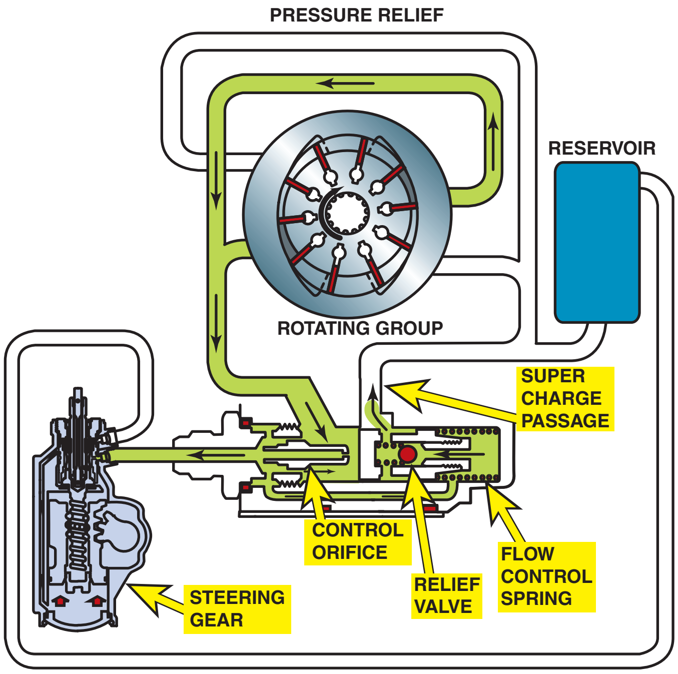

PRESSURE RELIEF
RESERVOIR
ROTATING GROUP
SUPER CHARGE PASSAGE
CONTROL ORIFICE
RELIEF VALVE
FLOW CONTROL SPRING
STEERING GEAR

FIGURE 117–24 Pressure-relief mode. In this mode, the steering gear has blocked the flow of fluid from the pump and the pressure rises, which unseats the pressure-relief valve. Now, fluid flows back to the inlet through the pressure-relief orifice and passage.

VARIABLE-EFFORT STEERING

PURPOSE AND FUNCTION Variable-effort steering (VES) systems are designed to provide variable power-assisted steering. The amount of power assist

- Increases at lower vehicle speeds to aid parking maneuvers.
- Decreases at higher speeds for greater road feel.

As examples, General Motors uses four different VES systems including

- Electronic Variable Orifice (EVO)
- Two-Flow Electronic (TFE)
- Speed Sensitive Steering (SSS)
- Magnasteer®

ELECTRONIC VARIABLE ORIFICE (EVO) SYSTEM The main components of the EVO system include

- Vehicle speed sensor
- Power steering control module (PSCM)
- Steering wheel speed sensor
- Power steering gear
- Power steering pump and solenoid actuator

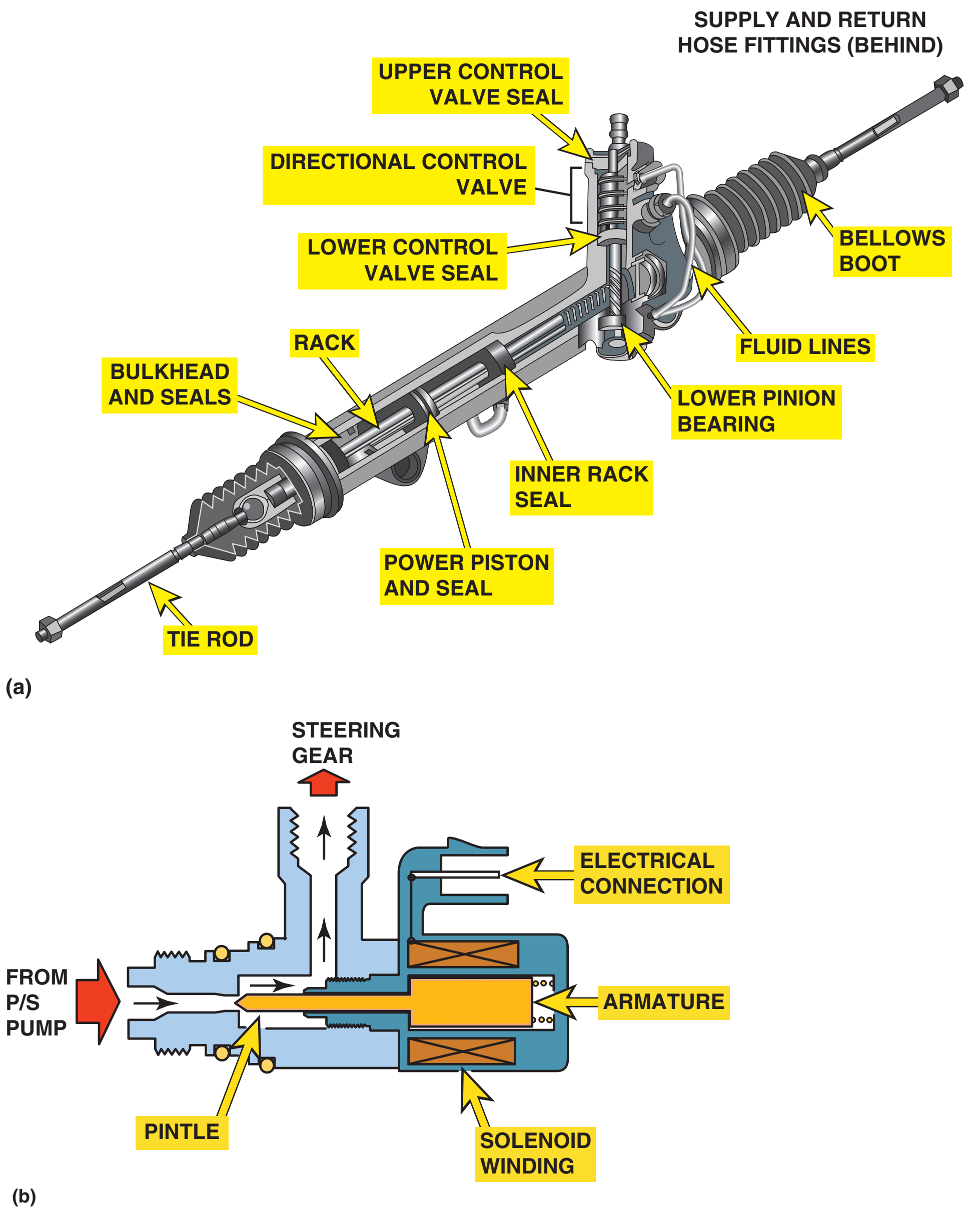

SUPPLY AND RETURN HOSE FITTINGS (BEHIND)
UPPER CONTROL VALVE SEAL
DIRECTIONAL CONTROL VALVE
LOWER CONTROL VALVE SEAL
BELLOWS BOOT
RACK
BULKHEAD AND SEALS
FLUID LINES
LOWER PINION BEARING
INNER RACK SEAL
POWER PISTON AND SEAL
TIE ROD
(a)
STEERING GEAR
ELECTRICAL CONNECTION
FROM P/S PUMP
ARMATURE
PINTLE
SOLENOID WINDING
(b)

FIGURE 117–25 (a) A typical rack and pinion steering gear assembly showing the location of the control valve, power piston, and inner rack seal. (b) EVO actuator assembly.

The actuator is a solenoid-operated pintle valve. Electrical current flowing through the solenoid controls the position of the pintle in relation to the orifice. ● **SEE FIGURE 117–25**.

- As the vehicle speed increases, the control module provides a higher current flow and the solenoid positions the pintle to change the size of the orifice. This increased speed results in a reduced amount of hydraulic flow and provides less hydraulic pressure to the steering gear.
- The control module uses the signal from the vehicle speed sensor to calculate the required amperage for the solenoid. The amperage has a direct effect on steering effort and the flow rate to the gear. As the vehicle speed increases, the solenoid extends the pintle and reduces the size of the orifice. Hydraulic pressure is being reduced as the vehicle speed increases and less power assist is available.
- The other sensor for the EVO system is the steering wheel speed sensor. This sensor is used to determine if the vehicle operator is performing an evasive steering maneuver.
- In this situation, the controller increases the hydraulic pressure to assist the operator. The faster the driver turns the steering wheel, the stronger the signal generated by the sensor. The faster the steering wheel is rotated, the more the solenoid retracts the pintle and enlarges the size of the orifice. This increases hydraulic pressure to the steering gear and provides more power assist for the operator.

TWO-FLOW ELECTRONIC (TFE) SYSTEM The main components of the TFE system include

- Power steering pump and solenoid actuator
- Steering rack-and-pinion gear
- Control module
- Powertrain control module (PCM)

The TFE actuator is a solenoid-operated pintle valve. The pintle valve has only two positions:

1. Maximum assist
2. Reduced assist

When the solenoid is provided a ground from the control module, the pintle extends out from the orifice and provides maximum assist. When the control module opens the ground path, the pintle moves in to restrict the orifice and thus reduces steering assist. The PCM provides the control module with a vehicle speed signal. The logic circuits in the control module determine when to energize the solenoid.

- The solenoid is energized whenever the vehicle speed is approximately 20 MPH (32 km/h) or lower and the pintle is extended, causing the power steering pressure to increase. This provides maximum assist and the steering effort is low.
- When the vehicle speed is higher than 20 MPH (32 km/h), the pintle is moved in and the steering pressure is low. This provides reduced assist and higher steering effort.

SPEED SENSITIVE STEERING (SSS) SYSTEM The major components of the SSS system include

- Power steering pump
- SSS actuator
- Steering gear
- Road sensing suspension (RSS) control module

The actuator is a solenoid-operated valve that controls the flow of fluid into the chambers of the steering gear valve. As more fluid flows into the chamber, pressure is built against the four pistons that are located around the spool shaft. As the pistons are loaded and pushed against the spool shaft, steering effort is increased. Unlike the EVO and TFE systems, the SSS system uses hydraulic pressure to resist movement in the steering gear. The amount of fluid allowed into the chambers is based on the electrical current flow through the solenoid. The road sensing suspension control module, using the signal from the vehicle speed sensor, calculates the required amperage for the solenoid.

- The amperage has a direct effect on steering effort and the hydraulic flow rate into the chambers of the spool shaft.
- As the vehicle's speed increases, the steering effort is increased. The steering effort adjustment begins at a vehicle speed of 20 MPH (32 km/h).

MAGNASTEER® Another type of variable effort power steering system used by General Motors is the Magnasteer® system. This system uses a variable bidirectional magnetic rotary actuator built into the steering rack. The bidirectional magnetic rotary actuator has no effect on the hydraulic operation of the steering rack. The main components in the system include

- Power steering pump
- Magnasteer® actuator assembly
- Steering gear
- Electronic brake control module (EBCM)

The Magnasteer® system uses a conventional rack-and-pinion steering gear and an engine-driven hydraulic pump to provide power assist. The Magnasteer® actuator consists of the following:

- A permanent magnet attached to the rotary input shaft
- A pole-piece assembly attached to the pinion
- An electromagnetic coil mounted in the steering gear housing

Integrated with the pinion shaft is a spool valve that senses the level of torque in the shaft and applies hydraulic pressure to the steering rack whenever assistance is needed.

The electromagnet acts in parallel with the input shaft from the steering wheel to open or close the spool valve. The electromagnet generates variable torque, which can either increase or decrease the amount of steering torque that is needed to open the spool valve. ● **SEE FIGURES 117–26 AND 117–27**.

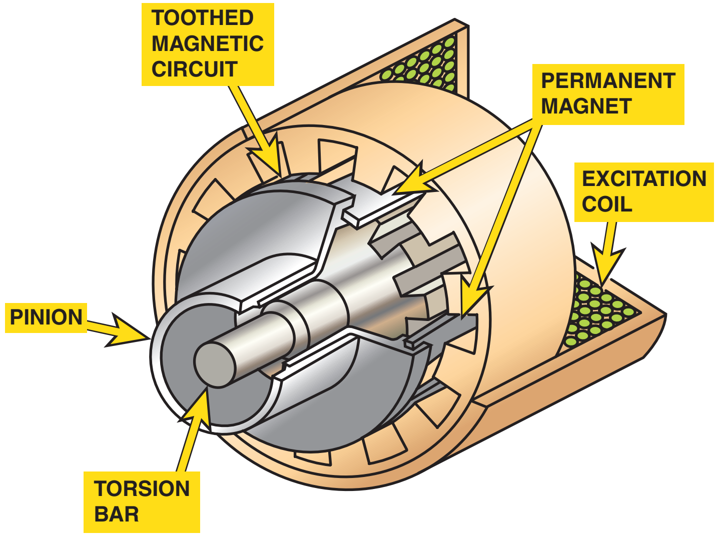


FIGURE 117–26 Integrated with the pinion shaft is a spool valve that senses the level of torque in the shaft and applies hydraulic pressure to the steering rack whenever assistance is needed. The electromagnet acts in parallel with the input shaft from the steering wheel to open or close the spool valve. The electromagnet generates variable torque, which can either increase or decrease the amount of steering torque that is needed to open the spool valve.

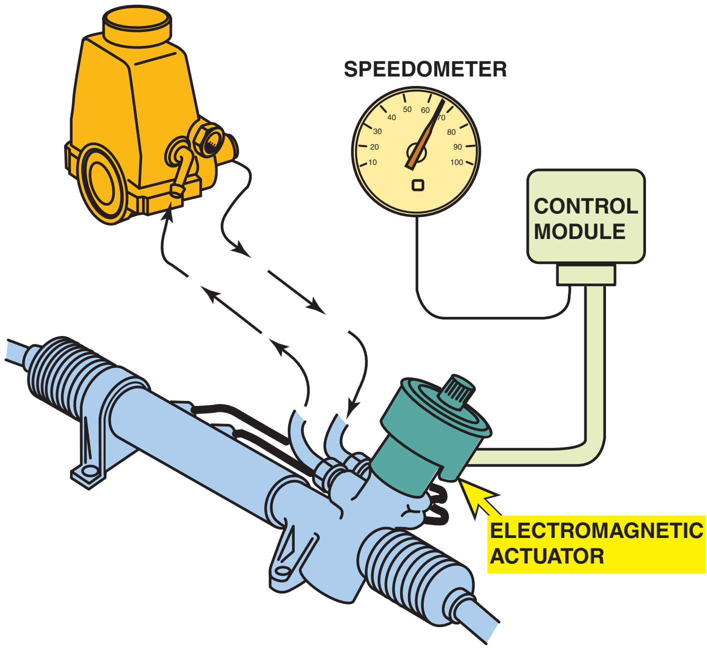


FIGURE 117–27 Magnasteer® system.

To vary the amount of steering assist, the EBCM uses the signal from the wheel speed sensor to calculate the required amperage and direction of current flow to the Magnasteer® actuator.

The amperage and direction of current flow have a direct effect on steering effort and the flow rate to the rack piston.

- When the vehicle is stationary, approximately 1.6 amperes of current is flowing through the electromagnetic coil.
- As the vehicle speed increases to approximately 45 MPH, the current decreases to 0 amps. The EBCM then switches the direction of current flow. Current flow through the electromagnetic coil causes either a magnetic attraction or repelling in the Magnasteer® actuator.

- At low vehicle speeds below 45 MPH, the direction of current flow creates a magnetic field that opposes the permanent magnet. The repelling force of the magnetic field assists the spool valve in moving out of alignment with the valve body, and this increases the power assist. With vehicle speeds below 45 MPH, increased current provides increased steering assist.
- At vehicle speeds above 45 MPH, the direction of current through the electromagnetic coil creates a magnetic field that attracts the permanent magnet. The magnet helps keep the spool valve aligned with the valve body, and this reduces the power assist and provides a greater road feel. As the vehicle speed increases, the amount of effort required to overcome the attracting force of the magnetic field increases. With vehicle speeds above 45 MPH, increased current flow provides decreased steering assist.

POWER STEERING DIAGNOSIS

ITEMS TO CHECK Power steering systems are generally very reliable, yet many problems, such as hard steering, are caused by not correcting simple service items such as the following:

1. A loose, worn, or defective power steering pump drive belt. This can cause jerky steering and belt noise, especially when turning. It is generally recommended that all belts, including the serpentine (poly V) belt, be replaced every four years. If the vehicle does not use a belt tensioner, then a belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications or use the following table for an example of the proper tension based on the size of the belt. ● **SEE CHART 117–1**.

   Replace any serpentine belt if more than three cracks appear in any one rib within a 3 inch span.

NOTE: Do not guess at the proper belt tension. Always use a belt tension gauge or observe the marks on the tensioner. ● **SEE FIGURE 117–28**.

2. A bent or misaligned drive pulley is usually caused by an accident or improper reassembly of the power steering pump after an engine repair procedure. This can cause a severe grinding noise whenever the engine is running and may sound like an engine problem.

SERPENTINE BELTS	
NUMBER OF RIBS USED	TENSION RANGE (LB)
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145

CHART 117–1

Belt tension is related to the number of ribs and usually falls within the range shown. Always check service information for the exact belt tension for the vehicle being serviced.

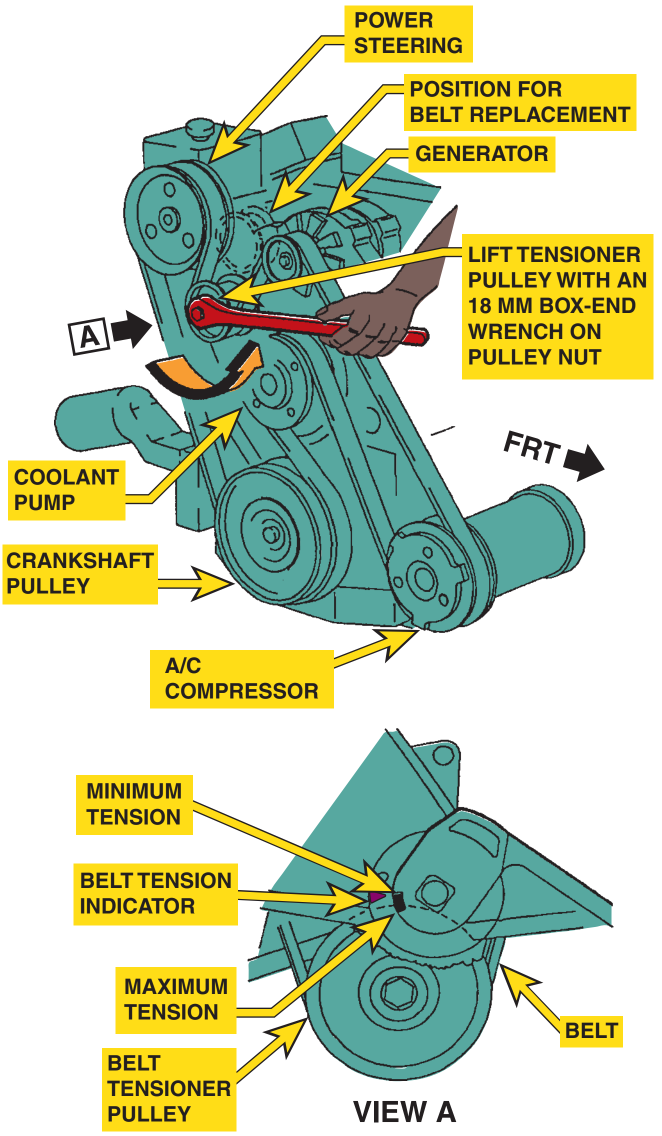


FIGURE 117–28 A typical service manual illustration showing the belt tensioner indicator marks.

3. Low or contaminated power steering fluid is usually caused by a slight leak at the high-pressure hose or defective inner rack seals on a power rack-and-pinion power steering system. This can cause a loud whine and a lack of normal power steering assist. See the Tech Tip, "The Visual Test."
4. Broken or loose power steering pump mounting brackets. In extreme cases, the pump mounting bolts can be broken. These problems can cause jerky steering. It is important to inspect the pump mounting brackets and hardware carefully when diagnosing a steering-related problem. The brackets tend to crack at the adjustment points and pivot areas. Tighten all the hardware to ensure the belt will remain tight and not slip, which would cause noise or a power-assist problem.
5. Underinflated tires.
6. Engine idle speed below specifications.
7. A defective power steering pressure switch, if equipped. If this switch fails, the computer will not increase engine idle speed while turning.
8. Internal steering gear mechanical binding.

As part of a complete steering system inspection and diagnosis, a steering wheel turning effort test should be performed. The power steering force, as measured by a spring scale during turning, should be less than 5 pounds (2.3 kg).

CAUTION: Some vehicles use power steering reservoir caps with left-hand threads. Always clean the top of the cap and observe all directions and cautions.

POWER STEERING FLUID

PURPOSE AND FUNCTION The correct power steering (PS) fluid is *critical* to the operation and service life of the power steering system. The exact power steering fluid can be found in the following places:

- On the cap of the power steering reservoir
- In the owner's manual
- In service information

TECH TIP

The Visual Test

Whenever diagnosing any power steering complaint, check the level *and* condition of the power steering fluid. Often this is best accomplished by putting your finger down into the power steering fluid reservoir and pulling it out to observe the texture and color of the fluid. ● **SEE FIGURE 117–29**.

A common problem with some power rack-and-pinion units is the wearing of grooves in the housing by the Teflon sealing rings of the spool (control) valve. When this wear occurs, aluminum particles become suspended in the power steering fluid, giving it a grayish color and thickening the fluid. Normally, clear power steering fluid that is found to be grayish in color and steering that is difficult when cold are clear indications as to what has occurred and why the steering is not functioning correctly.

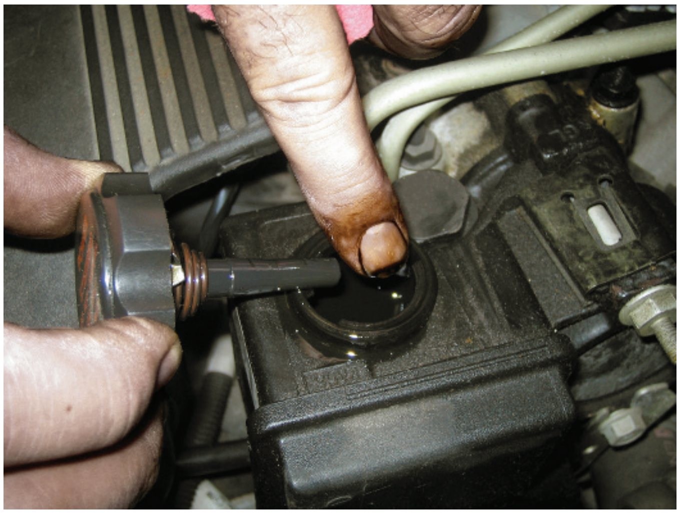


FIGURE 117–29 A check of the power steering fluid should include inspecting not only the level but the condition and color of the fluid, which could indicate a possible problem with other components in the steering system.

POWER STEERING CHECKS Power steering checks include the following inspections:

1. Check the power steering fluid level. Bleed the air from the system by turning the steering wheel lock-to-lock with the engine at idle speed.
2. Check the condition and tension of the drive belt. If in doubt, replace the belt.
3. Inspect the condition of all hoses, checking for any soft hose or places where the hose could touch another component.
4. Check the tightness of all mounting bolts of the pump and gear.

POWER STEERING FLUID FLUSHING PROCEDURE Whenever there is any power steering service performed, such as replacement of a defective pump or steering gear or rack-and-pinion unit, the entire system should be flushed. If all of the old fluid is not flushed from the system, small pieces of a failed bearing or rotor could be circulated through the system. These metal particles can block paths in the control valve and cause failure of the new power steering pump or gear assembly.

Besides flushing the old power steering fluid from the system and replacing it with new fluid, many technical experts recommend installing a filter in the low-pressure return line as an added precaution against serious damage from debris in the system. Power steering filters are commonly available through vehicle dealer parts departments, as well as aftermarket sources from local auto supply stores. Always follow the vehicle manufacturer's recommended flushing procedure. Two people are needed to flush the system. Use the following steps:

STEP 1 Raise the front wheels off the ground.

STEP 2 Remove the low-pressure return hose from the pump and plug the line fitting on the pump.

STEP 3 Place the low-pressure return hose into an empty container.

STEP 4 Fill the pump reservoir with fresh fluid and start the engine.

STEP 5 As the old and dirty power steering fluid is being pumped into the container, keep the reservoir full of clean fluid while the assistant turns the steering wheel full lock one way to full lock the other way.

CAUTION: Never allow the pump reservoir to run dry of power steering fluid. Severe internal pump damage can result.

STEP 6 When the fluid runs clean, stop the engine and reattach the low-pressure return hose to the pump reservoir.

STEP 7 Restart the engine and fill the reservoir to the full mark. Turn the steering wheel back and forth, avoiding the stops one or two times to bleed any trapped air in the system.

BLEEDING AIR OUT OF THE SYSTEM If the power steering fluid is tan, there may be air bubbles trapped in the fluid. Stop the engine and allow the air to burp out to the surface for several minutes. Lift the vehicle off the ground, then rotate the steering wheel. This method prevents the breakup of large air bubbles into thousands of smaller bubbles that are more difficult to bleed out of the system.

NOTE: To help rid the power steering system of unwanted trapped air, it is recommended that the engine be cranked and that the wheels be turned from stop to stop with the tires off the ground. Check service information for the specified procedure to follow to disable ignition or fuel-injection system to keep the engine from starting. Do not crank the engine for longer than 15 seconds to prevent starter damage due to overheating. Allow the starter to cool at least 30 seconds before cranking again.

Sometimes trapped air just cannot be bled out of the system using ordinary methods. This trapped air makes the pump extremely noisy and this noise sometimes convinces the technician that the pump itself is defective. If the power steering system has been opened for repairs and the system has been drained, trapped air may be the cause.

TECH TIP

Multiple-Purpose Power Steering Fluid

Multiple-purpose power steering fluid does not mean *all*-purpose power steering fluid. Always check the power steering reservoir cap, service information, or owner's manual for the exact fluid to be used in the vehicle being serviced. The main reason for using the specified power steering fluid is the compatibility of the fluid with the materials used in seals and hoses of the system. Using the wrong fluid (substituting ATF, for example) can lead to seal or hose deterioration and/or failure and fluid leaks. Always use the power steering fluid recommended by the manufacturer. The correct fluid to use is often imprinted on or near the power steering reservoir fill cap or is found in the owner's manual or service information. ● **SEE FIGURE 117–30**.

1 12345867
Gr. 8.800
GM
Goodwrench
Power Steering
Fluid
Cold Climate
CAUTION!
MAY CAUSE SKIN AND EYE IRRITATION.
Read Cautions on Back Panel
NET CONTENTS
32 FL. OZ. (0.946 LITRES)

FIGURE 117–30 Some power steering fluid is unique to the climate, such as this cold climate fluid recommended for use in General Motors vehicles when temperatures are low.

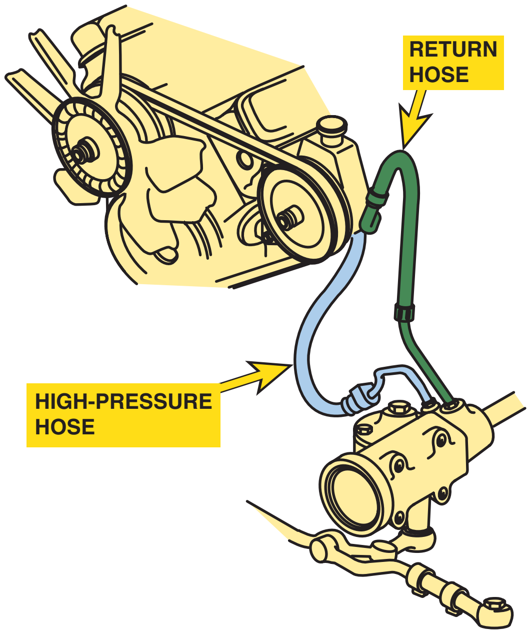


FIGURE 117–31 Inspect both high-pressure and return power steering hoses. Make sure the hoses are routed correctly and not touching sections of the body to prevent power steering noise from being transferred to the passenger compartment.

HOSE INSPECTION Both high-pressure supply and low-pressure return hoses should be inspected as part of any thorough vehicle inspection. While the low-pressure return hose generally feels softer than the high-pressure return hose, neither should feel *spongy*. A soft, spongy hose should always be replaced. ● **SEE FIGURE 117–31**.

When replacing any power steering hose, make certain that it is routed the same as the original and does not interfere with any accessory drive belt, pulley, or other movable component such as the intermediate steering shaft.

PRESSURE TESTING Use of a power steering pressure tester involves the following steps:

STEP 1 Disconnect the pressure hose at the pump.

STEP 2 Connect the hoses of the tester to the pump and the disconnected pressure line. ● **SEE FIGURE 117–32**.

STEP 3 Open the valve on the tester.

STEP 4 Start the engine. Allow the power steering system to reach operating temperatures.

STEP 5 The pressure gauge should register 80 to 125 PSI (550 to 860 kPa). If the pressure is greater than 150 PSI (1,400 kPa), check for restrictions in the system, including the operation of the poppet valve located in the inlet of the steering gear.

STEP 6 Fully close the valve three times. (Do not leave the valve closed for more than five seconds!) All three readings should be within 50 PSI (345 kPa) of each other and the peak pressure should be higher than 1,000 PSI (6,900 kPa).

STEP 7 If the pressure readings are high enough *and* within 50 PSI (345 kPa) of each other, the pump is operating normally.

STEP 8 If the pressure readings are high enough, yet not within 50 PSI (345 kPa) of each other, the flow control valve is sticking.

STEP 9 If the pressure readings are less than 1,000 PSI (6,900 kPa), replace the flow control valve and recheck. If the

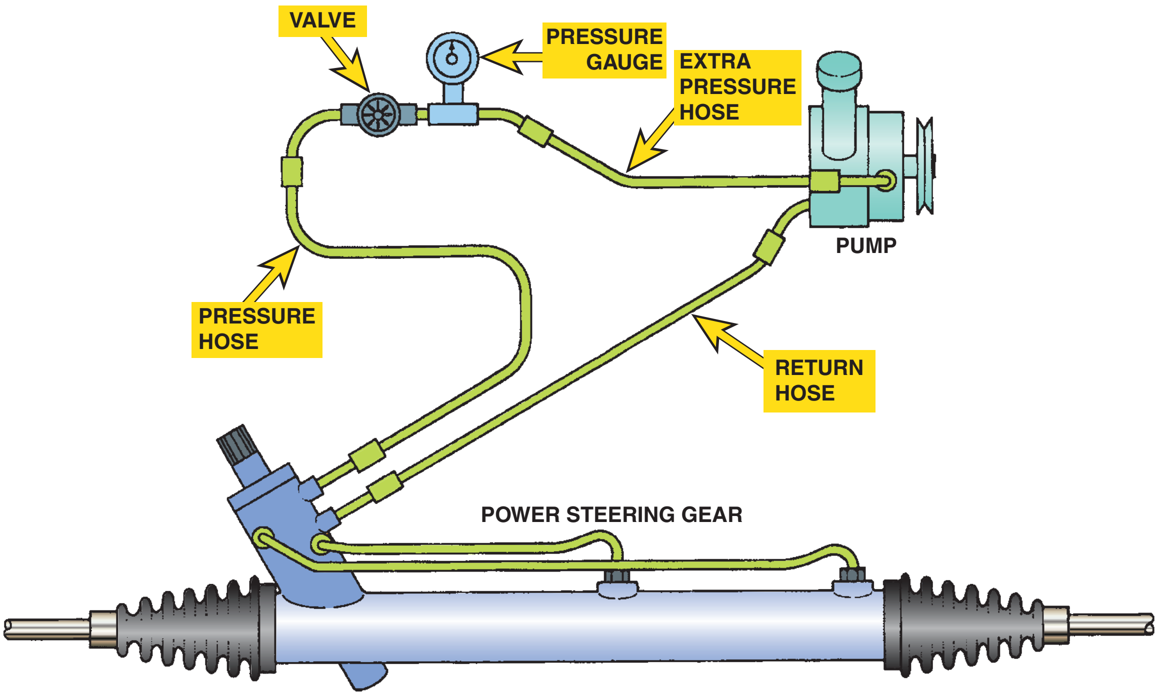


FIGURE 117–32 A drawing showing how to connect a power steering analyzer to the system.

CASE STUDY

The Noisy Power Steering Pump

A customer complained that the power steering on their Dodge Grand Caravan minivan had a very loud whining/growling/squealing noise for about 3–10 seconds on cold mornings at start-up. The owner had received a quote for several hundred dollars to replace the power steering pump, but then asked another shop for a second opinion. The second shop had experience with this issue and recommended replacing the power steering filter located in the bottom of the power steering pump reservoir. The owner agreed to have the filter and the fluid replaced for an amount far less than the previous quote. After replacing the filter and flushing the power steering fluid, the power steering was quiet and operated like new.

Summary:

Complaint—Power steering was noisy especially when cold.
Cause—The screen in the bottom of the reservoir plugs up and starves the pump of oil causing the noise.
Correction—The filter was replaced and the fluid flushed.

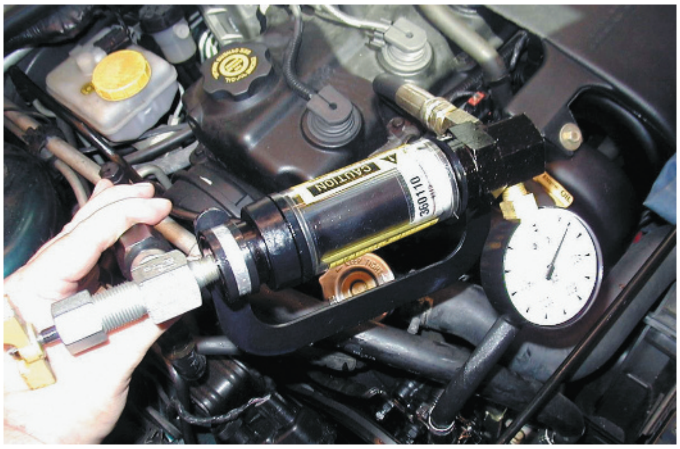


FIGURE 117–33 A power steering analyzer that measures both pressure and volume. The shut-off valve is used to test the maximum pressure of the pump.

pressures are still low, replace the rotor and vanes in the power steering pump or the entire pump assembly.

STEP 10 If the pump is working as designed, turn the steering wheel to both stops. If the pressure at both stops is not the same as the maximum pressure, the steering gear (or rack and pinion) is leaking internally and should be repaired or replaced. Many vehicle manufacturers recommend using a power steering analyzer that measures both pressure and volume, as shown in ● **FIGURE 117–33**.

Knowing the volume flow in the system provides information to the technician in addition to that of the pressure gauge. Many manufacturer's diagnostic procedures specify volume measurements and test results that can help pinpoint flow control or steering gear problems. Always follow the vehicle manufacturer's recommended testing procedures. ● **SEE CHART 117–2** for pressure and volume measurements specified by the manufacturer.

PUMP SERVICE Some power steering pump service can usually be performed without removing the pump, including the following:

1. Replacing the high-pressure and return hoses
2. Removing and cleaning the flow control valve assembly ● **SEE FIGURE 117–34**.

TYPICAL POWER STEERING PRESSURES AND VOLUME SPECIFICATIONS

STEERING ACTION	PRESSURE, PSI (kPa)	VOLUME* (Gal/min) (L./min)
Straight ahead, no steering	Less than 150 PSI (1,000 kPa)	2.0–3.3 gpm (10–15 lpm)
Slow cornering	300–450 PSI (2,000–3,000 kPa)	Within 1 gpm (4 lpm) of straight ahead)
Full turn at stops	750–1,450 PSI** (5,200–10,000 kPa)	Less than 1 gpm (4 lpm)

* Volume is determined by orifice size in the outlet of the pump and is matched to the steering gear.

** Upper-limit pressure is determined by the calibration of the pressure-relief valve.

CHART 117–2

Power steering pressures are related to the force applied to the steering wheel by the driver. The lowest pressure occurs while driving straight and the highest pressure occurs during turns to the steering stops.

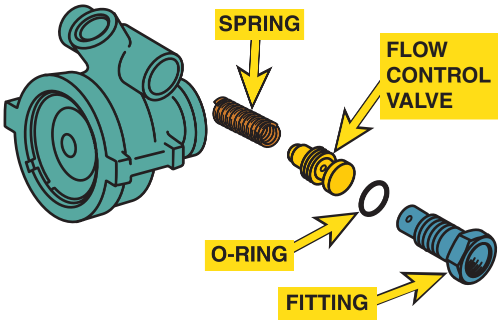


FIGURE 117–34 Typical power steering pump showing the order of assembly. The high-pressure (outlet) hose attaches to the fitting (#16). The flow control valve can be removed from the pump by removing the fitting.

Most power steering pump service requires the removal of the pump from the engine mounting and/or removal of the drive pulley.

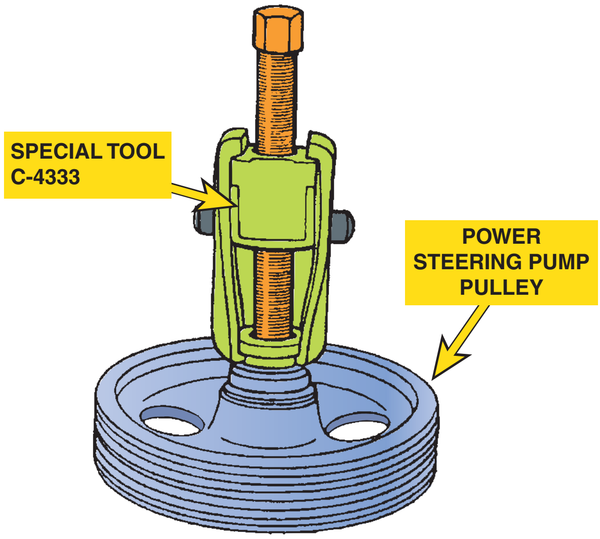
NOTE: Most replacement pumps are not equipped with a pulley. The old pulley must be removed and installed on the new pump. The old pulley should be carefully inspected for dents, cracks, or warpage. If the pulley is damaged, it must be replaced. The pulley must be removed and installed with a pulley removal and installation tool. ● SEE FIGURE 117–35.

CAUTION: Do not hammer the pump shaft or pulley in an attempt to install the pulley. The shock blows will damage the internal components of the pump.

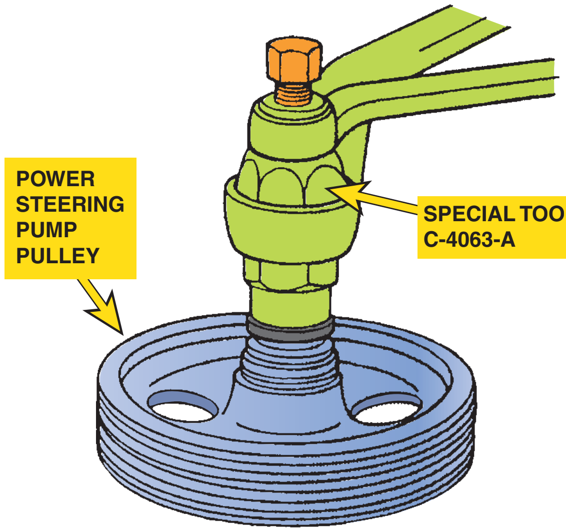
TECH TIP

Pocket the Ignition Key to Be Safe

When replacing any steering gear such as a rack-and-pinion steering unit, be sure that no one accidentally turns the steering wheel! If the steering wheel is turned without being connected to the steering gear, the airbag wire coil (clock spring) can become off center. This can cause the wiring to break when the steering wheel is rotated after the steering gear has been replaced. To help prevent this from occurring, simply remove the ignition key from the ignition (make sure the steering wheel is locked) and put it in your pocket while servicing the steering gear.



REMOVE DRIVE PULLEY (TYPICAL)

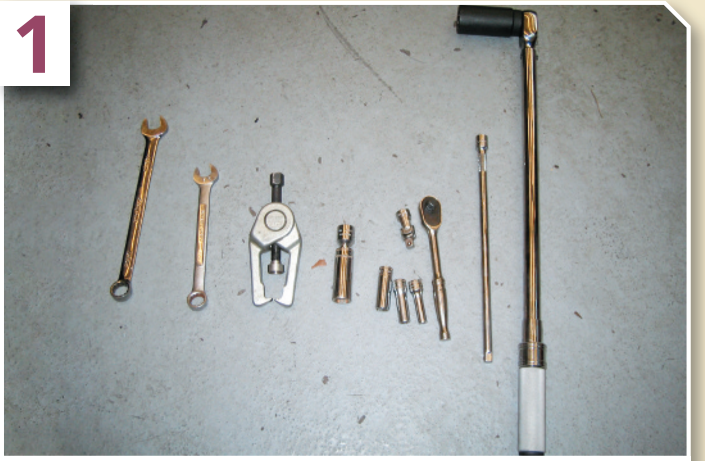


INSTALL DRIVE PULLEY (TYPICAL)

FIGURE 117–35 Typical tools required to remove and install a drive pulley on a power steering pump. Often these tools can be purchased at a relatively low cost from automotive parts stores and will work on many different makes of vehicles.

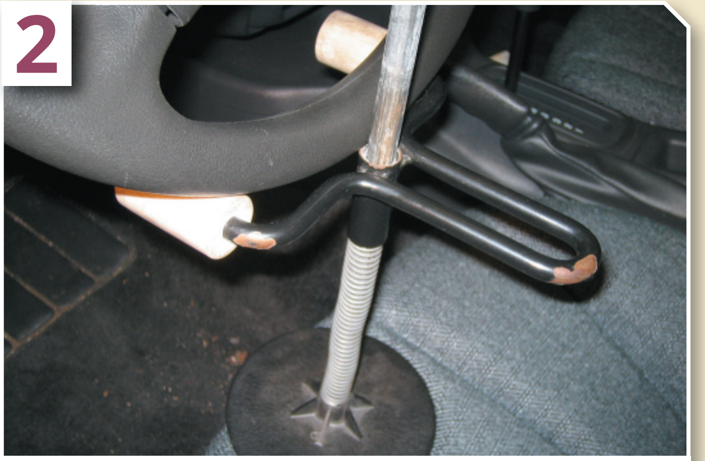
STEERING RACK REMOVAL AND INSTALLATION STEP BY STEP

1



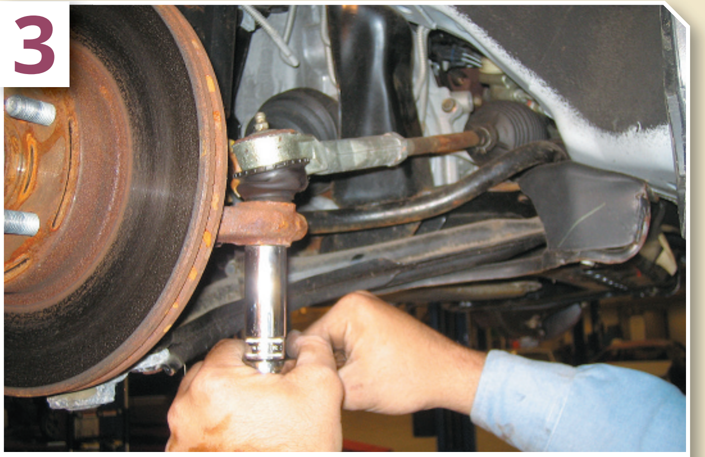
The tools required include a tie rod end puller and basic hand tools.

2



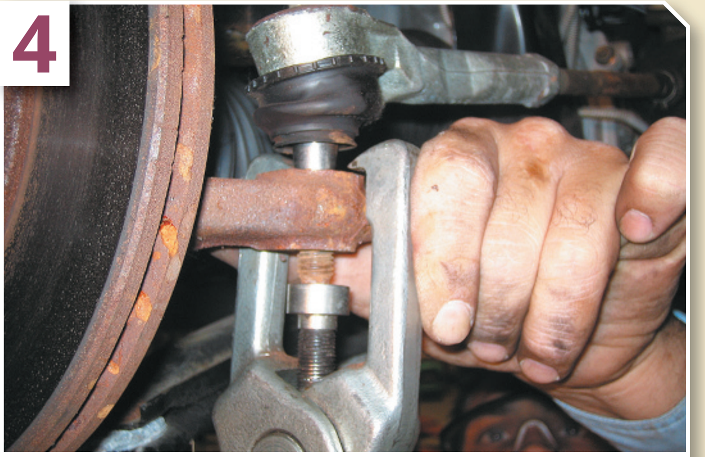
To help keep the steering wheel from rotating when the steering rack assembly is removed, a steering wheel lock is being used.

3



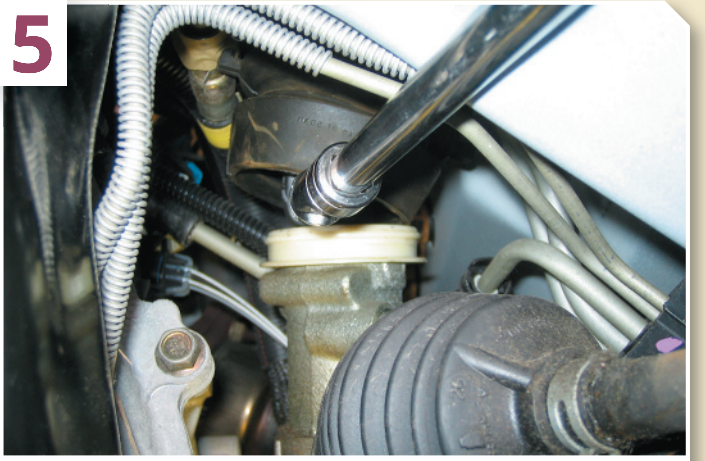
After safely hoisting the vehicle and removing the front wheels, the outer tie rod end retaining nuts are removed.

4



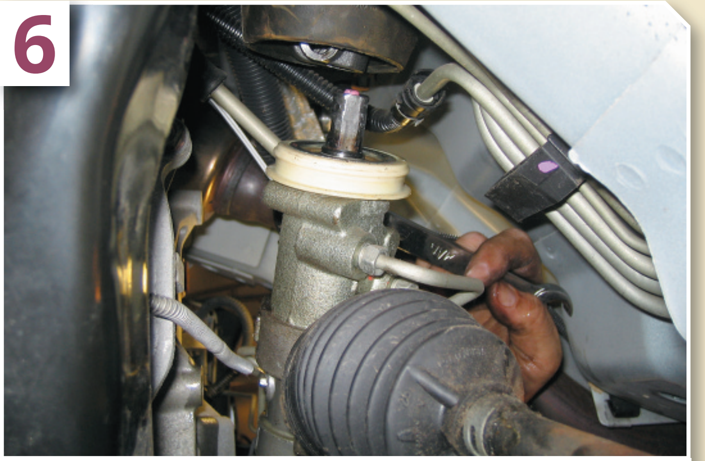
Use a tie rod taper breaker to separate the outer tie rods from the steering knuckle without harming the rubber grease boots.

5



After moving the protective cover aside, the bolt used to retain the intermediate shaft to the steering gear stub shaft is removed.

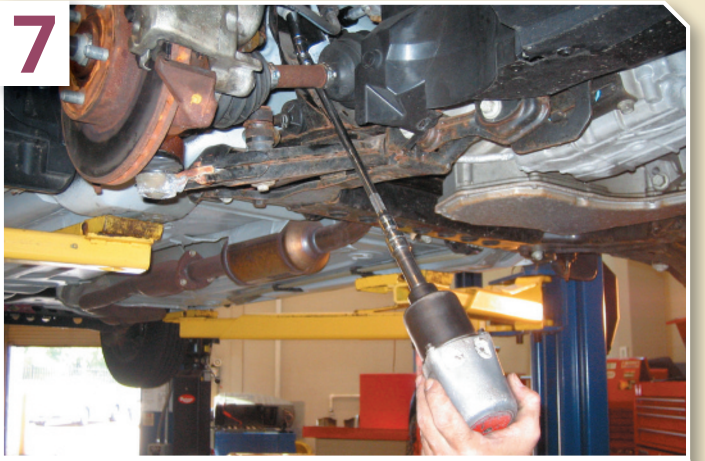
6



The hydraulic lines attached to the steering rack to the power steering rack assembly are removed using a line wrench.

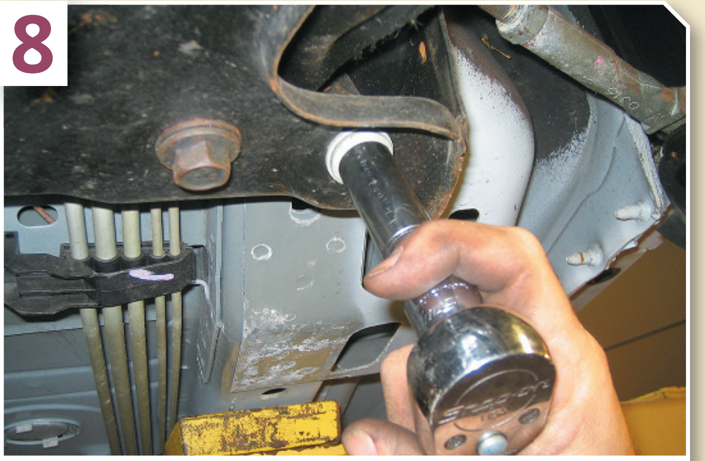
STEERING RACK REMOVAL AND INSTALLATION

7



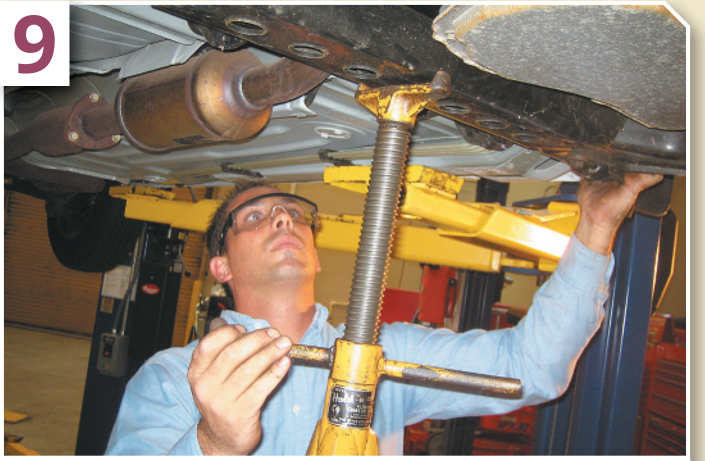
After supporting the engine cradle using a tall safety stand, an air impact wrench with a long extension is used to remove the engine cradle bolts.

8



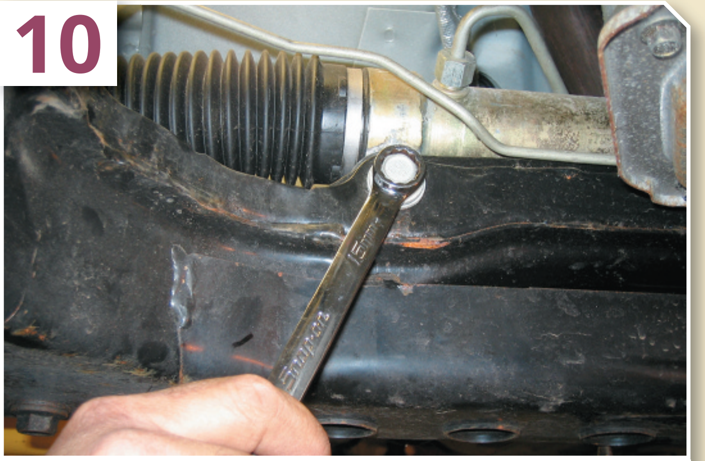
Removing the lower engine cradle bolts. This will allow the cradle to be lowered to gain access to the steering rack assembly.

9



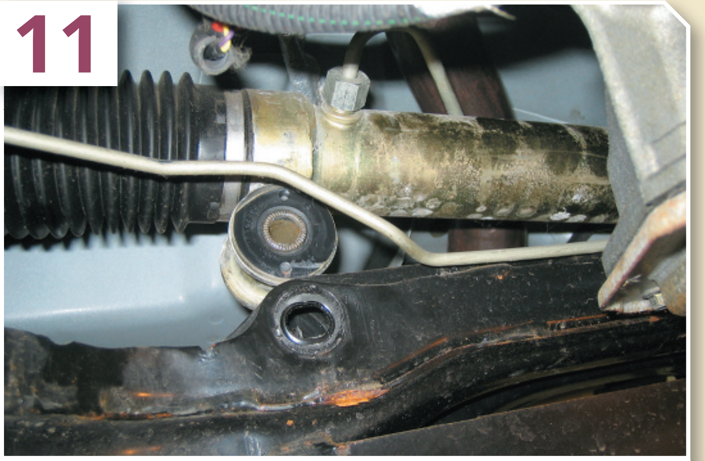
The screw jack on the tall safety stands is rotated allowing the engine cradle to be lowered.

10



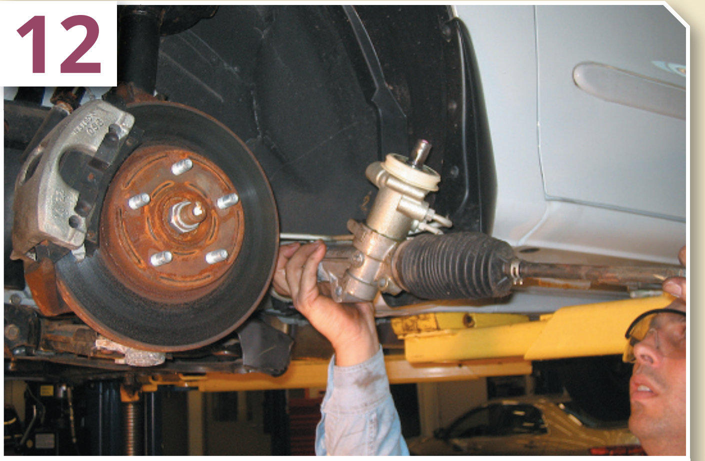
Removing the steering rack attachment bolts.

11



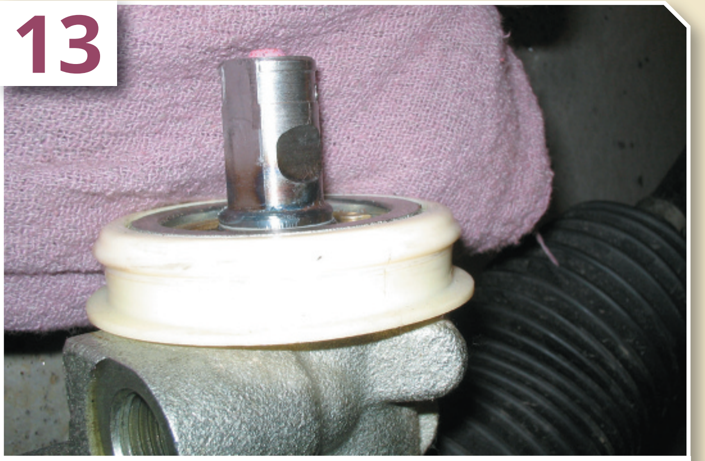
The steering rack assembly can be lifted out of the support brackets.

12



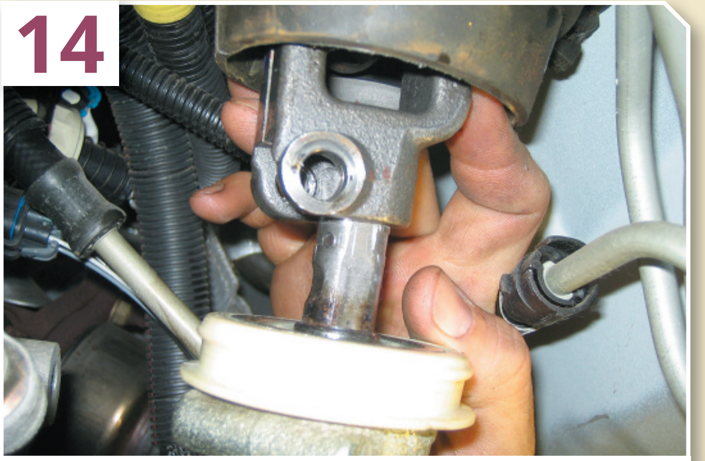
On this General Motors vehicle, the steering rack assembly is removed from the driver's side.

13



Before reinstalling the steering gear assembly, note the notch on the stub shaft. This notch has to be aligned with the intermediate shaft retaining bolt when it is placed back into the vehicle.

14

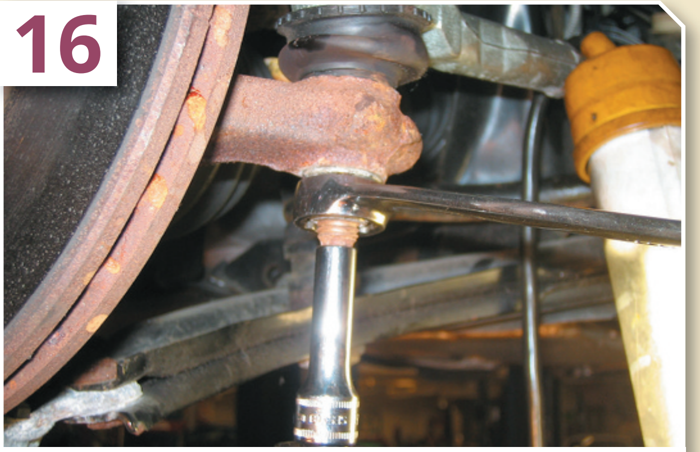


Installation is the reverse of removal. Be sure that the rack is centered and check that the throughbolt is properly aligned with the notch in the steering rack stub shaft.

15

While using a tall safety stand to support the engine cradle, the retaining bolts are installed.

16



A socket is being used to keep the tapered tie rod end from rotating while the retaining nut is tightened with a wrench.

17

After the hydraulic lines and retaining bolts have been installed, the power steering pump reservoir is filled using the specified fluid.

18

To bleed the trapped air out of the system, the steering wheel is rotated lock to lock with engine off and the wheels off the ground. Check for leaks then perform a test-drive to verify a proper repair.

REVIEW QUESTIONS

1. What are five possible causes for hard steering?
2. What is the procedure for flushing a power steering system?
3. How is a pressure test of a power steering system performed?
4. What is an integral power steering system?
5. What tool is needed to remove and install a power steering pump pulley?

CHAPTER QUIZ

1. A hydraulic system uses ___________ to transfer force from one place to another.
   - **a.** fluid
   - **b.** pipes and hoses
   - **c.** different-sized pistons
   - **d.** All of the above
2. High-pressure hoses have to be used on the high-pressure side of the power steering system because pressures can reach as high as ___________.
   - **a.** 200 PSI
   - **b.** 750 PSI
   - **c.** 1,400 PSI
   - **d.** 2,500 PSI
3. Some vehicles are equipped to signal the computer whenever the power steering pressures increase so that the idle speed can be increased to prevent stalling during turns at low speeds. What component signals the computer?
   - **a.** Pressure-relief valve
   - **b.** Power steering pressure switch
   - **c.** Rotary valve
   - **d.** Flow control valve
4. Integral power steering gears use ___________ for lubrication of the unit.
   - **a.** SAE 80W-90 gear lube
   - **b.** chassis grease (NLGI #2)
   - **c.** power steering fluid in the system
   - **d.** molybdenum disulfide
5. Electronically controlled variable-assist power steering systems vary the amount of boost by ___________.
   - **a.** varying the pump output orifice size
   - **b.** speeding up or slowing down the power steering pump
   - **c.** changing the flow of fluid through the steering gear
   - **d.** bypassing some of the fluid back into the reservoir
6. What can cause hard steering on a vehicle equipped with hydraulic power-assisted steering system?
   - **a.** Low tire pressure
   - **b.** Slipping P.S. pump drive belt
   - **c.** Low or contaminated power steering fluid
   - **d.** Any of the above
7. Two technicians are discussing the proper procedure for bleeding air from a power steering system. Technician A says that the front wheels of the vehicle should be lifted off the ground before bleeding. Technician B says that the steering wheel should be turned left and right with the engine off during the procedure. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. A power steering system should be checked for ___________.
   - **a.** power steering fluid level
   - **b.** condition of the drive belt
   - **c.** condition of the hoses
   - **d.** All of the above
9. When pressure testing a hydraulic assisted power steering system, the highest pressures were greater than 50 PSI of each other. This indicates a problem with the ___________.
   - **a.** pump rotor
   - **b.** pump vanes
   - **c.** flow control valve
   - **d.** defective hose
10. The specified power steering fluid is found where?
    - **a.** On the cap of the power steering reservoir
    - **b.** In the owner's manual
    - **c.** In service information
    - **d.** All of the above

Chapter **118**

ELECTRIC POWER STEERING SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the purpose, function, and types of electric power steering systems.
- Discuss electric power steering parts and operation.
- Discuss the power steering control module.
- Discuss the diagnosis of electric power steering system faults.
- Describe the self-parking feature and its relationship to power steering.
- Describe electrohydraulic power steering.

KEY TERMS:

Brake pedal position (BPP) sensor 1473 • Column-mounted electric power steering (C-EPS) 1467 • Direct-drive electric power steering (D-EPS) 1467 • Electric power-assisted steering (EPAS) 1467 • Electric power steering (EPS) 1467 • Electrohydraulic power steering (EHPS) 1472 • Pinion-mounted electric power steering (P-EPS) 1468 • Power steering control module (PSCM) 1470 • Rack-and-pinion electric power steering (R-EPS) 1467 • Self-parking 1471 • Steering position sensor (SPS) 1470 • Steering shaft torque sensor 1470

ELECTRIC POWER STEERING OVERVIEW

PURPOSE AND FUNCTION Many of today's vehicles use **electric power steering (EPS)** systems, which is also called **electric power-assisted steering (EPAS)**. Electric power steering takes the place of hydraulic components that were previously used by using an electric motor to provide power assist effort.

ADVANTAGES The advantages include

- Improved fuel economy. Ford and Honda both state that fuel economy improves 3% to 5% in the absence of a power steering pump and the weight of the hydraulic system needed for conventional hydraulically operated power steering systems.
- Increase in usable power. Ford estimates that by using electric power steering instead of a conventional hydraulic system results in a three horsepower increase in engine output without any other changes.
- Allows the vehicle manufacturer to save vehicle weight and complexity because there is no need for all of the hydraulic lines and engine-driven pump.
- Improved cold weather starting because of reduced engine load without the drag of a power steering pump.
- Simple two-wire connection in many cases, making vehicle assembly and vehicle service easier.

TYPES OF EPS SYSTEMS There are two basic types of EPS systems:

1. **Rack mounted.** The rack-mounted system has the assist motor attached to the rack and is often called a **rack-and-pinion electric power steering (R-EPS)** system. Another design has the assist motor surrounding the rack and this style is called a **direct-drive electric power steering (D-EPS)** system. ● **SEE FIGURES 118–1 AND 118–2**.
2. **Column mounted. Column-mounted electric power steering (C-EPS)** has sensors and the assist motor located inside the vehicle so they are not exposed to the heat and outside elements as is the rack-mounted system.

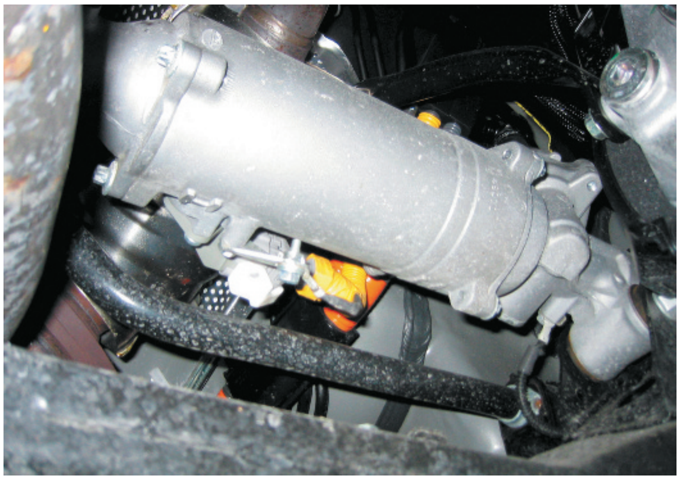


FIGURE 118–1 A rack-mounted electric power steering gear on a Lexus RX 400h taken from underneath the vehicle.

● **SEE FIGURE 118–3**. This is the most commonly used type and involves using a manual rack-and-pinion steering gear assembly with a motor assist in the steering column. While not directly mounted on the column itself, another type of electric power steering is the **pinion-mounted electric power steering (P-EPS)** system. This system has the assist motor connected to the pinion shaft of the rack-and-pinion steering gear. ● **SEE FIGURE 118–4**.

EPS SYSTEM PARTS AND OPERATION

TYPES OF MOTOR USED Most electric power steering units use a DC brushless electric motor. Some operate from 42 volts while others operate from 12 volts. The Toyota system on a Prius uses a DC motor, reduction gear, and torque sensor, all mounted to the steering column. ● **SEE FIGURE 118–5**.

EPS CONTROL UNIT The electric power steering (EPS) is controlled by the EPS electronic control unit (ECU), which calculates the amount of needed assist based on the input from the steering torque sensor. The steering torque sensor is a noncontact sensor that detects the movement and torque applied to the torsion bar. The torsion bar twists when the drive exerts torque to the steering wheel, and the more torque applied, the farther the bar will twist. This generates a higher-voltage signal to the EPS ECU. The EPS control unit can vary the amperage to the assist motor based on input from the torque and steering wheel sensors. The control unit also monitors the temperature of the motor and can reduce the amount of power assist if the motor temperature increases too much. ● **SEE FIGURE 118–6**.

The steering shaft torque sensor and the steering wheel position sensor are serviced as an assembly and are not individually replaceable. The steering column assembly does not include the power steering motor and module assembly. Column-mounted EPS systems use detection rings to measure the differences in relative motion between the upper (input) and lower (output) steering column shafts. Detection rings 1 and 2 are mounted on the input shaft and detection ring 3 is mounted on the output shaft. The input shaft and the output shaft are connected by a torsion bar. When the steering wheel is turned, the difference in relative motion between detection rings 2 and 3 is sensed by the detection coil and it sends two signals to the EPS ECU. These two signals are called Torque Sensor Signal 1 and Torque Sensor Signal 2. The EPS ECU uses these signals to control the amount of assist, and also uses the signals for diagnosis.

NOTE: If the steering wheel, steering column, or steering gear is removed or replaced, the system must be recalibrated, which resets the zero point of the torque sensors.

The Honda electric power steering uses an electric motor to provide steering assist, and torque sensor is used to measure road resistance and the direction that the driver is turning the steering wheel. The torque sensor input and the vehicle speed are used by the EPS controller to supply the EPS motor with

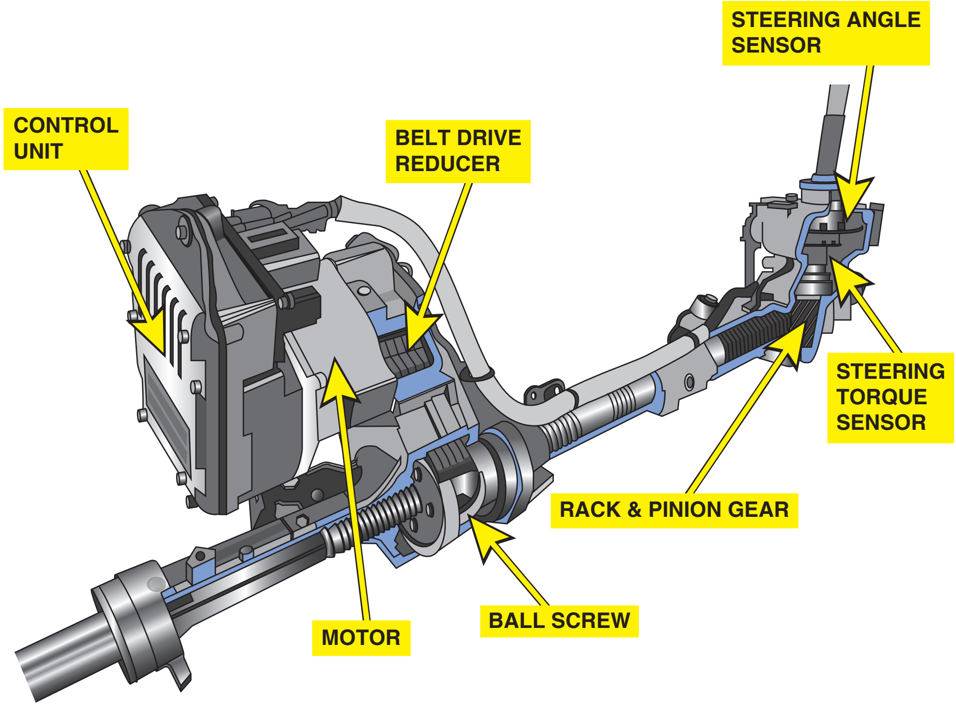


FIGURE 118–2 A belt-driven electric power steering system used on many Ford vehicles.

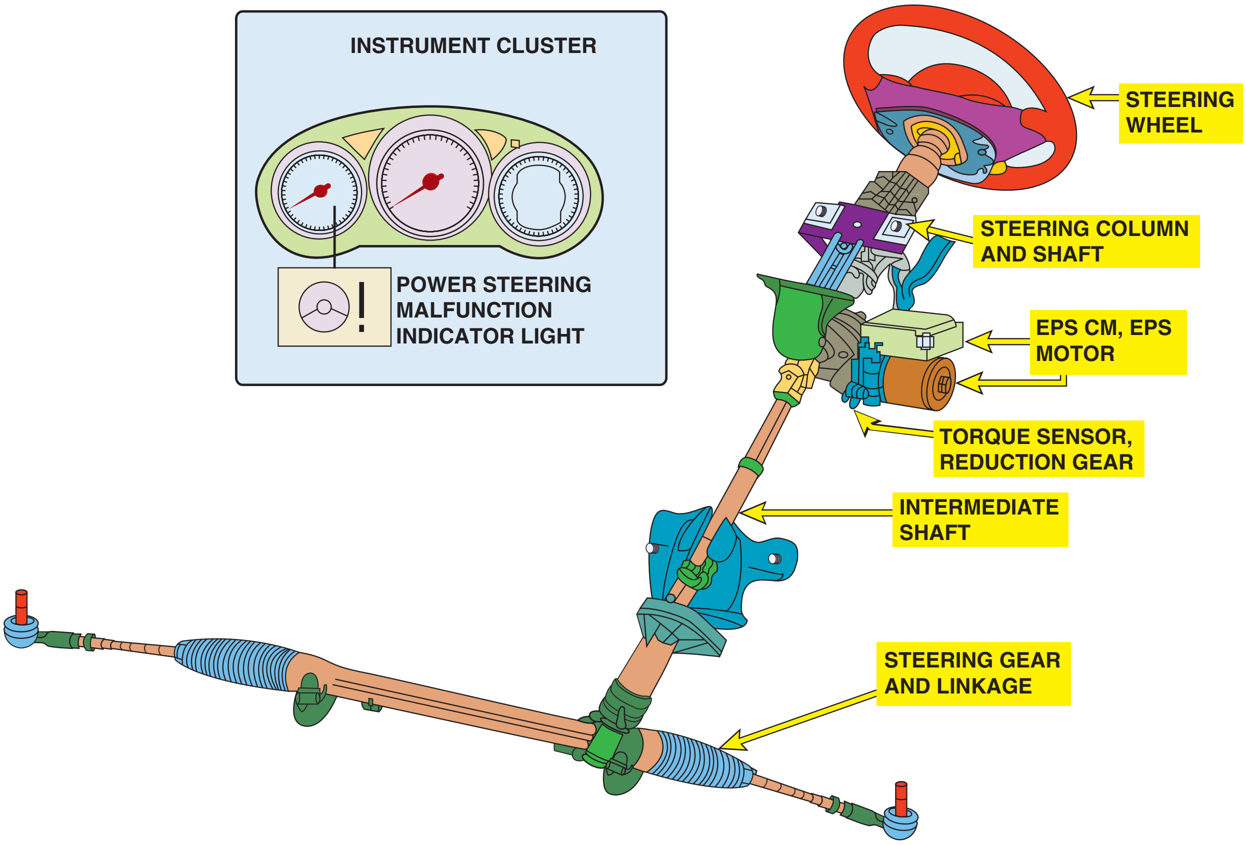

INSTRUMENT CLUSTER
POWER STEERING MALFUNCTION INDICATOR LIGHT
STEERING WHEEL
STEERING COLUMN AND SHAFT
EPS CM, EPS MOTOR
TORQUE SENSOR, REDUCTION GEAR
INTERMEDIATE SHAFT
STEERING GEAR AND LINKAGE

FIGURE 118–3 A typical column-mounted electric power steering (EPS) system showing the location of the major components involved including the dash warning light symbol.

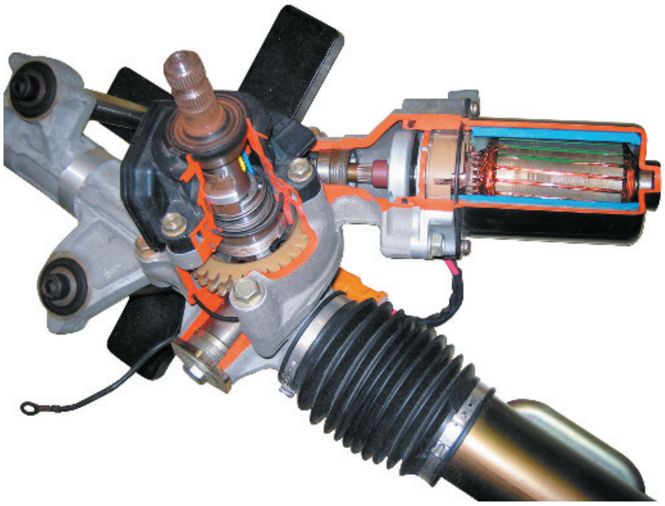


FIGURE 118–4 Honda electric power steering unit cutaway, which is an example of pinion-mounted electric power steering system.

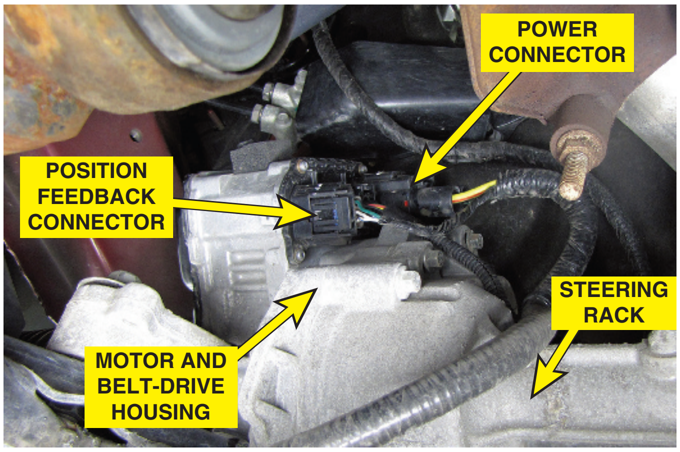

POWER CONNECTOR
POSITION FEEDBACK CONNECTOR
STEERING RACK
MOTOR AND BELT-DRIVE HOUSING

FIGURE 118–5 A Ford electric power steering rack-mounted motor that drives the rack through a toothed belt. This assembly is located on the passenger side of the vehicle opposite to where the steering column shaft is attached to the rack.

the specified current to help assist the steering effort. ● **SEE FIGURE 118–7**.

The motor turns the pinion shaft using a worm gear. The worm gear is engaged with the worm wheel so that the motor turns the pinion shaft directly when providing steering assist. If a major fault were to occur, the control module would first try to maintain power-assisted steering even if some sensors had failed. If the problem is serious, then the vehicle can be driven and steered manually. The EPS control unit will turn on the EPS dash warning light if a fault has been detected. A fault in the system will *not* cause the malfunction indicator light (MIL) to come on because that light is reserved for emission-related faults only. However, another warning light may be turned on to warn the driver of a problem with the electric power steering system. Fault codes can be retrieved by using a scan tool. Check service information for the exact procedures to follow when diagnosing electric power steering faults.

EPS INPUTS AND OUTPUTS The EPS system includes the following components and input signals from sensors and output signals to actuator components:

- Powertrain control module (PCM)
- Body control module (BCM)
- Power steering control module (PSCM)

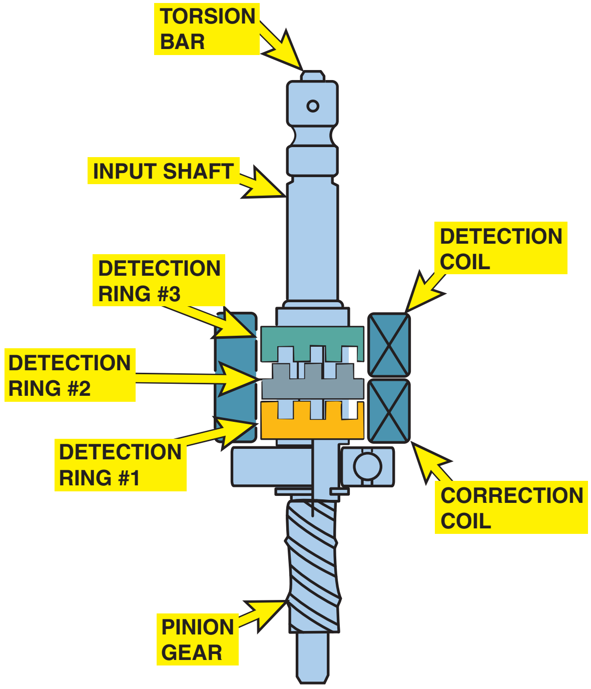


FIGURE 118–6 The torque sensor converts the torque the driver is applying to the steering wheel into a voltage signal.

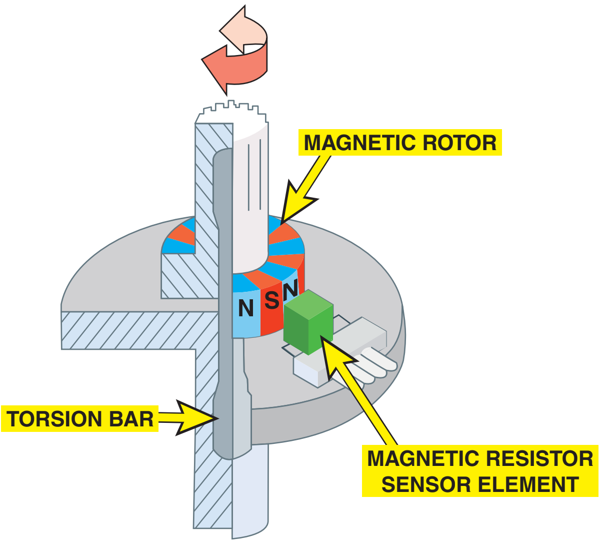


FIGURE 118–7 A cutaway view showing the operation of the torque sensor used in electric power steering systems.

- Battery voltage
- Steering shaft torque sensor
- Steering wheel position sensor
- Power steering motor
- Driver information center (DIC)
- Serial data communications circuits to perform the system functions

The **power steering control module (PSCM)** and the power steering motor are serviced as an assembly and are serviced separately from the steering column assembly. ● **SEE FIGURE 118–8**.

The steering shaft torque sensor and the steering wheel position sensor are not serviced separately from each other or from the steering column assembly. The steering column assembly does not include the power steering motor and module assembly.

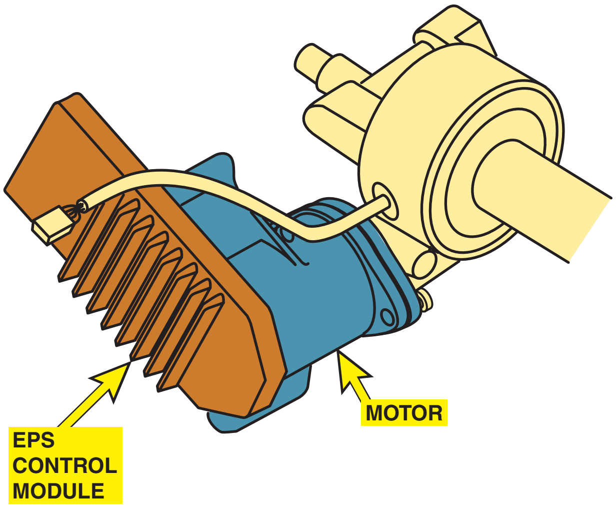


FIGURE 118–8 The power steering control module (PSCM) is attached to the motor of the electric power steering assembly.

STEERING SHAFT TORQUE SENSOR

The PSCM uses the **steering shaft torque sensor** as a main input for determining steering direction and the amount of assist needed. The steering column has an input shaft, from the steering wheel to the torque sensor, and an output shaft, from the torque sensor to the steering shaft coupler. The input and output shafts are separated by a section of torsion bar, where the torque sensor is located. The torque sensor includes two different sensors in one housing. The sensors are used to detect the direction the steering wheel is being rotated.

- When torque is applied to the steering column shaft during a right turn, the sensor signal 1 voltage increases, while the sensor signal 2 voltage decreases.
- When torque is applied to the steering column shaft during a left turn, the sensor signal 1 voltage decreases, while the sensor signal 2 voltage increases.

The PSCM recognizes this change in signal voltage as steering direction and steering column shaft torque.

STEERING WHEEL POSITION SENSOR

The PSCM uses the **steering position sensor (SPS)** to determine the steering system on-center position. Because the power steering motor provides a slight amount of return-to-center assist, the PSCM will command the power steering motor to the steering system center position and not beyond. The sensor is a 5 volt dual-analog signal device with a signal voltage range of 0 to 5 volts. The sensor's signal 1 and signal 2 voltage values will increase and decrease within 2.5 to 2.8 volts of each other as the steering wheel is turned. ● **SEE FIGURE 118–9**.

POWER STEERING MOTOR

The power steering motor is a 12 volt brushless DC reversible motor with a 65 ampere rating. The motor assists steering through a worm gear and reduction gear located in the steering column housing. The motor draws about 750 to 1,000 watts or about 1 horsepower at full assist. The motor itself is usually replaced as an assembly or can be included with the control unit.

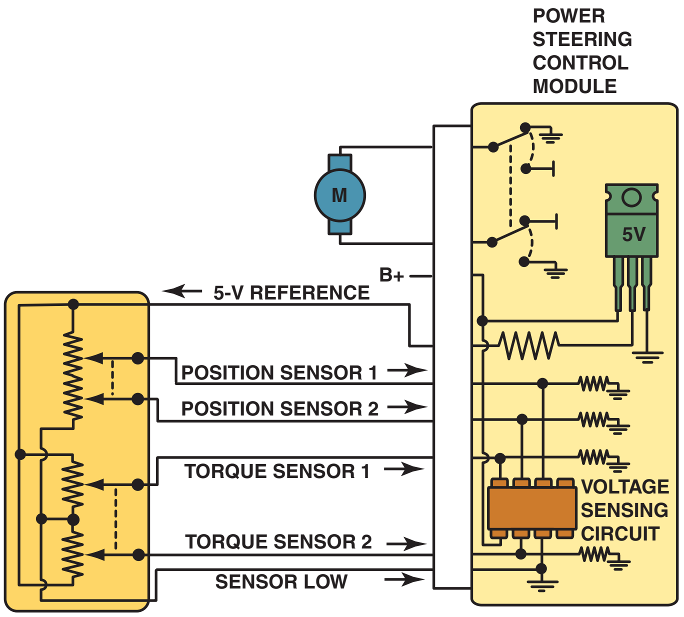


FIGURE 118–9 Schematic showing the electric power steering and the torque/position sensor.

POWER STEERING CONTROL MODULE (PSCM)

PURPOSE AND FUNCTION The PSCM uses a combination of steering shaft torque sensor input, vehicle speed, calculated system temperature, and steering tuning to determine the amount of steering assist.

OPERATION When the steering wheel is turned, the PSCM uses signal voltage from the steering shaft torque sensor to detect the amount of torque and steering direction being applied to the steering column shaft and then commands the proper amount of current to the power steering motor. The PSCM receives a vehicle speed message from the PCM by way of the serial data communications circuit. At low speeds, more assist is provided for easy turning during parking maneuvers, and at higher speeds, less assist is provided for improved road feel and directional stability.

FAULT DETECTION The PSCM and the power steering motor are not designed to handle 65 amperes continuously. If the power steering system is exposed to excessive amounts of static steering conditions, the PSCM will go into a protection mode to avoid thermal damage due to overheating of the power steering components. In this mode, the PSCM will limit the amount of current commanded to the power steering motor, which reduces system temperature and steering assist levels.

EPS DIAGNOSIS

The PSCM has the ability to detect malfunctions within the power steering system. Any malfunction detected will cause the driver information center to display the *power steering* warning message and/or the *service vehicle soon* indicator.

The PSCM must also be set up with the correct steering tunings, which are different in relation to the vehicle's powertrain configuration, model type, and tire and wheel size. A factory or aftermarket factory-level scan tool is needed to retrieve data and to perform relearn procedures if the unit is replaced. Always check service information for the exact procedures to follow when diagnosing and serving the electric power steering system.

DIAGNOSTIC TROUBLE CODE (DTC)	DESCRIPTION OF FAULT
C1511; C1512; C1513; C1514	Torque sensor fault detected
C1521	Short in motor circuit
U0073	EPS control module lost communications

CHART 118–1

Sample diagnostic trouble codes (DTCs) for the electric power steering system.

EPS DTCS Most electric power steering diagnostic trouble codes will be "C" codes for chassis-related faults or "U" codes for data communication faults. ● **SEE CHART 118–1** for same sample DTCs.

SELF-PARKING SYSTEM

PURPOSE AND FUNCTION Several vehicle manufacturers offer a **self-parking** feature that uses the electric power steering to steer the vehicle. The driver has control of the brakes.

SENSORS INVOLVED Most systems use the following sensors:

- Wheel speed sensor (WSS)
- Steering-angle sensor
- Ultrasonic sensors, which are used to plot a course into a parking space

SELF-PARK OPERATION Some systems, such as those manufactured by Valeo for Volkswagen, allow the driver to control the accelerator as well as the brakes, making it possible to add power to park uphill. The Toyota/Lexus system stops working if the accelerator is depressed during a self-parking event. The Toyota/Lexus system is camera-based and uses the navigation system to display the parking spot with touch screen controls. The system displays a green video box to indicate that the spot is large enough and a red box to indicate that the spot is too small. The driver positions a yellow flag on the video screen to mark the front corner of the parking spot and then the vehicle backs into the space at idle speed. The driver may have to complete the parking event by straightening the vehicle and pulling forward in the spot in some vehicles.

DIAGNOSIS AND TESTING Self-parking systems use many sensors to achieve the parking event, and a fault in any one sensor will disable self-parking. Before trying to diagnose a self-parking fault, be sure that the driver is operating the system as designed. For example, the self-parking event is cancelled if the accelerator pedal is depressed on some units. Always follow the factory-recommended diagnostic and testing procedures.

CASE STUDY

The Hard Steering Chevrolet

The owner of a Chevrolet complained that the steering wheel was harder to turn after the battery was jump started. The tow truck driver did not know what to do and advised the owner to take it to a shop to have it looked at but the driver did not think that jump starting the vehicle could affect the power steering. A technician at the shop determined that the electric power steering did not work because of a blown fuse. Apparently, the vehicle was jump started by connecting the positive jump cable to the main terminal toward the rear of the engine compartment instead of the terminal designed to be used to jump start the vehicle as the battery is located at the rear of this vehicle. ● **SEE FIGURE 118–10**.

After the blown fuse was replaced, the electric power steering worked correctly.

Summary:

Complaint—Owner complained that the steering felt stiff after the vehicle was jump started.

Cause—The jump start cables were connected to the wrong terminal, which caused the fuse to blow that controlled the electric power steering.

Correction—The blown fuse was replaced and the power steering system operation was restored to normal.

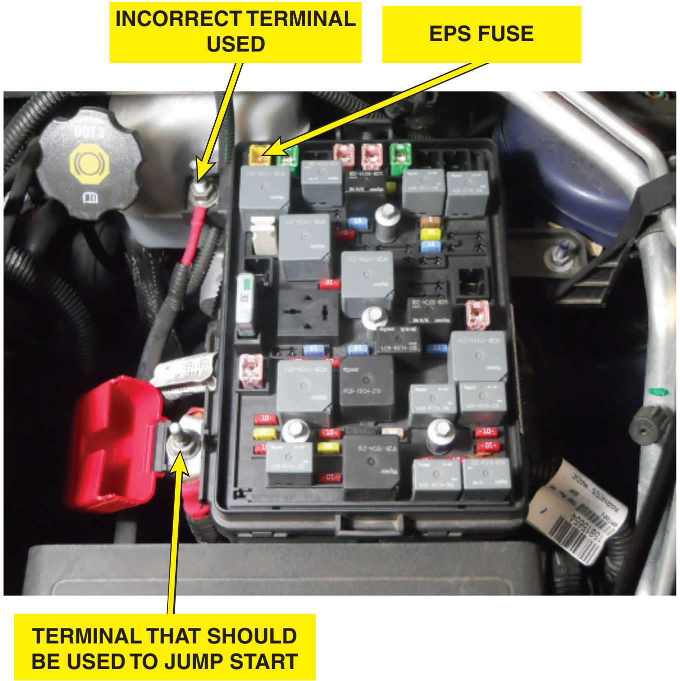


FIGURE 118–10 The blown fuse is the yellow 60 ampere fuse next to the terminal at the top.

ELECTROHYDRAULIC POWER STEERING

PURPOSE AND FUNCTION Electrohydraulic power steering is used on the Chevrolet Silverado mild hybrid truck and on the Mini Cooper. This system uses an electric motor to drive a hydraulic pump. The **electrohydraulic power steering (EHPS)** module controls the power steering motor, which has the function of providing hydraulic power to the brake booster and the steering gear. A secondary function includes the ability to improve fuel economy by operating on a demand basis and the ability to provide speed-dependent variable-effort steering. The EHPS module controls the EHPS power pack, which is an integrated assembly consisting of the following components:

- Electric motor
- Hydraulic pump
- Fluid reservoir
- Reservoir cap
- Fluid-level sensor
- Electronic controller
- Electrical connectors

● **SEE FIGURE 118–11**.

EHPS MODULE The electrohydraulic power steering (EHPS) module is operated from the 36 volt (nominal) power supply. The EHPS module uses class 2 for serial communications. A 125 ampere, 36 volt fuse is used to protect the EHPS module. If this fuse were to blow open, the EHPS system would not operate and communication codes would be set by the modules that communicate with the EHPS module. The powertrain control module (PCM) is the gateway that translates controller area network (CAN) messages into class 2 messages when required for diagnostic purposes. The EHPS module receives the following messages from the CAN bus:

- Vehicle speed
- Service disconnect status

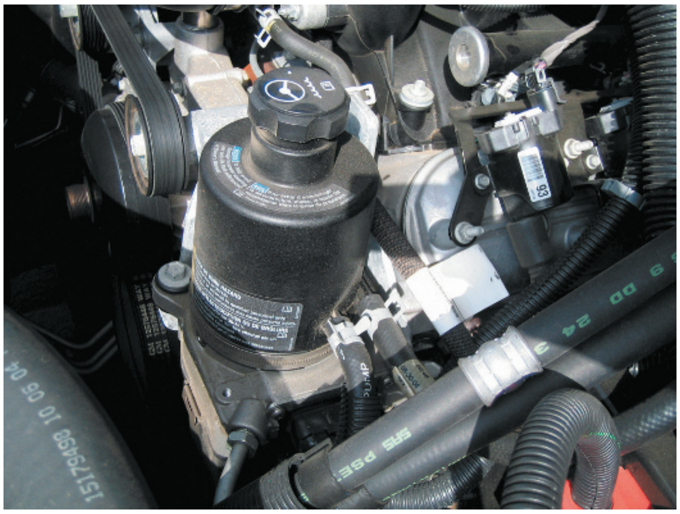


FIGURE 118–11 An electrohydraulic power steering assembly on a Chevrolet hybrid pickup truck.

- PRNDL (shift lever) position
- Torque converter clutch (TCC)/cruise dump signal (gives zero-adjust brake switch position)

The EHPS module receives several signals through wiring. The signals received and used by the EHPS module include

- The digital steering wheel speed signals from the steering wheel sensor mounted on the steering column. The steering wheel speed sensor output contains three digital signals that indicate the steering wheel position. The signals are accurate to within 1 degree. The index output references a steering wheel position of 0 degrees plus or minus 10 degrees (steering wheel centered) and is repeated every 360 degrees of steering wheel rotation.
- An analog brake pedal position signal from the brake pedal–mounted **brake pedal position (BPP) sensor**. The BPP sensor outputs an analog signal, referenced to 5 volts, that increases or decreases with brake pedal depression. The electrical range of the BPP sensor motion is −55 degrees to +25 degrees. The mechanical range of the BPP sensor is −70 degrees to +40 degrees.

REVIEW QUESTIONS

1. What are the types of electric power steering systems?
2. What sensors are needed for EPS systems?
3. What are the advantages of using an electric power steering system?
4. What type of motor is used in electric power steering systems?
5. How does an electrohydraulic power steering work?

CHAPTER QUIZ

1. The two basic types of electric power steering include ___________.
   - **a.** engine mounted and column mounted
   - **b.** column mounted and rack mounted
   - **c.** electrohydraulic and rack mounted
   - **d.** engine driven and battery powered
2. The advantages of electric power steering compared to hydraulic power steering include ___________.
   - **a.** less weight
   - **b.** improved fuel economy
   - **c.** increased usable engine power
   - **d.** All of the above
3. What type of motor is used in most electric power steering (EPS) systems?
   - **a.** AC brush type
   - **b.** DC brushless
   - **c.** Stepper
   - **d.** None of the above
4. Two technicians are discussing electric power steering (EPS) systems. Technician A says that some systems operate on 12 volts. Technician B says that some systems operate on 42 volts such as some hybrid electric vehicles. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. A typical electric motor used in electric power steering systems produces about how much power?
   - **a.** ¼ horsepower
   - **b.** ½ horsepower
   - **c.** ¾ horsepower
   - **d.** 1 horsepower
6. What is the relationship between the power steering control module (PSCM) and the powertrain control module (PCM)?
   - **a.** Usually wired between the two
   - **b.** No connection between the two
   - **c.** Uses serial data lines between the two modules
   - **d.** Mounted together on the electric power steering (EPS) motor
7. If a fault is detected in the electric power steering system, what dash light is turned on?
   - **a.** The “check engine” light
   - **b.** The “service vehicle soon” light
   - **c.** The power steering warning light
   - **d.** Either b or c
8. What diagnostic equipment is usually needed to diagnose faults or relearn the electric power steering system?
   - **a.** Special electronic diagnostic equipment designed to test each specific system
   - **b.** Factory or factory-level scan tool
   - **c.** A breakout box
   - **d.** A 12-volt test light
9. Self-park systems use what sensors and EPS to achieve the parking maneuver?
   - **a.** Wheel speed sensors (WSS)
   - **b.** Steering wheel position sensor
   - **c.** Ultrasonic sensors
   - **d.** All of the above
10. Electrohydraulic power steering systems use ___________.
    - **a.** an electric motor to power a hydraulic pump
    - **b.** a conventional hydraulic power steering gear
    - **c.** an engine-driven hydraulic power steering pump and an electric motor steering gear
    - **d.** Both a and b

Chapter 119

WHEEL ALIGNMENT PRINCIPLES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Define wheel alignment.
- Discuss alignment-related problems.
- Discuss camber.
- Discuss caster.
- Discuss toe.
- Discuss steering axis inclination (SAI).
- Discuss included angle.
- Discuss scrub radius.
- Discuss turning radius.
- Discuss setback.
- Discuss thrust angle.
- Discuss tracking.
- Explain the importance of four-wheel alignment.

KEY TERMS:

BJI 1483 • Camber 1475 • Camber roll 1478 • Caster 1478 • Dog tracking 1486 • Drift 1474 • Four-wheel alignment 1487 • Included angle 1483 • KPI 1483 • Lead 1474 • MSI 1483 • Pull 1474 • Returnability 1479 • Road crown 1475 • SAI 1483 • Scrub radius 1484 • Setback 1486 • Shimmy 1475 • Steering dampener 1479 • Steering offset 1485 • Thrust line 1486 • Toe 1480 • TOOT 1485 • Tramp 1475 • Wander 1475

DEFINITION OF A WHEEL ALIGNMENT

A wheel alignment is the adjustment of the suspension and steering to ensure proper vehicle handling with minimum tire wear. When a vehicle is new, the alignment angles are set at the factory. After many miles and/or months of driving, the alignment angles can change slightly. The change in alignment angles may result from one or more of the following conditions:

1. Wear of the steering and the suspension components
2. Bent or damaged steering and suspension parts
3. Sagging springs, which can change the ride height of the vehicle and therefore the alignment angles

By adjusting the suspension and steering components, proper alignment angles can be restored. An alignment includes checking and adjusting, if necessary, both front and rear wheels.

ALIGNMENT-RELATED PROBLEMS

Most alignment diagnosis is symptom-based diagnosis. This means that the problem with the alignment is determined from symptoms such as excessive tire wear or a pull to one side of the road.

PULL A **pull** is generally defined as a definite tug on the steering wheel toward the left or the right while driving straight on a level road. ● **SEE FIGURE 119–1**. Bent, damaged, or worn suspension and/or steering components can cause this problem, as well as a tire problem.

LEAD OR DRIFT A **lead** or **drift** is a mild pull that does not cause a force on the steering wheel that the driver must counteract. A lead or drift is observed by momentarily removing your hands

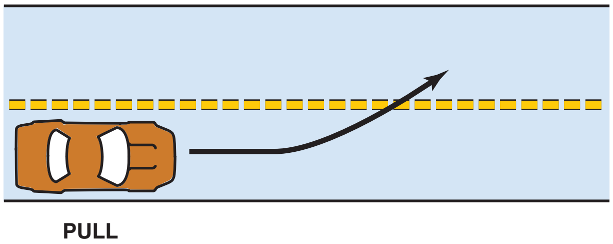


FIGURE 119–1 A pull is usually defined as a tug on the steering wheel toward one side or the other.

from the steering wheel while driving on a straight, level road. When the vehicle moves toward one side or the other, this is called a lead or a drift.

CAUTION: When test-driving a vehicle for a lead or a drift, make sure that the road is free of traffic and that your hands remain close to the steering wheel. Your hands should be held away from the steering wheel for just a second or two—just long enough to check for a lead or drift condition.

ROAD CROWN EFFECTS Most roads are constructed with a slight angle to permit water to drain from the road surface. On a two-lane road, the center of the road is often higher than the berms, resulting in a **road crown**. ● **SEE FIGURE 119–2**.

On a four-lane expressway (freeway), the crown is often *between the two sets* of lanes. Because of this slight angle to the road, some vehicles may lead or drift away from the road crown. In other words, it may be perfectly normal for a vehicle to lead toward the right while being driven in the slow lane and toward the left while being driven in the fast (or inside) lane of a typical divided highway.

WANDER A **wander** is a condition where constant steering wheel corrections are necessary to maintain a straight-ahead direction on a straight, level road. ● **SEE FIGURE 119–3**.

Worn suspension and/or steering components are the most likely cause of this condition. Incorrect or unequal alignment angles such as caster and toe, as well as defective tire(s), can also cause this condition.

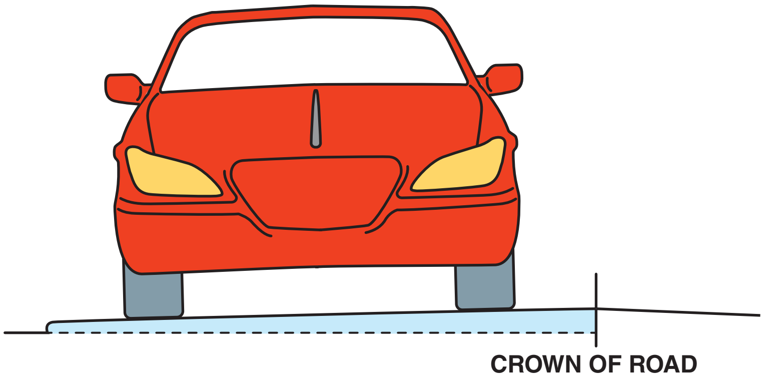


FIGURE 119–2 The crown of the road refers to the angle or slope of the roadway needed to drain water off the pavement.

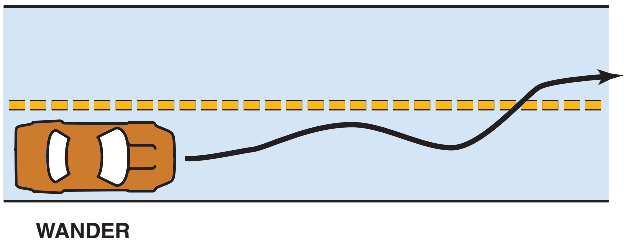


FIGURE 119–3 Wander is an unstable condition requiring constant driver corrections.

STIFF STEERING OR SLOW RETURN TO CENTER Hard-to-steer problems are commonly caused by leaks, either low tire pressure (due to the leak of air) or lack of proper power steering (due to the leak of power steering fluid). Other causes include excessive positive caster on the front wheels or binding steering linkage.

TRAMP OR SHIMMY VIBRATION **Tramp** is a vertical-type (up-and-down) vibration usually caused by out-of-balance or defective tires or wheels. **Shimmy** is a back-and-forth vibration that can be caused by an out-of-balance tire or defective wheel or by an alignment problem.

NOTE: Wheel alignment will not correct a tramp-type vibration.

CAMBER

DEFINITION **Camber** *is the inward or outward tilt of the wheels from true vertical as viewed from the front or rear of the vehicle.*

1. If the top of the tire is tilted out, then camber is positive (+), as shown in ● **FIGURE 119–4**.
2. If the top of the tire is tilted in, then camber is negative (–), as shown in ● **FIGURE 119–5**.

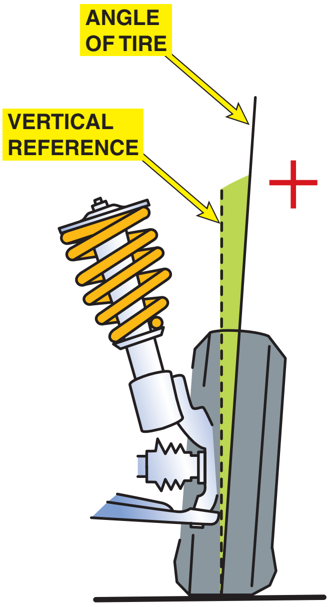


FIGURE 119–4 Positive camber. The dotted line represents true vertical, and the solid line represents the angle of the wheel.

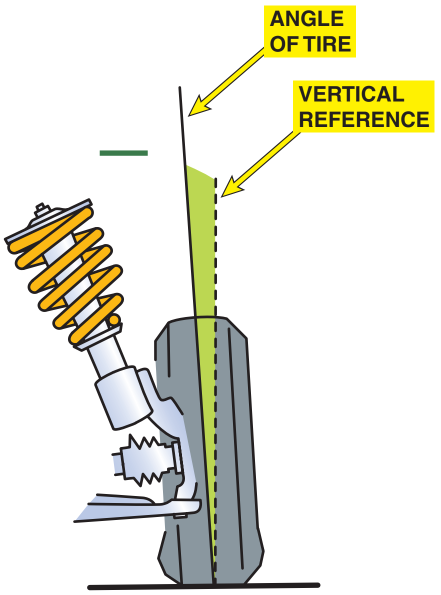


FIGURE 119–5 Negative camber. The dotted line represents true vertical and the solid line represents the angle of the wheel.

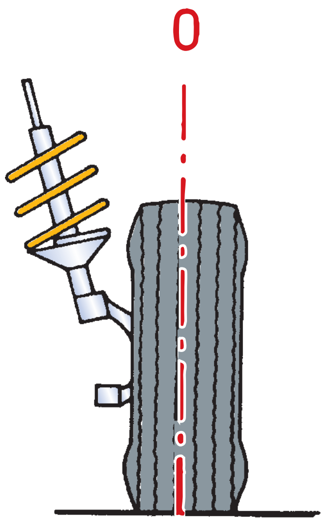


FIGURE 119–6 Zero camber. Note that the angle of the tire is true vertical.

3. Camber is zero (0 degrees) if the tilt of the wheel is true vertical, as shown in ● **FIGURE 119–6**.
4. Camber is measured in degrees or fractions of degrees.
5. *Camber can cause tire wear if not correct.*
   - **a.** *Excessive positive camber* causes scuffing and wear on the outside edge of the tire, as shown in ● **FIGURE 119–7**.
   - **b.** *Excessive negative camber* causes scuffing and wear on the inside edge of the tire, as shown in ● **FIGURE 119–8**.
6. Camber can cause pull if it is unequal side to side. **The vehicle will pull toward the side with the most positive camber.** A difference of more than 1/2 degree from one side to the other will cause the vehicle to pull. ● **SEE FIGURES 119–9 THROUGH 119–11**.
7. Incorrect camber can cause excessive wear on wheel bearings, as shown in ● **FIGURES 119–12 AND 119–13**. Many vehicle manufacturers specify positive camber so that the vehicle's weight is applied to the larger inner wheel bearing and spindle. As the vehicle is loaded or when the springs sag, camber usually decreases. If camber is kept positive, then the running camber is kept near zero degrees for best tire life.

NOTE: Many front-wheel-drive vehicles that use sealed wheel bearings often specify negative camber.

8. Camber is *not* adjustable on many vehicles.
9. If camber is adjustable, the change is made by moving the upper or the lower control arm or strut assembly by means of one of the following methods:
   - **a.** Shims
   - **b.** Eccentric cams
   - **c.** Slots
10. Camber should be equal on both sides; however, if camber cannot be adjusted exactly equal, make certain that there is more camber on the front of the left side to help compensate for the road crown (1/2 degree maximum difference).

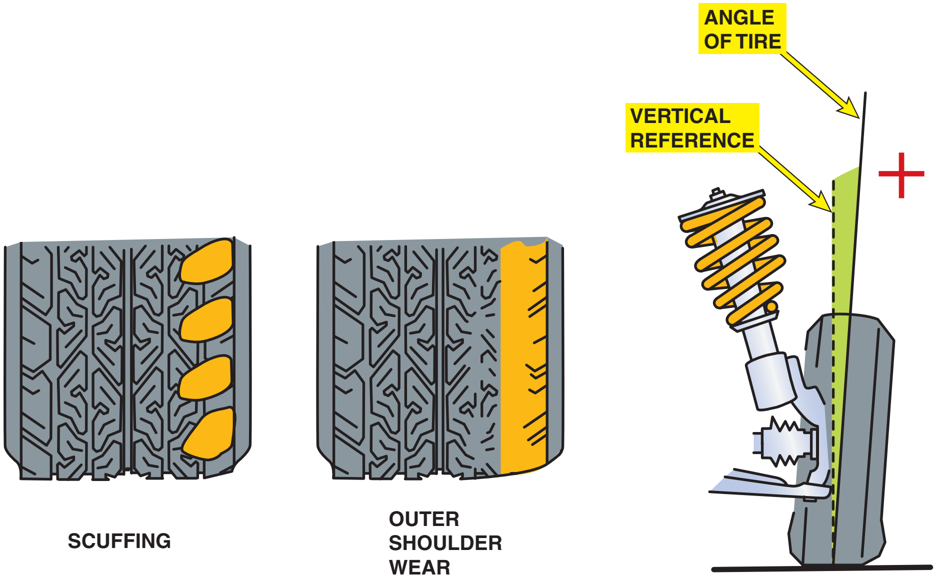


FIGURE 119–7 Excessive positive camber and how the front tires would wear due to the excessive camber.

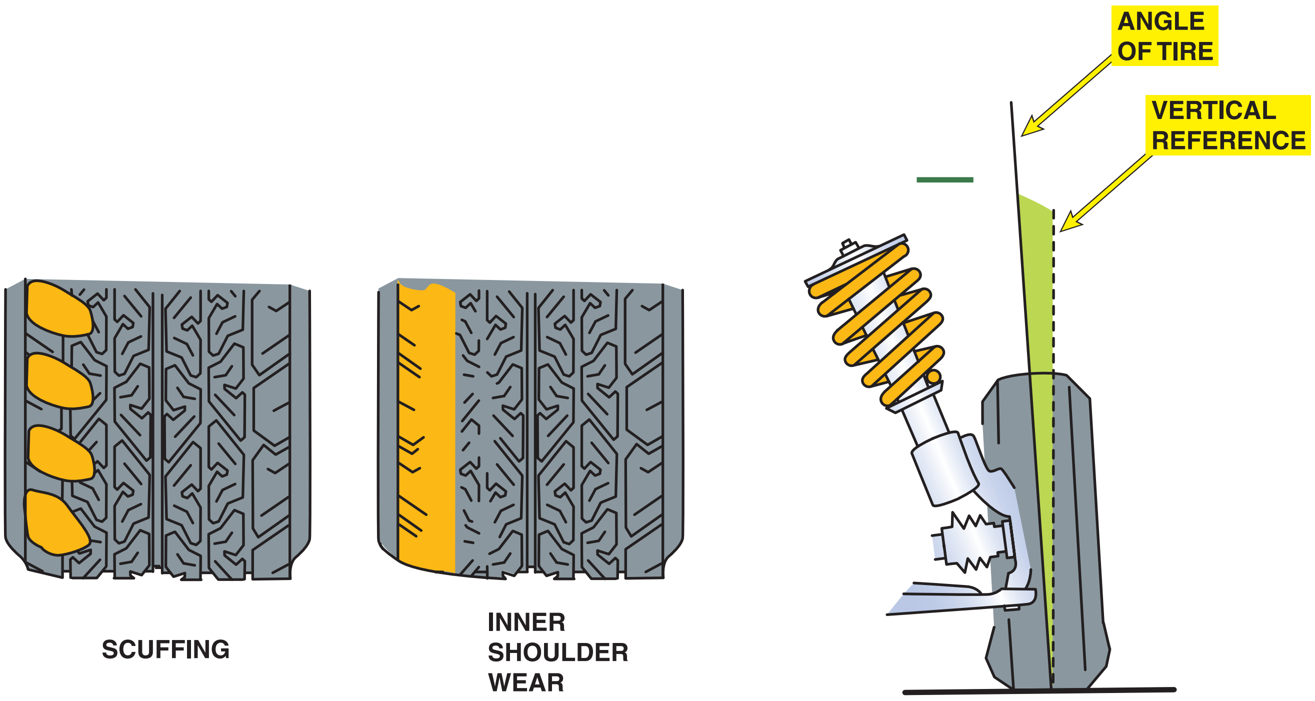

ANGLE OF TIRE
VERTICAL REFERENCE
–
SCUFFING
INNER SHOULDER WEAR

FIGURE 119–8 Excessive negative camber and how the front tires would wear due to the excessive camber.

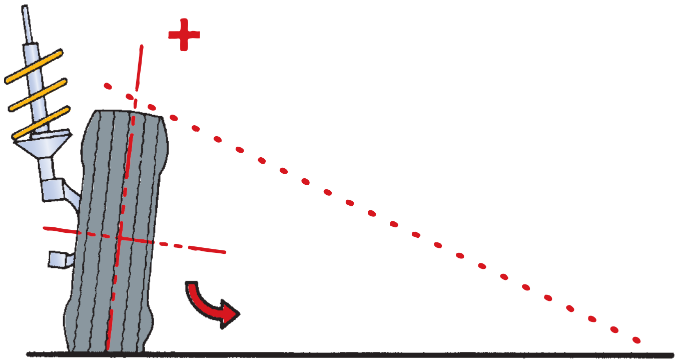


FIGURE 119–9 Positive camber tilts the tire and forms a cone shape that causes the wheel to roll away or pull outward toward the point of the cone.

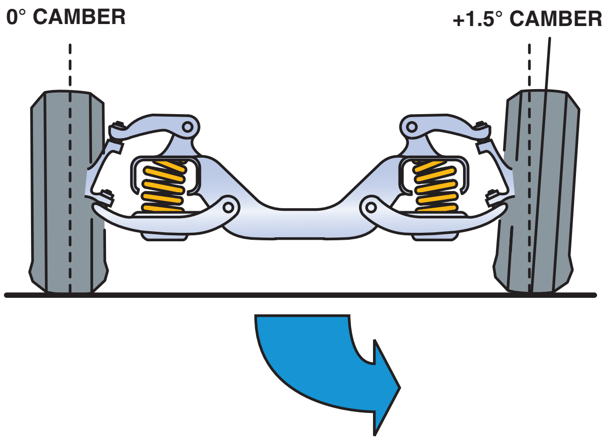

0° CAMBER
+1.5° CAMBER

FIGURE 119–11 If camber angles are different from one side to the other, the vehicle will pull toward the side with the most camber.

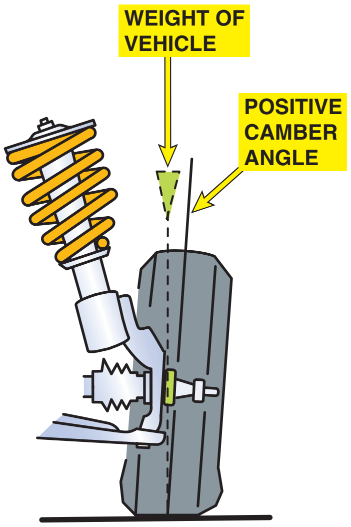

WEIGHT OF VEHICLE
POSITIVE CAMBER ANGLE

FIGURE 119–12 Positive camber applies the vehicle weight toward the larger inner wheel bearing. This is desirable because the larger inner bearing is designed to carry more vehicle weight than the smaller outer bearing.

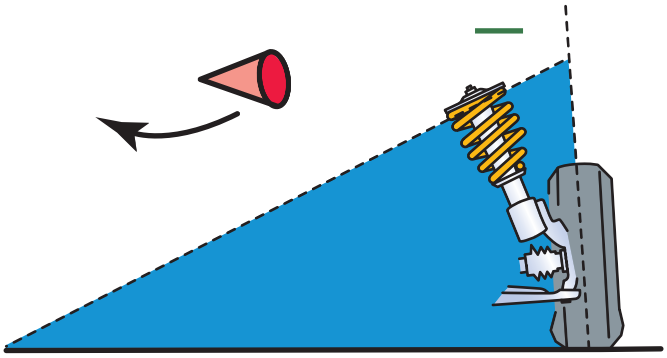


FIGURE 119–10 Negative camber creates a pulling force toward the center of the vehicle.

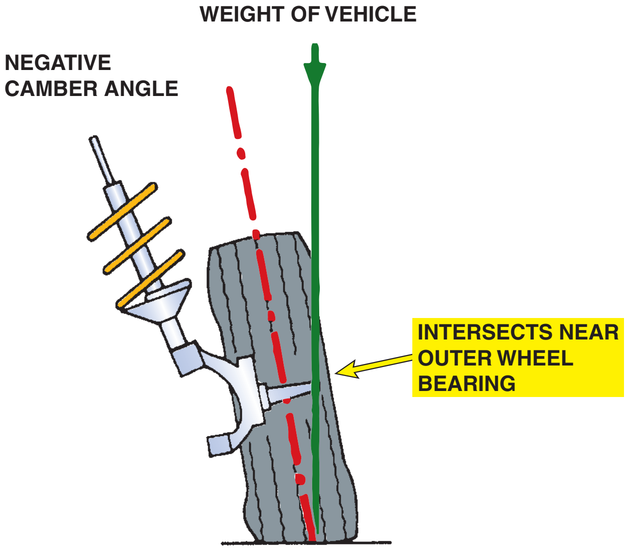


FIGURE 119–13 Negative camber applies the vehicle weight to the smaller outer wheel bearing. Excessive negative camber, therefore, may contribute to outer wheel bearing failure.

CASTER

Caster *is the forward or rearward tilt of the steering axis in reference to a vertical line as viewed from the side of the vehicle*. The steering axis is defined as the line drawn through the upper and lower steering pivot points. On an SLA suspension system, the upper pivot is the upper ball joint and the lower pivot is the lower ball joint. On a MacPherson strut system, the upper pivot is the center of the upper bearing mount and the lower pivot point is the lower ball joint. Zero caster means that the steering axis is straight up and down, also called 0 degrees or perfectly vertical, as shown in ● **FIGURE 119–14**.

1. Positive (+) caster is present when the upper suspension pivot point is behind the lower pivot point (ball joint) as viewed from the side. ● **SEE FIGURE 119–15**.
2. Negative (–) caster is present when the upper suspension pivot point is ahead of the lower pivot point (ball joint) as viewed from the side. ● **SEE FIGURE 119–16**.

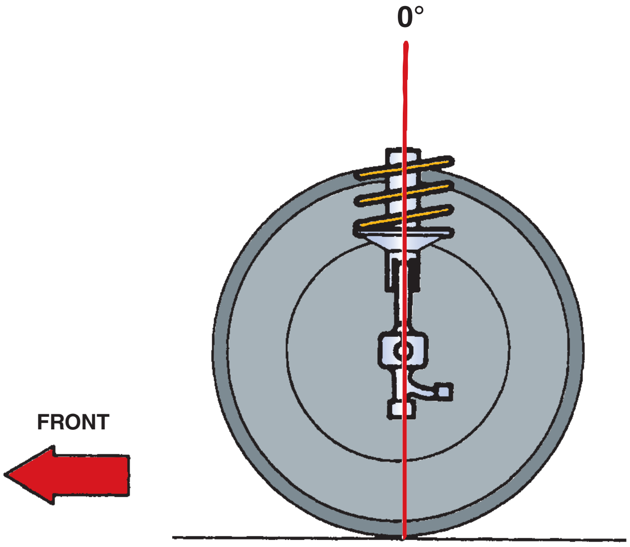


FIGURE 119–14 Zero caster.

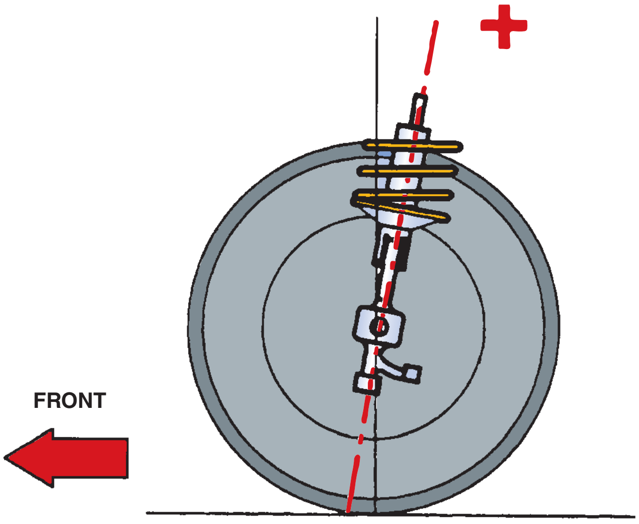


FIGURE 119–15 Positive (+) caster.

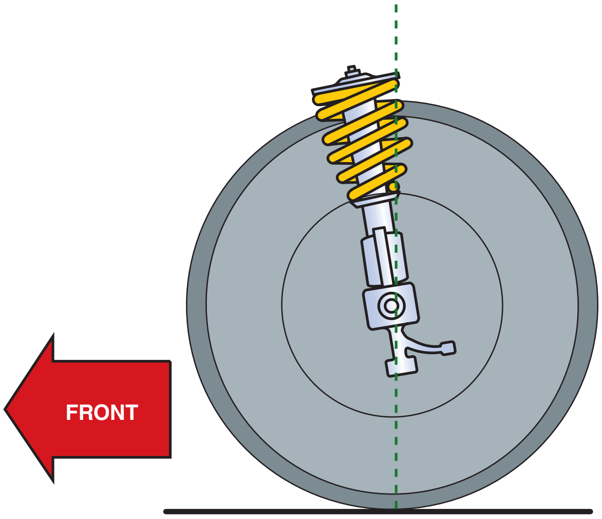


FIGURE 119–16 Negative (–) caster is seldom specified on today's vehicles because it tends to make the vehicle unstable at highway speeds. Negative caster was specified on some older vehicles not equipped with power steering to help reduce the steering effort.

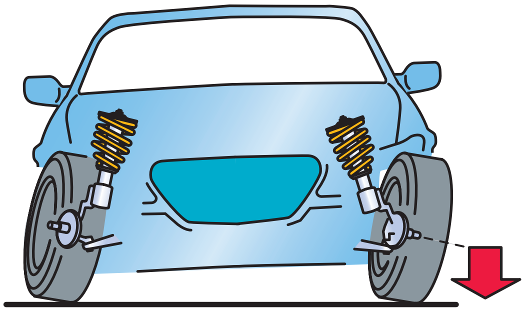


FIGURE 119–17 As the spindle rotates, it lifts the weight of the vehicle due to the angle of the steering axis.

3. Caster is measured in degrees or fractions of degrees.
4. Caster is not a tire-wearing angle, but positive caster does cause changes in camber during a turn. ● **SEE FIGURE 119–17**. This condition is called **camber roll** (see the Tech Tip titled "Caster Angle Tire Wear").

5. Caster is a stability angle.
    a. If caster is positive, the vehicle steering will be very stable (will tend to go straight with little steering wheel correction needed). This degree of caster helps with steering wheel **returnability** after a turn. ● **SEE FIGURE 119–18**.
    b. If the caster is positive, steering effort will increase with increasing positive caster. Greater road shocks will be felt by the driver when driving over rough road surfaces. ● **SEE FIGURE 119–19**. Vehicles with as many as 11 degrees positive caster, such as many Mercedes vehicles, usually use a steering dampener to control possible shimmy at high speeds and to dampen the snap-back of the spindle after a turn. ● **SEE FIGURE 119–20**.
    c. If caster is negative, or excessively unequal, the vehicle will not be as stable and will tend to wander (constant steering wheel movement will be required to maintain straight-ahead direction). If a vehicle is heavily loaded in the rear, caster increases. ● **SEE FIGURE 119–21**.

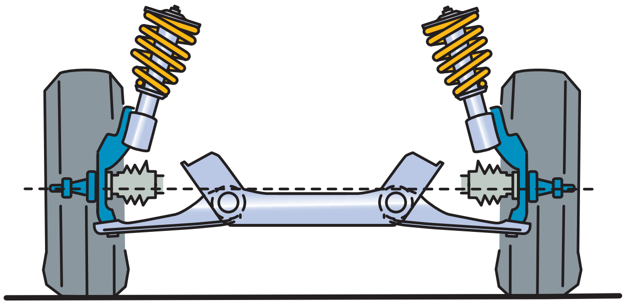


FIGURE 119–18 Vehicle weight tends to lower the spindle, which returns the steering to the straight-ahead position.

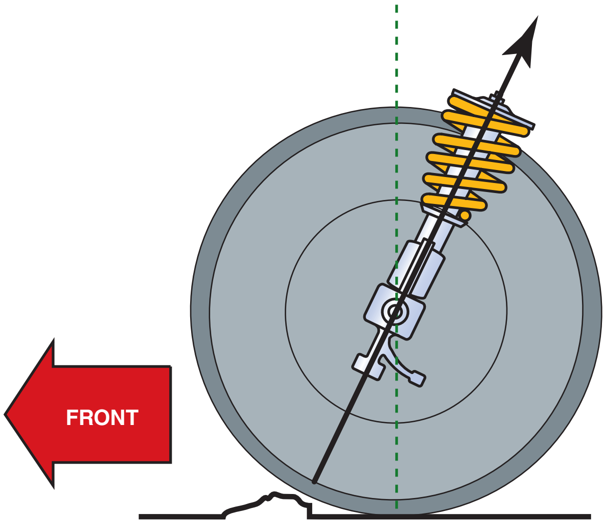


FIGURE 119–19 High caster provides a road shock path to the vehicle.

6. Caster can cause pull if unequal; **the vehicle will pull toward the side with the least positive caster.** However, the pulling force of unequal caster is only about one-fourth the pulling force of camber. It would require a difference of caster of one full degree to equal the pulling force of only 1/4 degree difference of camber.
7. Caster is *not* adjustable on many vehicles.
8. If caster is adjustable, it is changed by moving either the lower or the upper pivot point forward or backward by means of the following:
    a. Shims
    b. Eccentric cams
    c. Slots
    d. Strut rods

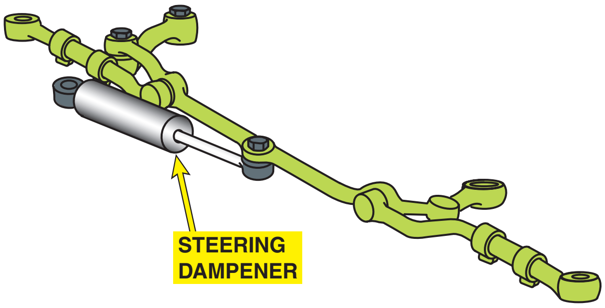


FIGURE 119–20 A **steering dampener** is used on many pickup trucks, sport-utility vehicles (SUVs), and many luxury vehicles designed with a high-positive-caster setting. The dampener helps prevent steering wheel kickback when the front tires hit a bump or hole in the road and also helps reduce steering wheel shimmy that may result from the high-caster setting.

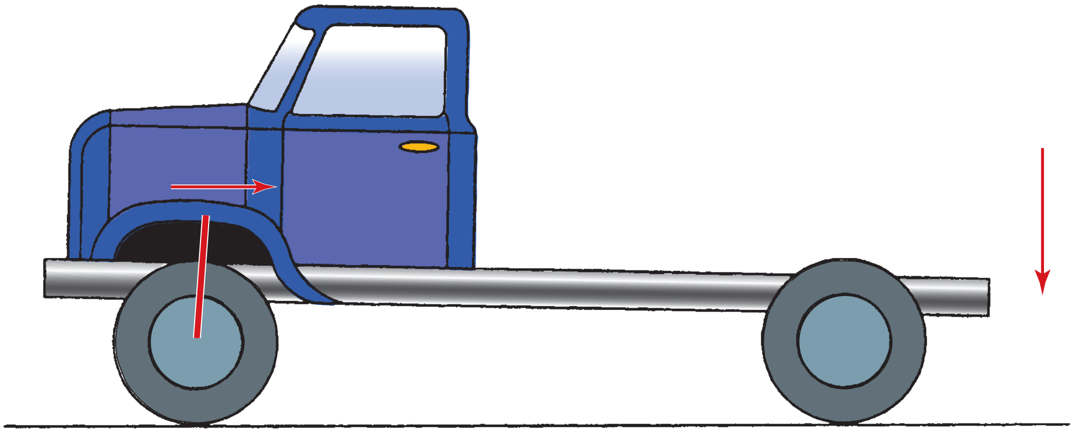


FIGURE 119–21 As the load increases in the rear of a vehicle, the top steering axis pivot point moves rearward, increasing positive (+) caster.

TECH TIP

Caster Angle Tire Wear

The caster angle is generally considered to be a *non-tire-wearing angle*. However, excessive or unequal caster can *indirectly* cause tire wear. When the front wheels are turned on a vehicle with a lot of positive caster, they become angled. This is called *camber roll*. (Caster angle is a measurement of the difference in camber angle from when the wheel is turned inward compared to when the wheel is turned outward.) Most vehicle manufacturers have positive caster designed into the suspension system. This positive caster increases the directional stability.

However, if the vehicle is used exclusively in city driving, positive caster can cause tire wear to the outside shoulders of both front tires. ● **SEE FIGURE 119–22**.

TECH TIP

Think of a Bicycle

How caster affects steering stability and steering wheel returning to the straight-ahead position after a turn is made easy by remembering how a bicycle acts. Caster allows riders to travel straight ahead with their hands off the handle bars because the weight is behind the axle.

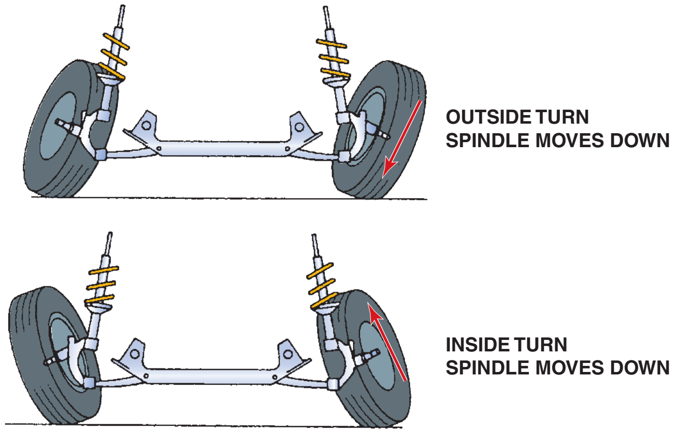


FIGURE 119–22 Note how the front tire becomes tilted as the vehicle turns a corner with positive caster. The higher the caster angle, the more the front tires tilt, causing camber-type tire wear.

9. Caster should be equal on both sides; however, if caster cannot be adjusted to be exactly equal, make certain that there is more caster on the right side (maximum 1/2 degree difference) to help compensate for the crown of the road.

NOTE: Caster is only measured on the front turning wheels of the vehicle. While some caster is built into the rear suspension of many vehicles, rear caster is not measured as part of a four-wheel alignment.

TOE

Toe *is the difference in distance between the front and rear of the tires*. Toe is the most important of the alignment angles. As viewed from the top of the vehicle (a bird's-eye view), zero toe means that both wheels on the same axle are parallel, as shown in ● **FIGURE 119–23**.

Toe is also described as a comparison of horizontal lines drawn through both wheels on the same axle, as shown in ● **FIGURE 119–24**.

If the front of the tires is closer than the rear of the same tires, then the toe is called *toe-in* or positive (+) toe. ● **SEE FIGURE 119–25**.

If the front of the tires is farther apart than the rear of the same tires, then the wheels are *toed-out,* or have negative (–) toe. ● **SEE FIGURE 119–26**.

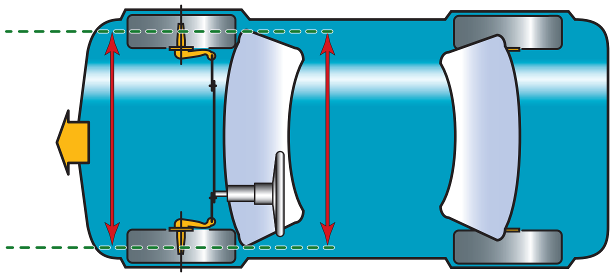


FIGURE 119–23 Zero toe. Note how both tires are parallel to each other as viewed from above the vehicle.

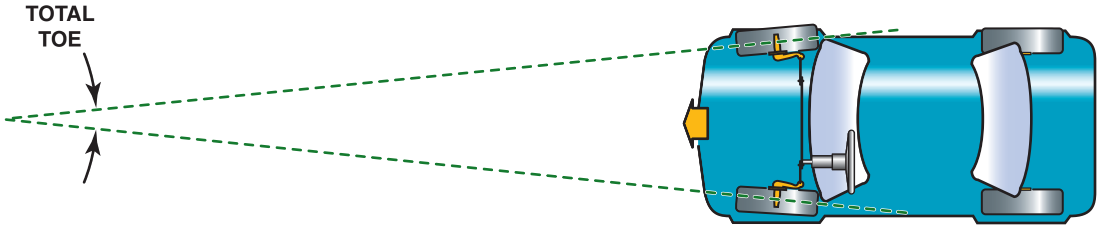


FIGURE 119–24 Total toe is often expressed as an angle. Because both front wheels are tied together through the tie rods and center link, the toe angle is always equally split between the two front wheels when the vehicle moves forward.

The purpose of the correct toe setting is to provide maximum stability with a minimum of tire wear when the vehicle is being driven.

1. Toe is measured in fractions of degrees or in fractions of an inch (usually 1/16 s), millimeters (mm), or decimals of an inch (such as 0.06 inch).
2. *Incorrect toe is the major cause of excessive tire wear!* ● **SEE FIGURE 119–27**.

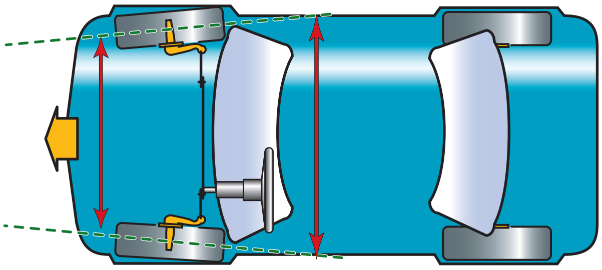


FIGURE 119–25 Toe-in, also called positive (+) toe.

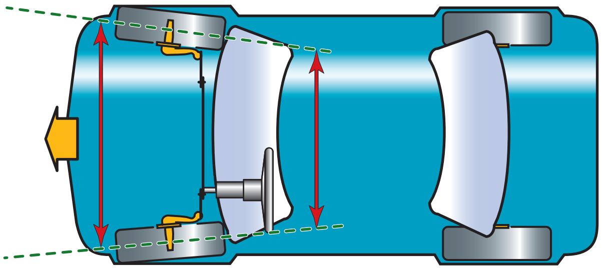


FIGURE 119–26 Toe-out, also called negative (–) toe.

NOTE: If the toe is improper by just 1/8 inch (3 mm), the resulting tire wear is equivalent to dragging a tire sideways 28 feet (8.5 m) for every mile traveled (1.6 km).

If not correct, toe causes camber-type wear on one side of the tire. ● **SEE FIGURES 119–28 AND 119–29**. Feather-edge wear is also common, especially if the vehicle is equipped with nonradial tires. ● **SEE FIGURE 119–30**.

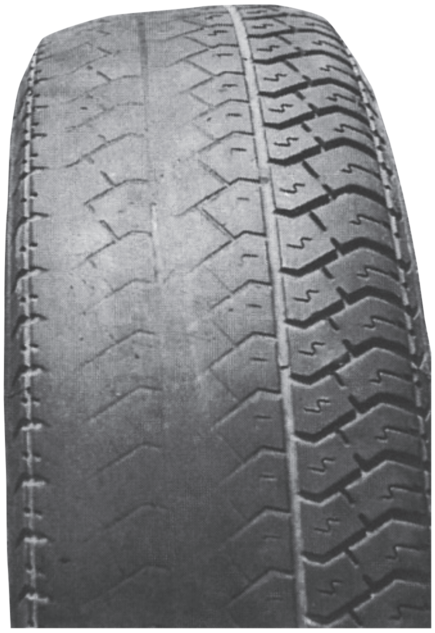


FIGURE 119–27 This tire is just one month old! It was new and installed on the front of a vehicle that had about 1/4 inch (6 mm)of toe-out. By the time the customer returned to the tire store for an alignment, the tire was completely bald on the inside. Note the almost new tread on the outside.

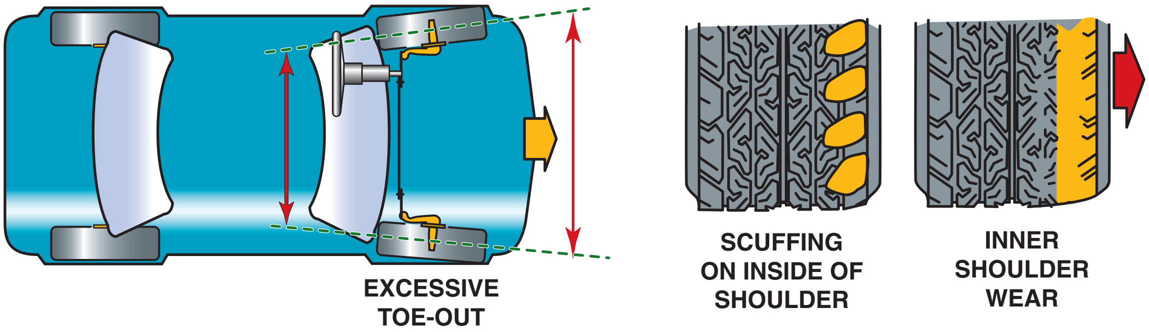


FIGURE 119–28 Excessive toe-out and the type of wear that can occur to the side of both front tires.

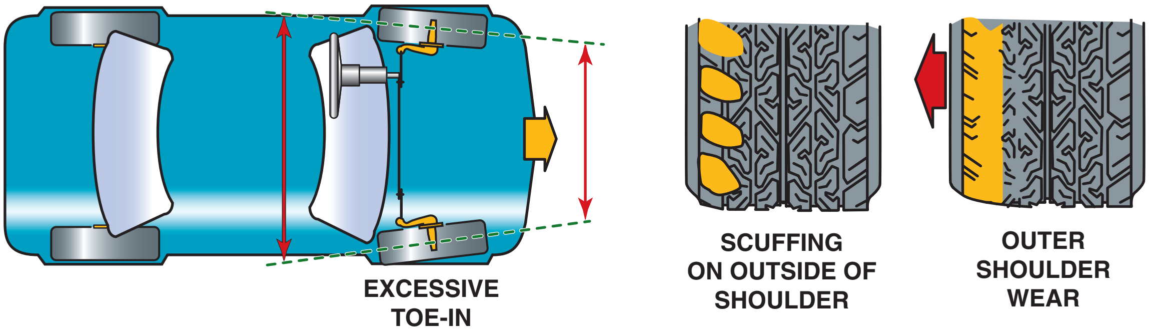


FIGURE 119–29 Excessive toe-in and the type of wear that can occur to the outside of both front tires.

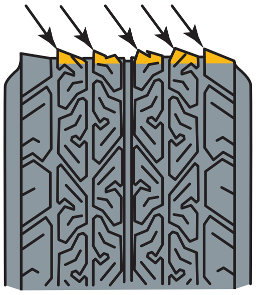


FIGURE 119–30 Feather-edge wear pattern caused by excessive toe-in or toe-out.

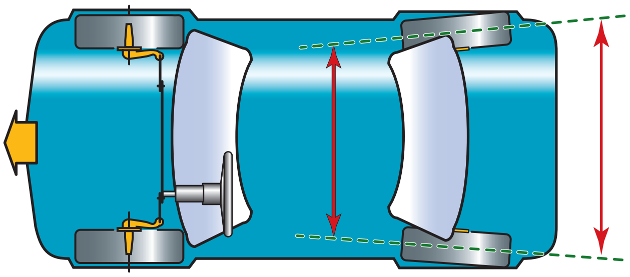


FIGURE 119–31 Rear toe-in (+). The rear toe (unlike the front toe) can be different for each wheel while the vehicle is moving forward because the rear wheels are not tied together as they are in the front.

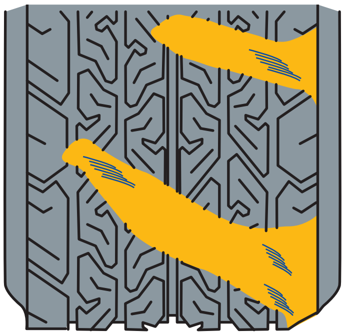


FIGURE 119–32 Incorrect toe can cause the tire to run sideways as it rolls, resulting in a diagonal wipe.

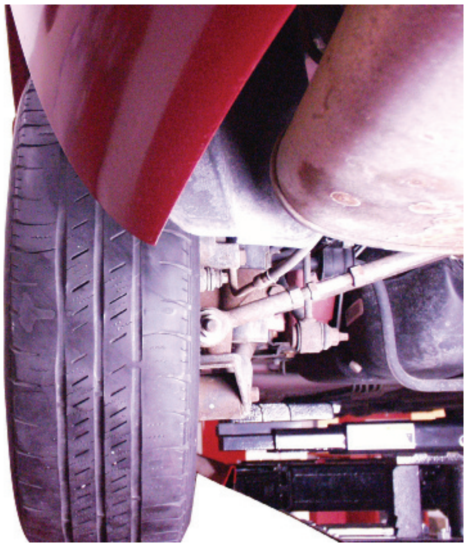


FIGURE 119–33 Diagonal wear such as shown here is usually caused by incorrect toe on the rear of a front-wheel-drive vehicle.

3. *Incorrect front toe does not cause a pull condition*. Incorrect toe on the front wheels is split equally as the vehicle is driven because the forces acting on the tires are exerted through the tie rod and steering linkage to both wheels.
4. *Incorrect (or unequal) rear toe can cause tire wear*. ● **SEE FIGURES 119–31 THROUGH 119–33**. If the toe of the rear wheels is not equal, the steering wheel will not be straight and will pull toward the side with the most toe-in.

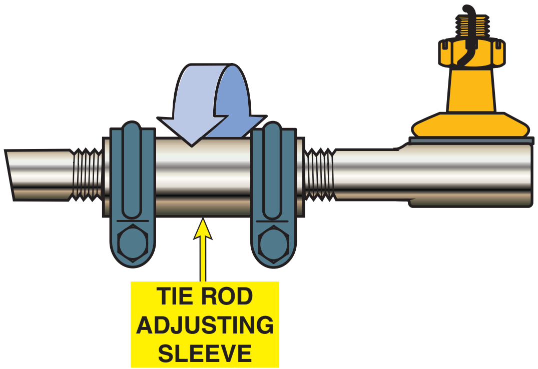


FIGURE 119–34 Toe on the front of most vehicles is adjusted by turning the tie rod sleeve, as shown.

5. All vehicles can be adjusted for front toe.
6. Front toe adjustment must be made correctly by adjusting the tie rod sleeves. ● **SEE FIGURE 119–34**.
7. Many vehicle manufacturers specify a slight amount of toe-in to compensate for the natural tendency of the front wheels to spread apart (become toed-out) due to centrifugal force of the rolling wheels acting on the steering linkage.

NOTE: Some manufacturers of front-wheel-drive vehicles specify a toe-out setting to compensate for the toe-in forces created by the engine drive forces on the front wheels.

8. Normal wear to the tie rod ends and other steering linkage parts usually causes toe-out.

Excessive front toe-out will cause wandering (lack of directional stability), especially during braking. Incorrectly set toe will cause an uncentered steering wheel. If toe is unequal in the *rear*, the vehicle will pull toward the side with the most toe-in.

FREQUENTLY ASKED QUESTION

Why Doesn't Unequal Front Toe on the Front Wheels Cause the Vehicle to Pull?

Each wheel could have individual toe, but as the vehicle is being driven, the forces on the tires tend to split the toe, causing the steering wheel to cock at an angle as the front wheels both track the same. If the toe is different on the rear of the vehicle, the rear will be "steered" similar to a rudder on a boat because the rear wheels are not tied together as are the front wheels.

TECH TIP

Smooth In, Toed-In; Smooth Out, Toed-Out

Whenever the toe setting is not zero, a rubbing action occurs that causes a feather-edge-type wear. ● **SEE FIGURE 119–35**. A quick, easy method to determine if incorrect toe could be causing problems is simply to rub your hand across the tread of the tire. If it feels smoother moving your hand toward the center of the vehicle than when you move your hand toward the outside, then the cause is excessive toe-in. The opposite effect is caused by toe-out. This may be felt on all types of tires, including radial-ply tires where the wear may not be seen as feather edged. Just remember this simple saying: "Smooth in, toed-in; smooth out, toed-out."

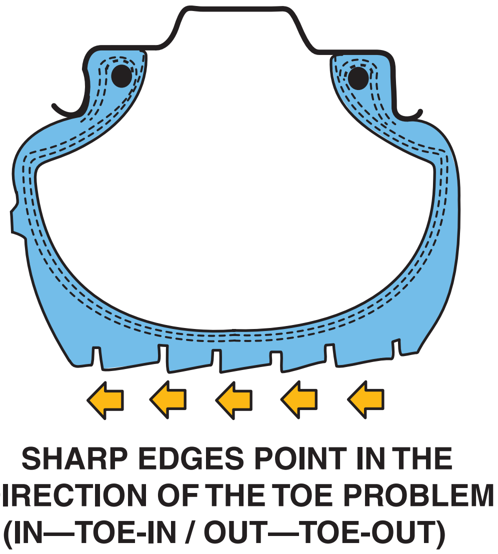

SHARP EDGES POINT IN THE DIRECTION OF THE TOE PROBLEM (IN—TOE-IN / OUT—TOE-OUT)

FIGURE 119–35 While the feathered or sawtooth tire tread wear pattern may not be noticeable to the eye, this wear can usually be felt by rubbing your hand across the tread of the tire.

STEERING AXIS INCLINATION

The steering axis is the angle formed between true vertical and an imaginary line drawn between the upper and lower pivot points of the spindle. ● **SEE FIGURE 119–36. Steering axis inclination (SAI)** is the inward tilt of the steering axis. SAI is also known as **kingpin inclination (KPI)** and is the imaginary line drawn through the kingpin as viewed from the front. SAI is also called **ball-joint inclination (BJI)**, if SLA-type suspension is used, or **MacPherson strut inclination (MSI)**.

The purpose of SAI is to provide an upper suspension pivot location that causes the spindle to travel in an arc when turning, which tends to raise the vehicle, as shown in ● **FIGURE 119–37**.

Vehicle weight tends to keep the front wheels in a straight-ahead position when driving, thereby increasing vehicle stability, directional control, and steering wheel returnability. The greater the SAI, the more stable the vehicle. It also helps center the steering wheel after making a turn and reduces the need for excessive positive caster. The SAI/KPI angle of all vehicles ranges between 2 and 16 degrees. Front-wheel-drive vehicles usually have greater than 9 degrees SAI (typically 12 to 16 degrees) for directional stability, whereas rear-wheel-drive vehicles usually have less than 8 degrees of SAI. The steering axis inclination angle and the camber angle together are called the *included angle*.

INCLUDED ANGLE

The **included angle** is the SAI added to the camber reading of the front wheels only. *The included angle is determined by the design of the steering knuckle, or strut construction*. ● **SEE FIGURES 119–38 AND 119–39**.

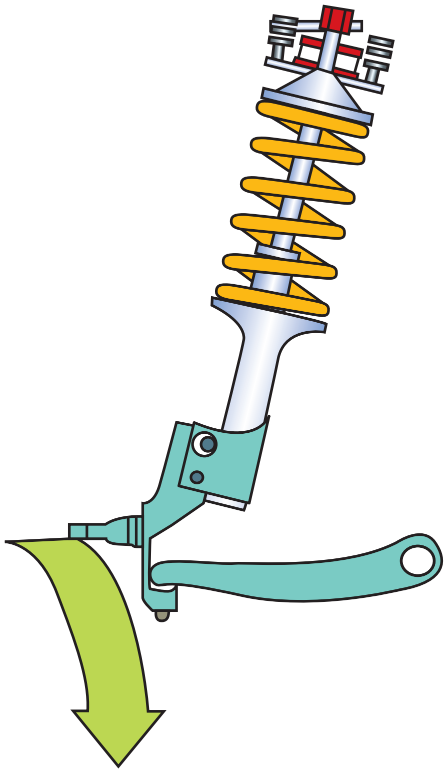


FIGURE 119–37 The SAI causes the spindle to travel in an arc when the wheels are turned. The weight of the vehicle is therefore used to help straighten the front tires after a turn and to help give directional stability.

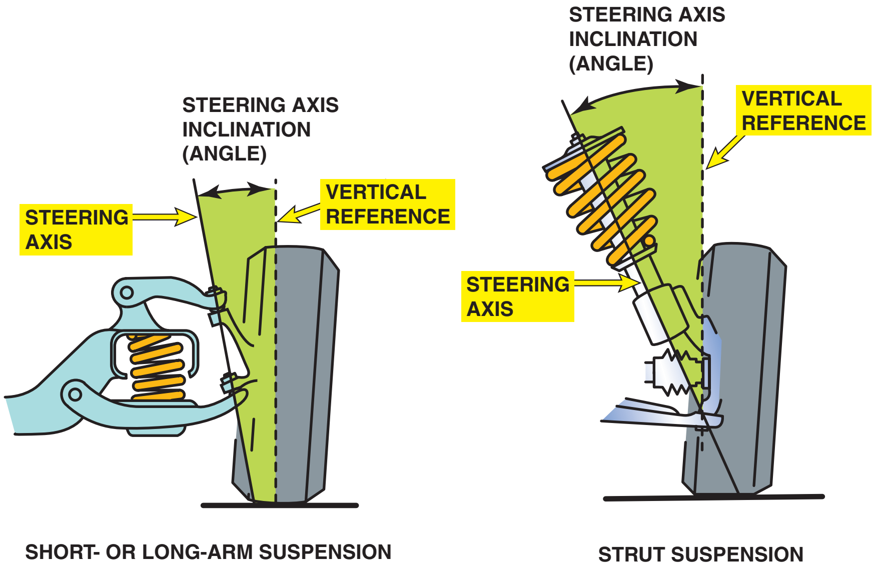

STEERING AXIS INCLINATION (ANGLE)
STEERING AXIS
VERTICAL REFERENCE
SHORT- OR LONG-ARM SUSPENSION
STEERING AXIS INCLINATION (ANGLE)
VERTICAL REFERENCE
STEERING AXIS
STRUT SUSPENSION

FIGURE 119–36 The left illustration shows that the steering axis inclination angle is determined by drawing a line through the center of the upper and lower ball joints. This represents the pivot points of the front wheels when the steering wheel is rotated during cornering. The right illustration shows that the steering axis inclination angle is determined by drawing a line through the axis of the upper strut bearing mount assembly and the lower ball joint.

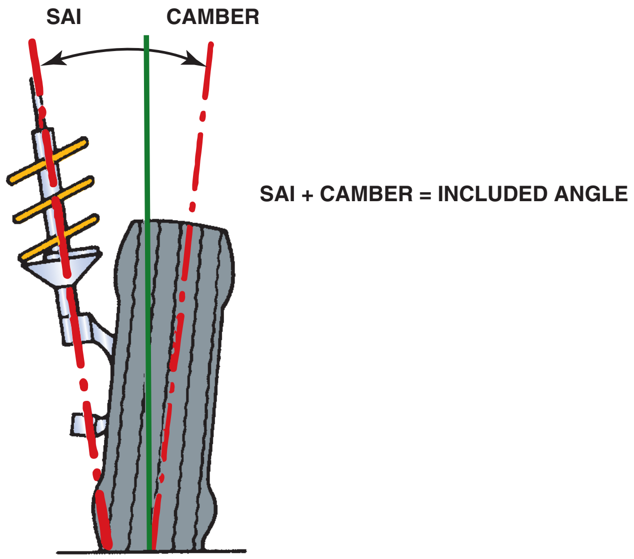

SAI
CAMBER
SAI + CAMBER = INCLUDED ANGLE

FIGURE 119–38 Included angle on a MacPherson-strut-type suspension.

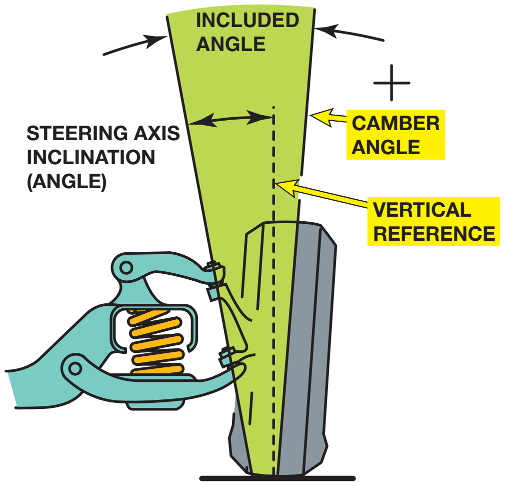

INCLUDED ANGLE
+
STEERING AXIS INCLINATION (ANGLE)
CAMBER ANGLE
VERTICAL REFERENCE

FIGURE 119–39 Included angle on an SLA-type suspension. The included angle is the SAI angle and the camber angle added together.

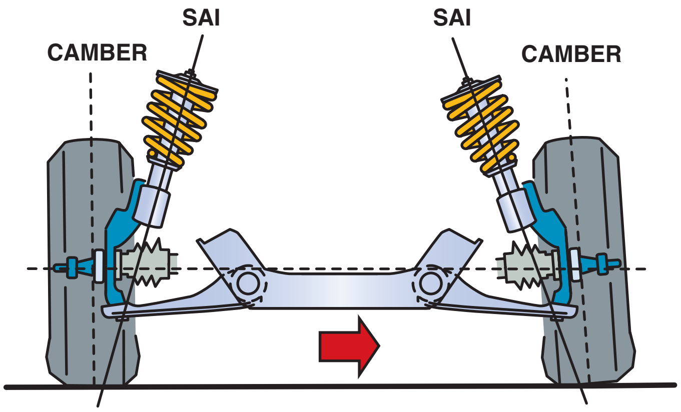

CAMBER
SAI
SAI
CAMBER

FIGURE 119–40 Cradle placement. If the cradle is not replaced in the exact position after removal for a transmission or clutch replacement, the SAI, camber, and included angle will not be equal side to side.

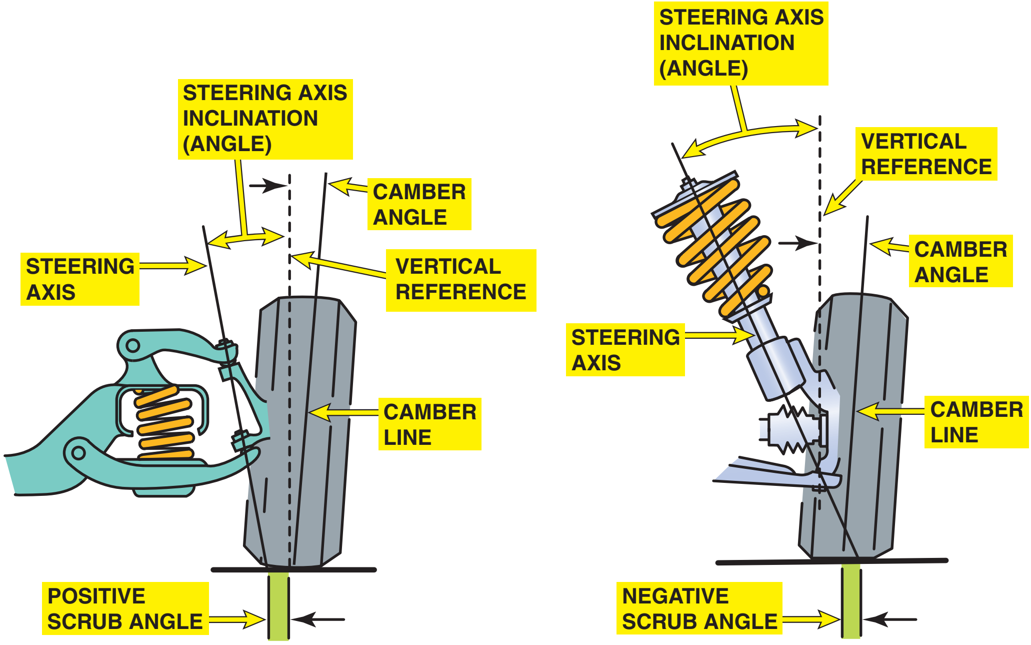
The included angle is an important angle to measure for diagnosis of vehicle handling or tire wear problems. For example, if the cradle is out of location due to previous service work or an accident, knowing SAI, camber, and the included angle can help in determining what needs to be done to correct the problem.

● **FIGURE 119–40** shows the included angle is equal on both sides but the camber and SAI are not equal. For best handling, both the included angle and SAI should be within 1/2 degree of the other side of the vehicle.

SCRUB RADIUS

Scrub radius refers to the *distance* between the line through the steering axis and the centerline of the wheel at the contact point with the road surface. ● **SEE FIGURE 119–41**.

Scrub radius is *not* adjustable and cannot be measured. Scrub radius can be zero, positive, or negative. Zero scrub radius means that the line through the steering axis intersects the centerline of the tire at the road surface. Positive scrub radius means


STEERING AXIS INCLINATION (ANGLE)
CAMBER ANGLE
STEERING AXIS
VERTICAL REFERENCE
CAMBER LINE
POSITIVE SCRUB ANGLE
STEERING AXIS INCLINATION (ANGLE)
VERTICAL REFERENCE
CAMBER ANGLE
STEERING AXIS
CAMBER LINE
NEGATIVE SCRUB ANGLE

SHORT- OR LONG-ARM SUSPENSION

STRUT SUSPENSION

FIGURE 119–41 A positive scrub radius (angle) is usually built into most SLA front suspensions, and a negative scrub radius is usually built into most MacPherson-strut-type front suspensions.

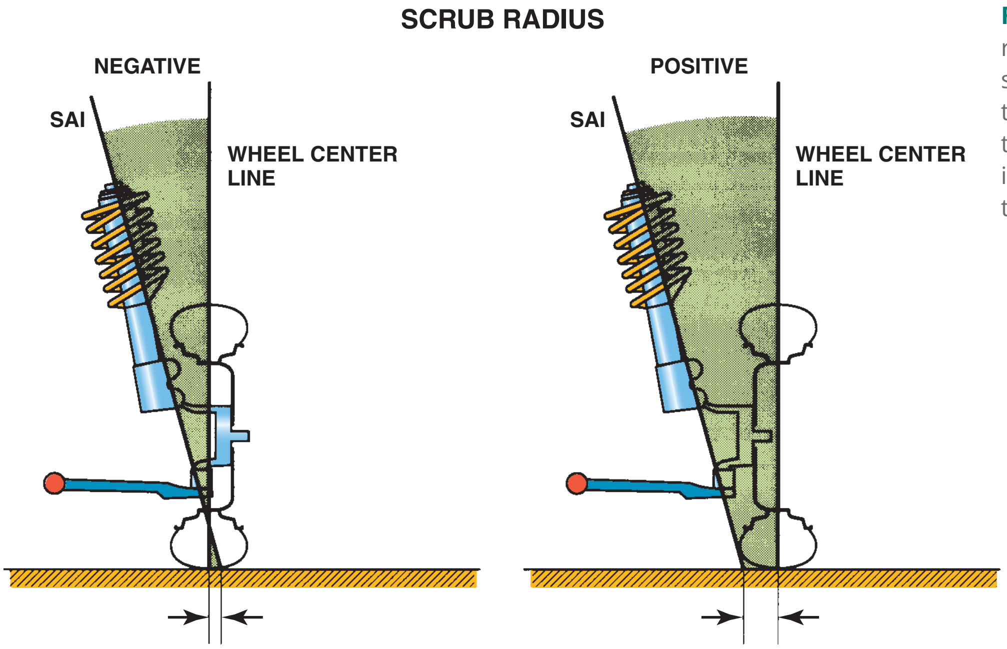


FIGURE 119–42 With negative scrub radius, the imaginary line through the steering axis inclination (SAI) intersects the road outside of the centerline of the tire. With positive scrub radius, the SAI line intersects the road inside the centerline of the tires.

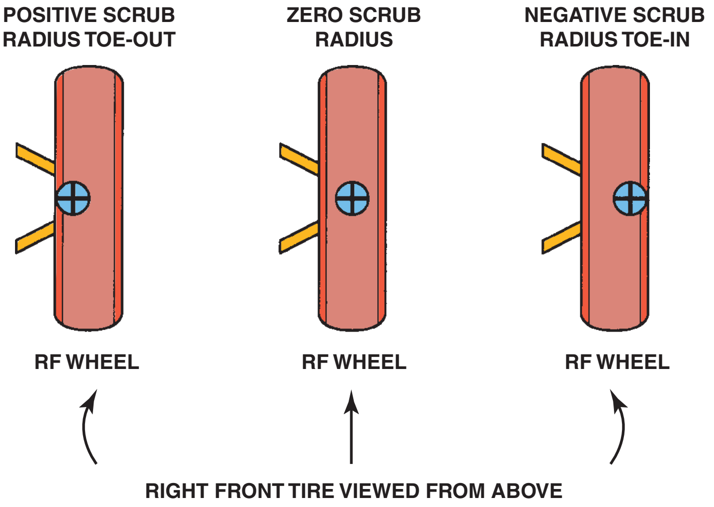

POSITIVE SCRUB RADIUS TOE-OUT
ZERO SCRUB RADIUS
NEGATIVE SCRUB RADIUS TOE-IN
RF WHEEL
RF WHEEL
RF WHEEL
RIGHT FRONT TIRE VIEWED FROM ABOVE

FIGURE 119–43 With a positive scrub radius, the pivot point, marked with a + mark, is inside the centerline of the tire and will cause the wheel to turn toward the outside, especially during braking. Zero scrub radius does not create any force on the tires and is not usually used on vehicles because it does not create an opposing force on the tires, which in turn makes the vehicle more susceptible to minor bumps and dips in the road. Negative scrub radius, as is used with most front-wheel-drive vehicles, generates an inward force on the tires.

that the line intersects the centerline of the tire below the road surface. Negative scrub radius means that the line intersects the centerline of the tire above the road surface. Scrub radius is also called **steering offset** by some vehicle manufacturers. If a wheel is permitted to roll rather than pivot, then steering will be more difficult because a tire can pivot more easily than it can roll while turning the front wheels. If the point of intersection is inside the centerline of the tire and below the road surface, this creates a toe-out force on the front wheels. Negative scrub radius is required on front-wheel-drive vehicles to provide good steering stability during braking. ● **SEE FIGURES 119–42 AND 119–43.**

Scrub radius is designed into each vehicle to provide acceptable handling and steering control under most conditions. Scrub radius also causes resistance to rolling of the front wheels to exert force on the steering linkage. This tends to dampen the effect of minor movements of the front wheels. Negative scrub radius causes the tire to toe-in during acceleration, braking, or traveling over bumps.

NOTE: It is this tendency to toe-in caused by the negative scrub radius and engine torque that requires many front-wheel-drive vehicles to specify a toe-out setting for the front-drive wheels.

Zero scrub radius is acceptable; positive scrub radius is less desirable because it causes the wheel to toe-out during acceleration, braking, or traveling over bumps and causes instability. Positive scrub radius is commonly used on rear-wheel-drive vehicles and requires a toe-in setting to help compensate for the tendency to toe-out.

A bent spindle can cause a change in the scrub radius and could cause hard steering, wander, or pull.

Also, changing tire or wheel sizes can affect the centerline location of the wheel or the height of the tire assembly and will change the scrub radius, which can negatively affect the steering control. When larger-diameter tires and positive-offset wheels are installed, the scrub radius becomes positive and the wheels tend to toe-out, causing wander, poor handling, and tire wear.

TURNING RADIUS (TOE-OUT ON TURNS)

Whenever a vehicle turns a corner, the inside wheel has to turn at a sharper angle than the outside wheel because the inside wheel has a shorter distance to travel. ● **SEE FIGURE 119–44.**

Turning radius is also called **toe-out on turns**, abbreviated TOT or **TOOT**, and is determined by the angle of the steering knuckle arms. **Turning radius is a nonadjustable angle.**

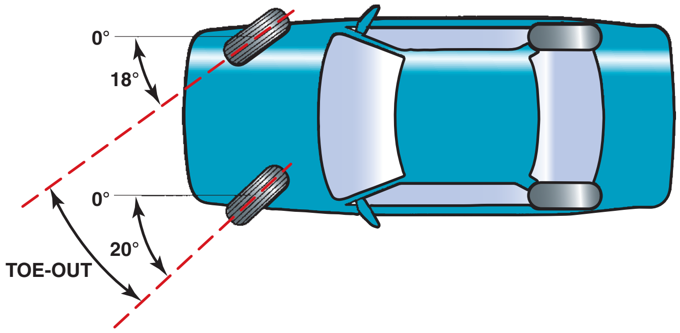


FIGURE 119–44 To provide handling, the inside wheel has to turn at a greater turning radius than the outside wheel.

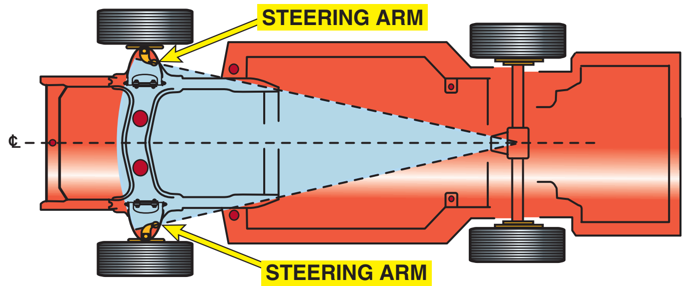


FIGURE 119–45 The proper toe-out on turns is achieved by angling the steering arms.

The turning radius can and should be measured as part of an alignment to check if the steering arms are bent or damaged. Symptoms of out-of-specification turning angle include the following:

1. Tire squeal noise during normal cornering, even at low speeds
2. Scuffed tire wear

The proper angle of the steering arms is where imaginary lines drawn from the steering arms should intersect exactly at the center of the rear axle. ● **SEE FIGURE 119–45**. This angle is called the Ackerman Effect (named for its promoter, an English publisher, Rudolph Ackerman, circa 1898).

SETBACK

Setback is the angle formed by a line drawn perpendicular (at 90 degrees) to the front axles. ● **SEE FIGURE 119–46**.

Setback is a nonadjustable measurement, even though it may be corrected. Positive setback means the right front wheel is set back farther than the left; negative setback means the left front wheel is set back farther than the right.

Setback can be measured with a four-wheel alignment machine or can be determined by measuring the wheel base on both sides of the vehicle.

NOTE: The wheel base of any vehicle is the distance between the center of the front wheel and the center of the rear wheel on the same side. The wheel base should be within 1/8 inch (3 mm) side to side.

The causes of setback include the following:

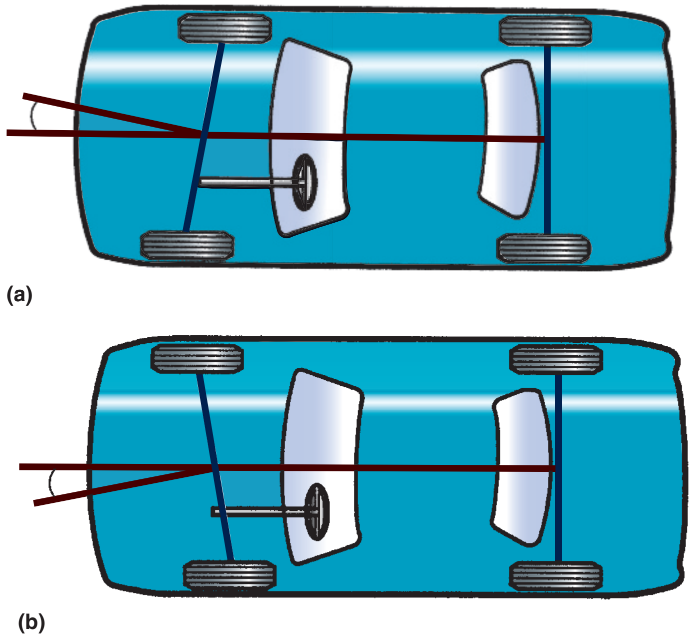


FIGURE 119–46 (a) Positive setback. (b) Negative setback.

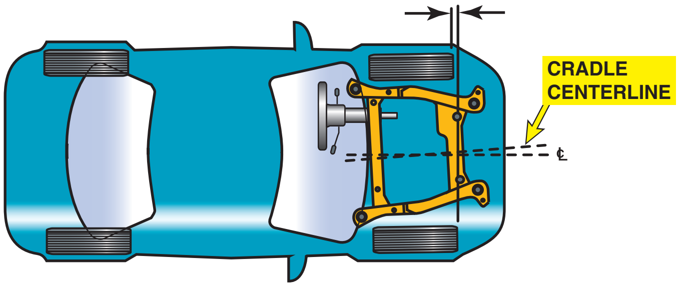


FIGURE 119–47 Cradle placement affects setback.

1. Cradle placement not correct on a front-wheel-drive vehicle. This can be caused by incorrectly installing the cradle after a transmission, clutch, or engine replacement or service. ● **SEE FIGURE 119–47**.
2. An accident that affected the frame or cradle of the vehicle and was unnoticed or not repaired.

Most vehicle manufacturers do not specify a minimum setback specification. However, a reading of 0.50 degrees or 0.5 inch (13 mm) or less of setback is generally considered to be acceptable.

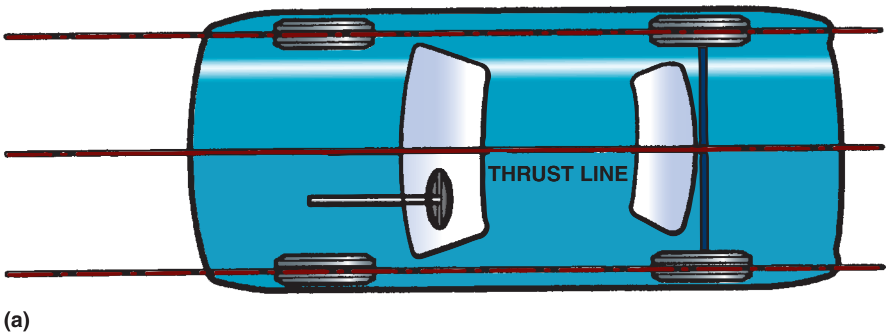
THRUST ANGLE

Thrust angle is the angle of the rear wheels as determined by the total rear toe. If both rear wheels have zero toe, then the thrust angle is the same as the geometric centerline of the vehicle. The total of the rear toe setting determines the **thrust line**, or the direction the rear wheels are pointed. ● **SEE FIGURE 119–48**.

On vehicles with an independent rear suspension, if both wheels do not have equal toe, the vehicle will pull in the direction of the side with the most toe-in.

TRACKING

The rear wheels should track directly behind the front wheels. If the vehicle has been involved in an accident, it is possible that the frame or rear axle mounting could cause **dog tracking**.



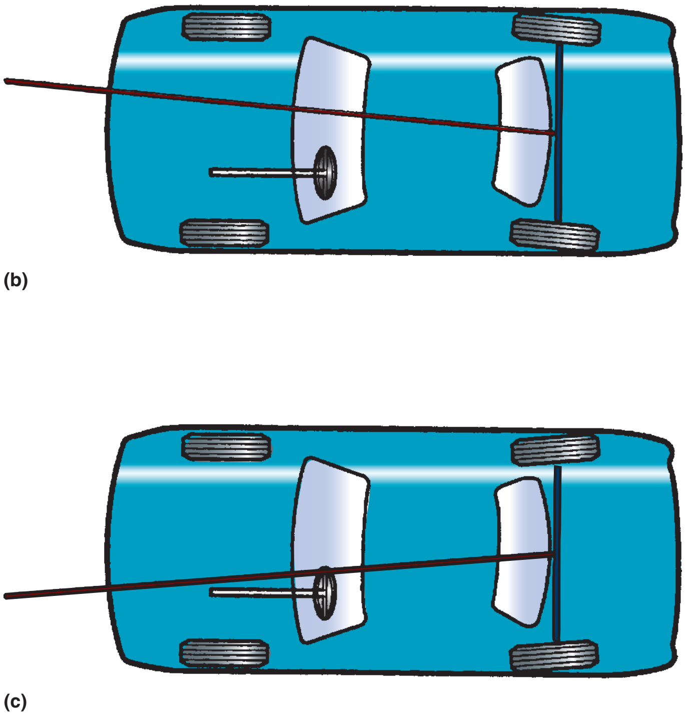


FIGURE 119–48 (a) Zero thrust angle. (b) Thrust line to the right. (c) Thrust line to the left.

Dog tracking is an alignment condition that is caused by having the rear wheel toe angles out of line with the front wheels causing the vehicle to travel slightly sideways similar to how a dog runs. ● **SEE FIGURE 119–49.**

To check the frame for possible damage, two diagonal measurements of the frame and/or body are required. The diagonal measurements from known points at the front and the rear should be within 1/8 inch (3 mm) of each other.

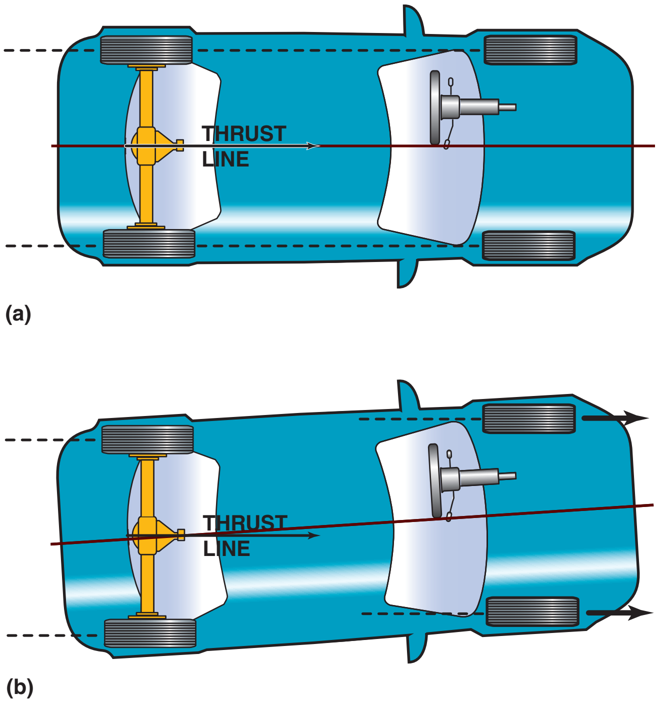


FIGURE 119–49 (a) Proper tracking. (b) Front wheels steering toward thrust line.

FOUR-WHEEL ALIGNMENT

Four-wheel alignment refers to the checking and/or adjustment of all four wheels. Four-wheel alignment is important for proper handling and tire wear. Some rear-wheel-drive vehicles equipped with independent rear suspension can be adjusted for camber and toe. Rear-wheel caster cannot be measured or adjusted because to measure caster, the wheels must be turned from straight ahead. Since rear wheels are securely attached, a caster *sweep* (turning the wheels to take a caster reading) is not possible. While rear camber can cause tire wear problems, by far the greatest tire wear occurs due to toe settings. *Unequal* toe in the rear can cause the vehicle to pull or lead. The rear camber and toe are always adjusted first before adjusting the front caster, camber, and toe. This procedure ensures that the thrust line and centerline of the vehicle are the same.

REVIEW QUESTIONS

1. What are the definitions for camber, caster, and toe?
2. What happens to tire wear and vehicle handling if toe, camber, and caster are out of specification or not equal side to side?
3. Why can knowing SAI, TOOT, and included angle help in the correct diagnosis of an alignment problem?
4. What does thrust angle mean?
5. How does SAI cause the vehicle to straighten the front tires after a turn?

CHAPTER QUIZ

1. All of these symptoms may be corrected by an alignment EXCEPT ___________.
   - **a.** wander
   - **b.** wheel tramp
   - **c.** pulling to one side
   - **d.** drifting to one side
2. When performing an alignment, which angle is the most important for tire wear?
   - **a.** Toe
   - **b.** Camber
   - **c.** Caster
   - **d.** SAI (KPI)
3. Positive camber means ___________.
   - **a.** the top of the tire is tilted outward
   - **b.** the top of the tire is tilted inward
   - **c.** the front of the tire is pointing inward
   - **d.** the front of the tire is pointing rearward
4. Which alignment angle is adjustable on all vehicles?
   - **a.** Camber
   - **b.** Caster
   - **c.** Toe
   - **d.** SAI (KPI)
5. What angle(s) could indicate bent or damaged parts?
   - **a.** Incorrect turning radius
   - **b.** Setback
   - **c.** Tracking
   - **d.** All of the above
6. If the top of the steering axis is tilted 2 degrees toward the rear of the vehicle, this is ___________.
   - **a.** positive camber
   - **b.** negative camber
   - **c.** negative caster
   - **d.** positive caster
7. Included angle is ___________.
   - **a.** SAI + caster
   - **b.** camber + caster
   - **c.** camber + SAI
   - **d.** toe + camber
8. Which angle determines the thrust angle?
   - **a.** Front toe
   - **b.** Rear toe
   - **c.** Rear camber
   - **d.** Front caster, SAI, and included angle
9. Two technicians are discussing scrub radius. Technician A says that scrub radius cannot be measured. Technician B says that scrub radius cannot be adjusted. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technician A and B
   - **d.** Neither Technician A nor B
10. When performing a four-wheel alignment, ___________ is/are the first adjustment(s) to make.
    - **a.** rear camber and toe
    - **b.** rear caster and toe
    - **c.** SAI and included angle
    - **d.** front wheel toe

Chapter

120

ALIGNMENT DIAGNOSIS AND SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose of an alignment and discuss the various checks that should be performed before aligning a vehicle.
- Explain the diagnosis of lead/pull.
- Explain the diagnosis of memory steer.
- Explain the diagnosis of torque steer.
- Describe alignment specifications.
- Describe alignment setup procedures.
- Discuss how to measure camber, caster, SAI, toe, and TOOT.
- Explain diagnostic angles.
- List the types of alignments.
- Discuss rear wheel adjustments.
- Describe how to adjust front camber/caster.
- Discuss setting toe.
- Discuss centering the steering wheel.
- Discuss the tolerance adjustment procedure.
- Explain how to reset the steering angle sensor (SAS).

KEY TERMS:

Degrees 1494 • Eccentric cam 1502 • Five-wheel alignment 1493 • Four-wheel alignment 1499 • Fractional 1494 • Geometric centerline 1497 • Memory steer 1491 • Minutes 1494 • Prealignment checks 1490 • Ride height 1490 • Spoke angle 1504 • Steering angle sensor (SAS) 1507 • Thrust line 1497 • Tolerance adjustment 1505 • Torque steer 1491 • Total toe 1496

ALIGNMENT PURPOSE AND PREALIGNMENT

PURPOSE OF AN ALIGNMENT Proper wheel alignment of all four wheels is important for the safe handling of any vehicle. When all four wheels are traveling the same path and/or being kept nearly vertical, tire life and fuel economy are maximized and vehicle handling is sure and predictable. A complete wheel alignment is a complex process that includes many detailed steps and the skill of a highly trained technician.

PREALIGNMENT CORRECTION TECHNIQUES There are four basic steps in the correction of any problem:

1. **Verify.** What, when, where, and to what extent does the problem occur?
2. **Isolate.** Eliminate known good parts and systems. Always start with the simple things first. For example, checking and correcting tire pressure and rotation of the tires should be one of the first things performed whenever trying to isolate the cause of an alignment-related problem.
3. **Repair the problem.** This step involves replacing any worn or damaged components and making sure that the alignment is within factory specifications. ● **SEE FIGURE 120–1.**

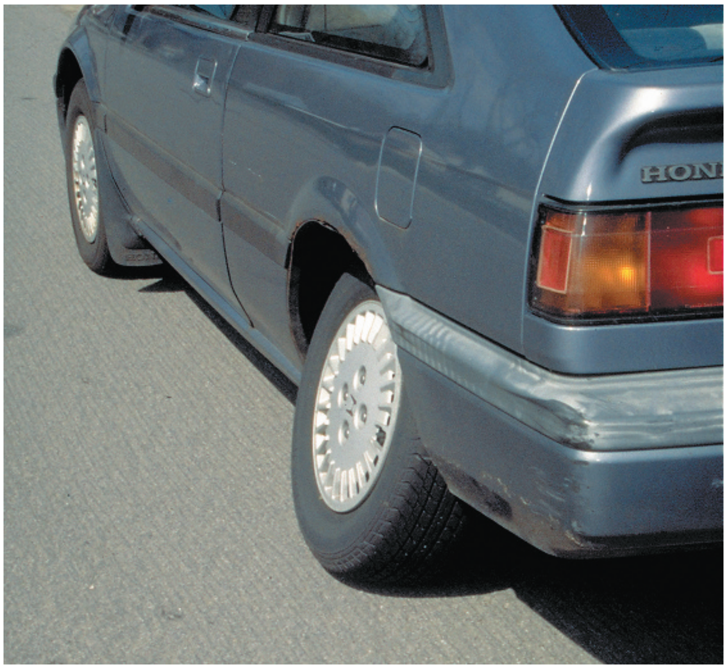


FIGURE 120–1 The owner of this Honda thought that all it needed was an alignment. Obviously, something more serious than an alignment caused this left rear wheel to angle inward at the top.

TECH TIP

Align and Replace at the Same Time

Magnetic bubble-type camber/caster gauges can be mounted directly on the hub or on an adapter attached to the wheel or spindle nut on front-wheel-drive vehicles. ● **SEE FIGURE 120–2**. Besides being used as an alignment setting tool, a magnetic alignment head is a great tool to use whenever replacing suspension components.

Any time a suspension component is replaced, the wheel alignment should be checked and corrected as necessary. An easy way to avoid having to make many adjustments is to use a magnetic alignment head on the front wheels to check camber with the vehicle hoisted in the air *before* replacing front components, such as new MacPherson struts. Then, before tightening all of the fasteners, check the front camber readings again to make sure they match the original setting. This is best done when the vehicle is still off the ground. For example, a typical front-wheel-drive vehicle with a MacPherson strut suspension may have a camber reading of +1/4 degree on the ground and +2 degrees while on the hoist with the wheels off the ground. After replacing the struts, simply return the camber reading to +2 degrees and it should return to the same +1/4 degree when lowered to the ground.

Though checking and adjusting camber before and after suspension service work does not guarantee a proper alignment, it does permit the vehicle to be moved around with the alignment fairly accurate until a final alignment can be performed.

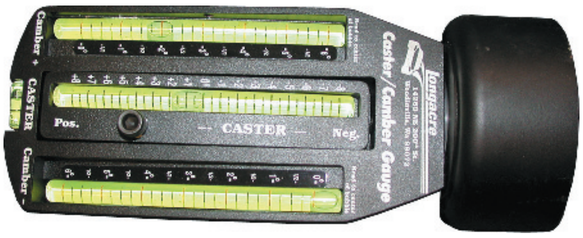


FIGURE 120–2 Magnetic bubble-type camber/caster gauge. To help it keep its strong magnetism, it is best to keep it stored stuck to a metal plate or metal tool box.

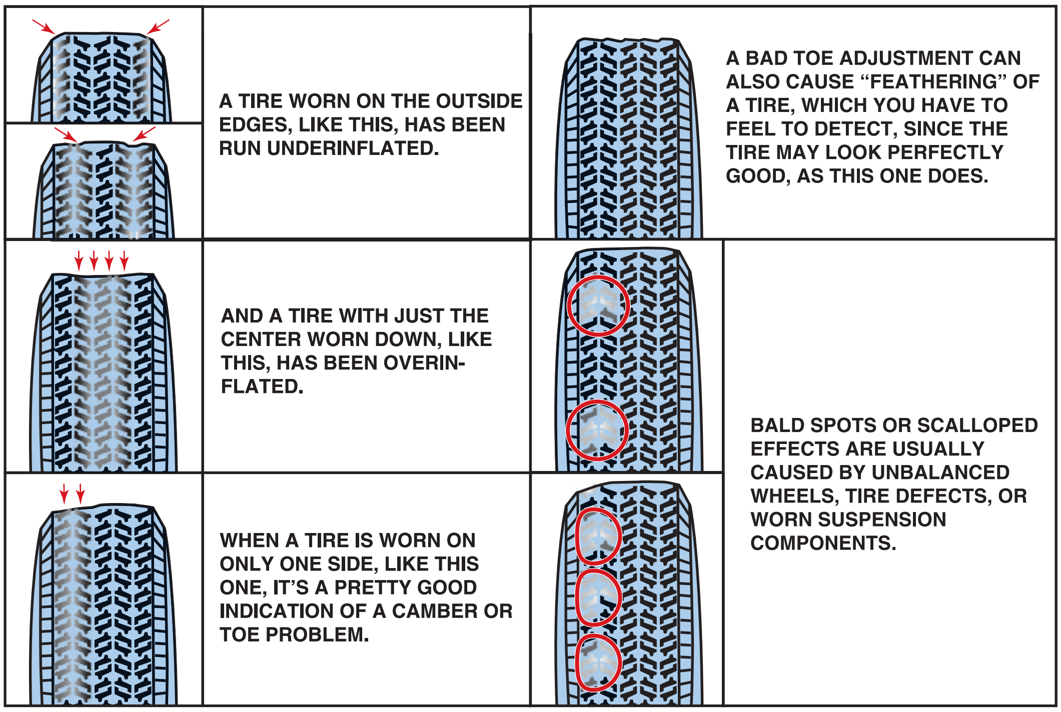
4. **Recheck**. *Always* test-drive the vehicle after making a repair. Never allow the customer to be the first to drive the vehicle after any service work.

A thorough inspection of the steering, suspension, and tires should be performed *before* the alignment of the vehicle is begun.

PREALIGNMENT CHECKS Before checking or adjusting the front-end alignment, the following items should be checked and corrected, if necessary, as part of the **prealignment checks**:

1. Check all the tires for proper inflation pressures. Tires should be approximately the same size and tread depth, and the recommended size for the vehicle. ● **SEE FIGURE 120–3**.
2. Check the wheel bearings for proper adjustment.

NOTE: Some alignment technicians think that the vehicle must have new tires installed before an accurate alignment can be performed. Excessively worn tires, especially if only one tire is worn, can cause the vehicle to lean slightly. It is this unequal ride height that is the important fact to consider. If, for example, all four tires are equally worn, then the vehicle *can* be properly aligned. (Obviously, excessively worn



A TIRE WORN ON THE OUTSIDE EDGES, LIKE THIS, HAS BEEN RUN UNDERINFLATED.

AND A TIRE WITH JUST THE CENTER WORN DOWN, LIKE THIS, HAS BEEN OVERINFLATED.

WHEN A TIRE IS WORN ON ONLY ONE SIDE, LIKE THIS ONE, IT'S A PRETTY GOOD INDICATION OF A CAMBER OR TOE PROBLEM.

A BAD TOE ADJUSTMENT CAN ALSO CAUSE "FEATHERING" OF A TIRE, WHICH YOU HAVE TO FEEL TO DETECT, SINCE THE TIRE MAY LOOK PERFECTLY GOOD, AS THIS ONE DOES.

BALD SPOTS OR SCALLOPED EFFECTS ARE USUALLY CAUSED BY UNBALANCED WHEELS, TIRE DEFECTS, OR WORN SUSPENSION COMPONENTS.

FIGURE 120–3 Typical tire wear chart as found in a service manual. Abnormal tire wear usually indicates a fault in a steering or suspension component that should be corrected or replaced before an alignment is performed.

tires should be replaced, and it would be best to align the vehicle with the replacement tires installed to be assured of an accurate alignment.)

3. Check for loose ball joints or torn ball joint boots.
4. Check the tie rod ends for damage or looseness.
5. Check the center link or rack bushings for play.
6. Check the pitman arm for any movement.
7. Check for runout of the wheels and the tires.
8. Check for vehicle ride height (should be level front to back as well as side to side). Make sure that the factory load-leveling system is functioning correctly, if the vehicle is so equipped. Check height according to the manufacturer's specifications. ● **SEE FIGURES 120–4 AND 120–5**.

NOTE: Manufacturers often have replacement springs or spring spacers that can be installed between the coil spring and the spring seat to restore proper ride level.

9. Check for steering gear looseness at the frame.
10. Check for improperly operating shock absorbers.
11. Check for worn control arm bushings.
12. Check for loose or missing stabilizer bar attachments.

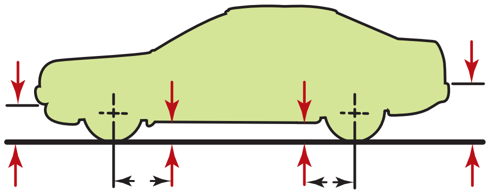


FIGURE 120–4 Measuring points for ride (trim) height vary by manufacturer.

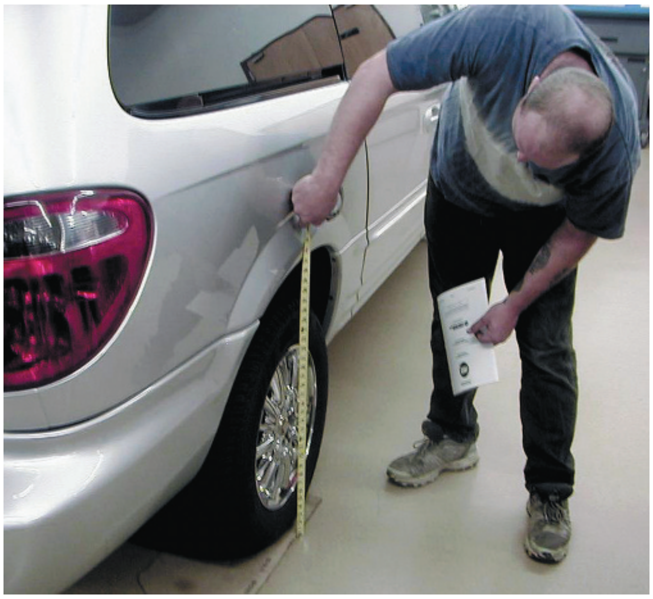


FIGURE 120–5 Measuring to be sure the left and right sides of the vehicle are of equal height. If this measurement is not equal side to side by as little as 1/8 inch (3 mm), it can affect the handling of the vehicle.

13. Check the trunk for excess loads.
14. Check for dragging brakes.

NOTE: Checking for dragging brakes is usually performed when installing alignment heads to the wheels prior to taking an alignment reading. A brake dragging can cause the vehicle to pull or lead toward the side with the dragging brake.

LEAD/PULL

DIAGNOSIS Many alignment requests come from customers attempting to have a lead or pull condition corrected. Before aligning the vehicle, verify the customer complaint first, then perform a careful inspection.

1. Inspect all tires for proper inflation. Both tires on the same axle (front and rear) should be the same size and brand. A lead/pull problem could be due to a defect or condition in one or more of the tires, as shown in ● **FIGURE 120–6**. Before attempting to correct the lead/pull condition by changing alignment angles, try rotating the tires front to back or side to side.
2. Road test the vehicle on a straight, level road away from traffic, if possible. Bring the vehicle to about 40 MPH (65 km/h), shift into neutral, and feel for a pull in the steering, either to the left or to the right. A lead or drift is less severe than a pull, and may occur only if you momentarily remove your hands from the steering wheel while driving.
3. If the lead/pull problem is sometimes toward the left and other times toward the right, check for a **memory steer** condition. If the lead/pull problem occurs during acceleration and deceleration, check for a **torque steer** condition.

MEMORY STEER

DIAGNOSIS **Memory steer** is a term used to describe the lead or pull of a vehicle caused by faults in the steering or suspension system. Often a defective upper strut bearing or steering gear can cause a pulling condition in one direction after making a turn in

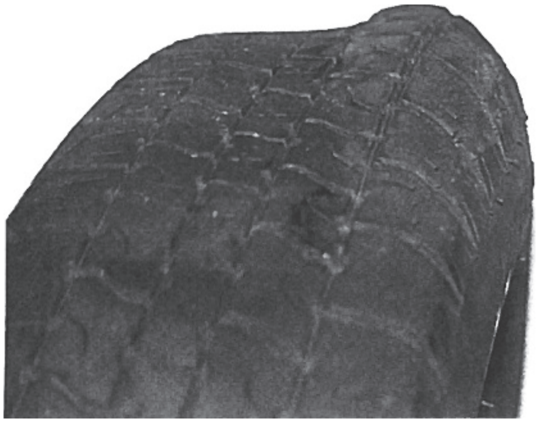


FIGURE 120–6 The bulge in this tire was not noticed until it was removed from the vehicle as part of a routine brake inspection. After replacing this tire, the vehicle stopped pulling and vibrating.

the same direction. It is as if the vehicle had a memory and pulled in the same direction. To test for memory steer, follow these simple steps during a test-drive:

1. With the vehicle stopped at an intersection or in a parking area, turn the steering wheel completely to the left stop and then straighten the wheel without going past the straight-ahead position.
2. Lightly accelerate the vehicle and note any tendency of the vehicle to lead or pull toward the left.
3. Repeat the procedure, turning the steering wheel to the right.

If the vehicle first pulls to the left, then pulls to the right, the vehicle has a memory steer condition.

CORRECTION A binding suspension or **steering component** is the most likely cause of memory steer. Disconnect each wheel from its tie rod end and check for free rotation of movement of each wheel. Each front wheel should rotate easily without binding or roughness. Repair or replace components as necessary to eliminate the binding condition.

NOTE: One of the most common causes of memory steer is the installation of steering or suspension components while the front wheels are turned. Most steering and suspension parts contain rubber, which has a memory if moved from its installed position. If the memory steer condition is only in one direction, then this is the most likely cause. The rubber component exerts a force on the suspension or steering that causes the vehicle to pull toward the side that the wheels were turned toward when the part was installed.

TORQUE STEER

DIAGNOSIS Torque steer occurs in front-wheel-drive vehicles when engine torque causes a front wheel to change its angle from straight ahead. ● **SEE FIGURE 120–7**. This resulting pulling effect is most noticeable during rapid acceleration, especially whenever upshifting of the transmission creates a sudden change in torque being applied to the front wheels. When turning and accelerating at the same time, torque steer has a tendency to straighten the vehicle, so more steering effort may be required to make the turn. Then, if the accelerator is released, a reversing force is applied to the front wheels. Now the driver must take corrective steering motions to counteract the change in steering effect of engine torque.

Torque steer sequence of events

Torque to wheel	a toe-in condition
More torque	more toe-in
Unequal torque	unequal toe-in
Unequal driveshaft angles	unequal torque to the wheels

Most manufacturers try to reduce torque steer in the design of their vehicles by keeping drive axle angles low and equal side to side. If the engine and transaxle are level and the drive axle shafts are kept level, then the torque from the engine will be divided equally between the front wheels.

CORRECTION The service technician cannot change the design of a vehicle, but the technician can, and should, check and correct problems that often cause torque steer. **Check to be sure that the condition is not normal**. It is normal for front-wheel-drive vehicles to exert a tug on the steering wheel and steer toward one side (usually to the right) during acceleration. This is especially noticeable when the transmission shifts from first to second gear under heavy acceleration. To determine how severe the problem is, place a strip of masking tape at the top of the steering wheel. Drive the vehicle and observe the amount of movement required to steer the vehicle straight during heavy acceleration. Repeat the test with a vehicle of similar make and model. If the torque steer is excessive, determine and correct the cause by carefully following the prealignment inspection steps and checking for a level powertrain.

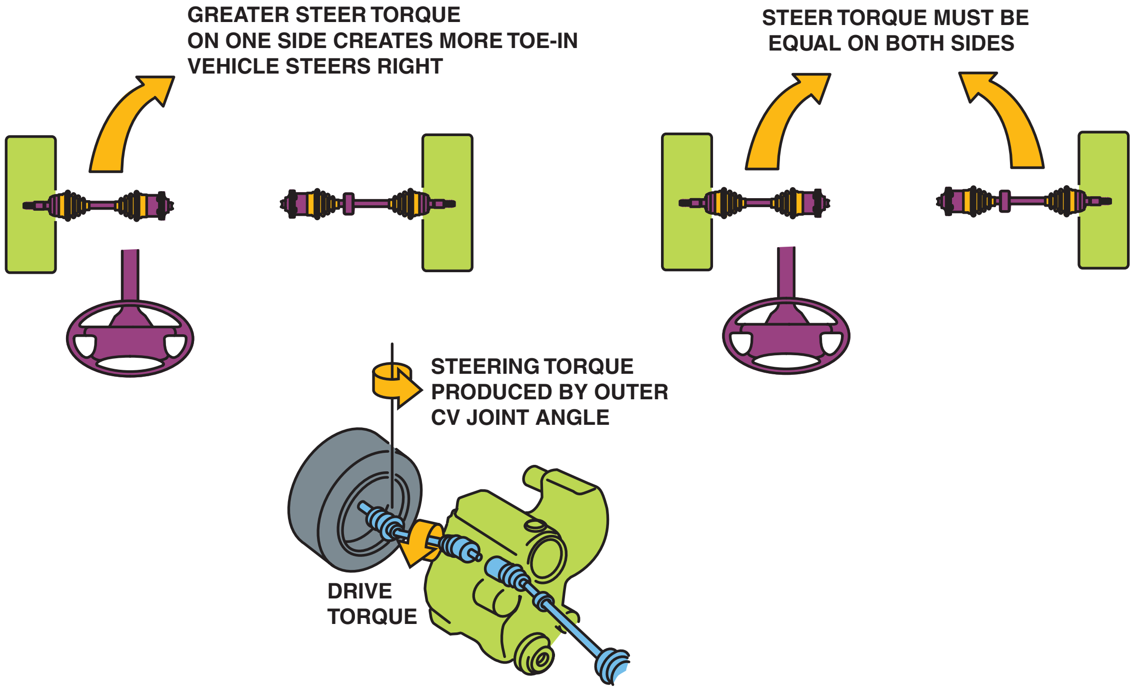


FIGURE 120–7 Equal outer CV joint angles produce equal steer torque (toe-in). If one side receives more engine torque, that side creates more toe-in and the result is a pull toward one side, especially during acceleration.

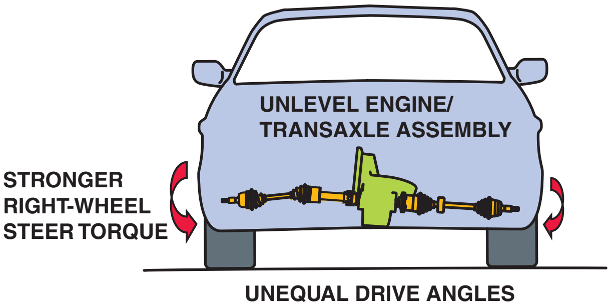


FIGURE 120–8 Broken or defective engine or transaxle mounts can cause the powertrain to sag, causing unequal drive axle shaft CV joint angles.

A defective engine mount can cause the entire drivetrain to sag on one end. If the engine and transaxle of any front-wheel-drive vehicle is not level, the drive axle shaft angles will not be equal, as shown in ● **FIGURE 120–8**.

Hold a straightedge along the engine's supporting frame and measure up to points along the transaxle pan rail or the drive axle shaft. Side-to-side distances should be equal. Standard alignment shims can be used to shim the mounts and level the drivetrain.

CASE STUDY

The Five-Wheel Alignment

The steering wheel should always be straight when driving on a straight, level road. If the steering wheel is not straight, the customer will often think that the wheel alignment is not correct. One such customer complained that the vehicle pulled to the right while driving on a straight road. The service manager test-drove the vehicle and everything was perfect, except that the steering wheel was not perfectly straight, even though the toe setting was correct. Whenever driving on a straight road, the customer would "straighten the steering wheel" and, of course, the vehicle went to one side. After adjusting toe with the steering wheel straight, the customer and the service manager were both satisfied. The technician learned that regardless of how accurate the alignment, the steering wheel must be straight; it is the "fifth wheel" that the customer notices most. Therefore, a **five-wheel alignment** rule includes a check of the steering wheel.

NOTE: Many vehicle manufactures now include the maximum allowable steering wheel angle variation from straight. This specification is commonly ±3 degrees (plus or minus 3 degrees) or less.

Summary:

Complaint—Owner complained that the vehicle pulled to one side after an alignment.
Cause—The steering wheel was not perfectly straight and when the driver straightened the wheel, it went to one side.
Correction—The technician straightened the steering using the tie rod end ends while maintaining the specified toe setting.

If torque steer is still excessive, check all alignment angles, including SAI and included angle. Unequal alignment angles can cause a pull or a lead condition. SAI and included angle should be within 1/2 (0.5) degree side to side for best results. A vehicle will tend to pull toward the side with the least SAI.

ALIGNMENT SPECIFICATIONS

Before attempting any alignment, consider the following:

1. Determine the make, model, and year of the vehicle.
2. Determine if the vehicle is equipped with power steering or manual steering. (Some older models use lower caster specifications for manual steering to reduce steering effort.)
3. Check the trunk and with the customer to determine the normal load being carried. Sometimes customers take out heavy things they normally carry or have something in the vehicle now that they normally do not carry.
4. Determine the correct specifications (if possible, check the specifications from two different sources to ensure correct readings).
5. Compensate for the lack of a full gas tank by placing an equal amount of weight in the luggage compartment. (Gasoline weighs 6 pounds per gallon [0.7 kg per l]—a 20 gallon gas tank, when full, weighs 120 pounds [80 liters weighs 54 kg].)
6. Determine the correct specifications for the *exact* vehicle being checked.

NOTE: Some alignment specifications are published as guidelines for acceptable values for state or local vehicle inspections. Be sure to use the *service* or *set to* specifications.

READING ALIGNMENT SPECIFICATIONS There are several methods used by vehicle manufacturers and alignment equipment manufacturers to specify alignment angles.

MAXIMUM/MINIMUM/PREFERRED METHOD This method indicates the preferred setting for each alignment angle and the minimum

TECH TIP

Keep the Doors Closed, but the Window Down

An experienced alignment technician became upset when a beginning technician opened the driver's door to lock the steering wheel in a straight-ahead position on the vehicle being aligned. The weight of the open door caused the vehicle to sag. This disturbed the level position of the vehicle and changed all the alignment angles.

The beginning technician learned an important lesson that day: Keep the window down on the driver's door so that the steering wheel and brakes can be locked without disturbing the vehicle weight balance by opening a door. The brake pedal must be locked with a pedal depressor to prevent the wheels from rolling as the wheels are turned during a caster sweep. The steering must be locked in the straight-ahead position when adjusting toe.

WHEEL ALIGNMENT SPECIFICATIONS

	CASTER	CROSS CASTER (LH–RH)	CAMBER	CROSS CAMBER (LH–RH)	TOE (TOTAL IN) DEGREES	STEERING WHEEL ANGLE	THRUST ANGLE
FRONT	+3°± 0.5°	0°± 0.75°	+ 0.3° ± 0.5°	0°± 0.75°	0°± 0.3°	0°±3°	– –
REAR	– –	– –	– 0.3° ± 0.5°	0°± 0.75°	+ 0.1° ± 0.2°	– –	0°± 0.1°

FIGURE 120–9 This alignment chart indicates the preferred setting with a plus or minus tolerance.

and maximum allowable value for each. The alignment technician should always attempt to align the vehicle to the preferred setting.

PLUS OR MINUS METHOD This method indicates the preferred setting with the lowest and highest allowable value indicated by a negative (−) and positive (+) sign, as in ● **FIGURE 120–9**. For example, if a camber reading is specified as +1/2 degree with a + and − value of 1/2 degree, it could be written as +1/2 degree ±1/2 degree. The minimum value would be 0 degrees (1/2° − 1/2° = 0°) and the maximum value would be +1 degree (+1/2° + 1/2° = 1°). The range would be from 0 to 1 degree.

NOTE: The angle is assumed positive unless labeled with a negative (−) sign in front of the number.

DEGREES, MINUTES, AND FRACTIONS

Specifications are often published in **fractional** or decimal **degrees**, or in degrees and **minutes**. There are 60 minutes (written as 60′) in 1 degree. ● **SEE CHART 120–1.**

To help visualize the amount of these various units, think of decimal degrees as representing money or cents (100 cents = 1 dollar).

0.75 = 75 cents, or 3/4 of a dollar

Minutes can be visualized as minutes in an hour (60' = 1 hour).

45′ = 3/4 of an hour

Now which is larger, 35 minutes or 0.40 degree? The larger angle is 35 minutes because this is slightly greater than 1/2 degree, whereas 0.40 minute is less than 1/2 degree.

FINDING THE MIDPOINT OF SPECIFICATIONS

Many manufacturers specify alignment angles within a range. If you are using equipment that requires a midpoint to be entered, use the following method to determine easily the midpoint of specifications.

FRACTIONS	DECIMAL DEGREES	MINUTES–SECONDS
1/4°	0.25°	0°15′
1/2°	0.50°	0°30′
3/4°	0.75°	0°45′
1°	1.0°	1° or 60′

CHART 120–1

Conversion chart for switching from fractional inches to decimal degrees or minutes and seconds.

Example 1:

Specification: 55′ to 2°25′

STEP 1 The first step is to determine the specification range or span, which is the total angle value from lowest to highest:

2° 25′
−55′
1°30′ Specification range

STEP 2 Dividing the specification range by 2 will give the midpoint of the range:

$$\frac{1^\circ 30'}{2} = \frac{90'}{2'} = 45'$$

STEP 3 To find the midpoint of the specifications, add the midpoint of the range to the smaller specification (or subtract from the larger specification):

45′ midpoint of range
+55′ lowest specification
1°40′ midpoint of specification

Example 2:

Specification: −0.5° to +0.80°

STEP 1 The total range of the specification is determined by adding 0.5 (1 / 2) to 0.80, totalling 1.30°.

NOTE: Since the lower specification is a negative number, we had to *add* the 0.5 degree to bring the lower range of the specification to zero. Then the total is simply the upper range specification added to the number required to bring the lower end of the range to zero.

STEP 2 Dividing the specification range by 2 gives the midpoint of the range:

$$\frac{1.30^\circ}{2} = 0.65^\circ$$

STEP 3 To find the midpoint of the specification, add the midpoint of the range to the smaller specification:

0.65° midpoint of range
+ (0.50°) lowest specification
+ 0.15° midpoint of specification

ALIGNMENT SETUP PROCEDURES

After confirming that the tires and all steering and suspension components are serviceable, the vehicle is ready for an alignment. Setup procedures for the equipment being used must always be followed. Typical alignment procedures include the following:

STEP 1 Drive onto the alignment rack straight and adjust the ramps and/or turn plates so that they are centered under the tires of the vehicle. ● **SEE FIGURE 120–10**.

STEP 2 Use chocks for the wheels to keep the vehicle from rolling off the alignment rack.

STEP 3 Attach and calibrate the wheel sensors to each wheel as specified by the alignment equipment manufacturer. ● **SEE FIGURE 120–11**. The calibration procedure is required whenever the head of the machine is attached to the wheel of the vehicle. All alignment angles and measurements are taken from the readings of the wheel sensors.

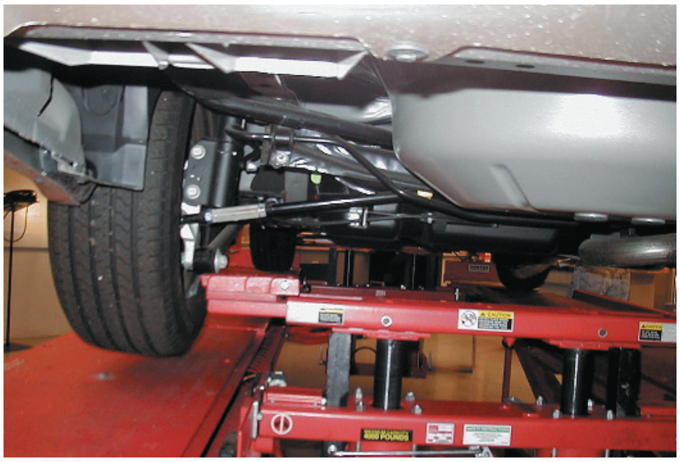


FIGURE 120–10 Using the alignment rack hydraulic jacks, raise the tires off the rack so that they can be rotated as part of the compensating process.

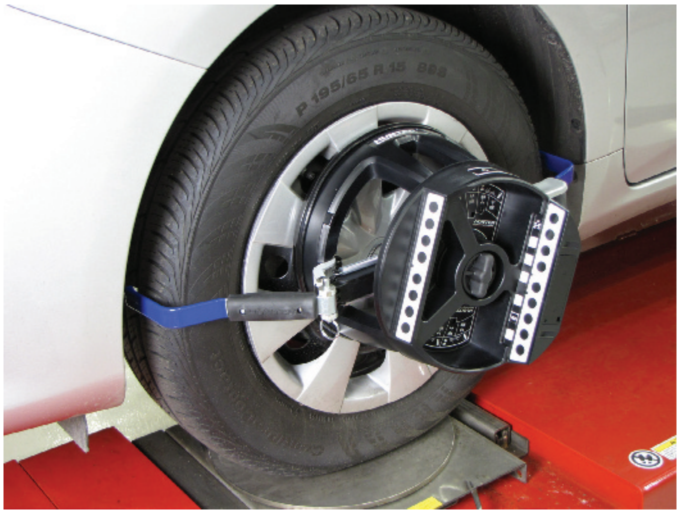


FIGURE 120–11 An optical-type wheel sensor. Compensation is achieved by simply rolling the vehicle backward and forward.

Calibration of these wheel sensors is needed for two reasons:

a. **The wheel may be bent.** If the wheel (rim) is bent, even slightly, this small amount of tilt would be read as an angle of the suspension.

NOTE: Compensating or calibrating the wheel sensor for a bent wheel does *not* correct (or repair) the bent wheel! The bent wheel is still present and can result in a shimmy-type vibration.

b. **The sensors may not be identically installed on the wheel.** Most sensors use three or four wheel-mounting locations. It is not possible to install all wheel sensors perfectly at the same depth on the wheel in all locations. If a sensor must be removed during the alignment process and reinstalled, it should be recalibrated. Always follow the manufacturer's recommended procedure for compensating the sensors.

STEP 4 Unlock all rack or turn plates.

STEP 5 Lower the vehicle and jounce the vehicle by pushing down on the front, then rear, bumper. This motion allows the suspension to become centered.

STEP 6 Following the procedures for the alignment equipment, determine all alignment angles.

MEASURING CAMBER, CASTER, SAI, TOE, AND TOOT

CAMBER Camber is measured with the wheels in the straight-ahead position on a level platform. Since camber is a vertical reference angle, alignment equipment reads camber directly.

CASTER Caster is measured by moving the front wheels through an arc inward, then outward, from straight ahead. This necessary movement of the front wheels to measure caster is called *caster sweep*. What the alignment measuring equipment is actually doing is measuring the camber at one wheel sweep and measuring the camber again at the other extreme of the caster sweep. *The caster angle itself is the difference between the two camber readings.*

SAI Steering axis inclination (SAI) is also measured by performing a caster sweep of the front wheels. While this angle can be read at the same time as caster on many alignment machines, most experts recommend that SAI be measured separately from the caster reading. When measuring SAI separately, the usual procedure involves raising the front wheels off the ground and leveling and locking the wheel sensors before performing a caster sweep. The reason for raising the front wheels is to allow the front suspension to extend to its full droop position. When the suspension is extended, the SAI is more accurately determined because the angle itself is expanded.

TOE Toe is determined by measuring the angle of both front and both rear wheels from the straight-ahead (0 degree) position. Most alignment equipment reads the toe angle for each wheel *and* the combined toe angle of both wheels on the same axle. This combined toe is called **total toe**. Toe angle is more accurate than the center-to-center distance, especially if oversize tires are installed on the vehicle. ● **SEE FIGURE 120–12**.

TOOT Toe-out on turns (TOOT) is a diagnostic angle and is normally not measured as part of a regular alignment, but it is recommended to be performed as part of a total alignment check. TOOT is measured by recording the angle of the front wheels as indicated on the alignment machine display or on the front turn plates. ● **SEE FIGURE 120–13**.

If, for example, the inside wheel is turned 20 degrees, then the outside wheel should indicate about 18 degrees on the turn plate. The exact angles are usually specified by the vehicle manufacturer. The turning angle should be checked only after the toe is correctly set. *The turning angle for the wheel on the outside of the turn should not vary more than 1 1/2 degrees from specifications.* For example, if the specification calls for the right wheel to be steered to the turn 20 degrees, the outside wheel should measure 18 degrees. This measurement should be within 1 1/2 degrees (16.5 to 19.5 degrees). If the TOOT is not correct, a bent steering arm is the usual cause. If TOOT is not correct, tire squealing noise is usually noticed while cornering and excessive tire wear may occur.

NOTE: Some front-wheel-drive vehicles use a nonsymmetrical (unequal) turning angle design. This design is found on various makes and models of vehicles to assist in controlling torque steer. The test procedure is the same except that the turning angle specifications include left-wheel and right-wheel angles when turned inward and outward and may be different readings without indicating a problem.

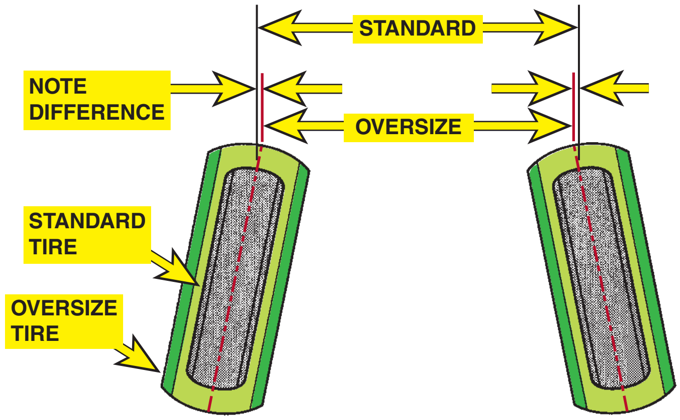


FIGURE 120–12 If toe for an oversize tire is set by distance, the toe angle will be too small. Toe angle is the same regardless of tire size.

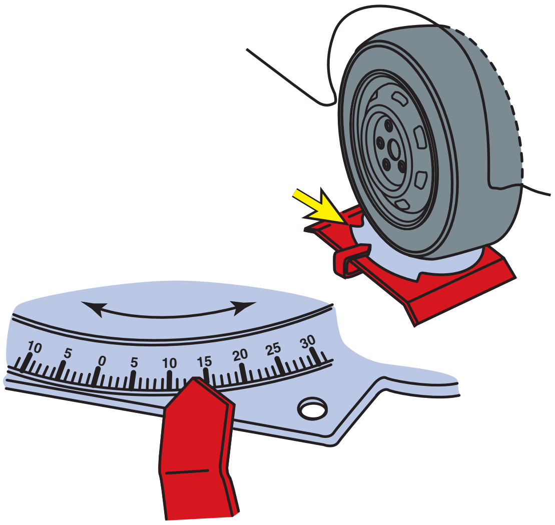


FIGURE 120–13 The protractor scale on the front turn plates allows the technician to test the turning radius by turning one wheel to an angle specified by the manufacturer and observing the angle of the other front wheel. Most newer alignment machines can display turning angle based on sensor readings, and therefore the protractor scale on the turn plate is not needed or used.

DIAGNOSTIC ANGLES

SAI, INCLUDED ANGLE, AND SETBACK Before starting an alignment, the smart technician checks the SAI, included angle, setback, and toe-out on turns to make sure that there is no hidden damage such as a bent spindle or strut that was not found during the prealignment inspection. *Setback is also a diagnostic angle and should be less than 0.5 inch (13 cm or 1/2 degree).* If setback is greater than 0.5 inch (13 cm or 1/2 degree), check the body, frame, and cradle for accident damage or improper alignment.

NOTE: If the SAI or included angle are unequal, suggesting a possible problem such as a bent strut, check the front and rear toe readings. Some alignment equipment cannot show accurate SAI readings if the front or rear toe readings are not within specifications.

CHECKING FOR BENT STRUTS, SPINDLES, OR CONTROL ARMS Even a minor bump against a curb can bend a spindle or a strut housing.

Before attempting to correct an alignment, check all the angles and use the appropriate diagnostic chart to check for hidden damage that a visual inspection may miss.

The chart in ● **FIGURE 120–14** can be used to determine what is wrong if the alignment angles are known. Simply use the chart that correctly identifies the type of suspension on the problem vehicle. The terms used regarding the specifications in ● **FIGURE 120–14** include

- **Correct** The alignment angle is within specifications.
- **Greater than Spec** The alignment angle is greater or higher than specified by the manufacturer.
- **Less than Specs** The alignment angle is less than or lower than specified by the manufacturer.

CHECKING FRAME ALIGNMENT OF FRONT-WHEEL-DRIVE VEHICLES Many front-wheel-drive vehicles mount the drive train (engine and transaxle) and lower suspension arms to a subframe or cradle. If the frame is shifted either left or right, this

DIAGNOSING SAI, CAMBER, AND INCLUDED ANGLE

SLA AND STRUT/SLA SUSPENSIONS

SAI	CAMBER	INCLUDED ANGLE	DIAGNOSIS
CORRECT	LESS THAN SPECS	LESS THAN SPECS	BENT STEERING KNUCKLE OR SPINDLE
LESS THAN SPECS	GREATER THAN SPECS	CORRECT	BENT LOWER CONTROL ARM
LESS THAN SPECS	GREATER THAN SPECS	GREATER THAN SPECS	BENT LOWER CONTROL ARM AND STEERING KNUCKLE OR SPINDLE
GREATER THAN SPECS	LESS THAN SPECS	CORRECT	BENT UPPER CONTROL ARM

STRUT SUSPENSIONS

SAI	CAMBER	INCLUDED ANGLE	DIAGNOSIS
CORRECT	LESS THAN SPECS	LESS THAN SPECS	BENT SPINDLE AND/OR STRUT
CORRECT	GREATER THAN SPECS	GREATER THAN SPECS	BENT SPINDLE AND/OR STRUT
LESS THAN SPECS	GREATER THAN SPECS	CORRECT	BENT CONTROL ARM OR STRUT TOWER OUT AT TOP
LESS THAN SPECS	GREATER THAN SPECS	GREATER THAN SPECS	BENT CONTROL ARM OR STRUT TOWER OUT AT TOP, ALSO BENT SPINDLE AND/OR STRUT
LESS THAN SPECS	LESS THAN SPECS	LESS THAN SPECS	BENT CONTROL ARM OR STRUT TOWER OUT AT TOP, ALSO BENT SPINDLE AND/OR STRUT
GREATER THAN SPECS	LESS THAN SPECS	CORRECT	STRUT TOWER IN AT TOP
GREATER THAN SPECS	GREATER THAN SPECS	GREATER THAN SPECS	STRUT TOWER IN AT TOP AND BENT SPINDLE AND/OR BENT STRUT

KINGPIN TWIN I-BEAM SUSPENSION

SAI (KPI)	CAMBER	INCLUDED ANGLE	DIAGNOSIS
CORRECT	GREATER THAN SPECS	GREATER THAN SPECS	BENT SPINDLE
LESS THAN SPECS	GREATER THAN SPECS	CORRECT	BENT I-BEAM
LESS THAN SPECS	GREATER THAN SPECS	GREATER THAN SPECS	BENT I-BEAM AND SPINDLE
GREATER THAN SPECS	LESS THAN SPECS	CORRECT	BENT I-BEAM

FIGURE 120–14 By checking the SAI, camber, and included angle, a damaged suspension component can be determined by using this chart.

can cause differences in SAI, included angle, setback, and camber. ● **SEE FIGURES 120–15 AND 120–16**. Adjust the frame if SAI and camber angles are different left and right side, yet the included angles are equal.

TECH TIP

Damage Analysis Tips

To check if a vehicle has been in a collision, technicians should look for the following:

1. Drive the vehicle through a water puddle to see if the tire marks are wider than the tires. If they are, then the front and rear wheels are not tracking correctly.
2. If the setback is out of specifications, then the front of the vehicle may be damaged.
3. If the thrust angle is out of specifications, then rear suspension damage is likely.

TYPES OF ALIGNMENTS

There are three types of alignment: geometric centerline, thrust line, and four-wheel alignment.

GEOMETRIC CENTERLINE Until the 1980s, most wheel alignment concerned only the front wheels. Vehicles, such as sports cars, that had independent rear suspensions were often aligned by backing the vehicle onto the alignment rack and adjusting the rear camber and/or toe. This type of alignment is simply an alignment that uses the **geometric centerline** of the vehicle as the basis for all measurements of toe (front or rear). ● **SEE FIGURE 120–17**.

This method is now considered to be obsolete.

THRUST LINE A **thrust line** alignment uses the thrust angle of the rear wheels and sets the front wheels parallel to the thrust line. ● **SEE FIGURE 120–18**.

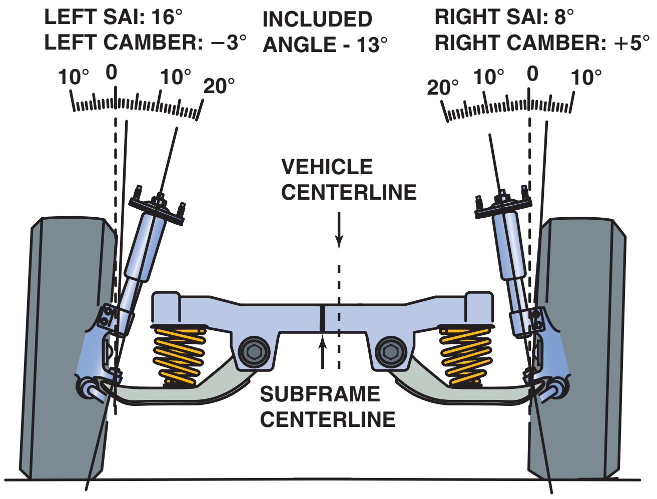

LEFT SAI: 16°
LEFT CAMBER: −3°
INCLUDED ANGLE - 13°
RIGHT SAI: 8°
RIGHT CAMBER: +5°
10°
0
10°
20°
20°
10°
0
10°
VEHICLE CENTERLINE
SUBFRAME CENTERLINE

FIGURE 120–15 In this example, both SAI and camber are far from being equal side to side. However, both sides have the same included angle, indicating that the frame may be out of alignment. An attempt to align this vehicle by adjusting the camber on both sides with either factory or aftermarket kits would result in a totally incorrect alignment.

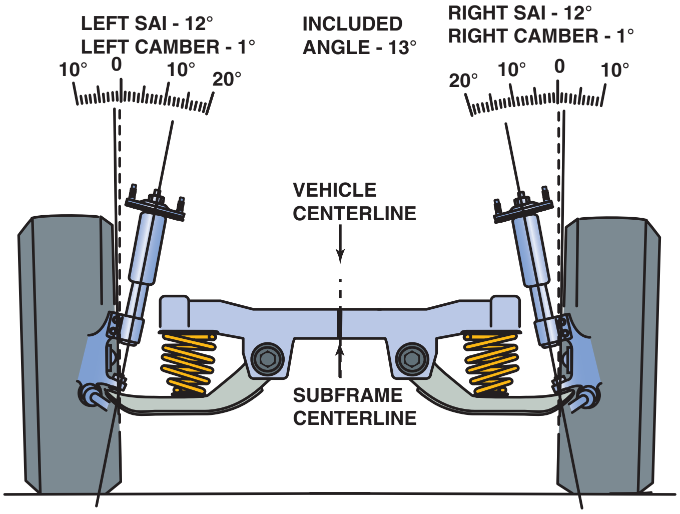

LEFT SAI - 12°
LEFT CAMBER - 1°
INCLUDED ANGLE - 13°
RIGHT SAI - 12°
RIGHT CAMBER - 1°
10°
0
10°
20°
20°
10°
0
10°
VEHICLE CENTERLINE
SUBFRAME CENTERLINE

FIGURE 120–16 This is the same vehicle as shown in *Figure 119–15*, except now the frame (cradle) has been shifted over and correctly positioned. Notice how both the SAI and camber become equal without any other adjustments necessary.

The thrust line is the bisector of rear total toe, or the actual direction in which the rear wheels are pointed. The rear wheels of any vehicle *should* be pointing parallel to the geometric centerline of the vehicle. However, if the rear toe angles of the rear wheels do not total exactly zero (perfectly in a line with the centerline of the vehicle), a thrust condition exists. The front wheels will automatically steer to become parallel to that condition. A crooked steering wheel may also result from an improper thrust condition.

NOTE: It has often been said that while the front wheels steer the vehicle, the rear wheels determine the direction in which the vehicle will travel. Think of the rear wheels as a rudder on a boat. If the rudder is turned, the direction of the boat changes due to the angle change at the rear of the boat.

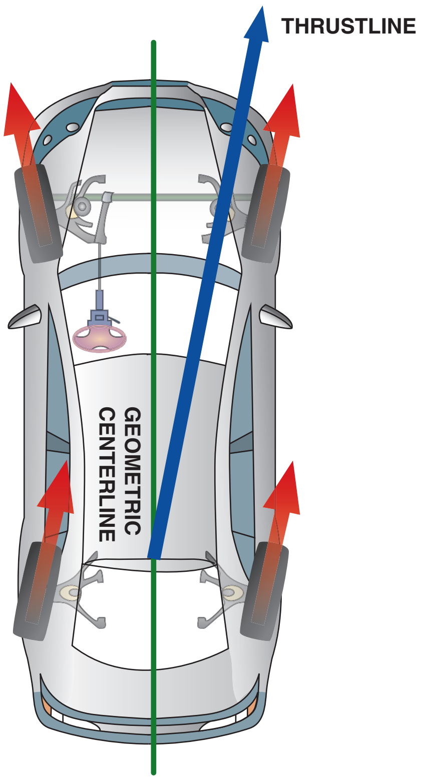

THRUSTLINE
GEOMETRIC CENTERLINE

FIGURE 120–17 Geometric-centerline-type alignment sets the front toe readings based on the geometric centerline of the vehicle and does not consider the thrust line of the rear wheel toe angles.

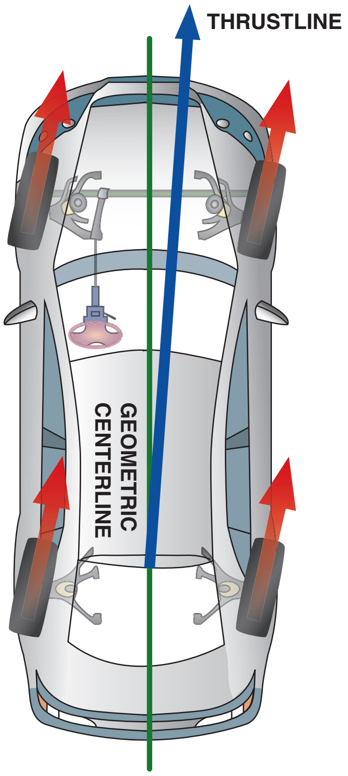

THRUSTLINE
GEOMETRIC CENTERLINE

FIGURE 120–18 Thrust line alignment sets the front toe parallel with the rear-wheel toe.

Thrust line alignment is *required* for any vehicle with a non-adjustable rear suspension. If a vehicle has an adjustable rear suspension, then a four-wheel alignment is necessary to ensure proper tracking.

FOUR-WHEEL ALIGNMENT

A **four-wheel alignment** is the most accurate alignment method and is necessary to ensure maximum tire wear and vehicle handling. The biggest difference between a thrust-line alignment and a four-wheel alignment is that the rear toe is adjusted to bring the thrust line to zero. In other words, the rear toe on both rear wheels is adjusted equally so that the actual direction in which the rear wheels are pointed is the same as the geometric centerline of the vehicle. ● **SEE FIGURE 120–19.**

The procedure for a four-wheel alignment includes these steps:

1. Adjust the rear camber (if applicable).
2. Adjust the rear toe (this should reduce the thrust angle to near zero).
3. Adjust the front camber and caster.
4. Adjust the front toe, being sure that the steering wheel is in the straight-ahead position.
5. Reset the steering angle sensor (if equipped).

SAMPLE ALIGNMENT SPECIFICATIONS AND READINGS

The service technician must know not only all of the alignment angles but also the interrelationship that exists among the angles. As an aid toward understanding these relationships, two examples are presented: Example 1 gives the front wheel angles that are acceptable when compared with the specifications; Example 2 gives four-wheel alignment and readings of a vehicle that are not within specifications.

Example 1: Wheel Alignment

Alignment Specifications

	Left	Right
Camber =	+1/2° ± 1/2°	+1/2° ± 1/2°
Caster =	+1° ± 1/2°	+1° ± 1/2°
Toe (total) =	1/8 in. ± 1/16 in.	

Actual Reading

	Left	Right
Camber =	+1/4°	0°
Caster =	+1°	+1 1/4°
Toe (total) =	1/8 in.	

Answer:

Alignment is perfect:

a. No tire wear

b. No pulling

Explanation:

Camber is within specifications.

Camber is within 1/2 degree difference side to side.

Camber is not equal, but there is more camber on the left (1/4 degree) than on the right, thereby helping to compensate for the road crown.

Caster is within specifications.

Caster is within 1/2 degree difference side to side.

Caster is not equal, but there is more caster on the right (1/4 degree) than on the left, thereby helping (very slightly) to compensate for road crown.

Toe is within specifications.

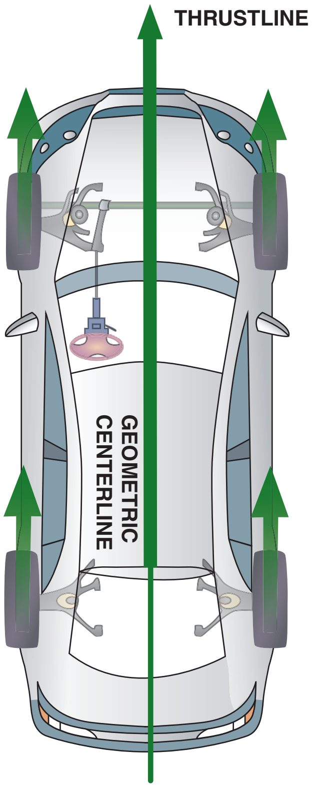


FIGURE 120–19 Four-wheel alignment corrects for any rear-wheel toe to make the thrust line and the geometric centerline of the vehicle both the same.

Example 2: Four-Wheel Alignment

Specifications

	Left	Right
Front camber =	+1/4° ± 1/2°	0° ± 1/2°
Front caster =	+3° ± 1/2°	+3° ± 1/2°
Front toe (total) =	3/16 in. ± 1/16 in.	
Rear camber =	0° ± 1/4°	0° ± 1/4°
Rear toe =	0 in. ± 1/16 in.	

Actual Reading

	Left	Right
Front camber =	−1/2°	−1°
Front caster =	+2 3/4°	+2°
Front toe =	−1/8 in. (toe-out)	
Rear camber =	0°	+1/4°
Rear toe =	1 1/2° (toe-in)	

Answer:

Alignment is incorrect.

a. Left front tire will wear slightly on the inside edge.

b. Right front tire will wear on the inside edge.

c. Vehicle could tend to pull slightly to the left due to the camber difference (may not pull at all due to the pulling effect of the road crown).

d. Vehicle could tend to pull slightly to the right due to the caster difference (3/4 degree more caster on the left).

TECH TIP

Ask Yourself These Three Questions

An older technician told a beginning technician that the key to success in doing a proper alignment is to ask yourself three questions about the alignment angles:

Question 1. **"Is it within specifications?"** For example, if the specification reads 1 degree ±1/2 degree, any reading between +1/2 degree and 1 1/2 degrees is within specifications. All vehicles should be aligned within this range. Individual opinions and experience can assist the technician as to whether the actual setting should be at one extreme or the other or held to the center of the specification range.

Question 2. **"Is it within 1/2 degree of the other side of the vehicle?"** Not only should the alignment be within specifications, but it should also be as equal as possible from one side to the other. The difference between the camber from one side to the other side is called cross-camber. Cross-caster is the difference between the caster angle from one side to another. Some manufacturers and technicians recommend that this side-to-side difference be limited to just 1/4 degree!

Question 3. **"If the camber and caster cannot be exactly equal side to side in the front, is there more camber on the left and more caster on the right to help compensate for road crown?"** Seldom, if ever, are the alignment angles perfectly equal. Sometimes one side of the vehicle is more difficult to adjust than the other side. Regardless of the reasons, if there *has* to be a difference in front camber and/or caster angle, follow this advice to avoid a possible lead or drift problem even if the answers to the first two questions are "yes."

FREQUENTLY ASKED QUESTION

How Does Normal Wear Affect the Alignment Angles?

As a vehicle ages, the springs sag and steering and suspension components wear.

- When springs sag, the ride height changes and the camber usually is reduced and often becomes negative compared to slightly positive when the vehicle was new in most cases.
- When tie rod ends and other steering components wear, the front wheels tend to toe out.
- Worn suspension components can cause excessive play making the vehicle unstable and cause the tires to wear abnormally.

Alignment alone cannot take the place of worn parts. All an alignment can do is try to compensate for the worn parts.

Toe is the most common angle that needs to be adjusted because any wear in the steering or suspension systems affect the toe.

e. Overall pull could be slight toward the left because it requires four times the caster difference to have the same pulling forces as camber.

f. Tires could wear slightly on both the inside edges due to toe-out.

g. The negative camber of the present alignment puts a heavy load on the outer wheel bearing, if RWD, because the load is being carried by the smaller outer wheel bearing instead of the larger inner wheel bearing.

Conclusion:

The vehicle would wear the inside edges of both front tires.
The vehicle may or may not pull slightly to the left.
The vehicle would not act as stable while driving—possible wander.

REAR WHEEL ADJUSTMENTS

ADJUSTING REAR CAMBER Adjusting rear camber is the first step in the four-wheel alignment process. Rear camber is rarely made adjustable, but can be corrected by using aftermarket alignment kits or shims. If rear camber is not correct, vehicle handling and tire life are affected. Before attempting to adjust or correct rear camber, carefully check the body and/or frame of the vehicle for accident damage, including the following:

1. Weak springs, torsion bars, or overloading (check ride height)
2. Bowed rear axle, trailing arm, or rear control arm
3. Suspension mount or body dimension not in proper location
4. Incorrectly adjusted camber from a previous repair

The cause of the incorrect rear camber could be accident-related and the body or frame may have to be pulled into correct position. ● **SEE FIGURES 120–20 THROUGH 120–22** for examples of various methods used to adjust rear camber.

USING PLASTIC OR METAL ALIGNMENT SHIMS Using plastic or metal alignment shims to correct angles in the rear of the vehicle is relatively simple and includes the following steps:

1. Take alignment readings and determine the change needed.
2. Select proper shims using the easy-to-read chart.

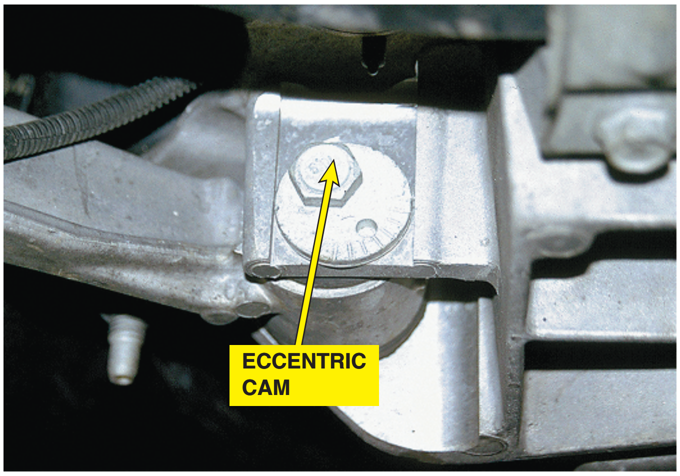


FIGURE 120–20 The rear camber is adjustable on this vehicle by rotating the eccentric cam and watching the alignment machine display.

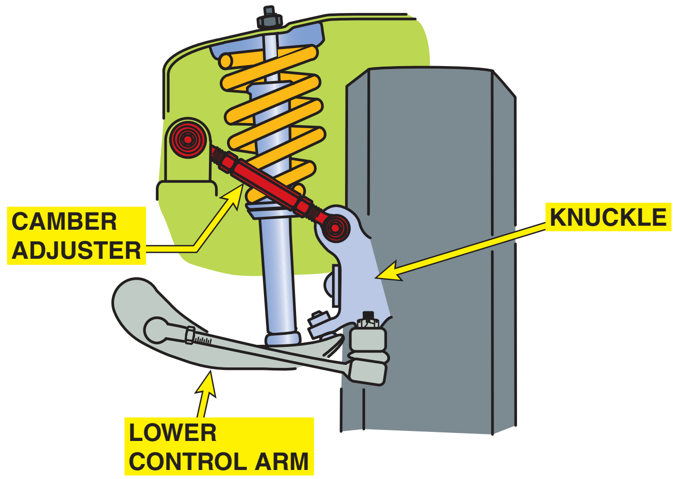


FIGURE 120–21 Some vehicles use a threaded fastener similar to a tie rod to adjust camber on the rear suspension.

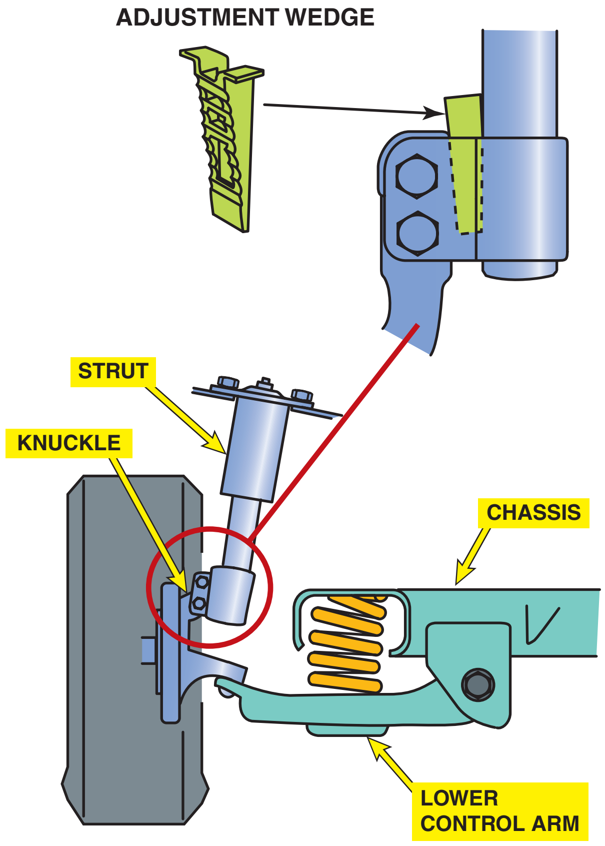


FIGURE 120–22 Aftermarket alignment parts or kits are available to change the rear camber.

TECH TIP

The Gritty Solution

Many times it is difficult to loosen a Torx bolt, especially those used to hold the backing plate onto the rear axle on many GM vehicles. ● **SEE FIGURE 120–23.**

A technique that always seems to work is to place some valve grinding compound on the fastener. The gritty compound keeps the Torx socket from slipping up and out of the fastener, and more force can be exerted to break loose a tight bolt. Valve grinding compound can also be used on Phillips head screws as well as other types of bolts, nuts, and sockets.

3. Using the template provided, mark and remove tabs to create a proper mounting bolt pattern.
4. Install shim.

ADJUSTING REAR TOE Many vehicle manufacturers provide adjustment for rear toe on vehicles that use an independent rear suspension. Rear toe adjusts the thrust angle. A thrust angle that exceeds 1/2 degree (0.5 degree) on a vehicle with a solid axle is an indication that a component may be damaged or out of place in the rear of the vehicle. Rear toe is often adjusted using an adjustable tie rod end or an eccentric cam on the lower control arm. Check a service manual for the exact method for the vehicle being aligned. Most solid rear axles do not have a method to adjust rear toe except for aftermarket shims or kits. ● **SEE FIGURES 120–24 THROUGH 120–26.**

NOTE: On vehicles equipped with four-wheel steering, refer to the service manual for the exact procedure to follow to lock or hold the rear wheels in position for a proper alignment check.

FRONT CAMBER/CASTER ADJUSTMENT METHODS

Many vehicles are constructed with only limited camber/caster factory adjustment. ● **SEE FIGURE 120–27** for a summary of which adjustments are *generally* possible for various types of vehicles and suspension systems.

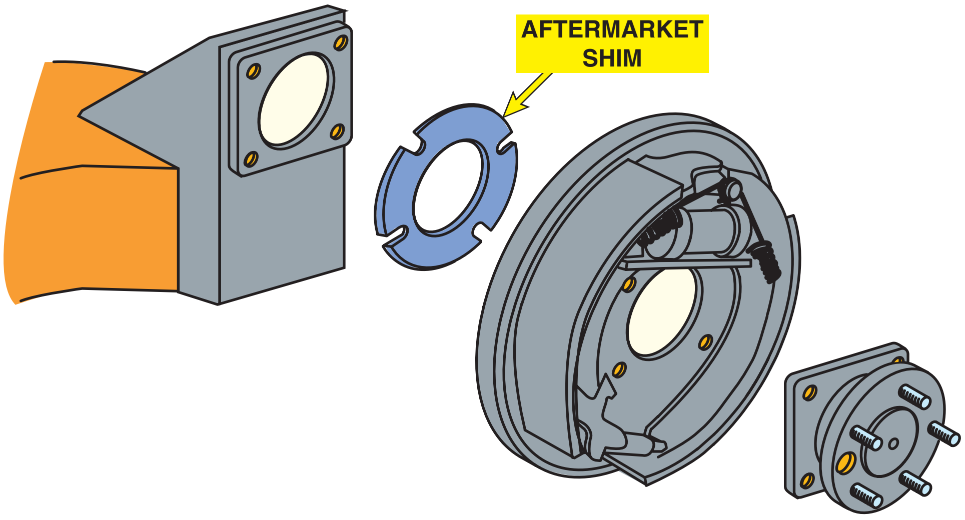


FIGURE 120–23 Full-contact plastic or metal shims can be placed between the axle housing and the brake backing plate to change rear camber, toe, or both.

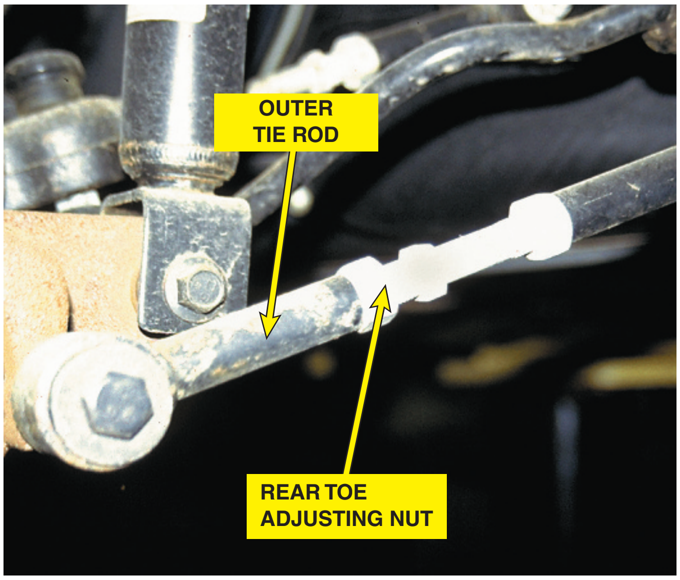


FIGURE 120–24 The rear toe was easily set on this vehicle. The adjusting nuts were easy to get to and turn. Adjusting rear toe is not this easy on every vehicle.

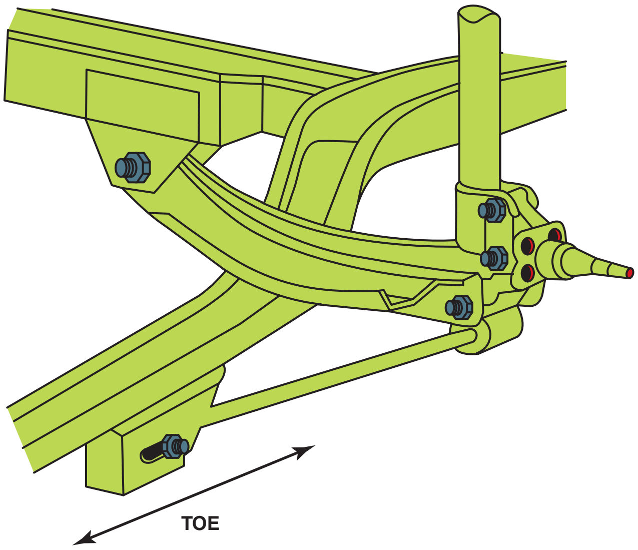


FIGURE 120–25 By moving various rear suspension members, the rear toe can be changed.

CAUTION: Most vehicle manufacturers warn technicians not to adjust camber by bending the strut assembly. Even though several equipment manufacturers make tools that are designed to bend the strut, most experts agree that it can cause harm to the strut itself.

Most SLA-type suspensions can be adjusted for caster and camber. Most manufacturers recommend adjusting caster, then camber, before adjusting the toe. As the caster is changed, such as when the strut rod is adjusted as shown in ● **FIGURE 120–28**, the camber and toe also change.

If the camber is then adjusted, the caster is unaffected. Many technicians adjust caster and camber at the same time using shims (● **SEE FIGURES 120–29 AND 120–30**), slots (● **SEE FIGURE 120–31**), or **eccentric cams** (● **SEE FIGURE 120–32**).

Regardless of the methods or procedures used, toe is always adjusted after all the angles are set because caster and camber both affect the toe. *Always follow the manufacturer's recommended alignment procedure*.

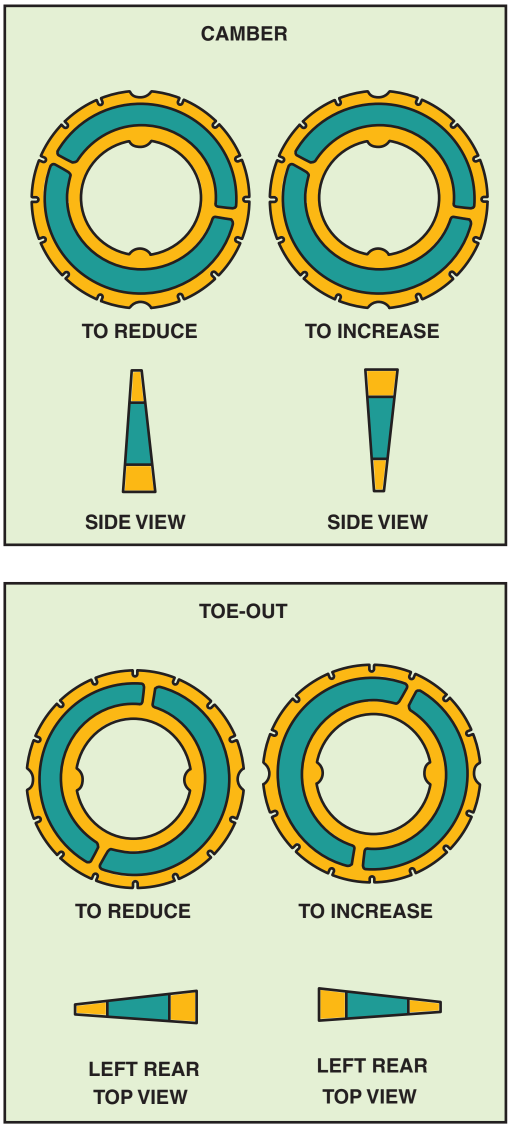


FIGURE 120–26 The use of these plastic or metal shims requires that the rear wheel as well as the hub assembly and/or backing plate be removed. Proper torque during reassembly is critical to avoid damage to the shims.

SETTING TOE

Front toe is the last angle that should be adjusted and is the most likely to need correction. This has led to many sayings in the alignment field:

> "Set the toe and let it go."
>
> "Do a toe and go."
>
> "Set the toe and collect the dough."

As wear occurs at each steering joint such as tie rod ends, the forces exerted on the linkage by the tire tend to cause a toe-out condition.

Front-wheel-drive (FWD) vehicles transmit engine power through the front wheels. Many manufacturers of FWD vehicles specify a toe-out setting. This toe-out setting helps compensate for the slight toe-in effect of the engine torque being transferred through the front wheels.

Most newer alignment equipment displays in degrees of toe instead of inches of toe. (See the toe unit conversion chart.) Just remember that positive (+) toe means toe-in and negative (–) toe means toe-out.

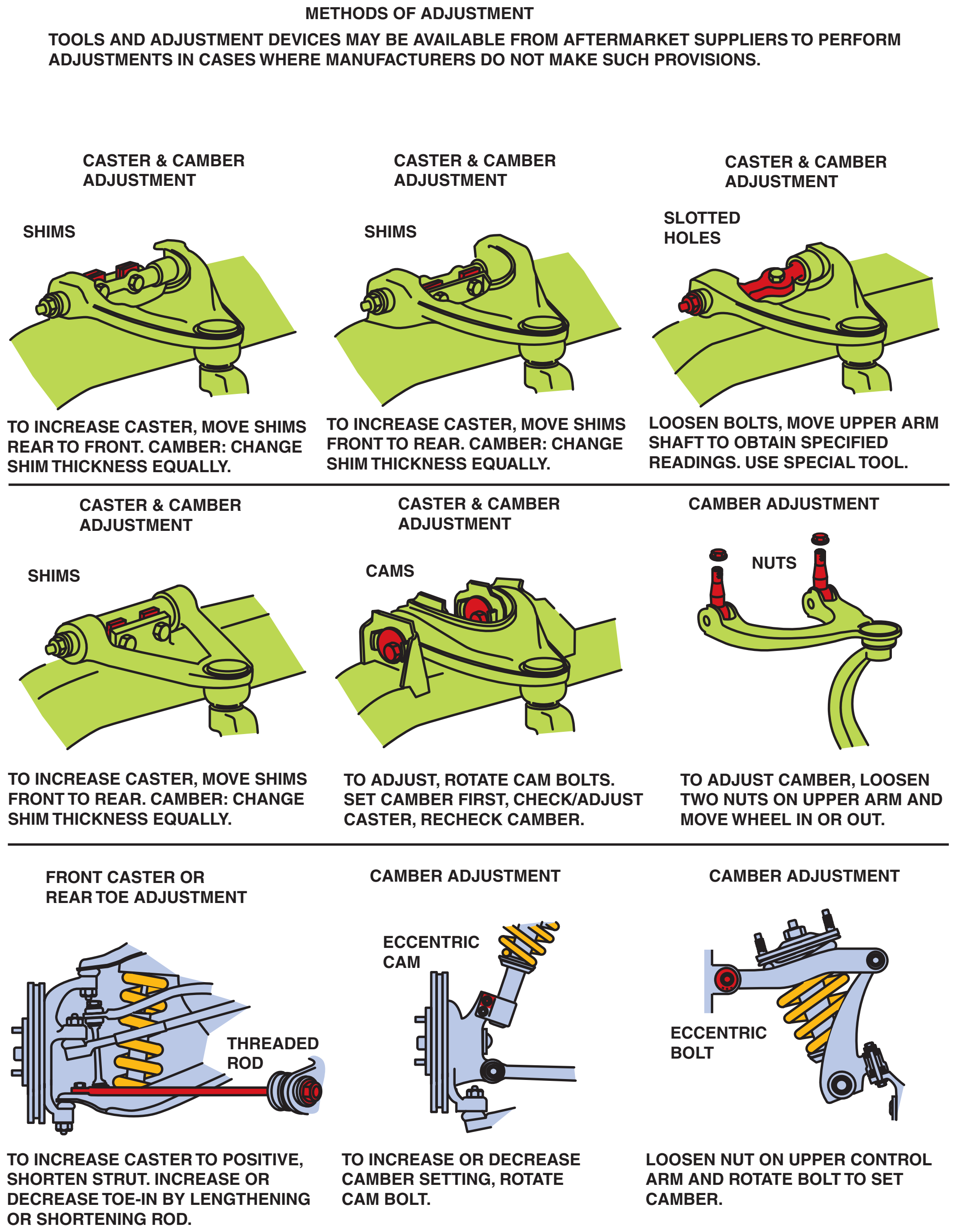

METHODS OF ADJUSTMENT
TOOLS AND ADJUSTMENT DEVICES MAY BE AVAILABLE FROM AFTERMARKET SUPPLIERS TO PERFORM ADJUSTMENTS IN CASES WHERE MANUFACTURERS DO NOT MAKE SUCH PROVISIONS.
CASTER & CAMBER ADJUSTMENT
SHIMS
TO INCREASE CASTER, MOVE SHIMS REAR TO FRONT. CAMBER: CHANGE SHIM THICKNESS EQUALLY.
CASTER & CAMBER ADJUSTMENT
SHIMS
TO INCREASE CASTER, MOVE SHIMS FRONT TO REAR. CAMBER: CHANGE SHIM THICKNESS EQUALLY.
CASTER & CAMBER ADJUSTMENT
SLOTTED HOLES
LOOSEN BOLTS, MOVE UPPER ARM SHAFT TO OBTAIN SPECIFIED READINGS. USE SPECIAL TOOL.
CASTER & CAMBER ADJUSTMENT
SHIMS
TO INCREASE CASTER, MOVE SHIMS FRONT TO REAR. CAMBER: CHANGE SHIM THICKNESS EQUALLY.
CASTER & CAMBER ADJUSTMENT
CAMS
TO ADJUST, ROTATE CAM BOLTS. SET CAMBER FIRST, CHECK/ADJUST CASTER, RECHECK CAMBER.
CAMBER ADJUSTMENT
NUTS
TO ADJUST CAMBER, LOOSEN TWO NUTS ON UPPER ARM AND MOVE WHEEL IN OR OUT.
FRONT CASTER OR REAR TOE ADJUSTMENT
THREADED ROD
TO INCREASE CASTER TO POSITIVE, SHORTEN STRUT. INCREASE OR DECREASE TOE-IN BY LENGTHENING OR SHORTENING ROD.
CAMBER ADJUSTMENT
ECCENTRIC CAM
TO INCREASE OR DECREASE CAMBER SETTING, ROTATE CAM BOLT.
CAMBER ADJUSTMENT
ECCENTRIC BOLT
LOOSEN NUT ON UPPER CONTROL ARM AND ROTATE BOLT TO SET CAMBER.

FIGURE 120–27 An example of the many methods that are commonly used to adjust front caster and camber.

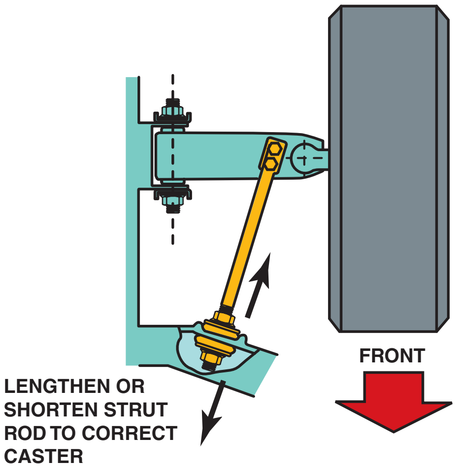

FRONT
LENGTHEN OR SHORTEN STRUT ROD TO CORRECT CASTER

FIGURE 120–28 If there is a nut on both sides of the strut rod bushing, then the length of the rod can be adjusted to change caster.

Toe Unit Conversions

Units	Conversions			
Fractional inches	1/16 in.	1/8 in.	3/16 in.	1/4 in.
Decimal inches	0.062 in.	0.125 in.	0.188 in.	0.250 in.
Millimeters	1.60 mm	3.18 mm	4.76 mm	6.35 mm
Decimal degrees	0.125°	0.25°	0.375°	0.5°
Degrees and minutes	0°8′	0°15′	0°23′	0°30′
Fractional degrees	1/8°	1/4°	3/8°	1/2°

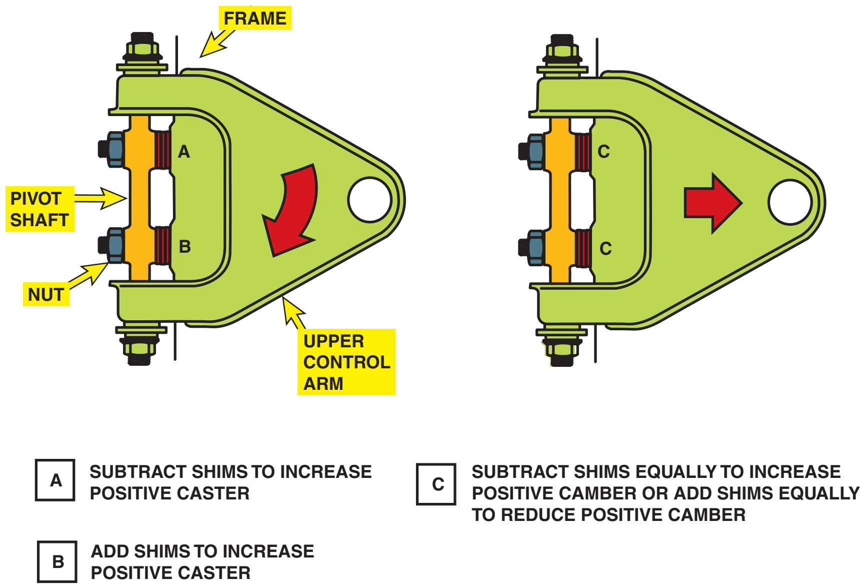

FRAME
PIVOT SHAFT
NUT
UPPER CONTROL ARM
A
B
C
C
A SUBTRACT SHIMS TO INCREASE POSITIVE CASTER
B ADD SHIMS TO INCREASE POSITIVE CASTER
C SUBTRACT SHIMS EQUALLY TO INCREASE POSITIVE CAMBER OR ADD SHIMS EQUALLY TO REDUCE POSITIVE CAMBER

FIGURE 120–29 Placing shims between the frame and the upper control arm pivot shaft is a popular method of alignment for many SLA suspensions. Both camber and caster can be easily changed by adding or removing shims.

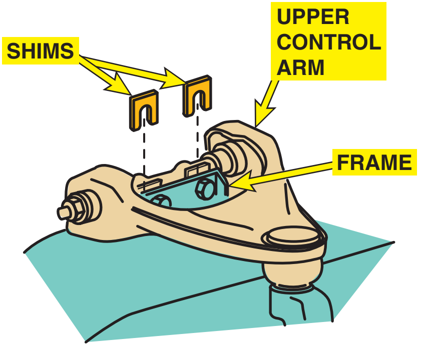

SHIMS
UPPER CONTROL ARM
FRAME

FIGURE 120–30 The general rule of thumb is that a 1/8 inch shim added or removed from both shim locations changes the camber angle about 1/2 degree. Adding or removing a 1/8 inch shim from one shim location changes the caster by about 1/4 degree.

To make sure the steering wheel is straight after setting toe, it *must* be locked in the straight-ahead position while the toe is being adjusted. Another term used to describe steering wheel position is **spoke angle**. To lock the steering wheel, always use a steering wheel lock that presses against the seat and the outer rim of the steering wheel. *Do not* use the locking feature of the steering column to hold the steering wheel straight. Always unlock the steering column, straighten the steering wheel, and install the steering wheel lock. ● **SEE FIGURES 120–33 THROUGH 120–35.**

NOTE: The engine must be started and the steering wheel straightened with the engine running to be assured of a straight steering wheel. Lock the steering wheel with the steering lock tool before stopping the engine.

After straightening the steering wheel, turn the tie rod adjustment until the toe for both wheels is within specifications. ● **SEE FIGURE 120–36.**

Test-drive the vehicle for proper handling and centerline steering. *Centerline steering* is a centered steering wheel with the vehicle traveling a straight course.

CENTERING THE STEERING WHEEL

Centerline steering *should* be accomplished by adjusting the tie rod length on both sides of the vehicle while the toe is set.

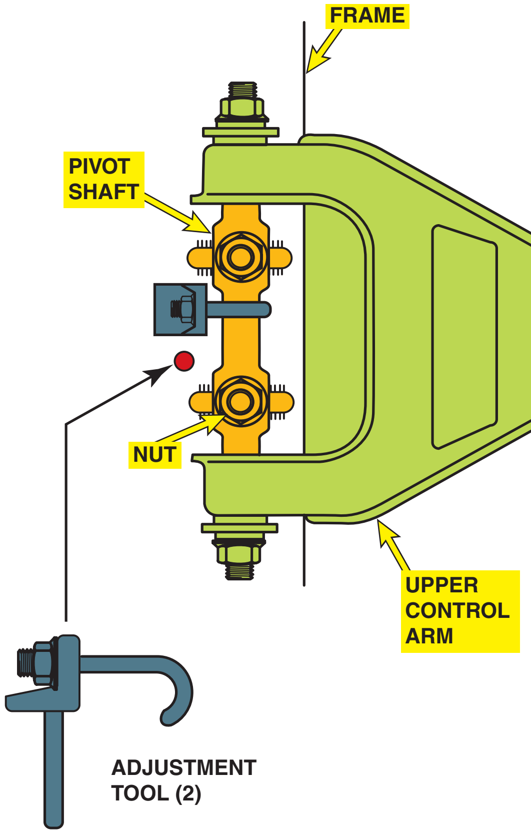

FRAME
PIVOT SHAFT
NUT
UPPER CONTROL ARM
ADJUSTMENT TOOL (2)

FIGURE 120–31 Some SLA-type suspensions use slotted holes for alignment angle adjustments. When the pivot shaft bolts are loosened, the pivot shaft is free to move unless held by special clamps as shown. By turning the threaded portion of the clamps, the camber and caster can be set and checked before tightening the pivot shaft bolts.

CAUTION: Do not attempt to straighten the steering wheel by relocating the wheel on the steering column on a vehicle with two tie rod end adjusters. The steering wheel is positioned at the factory in the center of the steering gear, regardless of type. If the steering wheel is not in the center, then the variable ratio section of the gear will not be in the center as it is designed. Another possible problem with moving the steering wheel from its designed straight-ahead position is that the turning radius may be different for right- and left-hand turns.

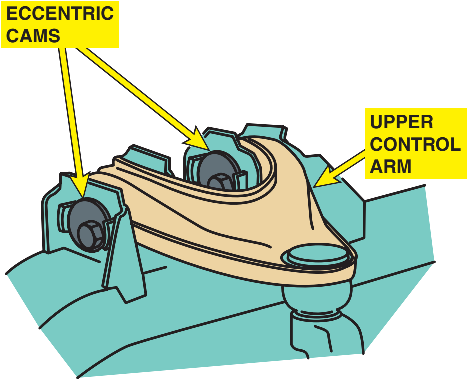


FIGURE 120–32 When the nut is loosened and the bolt on the eccentric cam is rotated, the upper control arm moves in and out. By adjusting both eccentric cams, both camber and caster can be adjusted.

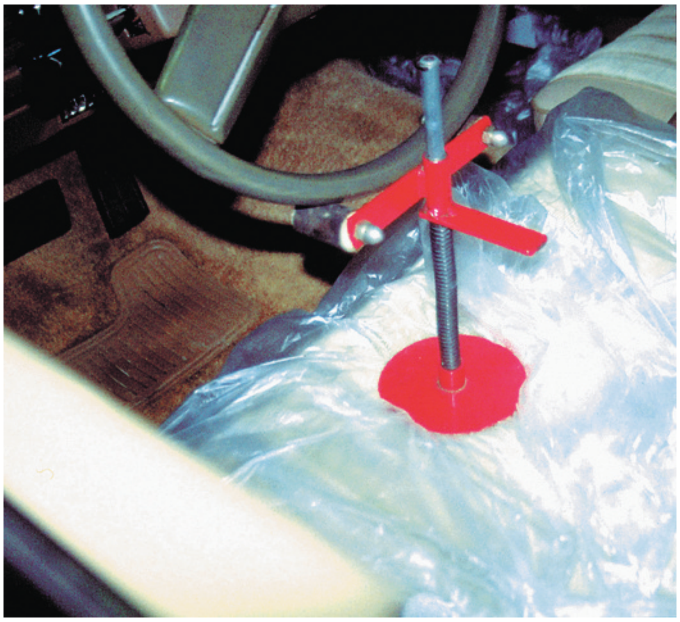


FIGURE 120–33 Many procedures for setting toe specify that the steering wheel be held in the straight-ahead position using a steering wheel lock, as shown. One method recommended by Hunter Engineering sets toe without using a steering wheel lock.

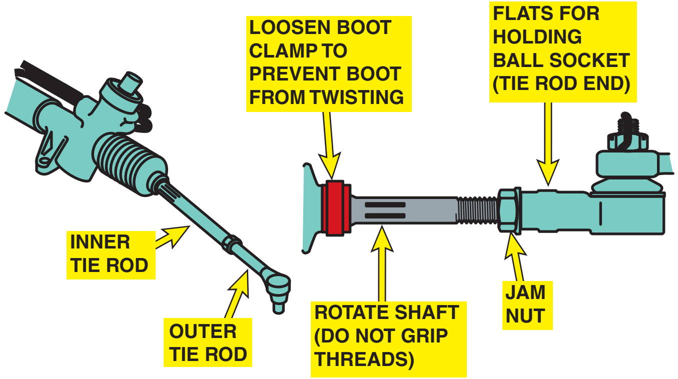

LOOSEN BOOT CLAMP TO PREVENT BOOT FROM TWISTING
FLATS FOR HOLDING BALL SOCKET (TIE ROD END)
INNER TIE ROD
OUTER TIE ROD
ROTATE SHAFT (DO NOT GRIP THREADS)
JAM NUT

FIGURE 120–34 Adjusting toe by rotating the tie rod on a vehicle equipped with rack-and-pinion steering.

TECH TIP

Autocross Vehicle Alignment

Vehicles used in autocrossing (individual timed runs through cones in a parking lot) or road racing usually perform best if the following alignment steps are followed:

1. **Increase caster (+).** Not only will the caster provide a good solid feel for the driver during high speed on a straight section of the course, but it will also provide some lean into the corners due to the camber change during cornering. A setting of 5 to 9 degrees positive caster is typical depending on the type of vehicle and the type of course.
2. **Adjust for 1 to 2 degrees of negative camber.** As a race vehicle corners, the body and chassis lean. As the chassis leans, the top of the tire also leans outward. By setting the camber to 1 to 2 degrees negative, the tires will be neutral while cornering, thereby having as much rubber contacting the road as possible.

NOTE: Though setting negative camber on a street-driven vehicle will decrease tire life, the negative setting on a race vehicle is used to increase cornering speeds, and tire life is not a primary consideration.

3. **Set toe to a slight toe-out position.** When the front toe is set negative (toe-out), the vehicle is more responsive to steering commands from the driver. With a slight toe-out setting, one wheel is already pointed in the direction of a corner or curve. Set the toe-out to −3/8 to −1/2 degree depending on the type of vehicle and the type of race course.

TOLERANCE ADJUSTMENT PROCEDURE

Many vehicles are designed and built without a method to change caster or camber, or both. (All vehicles have an adjustment for toe.) Before trying an aftermarket alignment correction kit, many technicians first attempt to correct the problem by moving the suspension attachment points within the build tolerance. All vehicles are constructed with a slight amount of leeway or tolerance; slight corrections can be made because bolt holes are almost always slightly larger than the bolt diameter, allowing for slight movement. When several fasteners are involved, such as where the powertrain cradle (subframe) attaches to the body of the front-wheel-drive vehicle, a measurable amount of alignment change (often over 1/2 degree) can be accomplished without special tools or alignment kits. The steps for **tolerance adjustment** include the following:

STEP 1 Determine which way the suspension members have to be moved to accomplish the desired alignment—for example, the right front may require more positive camber to correct a pulling or tire wear problem.

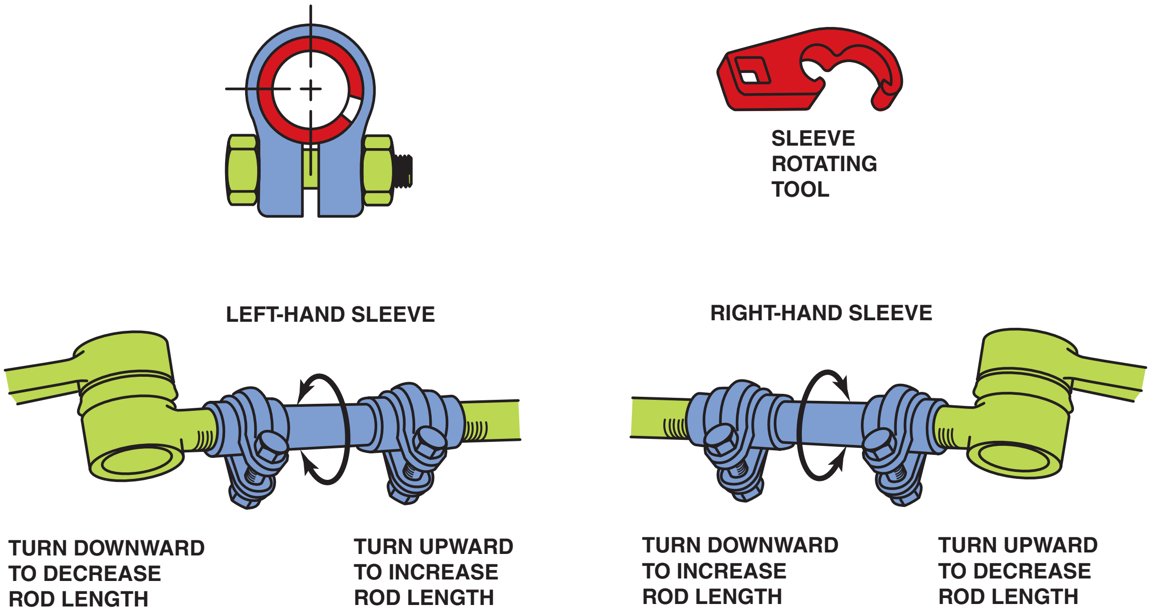


FIGURE 120–35 Toe is adjusted on a parallelogram-type steering linkage by turning adjustable tie rod sleeves. Special tie rod sleeve adjusting tools should be used that grip the slot in the sleeve and will not crush the sleeve while it is being rotated.

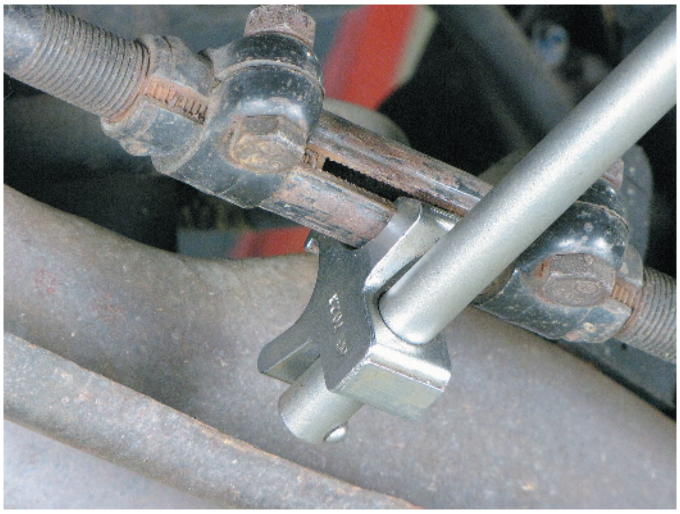


FIGURE 120–36 Special tie rod adjusting tools should be used to rotate the tie rod adjusting sleeves. The tool grips the slot in the sleeve and allows the service technician to rotate the sleeve without squeezing or damaging the sleeve.

STEP 2 Locate and loosen the cradle (subframe) bolts about four turns each. **Do Not Remove Any of the Bolts**.

STEP 3 Using prybars, move the cradle in the direction that will result in an improvement of the alignment angles. Have an assistant tighten the bolts as pressure is maintained on the cradle.

STEP 4 Measure the alignment angles and repeat the procedure if necessary.

AFTERMARKET ALIGNMENT METHODS Accurate alignments are still possible on vehicles without factory methods of adjustment by using alignment kits or parts. Aftermarket alignment kits are available for most vehicles. Even when there are factory alignment methods, sometimes the range of adjustment is not enough to compensate for sagging frame members or other normal or accident-related faults. ● **SEE FIGURES 120–38 AND 120–39**.

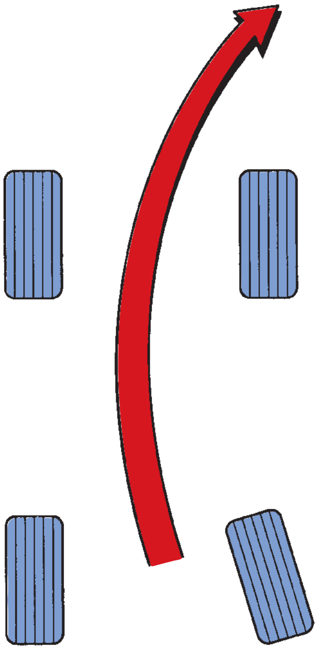


FIGURE 120–37 The toe-in on the right wheel creates a turning force toward the right.

ALIGNING ELECTRONIC-SUSPENSION VEHICLES When aligning a vehicle equipped with an electronic suspension, several additional steps may be required. Always check service information and read carefully all on-screen instructions on the alignment machine. Some examples of the steps that may be needed include

- Verify the exact type of electronic suspension. This step could include checking the regular production order (RPO) code.
- Check that the ride height (suspension height) is within factory specifications.
- The steering wheel angle, as well as the radar cruise control sensor, will often need to be recalibrated using a scan tool. This is needed because the steering wheel may be in

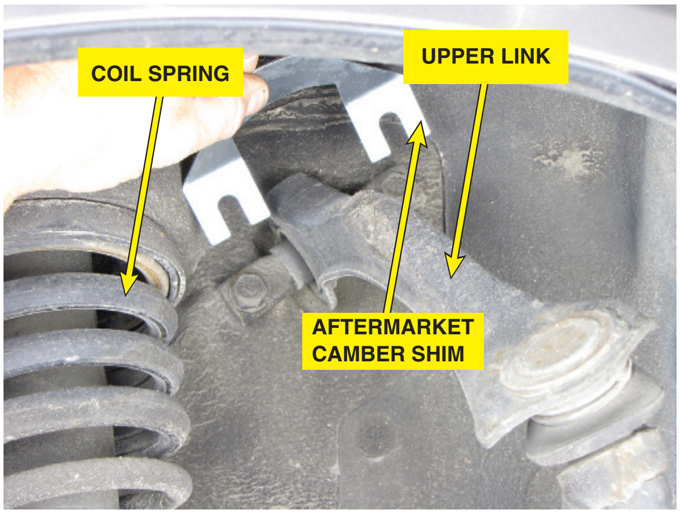


FIGURE 120–38 An aftermarket camber shim can be added to change the front camber on this Honda.

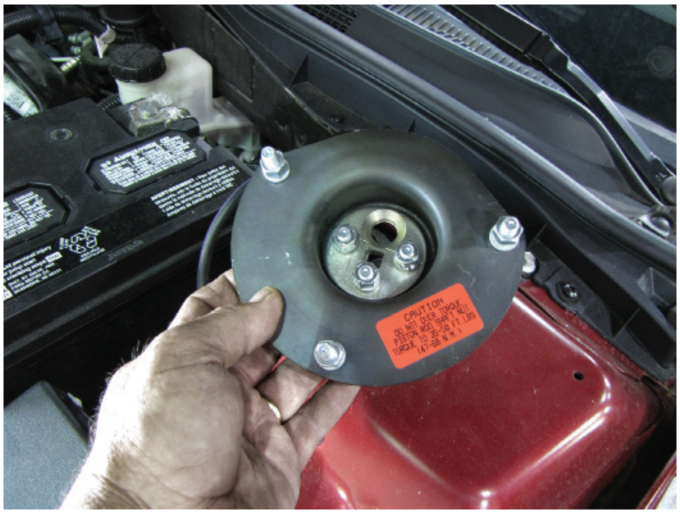


FIGURE 120–39 An aftermarket kit for this Ford is installed at the top of the strut tower and allows more camber and caster adjustment than is possible with the factory adjustment.

CASE STUDY

Left Thrust Line, but a Pull to the Right!

A new four-door sport sedan had been aligned several times at the dealership in an attempt to solve a pull to the right. The car had front-wheel-drive and four-wheel independent suspension. The dealer rotated the tires, and it made no difference. The alignment angles of all four wheels were in the center of specifications. The dealer even switched all four tires from another car in an attempt to solve the problem.

In frustration, the owner took the car to an alignment shop. Almost immediately the alignment technician discovered that the right rear wheel was slightly toed-in. This caused a pull to the right. ● **SEE FIGURE 120–39**.

The alignment technician adjusted the toe on the right rear wheel and reset the front toe. The car drove beautifully.

The owner was puzzled about why the new car dealer was unable to correct the problem. It was later discovered that the alignment machine at the dealership was out of calibration by the exact amount that the right rear wheel was out of specification. The car pulled to the right because the independent suspension created a rear steering force toward the left that caused the front to pull to the right. Alignment equipment manufacturers recommend that alignment equipment be calibrated regularly.

Summary:

Complaint—Owner complained that the vehicle pulled to the right after an alignment.
Cause—The rear toe on the right was toed in and out of specification.
Correction—The technician adjusted the rear toe on the right rear to factory specifications.

a different position after the alignment, and the steering wheel position sensor needs to be reset because the rear toe setting was changed. The rear thrust line could also have been changed. The radar cruise control needs to be calibrated to the revised rear thrust angle using a scan tool.

RESET STEERING ANGLE SENSOR (SAS)

PURPOSE The **steering angle sensor (SAS)** is usually located at the base of the steering column inside the vehicle and monitors the driver's steering input from straight ahead. It also monitors how fast the driver is turning the wheel and reports this information to body control module (BCM) in most applications. The steering angle sensor is an input to the following systems:

- Electronic stability control (ESC) system
- Electronic power steering (EPS)
- Variable-rate steering (VRS) system
- Antilock brake system (ABS)
- Lane departure warning (LDW) system
- Parking assist (PA) system

ANALOG STEERING ANGLE SENSOR An analog steering angle sensor is similar to a throttle position sensor with a three-wire connector:

- 5 volt reference
- chassis ground
- signal output

As the steering wheel is turned, the SAS produces a signal that varies between 0 and 5 volts as the wheel is turned 360 degrees. Most vehicles produce a positive voltage turning right and a negative voltage turning left. ● **SEE FIGURE 120–40**.

DIGITAL STEERING ANGLE SENSOR A digital SAS often uses LED light and a notched wheel that acts as a shutter with an optic

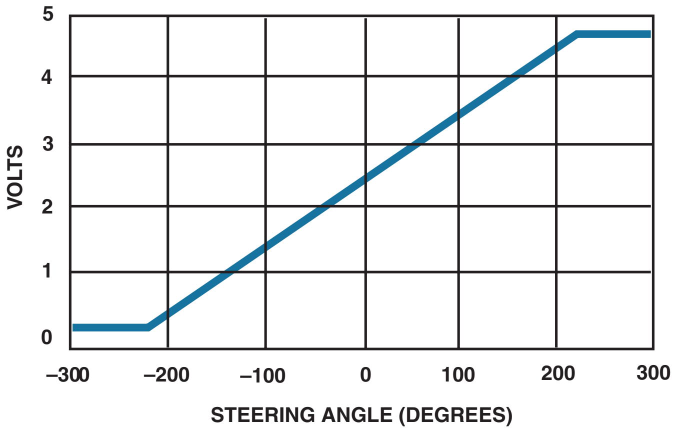


FIGURE 120–40 A typical analog-type steering angle sensor that uses a variable voltage as the steering wheel is rotated.

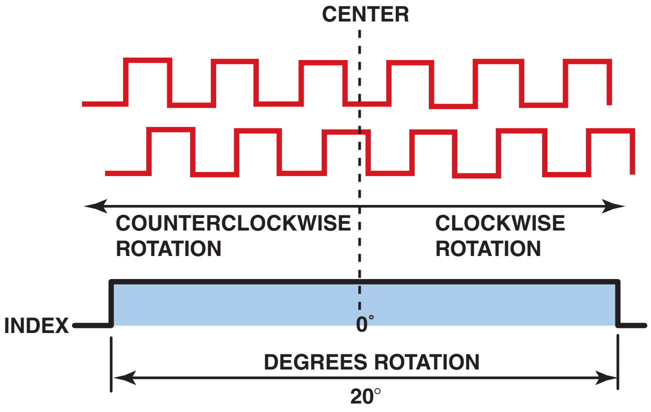


FIGURE 120–41 The output of a typical digital steering angle sensor.

sensor that measures the on and off segments of the light. These sensors produce a digital square wave signal with the frequency or pattern depending on the speed and direction the wheel is turning. ● **SEE FIGURE 120–41**.

RESETTING STEERING ANGLE SENSORS Many vehicles require the SAS be reset or recalibrated after an alignment is performed or parts in the steering system are replaced. There are two basic types of reset procedures including

1. **Self-calibration**—Some newer vehicles can self-calibrate by having the wheel turned from lock to lock and then centered and cycling the key or when they are driven straight on a level road for a certain amount of time.
2. **Scan tool calibration**—Many systems require recalibration using a scan tool or a special tester that plugs into the data link connector (DLC).

Check service information for the exact procedure to follow for the vehicle being aligned and serviced.

The following chart lists common alignment problems and their probable causes.

Symptom-Based Alignment Guide

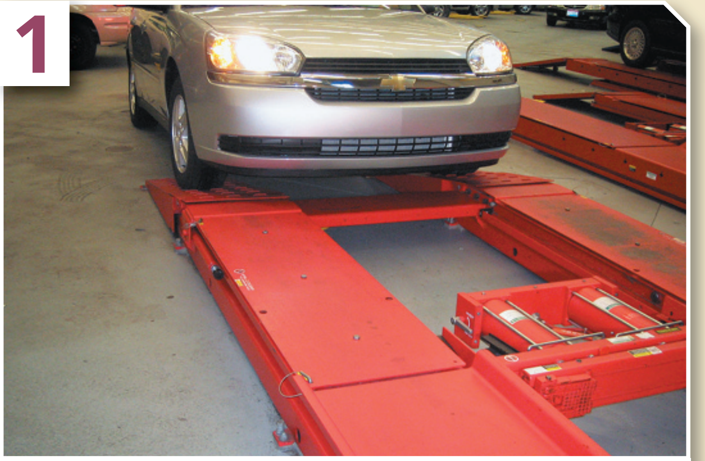
Problem	Probable Causes
Pull left/right	Uneven tire pressure, tire conicity, mismatched tires, unequal camber, unequal caster, brake drag, setback, suspension/frame sag, unbalanced power assist, bent spindle, bent strut, worn suspension components (front or rear), rear suspension misalignment.
Incorrect steering wheel position	Incorrect individual or total toe, rear wheel misalignment, excessive suspension or steering component play, worn rack-and-pinion attachment bushings, individual toe adjusters not provided.
Hard steering	Improper tire pressure, binding steering gear or steering linkage, low P/S fluid, excessive positive caster, lack of lubrication, upper strut mount(s), worn power steering pump, worn P/S belt.
Loose steering	Loose wheel bearings, worn steering or suspension components, loose steering gear mount, excessive steering gear play, loose or worn steering coupler.
Excessive road shock	Excessive positive caster, excessive negative camber, improper tire inflation, too wide wheel/tire combination for the vehicle, worn or loose shocks, worn springs.
Poor returnability	Incorrect camber or caster, bent spindle or strut, binding suspension or steering components, improper tire inflation.
Wander/instability	Incorrect alignment, defective or improperly inflated tires, worn steering or suspension parts, bent spindle or strut, worn or loose steering gear, loose wheel bearings.
Squeal/scuff on turns	Defective or improperly inflated tires, incorrect turning angle (TOOT), bent steering arms, excessive wheel setback, poor driving habits (too fast for conditions), worn suspension or steering parts.
Excessive body sway	Loose or broken stabilizer bar links or bushings, worn shocks or mountings, broken or sagging springs, uneven vehicle load, uneven or improper tire pressure.
Memory steer	Binding steering linkage, binding steering gear, binding upper strut mount, ball joint, or kingpin.
Bump steer	Misalignment of steering linkage, bent steering arm or frame, defective or sagged springs, uneven load, bent spindle or strut.
Torque steer	Bent spindle or strut, bent steering arm, misaligned frame, worn torque strut, defective engine or transaxle mounts, drive axle misalignment, mismatched or unequally inflated tires.

ALIGNMENT GUIDE

ALIGNMENT

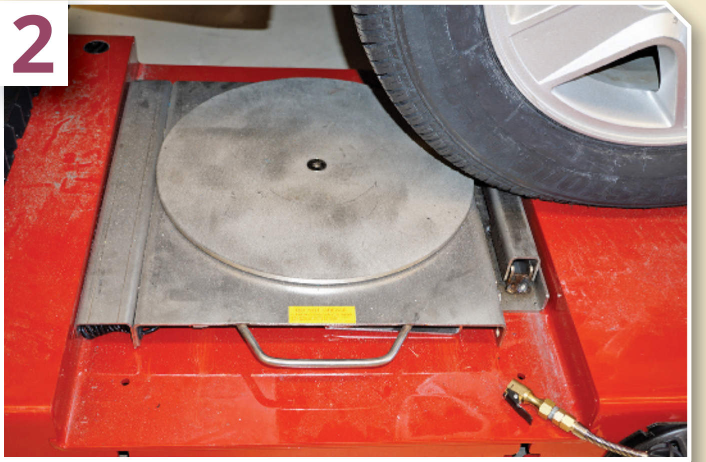
STEP BY STEP

1



Begin the alignment procedure by first driving the vehicle onto the alignment rack as straight as possible.

2

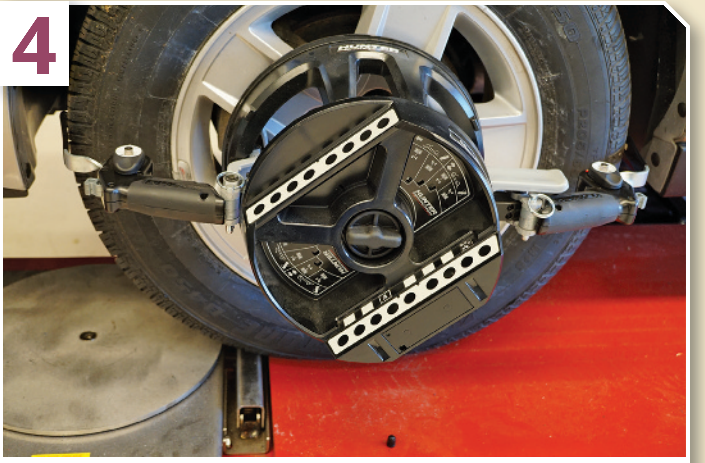


Stop just short of the turn plate and position the plate to center it on the tire tread.

3

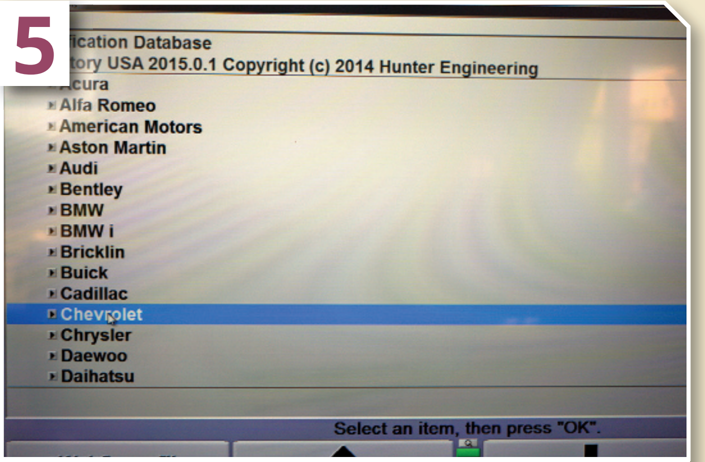
Check and adjust tire pressures and perform the prealignment checks necessary to be assured of proper alignment.

4



Securely mount the targets or alignment heads.

5



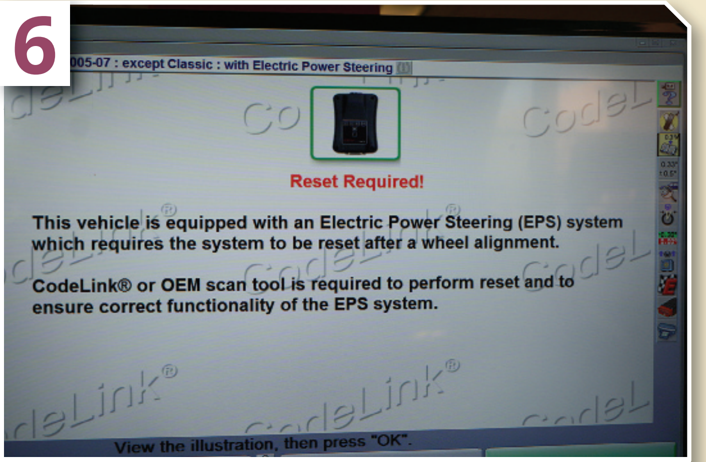
ication Database
tory USA 2015.0.1 Copyright (c) 2014 Hunter Engineering

- cura
- Alfa Romeo
- American Motors
- Aston Martin
- Audi
- Bentley
- BMW
- BMW i
- Bricklin
- Buick
- Cadillac
- Chevrolet
- Chrysler
- Daewoo
- Daihatsu

Select an item, then press "OK".

Select the exact vehicle on the aligner. The aligner may have a bar code reader to enter the vehicle VIN.

6



005-07 : except Classic : with Electric Power Steering

Reset Required!

This vehicle is equipped with an Electric Power Steering (EPS) system which requires the system to be reset after a wheel alignment.

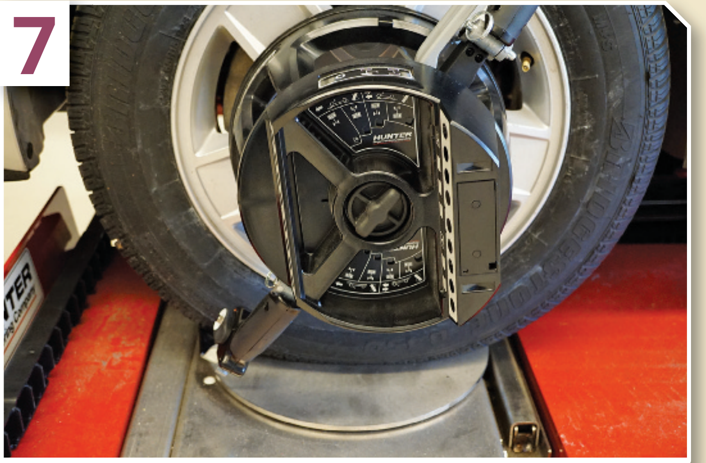
CodeLink® or OEM scan tool is required to perform reset and to ensure correct functionality of the EPS system.

View the illustration, then press "OK".

On this vehicle, a message is displayed concerning the electric power steering.

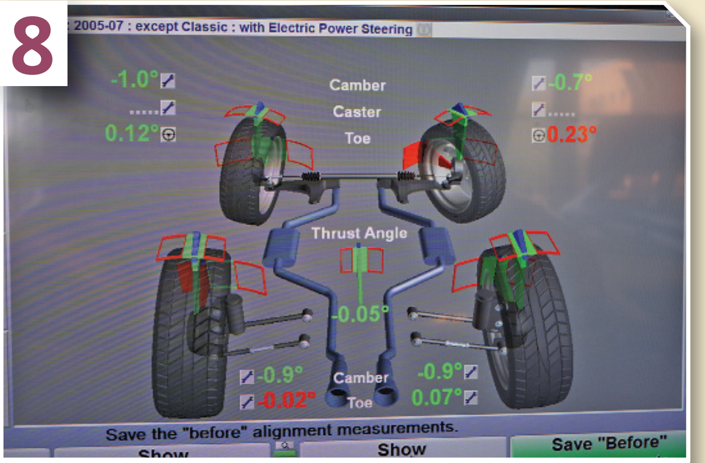
ALIGNMENT

7



This aligner uses a roll-forward compensation method.

8


2005-07 : except Classic : with Electric Power Steering

Save the "before" alignment measurements.

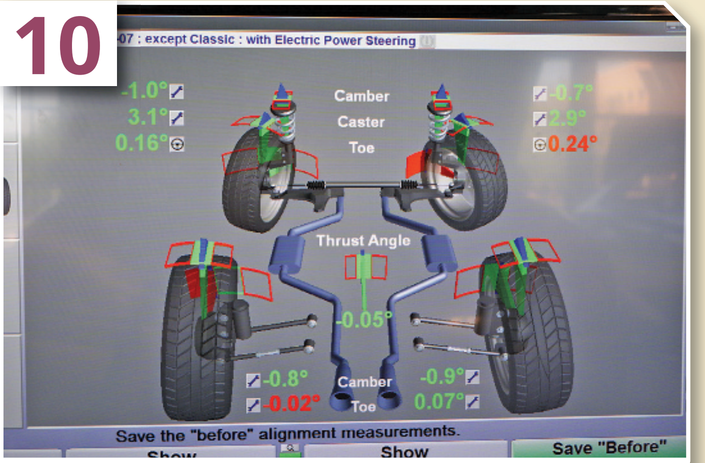
-1.0°
.....
0.12°
Camber
Caster
Toe
-0.7°
.....
0.23°
Thrust Angle
-0.05°
-0.9°
-0.02°
Camber
Toe
-0.9°
0.07°
Show
Show
Save "Before"

An alignment reading is displayed even though caster has not yet been measured. The readings marked in red indicate that they are not within specifications.

9

Before performing a caster sweep, install a brake pedal depressor to keep the front wheels from rotating when the steering wheel is turned.

10

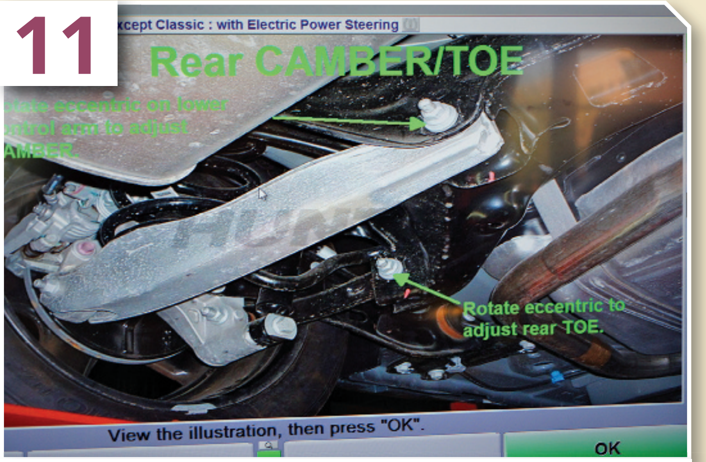

07 : except Classic : with Electric Power Steering

Save the "before" alignment measurements.

-1.0°
3.1°
0.16°
Camber
Caster
Toe
-0.7°
2.9°
0.24°
Thrust Angle
-0.05°
-0.8°
-0.02°
Camber
Toe
-0.9°
0.07°
Show
Show
Save "Before"

Perform the caster sweep by turning the front wheels inward, and then outward following the instructions on the screen.

11

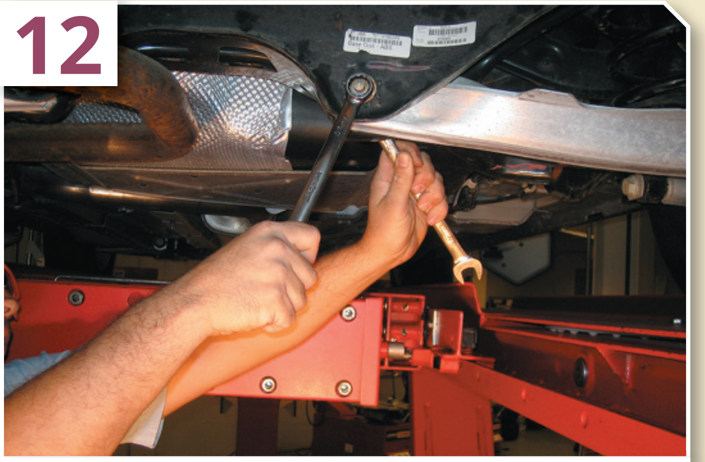

cept Classic : with Electric Power Steering

View the illustration, then press "OK".

Rear CAMBER/TOE
ate eccentric on lower
ntrol arm to adjust
AMBER
Rotate eccentric to adjust rear TOE.
OK

Most alignment machines will display where to make the alignment correction and will often include drawings and live action videos that show the procedure.

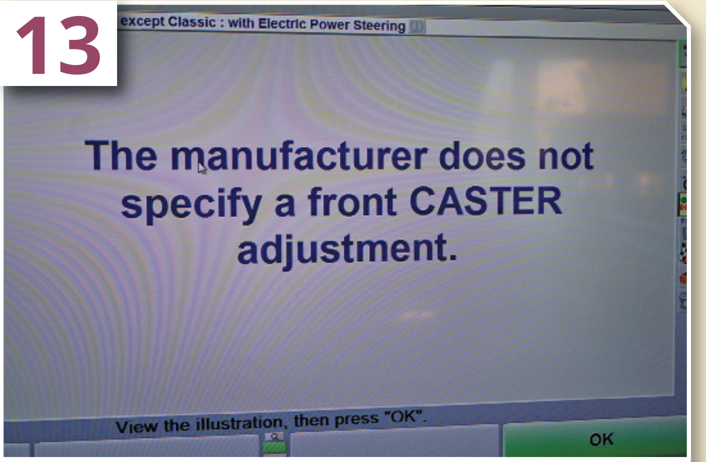
12



The rear toe is being adjusted by rotating the eccentric cam on the lower control arm while watching the display.

STEP BY STEP

13

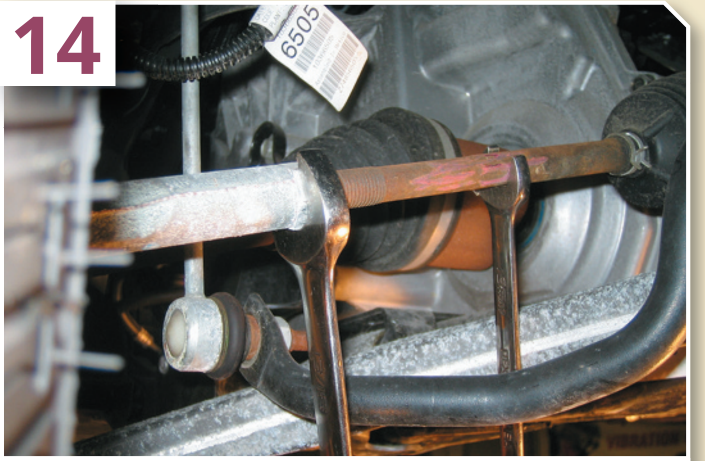

except Classic : with Electric Power Steering
OK

The manufacturer does not specify a front CASTER adjustment.

View the illustration, then press "OK".

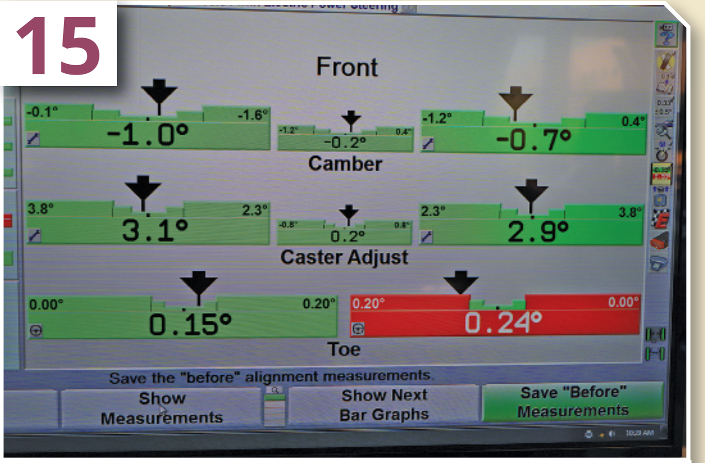
The alignment machine display indicates that front caster is not a factory-adjustable angle.

14



Adjusting the front toe on this vehicle involves loosening the jam nut (left wrench) and rotating the tie rod using the right wrench.

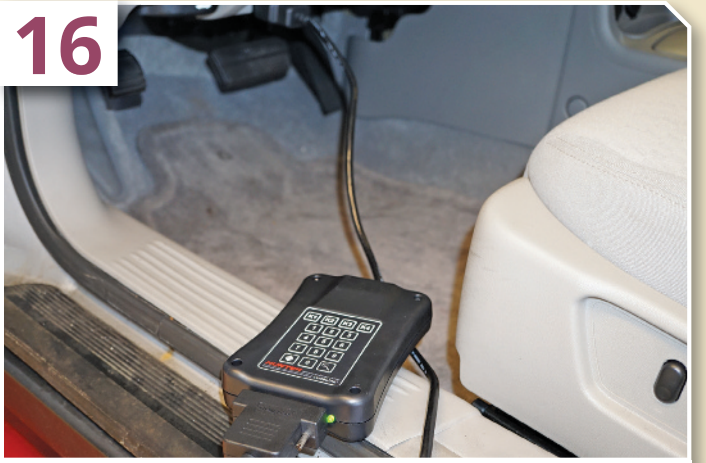
15


Front
-0.1°
-1.6°
-1.0°
-1.2°
0.4°
-0.2°
-1.2°
0.4°
-0.7°
Camber
3.8°
2.3°
3.1°
-0.8°
0.8°
0.2°
2.3°
3.8°
2.9°
Caster Adjust
0.00°
0.20°
0.15°
0.20°
0.00°
0.24°
Toe
Show Measurements
Show Next Bar Graphs
Save "Before" Measurements

Save the "before" alignment measurements.

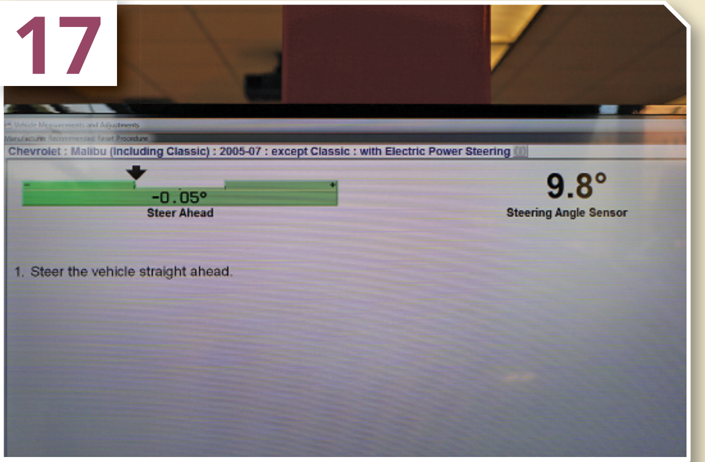
An adjustment of the right front toe is needed to achieve a perfect alignment.

16



A final step is needed for vehicles equipped with a steering angle sensor and/or electric power steering. The wireless reset tool is attached to the data connector.

17

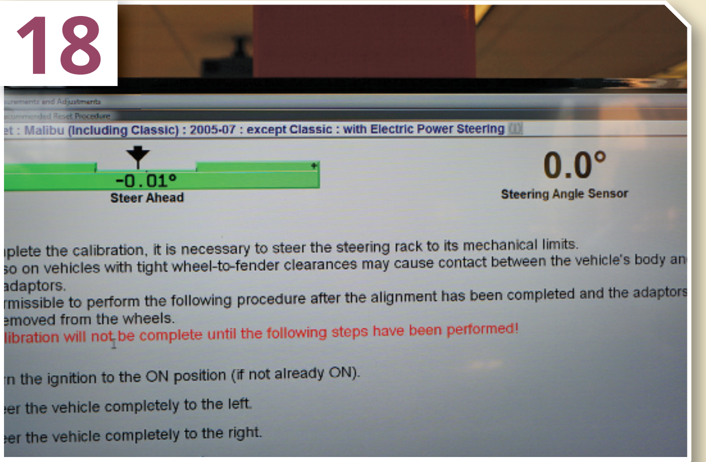

Vehicle Measurements and Adjustments
Manufacturer Recommended Reset Procedure
-0.05°
Steer Ahead
9.8°
Steering Angle Sensor

Chevrolet : Malibu (Including Classic) : 2005-07 : except Classic : with Electric Power Steering

1. Steer the vehicle straight ahead.

With the wheel straight ahead the sensor shows an incorrect reading.

18


-0.01°
Steer Ahead
0.0°
Steering Angle Sensor

et : Malibu (Including Classic) : 2005-07 : except Classic : with Electric Power Steering

plete the calibration, it is necessary to steer the steering rack to its mechanical limits.
so on vehicles with tight wheel-to-fender clearances may cause contact between the vehicle's body an
adaptors.
rmissible to perform the following procedure after the alignment has been completed and the adaptors
emoved from the wheels.
libration will not be complete until the following steps have been performed!

n the ignition to the ON position (if not already ON).

er the vehicle completely to the left.

er the vehicle completely to the right.

Follow the instructions on the screen to reset the electric power steering (EPS) sensors. The final alignment readings can be printed and attached to the work order.

REVIEW QUESTIONS

1. What are the 10 prealignment checks that should be performed before the wheel alignment is checked and/or adjusted?
2. What is the difference between a lead (drift) and a pull?
3. What are the causes and possible corrections for torque steer?
4. What are the causes and possible corrections for memory steer?
5. What are the necessary steps to follow for a four-wheel alignment?

CHAPTER QUIZ

1. Which of the following would NOT be included in a pre-alignment check?
   - **a.** Ride height
   - **b.** Tire size and inflation
   - **c.** Number of turns of the steering wheel lock to lock
   - **d.** Excessive load in trunk
2. Technician A says that if a pull occurs sometime to the left and sometimes to the right, this is called memory steer. Technician B says that if a vehicle pulls to one side only during acceleration then this is called torque steer. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Which angle is largest?
   - **a.** 0.55 degree
   - **b.** 45 minutes
   - **c.** 1/4 degree
   - **d.** 1/2 degree

Use the following information to answer question 4.

Specifications	**Min.**	**Preferred**	**Max.**
Camber (degree)	0	1.0	1.4
Caster (degree)	.8	1.5	2.1
Toe (inch)	−.10	.06	.15
Results	**L**	**R**	
Camber (degree)	−.1	.6	
Caster (degree)	1.8	1.6	
Toe (inch)	1.12	+.12	

4. The vehicle above will ___________.
   - **a.** pull toward the right and feather-edge both tires
   - **b.** pull toward the left
   - **c.** wear the outside of the left tire and the inside of the right tire
   - **d.** None of the above
5. After the vehicle is set up on the alignment rack, perform a(n) ___________ to check front caster.
   - **a.** angle measurement
   - **b.** runout check
   - **c.** caster sweep
   - **d.** height adjustment
6. A four-wheel alignment allows the ___________ to be adjusted to zero.
   - **a.** centerline
   - **b.** thrust line
   - **c.** rear toe
   - **d.** front toe
7. Technician A says that the front toe determines the thrust angle. Technician B says that a tolerance adjustment involves removing and reinstalling subframe bolts. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Which alignment procedure may be done using self-calibration?
   - **a.** Toe
   - **b.** Camber
   - **c.** Caster
   - **d.** Steering angle sensor (SAS)
9. Technician A says that the rear toe is the first angle to be adjusted in a four-wheel alignment. Technician B says that rear camber is the first angle to be adjusted in a four-wheel alignment. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. Hidden damage may be discovered by measuring ___________.
    - **a.** SAI
    - **b.** corner weight
    - **c.** with a carpenter's level
    - **d.** toe-in

SECTION XIII

MANUAL DRIVETRAINS (A3)

CHAPTERS

121 Clutch Components, Operation, and Replacement
122 Manual Transmissions/Transaxles
123 Driveshafts and Half Shafts
124 Driveshaft and Half Shafts Service
125 Drive Axles and Differentials
126 Four-Wheel Drive and All-Wheel Drive
127 Vibration and Noise Diagnosis and Correction

Chapter 121

CLUTCH COMPONENTS, OPERATION, AND REPLACEMENT

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose and function of a clutch.
- Discuss clutch discs.
- Discuss pressure plates.
- Discuss flywheels.
- Discuss dual-mass flywheels.
- Discuss pilot bearings.
- Describe clutch pedal linkages including hydraulic clutch systems.
- Discuss release (throwout) bearings.
- Discuss clutch pedal switches.
- Explain the diagnosis of common clutch problems, recommend the proper repair procedures, and explain how to remove and replace a clutch assembly.

KEY TERMS:

Actuator cylinder 1521 • Clutch disc 1513 • Clutch fork 1520 • Clutch pedal position switch 1522 • Clutch slippage 1523 • Clutch spin-down 1523 • Coil spring clutch 1517 • Cushion spring 1516 • Disc alignment 1527 • Disc runout 1526 • Dowel 1524 • Drag 1523 • Front bearing retainer 1514 • Gravity bleeding 1527 • Gear clash 1524 • Lever style (pressure plate) 1517 • Marcel spring 1516 • Master cylinder 1521 • Pilot bearing/bushing 1514 • Pressure plate 1513 • Quill 1514 • release bearings 1527 • Release (throwout) bearing 1513 • Safety switch 1522 • Torsional dampers 1516

CLUTCH ASSEMBLY

PURPOSE AND FUNCTION The clutch assembly is located between the engine and the transmission/transaxle. The purpose and function of a clutch include the following:

- To disconnect engine power from the transmission/transaxle to permit the engine to remain running when the vehicle is stopped with the transmission in gear and to permit the transmission/transaxle to be shifted
- To connect and transmit engine torque to the transmission/transaxle
- To dampen and absorb engine power impulses and drive train vibration
- To provide a smooth engagement and disengagement of torque between the engine and the transmission/transaxle

PARTS INVOLVED A clutch assembly consists of a **clutch disc** that is splined to the input shaft of the transmission/transaxle. When the driver depresses the clutch pedal, a **release bearing**, also called a **throwout bearing**, is forced against the diaphragm spring, part of the clutch cover assembly. This lifts the **pressure plate** releasing the clutch disc. The clutch cover assembly is bolted to and rotates with the flywheel. ● **SEE FIGURE 121–1.**

CLUTCH OPERATION The flywheel and pressure plate assembly are drive members because they are connected to the engine crankshaft and rotate anytime the engine is running. The clutch disc is a driven member and only rotates when the clutch pedal is released, which forces the disc to rotate with the flywheel and pressure plate assembly. Basic operation includes the following:

- When force is exerted on the center of the diaphragm spring by the release bearing, the apply force is released

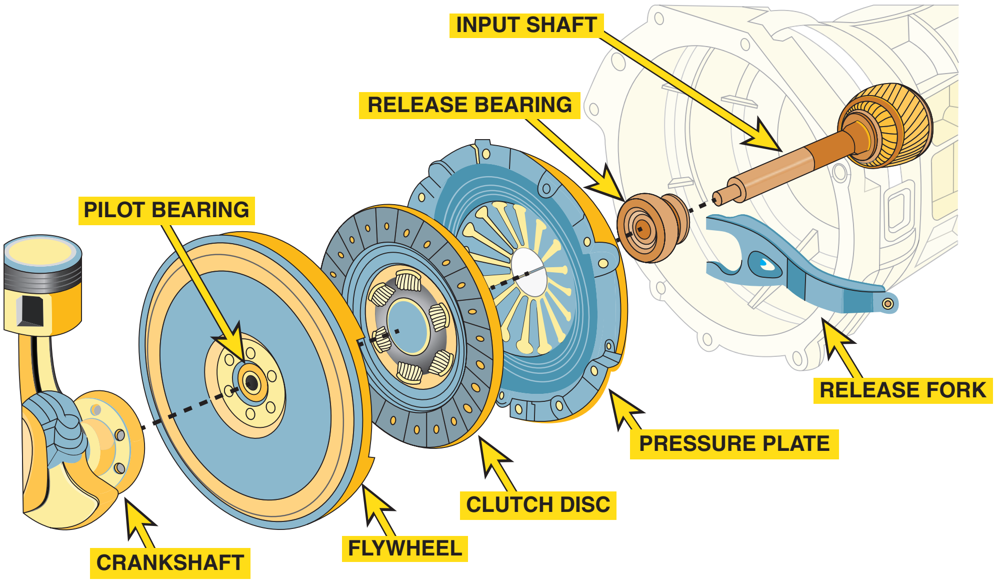


FIGURE 121–1 Typical automotive clutch assembly showing all related parts.

from the clutch disc that had been squeezed between the engine flywheel and the pressure plate.

- With the pressure removed from the clutch disc, the engine can be operated without transferring torque to the transmission/transaxle. Using a clutch also permits the transmission/transaxle to be shifted easily because a shift cannot be made easily if the transmission/transaxle is transferring engine torque.
- When the driver releases force on the clutch pedal, the pedal return spring and the diaphragm spring combine to return the clutch pedal to its at-rest position (clutch-engaged position).
- When the clutch pedal moves up, the pressure on the release bearing is released and the force against the pressure plate diaphragm spring is released, allowing the spring force of the pressure plate to clamp the clutch disc tightly between the flywheel and the pressure plate. ● **SEE FIGURE 121–2.**

Additional related parts include the **pilot bearing** (or **bushing**) that supports the front of the transmission input shaft. ● **SEE FIGURE 121–3.**

The release bearing is often supported and rides on the **front bearing retainer** (release bearing support shaft), also called a **quill**, or candlestick.

To summarize:

- When the clutch pedal is up, the clutch is engaged. (The pressure plate is pressing the clutch disc against the flywheel and rotating together.)
- When the clutch pedal is down (depressed), the clutch is disengaged. (The clutch disc is free and not rotating with the pressure plate.)

CLUTCH DISCS

PURPOSE AND FUNCTION

The clutch disc is splined to the input/clutch shaft of the transmission/transaxle. The purpose of the clutch disc is to transfer engine torque from the flywheel to the input shaft of the transmission/transaxle. The clutch disc is located between the flywheel and the pressure plate where it is clamped between the two when the clutch is engaged. The pressure plate spring exerts spring pressure against the pressure plate, which forces the disc against the flywheel.

COEFFICIENT OF FRICTION

The coefficient of friction, abbreviated with the Greek letter mu (μ), is the relative amount of friction between two surfaces. There must be friction between the members of the clutch friction surfaces for the clutch to function correctly:

- If the coefficient of friction of the clutch is too low, it might slip and not transmit the required torque.
- If the friction coefficient is too high, the clutch would become more aggressive and “grabby,” and engagement would be harsh and severe.

Each vehicle manufacture specifies the coefficient of friction for each vehicle. If a different clutch friction disc is installed or the lining becomes contaminated, then the coefficient can change and result in slippage or harsh clutch engagement. ● **SEE FIGURE 121–4.**

CLUTCH FRICTION MATERIAL

The clutch friction material must be able to withstand the heat generated by the friction during engagement and disengagement. Older clutch friction discs used a mixture of either molded or woven asbestos with various filler and binder materials. Asbestos is nearly an ideal friction material for brake lining and clutch facing because it has a very good coefficient of friction, excellent heat characteristics, and low cost. However, the possibility of technicians getting cancer from inhaling asbestos fibers has greatly reduced its use. Asbestos was replaced with fiberglass, aramid nonmetallic compounds, and/or metallic materials to obtain the desired friction and wear characteristics. Some of the materials used include

- powdered iron
- copper
- graphite
- ceramics

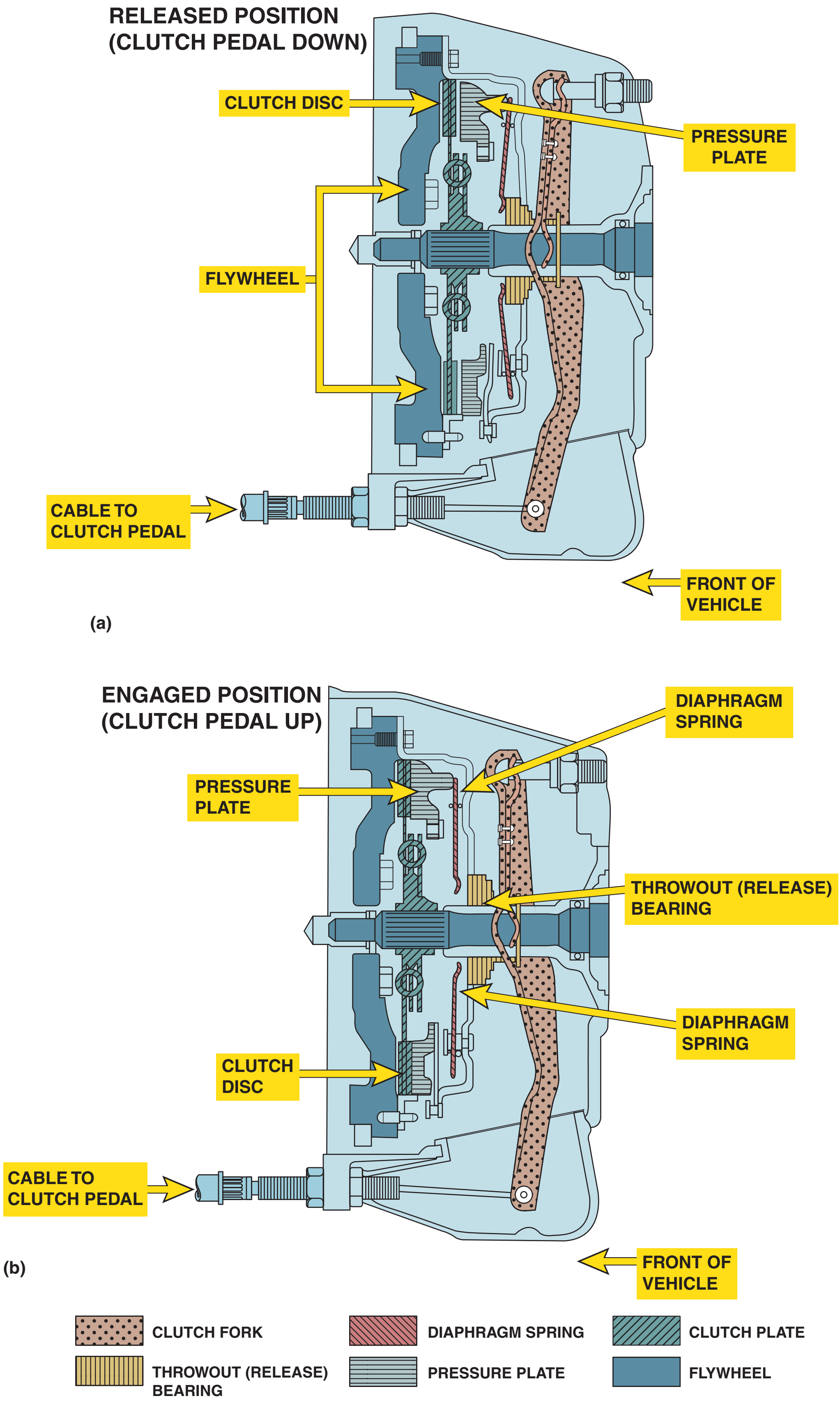

RELEASED POSITION (CLUTCH PEDAL DOWN)
CLUTCH DISC
PRESSURE PLATE
FLYWHEEL
CABLE TO CLUTCH PEDAL
FRONT OF VEHICLE
(a)
ENGAGED POSITION (CLUTCH PEDAL UP)
DIAPHRAGM SPRING
PRESSURE PLATE
THROWOUT (RELEASE) BEARING
DIAPHRAGM SPRING
CLUTCH DISC
CABLE TO CLUTCH PEDAL
FRONT OF VEHICLE
(b)
CLUTCH FORK
DIAPHRAGM SPRING
CLUTCH PLATE
THROWOUT (RELEASE) BEARING
PRESSURE PLATE
FLYWHEEL

FIGURE 121–2 (a) When the clutch is in the released position (clutch pedal depressed), the clutch fork is applying a force to the throwout (release) bearing, which pushes on the diaphragm spring, releasing the pressure on the friction disc. (b) When the clutch is in the engaged position (clutch pedal up), the diaphragm spring exerts force on the clutch disc, holding it between the flywheel and the pressure plate.

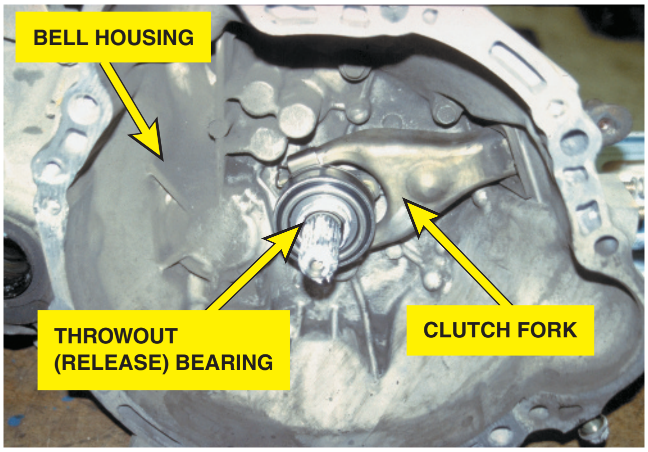


FIGURE 121–3 The transmission has just been removed. Note that this type of transmission incorporates the bell housing, which was therefore removed at the same time as the transmission. The clutch fork and throwout (release) bearing also came off together. All that remained attached to the engine was the flywheel, clutch disc, and pressure plate.

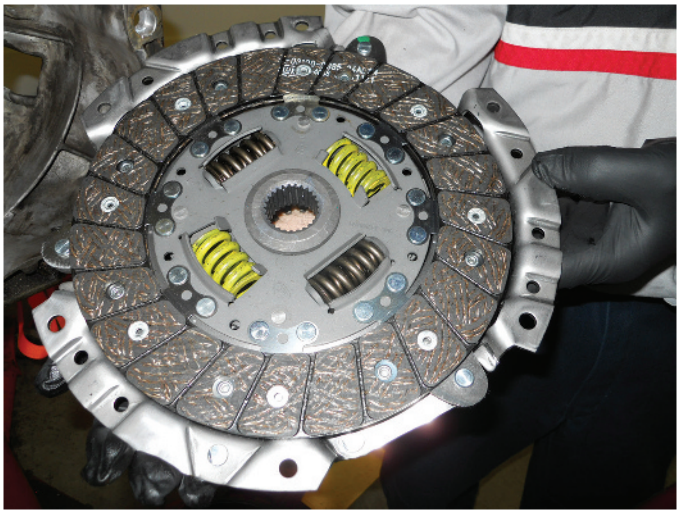


FIGURE 121–4 A replacement clutch is designed to meet the same friction specifications of the original so the new clutch will operate like new.

SURFACE GROOVES

Most nonmetallic facings have a series of radial grooves cut across their surface. The purpose and function of the grooves include

- Wipe dust and dirt from the surfaces of the flywheel and pressure plate.
- Allow airflow to help cool the friction surfaces.
- Prevent a vacuum that might cause the friction surfaces to stick together during disengagement. Sticking during disengagement will cause clutch drag.
- Some metallic discs have a series of radial slots cut across the facing, which allows the disc to expand without warping when it gets hot.

MARCEL SPRING

In the space between the friction surfaces is a wavy spring steel material called a **cushion spring** or **marcel spring**. ● **SEE FIGURE 121–5.**

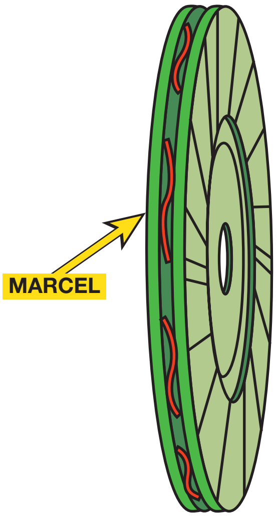


FIGURE 121–5 A marcel is a wavy spring that is placed between the two friction surfaces to cushion the clutch engagement.

The marcel spring helps to absorb the initial shock of rapid engagement and allows for a smooth engagement of the clutch.

RIVETS

The facing of the clutch disc is attached to the steel marcel spring by a series of brass rivets that are installed in counter bored holes or by bonding, which involves attaching the lining to the steel marcel spring by using adhesives (gluing). Some metallic facings are formed directly onto a steel backing. If there is less than 0.015 in. (0.38 mm) of facing above the rivets or backing, a disc is considered worn out.

HUB AND DAMPENER ASSEMBLY

The clutch hub has internal splines (from 10 to 26 teeth) that slide on the external splines of the transmission input/clutch shaft. Each time the clutch is engaged, the disc must slide forward slightly to contact the flywheel, and it must slide back to prevent drag on the flywheel when the clutch is disengaged. ● **SEE FIGURE 121–6.**

Around the center hub of the clutch disc are **torsional dampers** that are coil springs or rubber plugs that help dampen engine firing pulses from being transmitted into and through the transmission/transaxle.

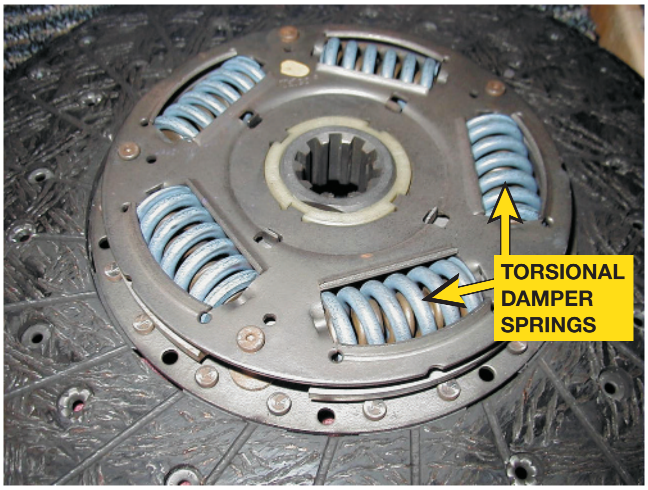


FIGURE 121–6 A typical stock clutch friction disc that uses coil spring torsional dampers.

An engine produces uneven power impulses that cause torsional vibration. The torsional damper reduces the torsional vibrations that result from the uneven engine power impulses from the rest of the drivetrain:

- As an engine goes through its power cycle, the crankshaft will speed up and slow down during each revolution.
- If these slight speed fluctuations are not removed by the damper, they could cause "gear rattle," vibration, noise, and increased wear.

The damper assembly is composed of the hub with four to eight openings, with one or more springs for each extension, a spring washer, and a friction washer. These parts are fitted between the web of the disc and a metal retainer and are held together by a series of rivets called *stop pins*, which also keep the hub from revolving too far, usually about 0.037 inch (9.5 mm). The damper springs are positioned by a series of windows in the web and retainer. The torque must pass through the damper springs on its way from the engine to the transmission, and any power impulses that tend to speed up the clutch hub will compress the springs. The springs will re-extend when there is a torque lag.

PRESSURE PLATES

PURPOSE AND FUNCTION

The purpose of the pressure plate assembly is to exert a force on the clutch disc so that engine torque can be transmitted from the engine to the transmission/transaxle. The required strong clamping force is provided by the pressure plate spring(s).

COMPONENT PARTS

The pressure plate assembly is a combination of

- Cover (also called a *hat*)
- Pressure springs, or diaphragm spring
- Release levers (also called *fingers*) on coil spring types
- Cast iron pressure ring (*driving plate*) that contacts the friction disc

A strong pressure plate spring force must be released by the force of the driver's foot to disengage the clutch. Most pressure plate covers are made of stamped steel with a nodular cast iron pressure ring, also called a driving plate. A smooth, machined area on one side forms the friction disc contact surface. When the clutch engages, spring force pushes the pressure plate toward the flywheel, so the friction disc is clamped between the flywheel and the pressure plate.

TYPES

Several styles of pressure plates have been used, including

- A coil spring style of pressure plate that uses coil springs and three or four release levers. A coil-spring-style pressure plate is also called the **lever style** because it uses levers to compress the coil springs. This type of pressure plate is often called a "three-finger" pressure plate. ● **SEE FIGURE 121–7**.
- A diaphragm spring style is the most used pressure plate design. It uses one large, round spring-steel spring to apply even force on the clutch disc called a *Belleville spring*. The relatively low height of the diaphragm design is highly favored for transverse engine vehicles where engine and transaxle lengths are critical. ● **SEE FIGURE 121–8.**

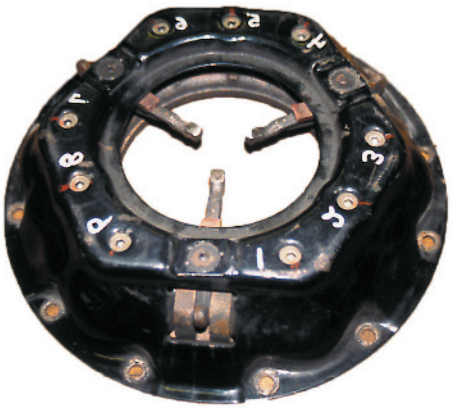


FIGURE 121–7 A coil spring (lever style) clutch pressure plate.

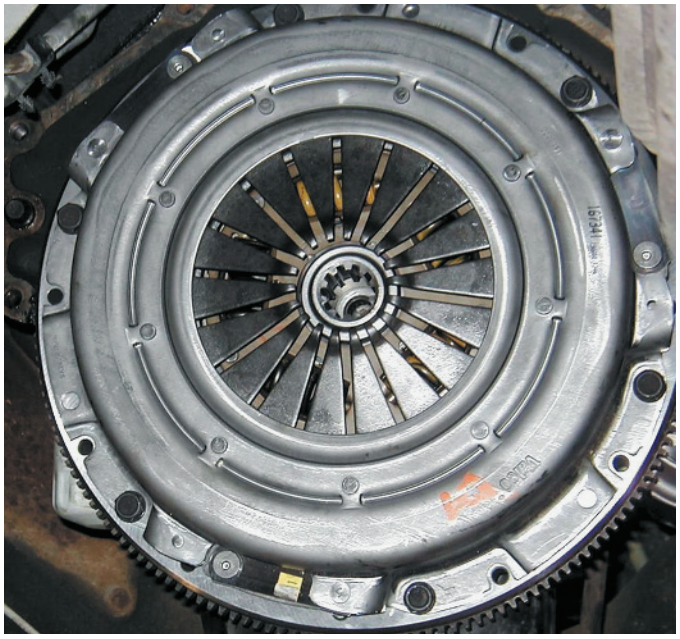


FIGURE 121–8 Typical diaphragm-style pressure plate that uses a Belleville spring.

ADVANTAGES OF A DIAPHRAGM-TYPE CLUTCH

Diaphragm-type pressure plates have several advantages over the other types including

1. Diaphragm-type clutch pressure plates tend to be smaller assemblies, weigh less, and have fewer parts than coil spring assemblies. The one-piece diaphragm spring does the job of all the release levers and coil springs in a **coil spring clutch**.
2. The driver must push harder on the clutch pedal to disengage a coil spring clutch than to disengage a comparable diaphragm spring design. The pedal effort for a coil spring clutch increases the farther down the pedal is pushed.
3. The pedal effort for a diaphragm spring clutch decreases during the second half of pedal travel. As the friction disc wears, coil springs expand and lose some of their clamping force. In contrast, the design of the diaphragm spring tends to increase its clamping force as the friction disc wears to half its original thickness. Then, as the friction disc continues to wear, the clamping force of the spring gradually returns to its original level. This happens without any obvious change in clutch pedal effort.

PRESSURE RING Pressure plate diameter is measured at the outside diameter of the pressure plate ring. It should always be the same size or slightly larger than the disc diameter. A pressure ring is simply a flat, heavy ring usually made from nodular cast iron. The heavy weight is necessary to dissipate heat and provides a heat sink so as not to warp. It also provides sufficient strength so it will spread the spring force evenly onto the disc. For high-RPM use, the ring is made from cast steel because centrifugal force can cause a cast iron ring to fail.

- When a clutch slips, heat is generated at the friction surfaces, and this heat will warm the facing, the pressure ring, and the flywheel.
- Excess heat will cause the pressure ring to expand to the point of warpage, destroying its flatness and causing poor ring-to-disc facing contact.
- The greater the mass of the pressure ring, the less the temperature will rise because the heat will spread through more metal, which will hold the heat longer.

Torque enters the pressure ring from the cover, either through a drive strap or a boss where the release levers extend through openings in the cover. Torque passes out through the friction contact with the facing on the disc.

TECH TIP

High-Engine Speed Shifting

Centrifugal force can also affect a diaphragm clutch. During a very high-RPM disengagement, if the fingers are moved far enough forward so that they pass over center (beyond flat), centrifugal force will try to throw the weight of the fingers in the other direction. Some people have experienced this during a shift at high RPM when the pedal stays on the floor while the engine overrevs. To prevent this, "bent finger" diaphragms are used for installations where high-RPM shifts might occur. The shape of the fingers keeps them from traveling over center. ● **SEE FIGURE 121–9.**

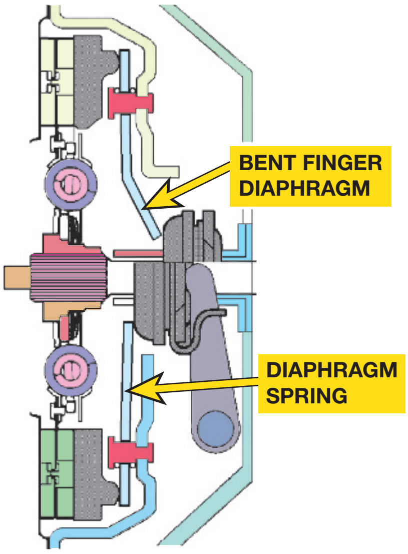


FIGURE 121–9 A bent finger diaphragm clutch. The shape of the fingers keeps the fingers and release bearing from going past center during clutch release.

COVER (HAT) The cover (hat) is the stamped-steel housing that transmits the torque from the flywheel to the pressure ring. It also provides a mounting place for the springs and release levers, where used, and it must be strong enough to contain the various forces without distorting.

FLYWHEELS

PURPOSE AND FUNCTION The engine flywheel serves four basic purposes:

1. Smooths out or dampens engine power pulses
2. Absorbs some of the heat created by clutch operation
3. Provides the mounting surface for the starter motor ring gear
4. Provides the application surface for the clutch friction disc

INERTIA A flywheel is heavy, or has a large mass, which creates inertia. Inertia is the tendency of a moving object to remain in motion, because of its weight, unless forced to slow. This inertia acts upon crankshaft rotation to smooth out or dampen engine power pulses. On a running engine, the crankshaft speeds up as a cylinder fires, then slows due to internal engine friction until the next cylinder fires. The inertia provided by the flywheel mass tends to keep crankshaft speed more constant.

Whenever friction exists between two moving parts, heat is generated. The flywheel absorbs some of the heat created by clutch operation by acting as a heat sink for the clutch friction disc.

STARTER RING GEAR An external ring gear is pressed or welded onto the flywheel along its outer circumference. The starter-drive gear meshes with the flywheel ring gear. Through gear reduction, the flywheel transfers starter motor rotation to the crankshaft to crank the engine. When the starter motor is engaged, the starter motor will spin but the engine will not crank if the ring gear on the flywheel is broken. Often the ring gear can be replaced separately without having to replace the flywheel in the event of a failure. ● **SEE FIGURE 121–10.**

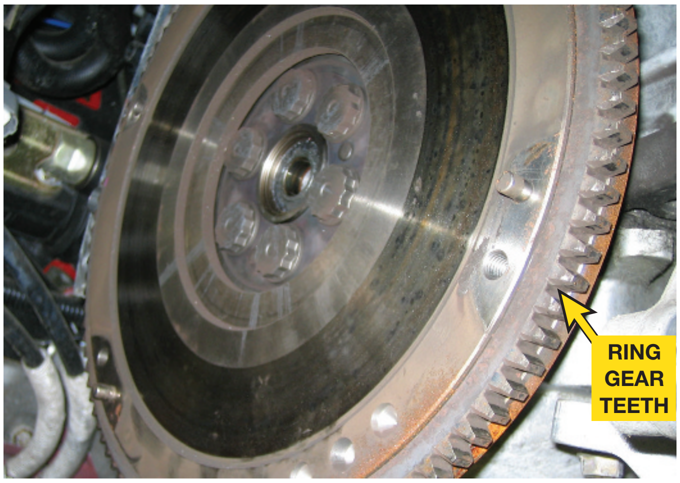


FIGURE 121–10 The ring gear, which is attached to the outer rim of the flywheel, provides the teeth needed to mesh with the starter pinion gear.

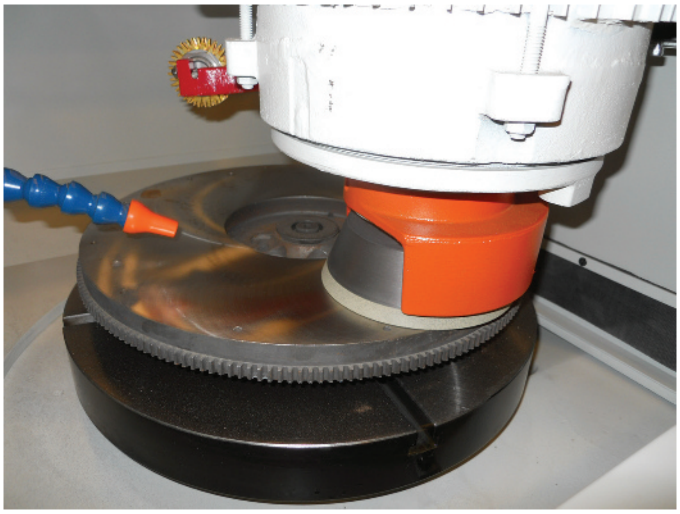


FIGURE 121–11 A flywheel being machined (ground) to provide the correct surface finish for the replacement clutch disc.

CONSTRUCTION The flywheel is constructed of cast iron and attaches to the end of the engine crankshaft. The carbon content of the cast iron (about 3%) provides a suitable surface for the clutch disc.

The carbon, in the form of graphite, acts as a lubricant to help provide a smooth engagement of the clutch. The face on the transmission side of the flywheel has a smooth, machined area that creates the application surface for the clutch friction disc. This surface must be properly finished to allow adequate slippage as the clutch engages and disengages, and to prevent slippage when the clutch is engaged. Being made from cast iron makes resurfacing easy. ● **SEE FIGURE 121–11.**

DUAL-MASS FLYWHEELS

PURPOSE AND FUNCTION Some vehicles, especially high-performance vehicles and vehicles equipped with diesel engines, use a dual-mass flywheel. The purpose of a dual-mass flywheel is to dampen engine vibrations and keep them from being transmitted to the passenger compartment through the transmission and shift linkage.

PARTS AND OPERATION A dual-mass flywheel consists of two separate flywheels connected at the center, with damper springs, friction material, and ball bearings between the two that allows some movement between the primary and secondary flywheel. By allowing a slight amount of movement between the two flywheels, the damper springs absorb engine torque peaks and normal vibration to provide smoother drive train operation. The damper assembly is completely sealed because it also contains a fluid or lubricant, typically silicone-based, which also helps absorb vibration and transmit torque. Typically, the two flywheels twist out of phase with each other by up to about 60 degrees to absorb torsional oscillations. The starter ring gear mounts on the primary flywheel. Power from the starter motor does not have to flow through the damper assembly to reach the engine crankshaft. The pilot bearing is also attached to the primary flywheel, and the clutch friction surface is usually the secondary flywheel. Assemblies with dual-mass flywheels often use a clutch disc that does not include the torsional load springs. ● **SEE FIGURE 121–12.**

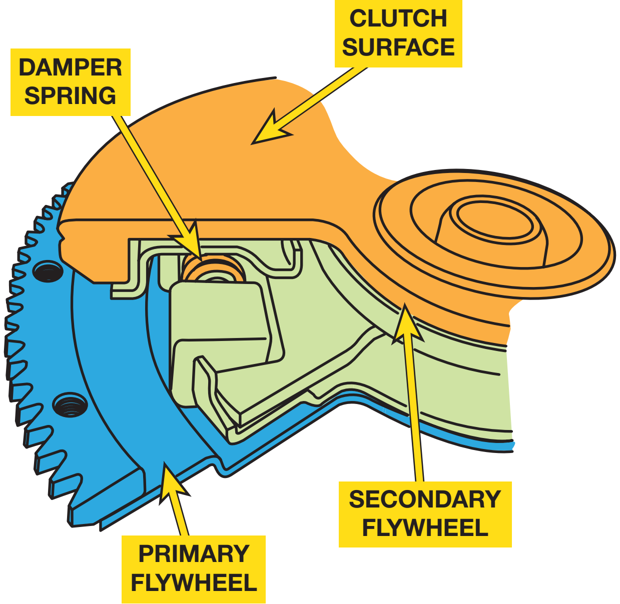


FIGURE 121–12 A dual-mass wheel consists of two flywheels connected with a spring between them to help absorb engine pulsations.

NOTE: If the dual-mass flywheel fails, the symptom is the same as a slipping clutch. The torque-limiting friction material connecting the primary and secondary flywheels can fail. This failure requires the replacement of the flywheel assembly.

PILOT BEARINGS

PURPOSE AND FUNCTION The engine end of a transmission input (clutch) shaft is supported by a pilot bearing that is pressed into the end of the crankshaft. ● **SEE FIGURE 121–13.**

NEED FOR A PILOT BEARING The transmission input shaft goes all the way from the transmission, through the clutch assembly, to the engine. Transmission bearings support the transmission end of the shaft. The pilot bearing or bushing supports it at

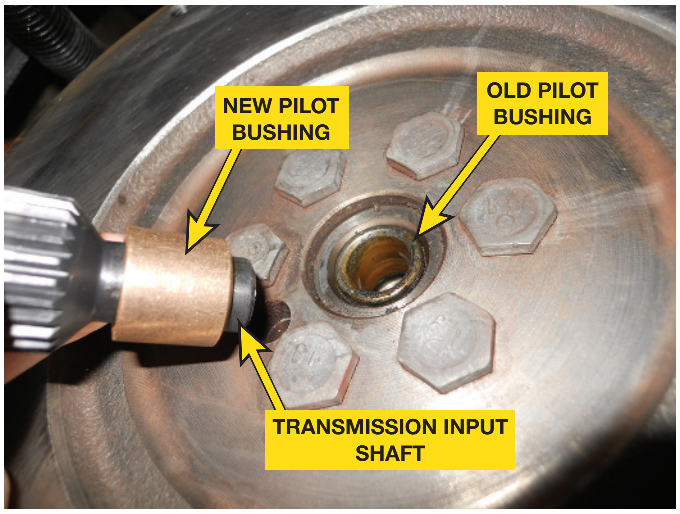


FIGURE 121–13 A pilot bearing or bushing, such as one being used on the rear-wheel-drive pickup truck, is pressed into the end of the engine crankshaft and supports the input shaft of the transmission.

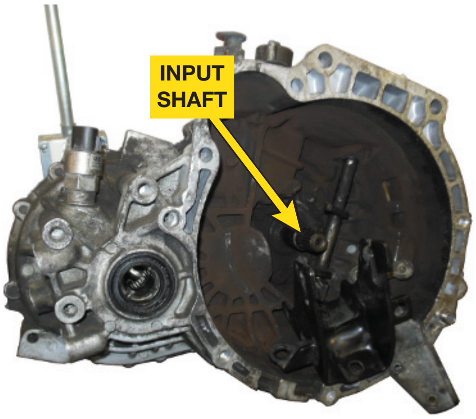


FIGURE 121–14 A manual transaxle assembly showing the short input shaft.

the engine end. A front-wheel-drive vehicle has a transaxle with an input shaft supported by a pair of bearings and a short input shaft that may not reach all the way to the flywheel. This design does not need a pilot bushing or bearing to support the engine end of the input shaft. ● **SEE FIGURE 121–14.**

CONSTRUCTION

Pilot bearings can be constructed using the following:

- Sintered bronze oilite bushing
- Needle bearing
- Ball bearing

The oilite bushing is impregnated with oil to lubricate it, whereas the other types of bearings are usually lubricated and then sealed.

OPERATION

At the engine, the transmission input shaft rests inside a small bore in the flywheel or crankshaft flange. The pilot bearing or bushing supports the engine end of the input shaft and provides a low-friction surface for the shaft to ride on. This keeps the shaft and friction disc perfectly aligned with the flywheel and pressure plate. The pilot bearing or bushing rotates with the crankshaft while the engine is running. When the clutch is released, the input shaft does not rotate when the engine is running. The pilot bearing or bushing lowers the friction between these two moving parts. ● **SEE FIGURE 121–15.**

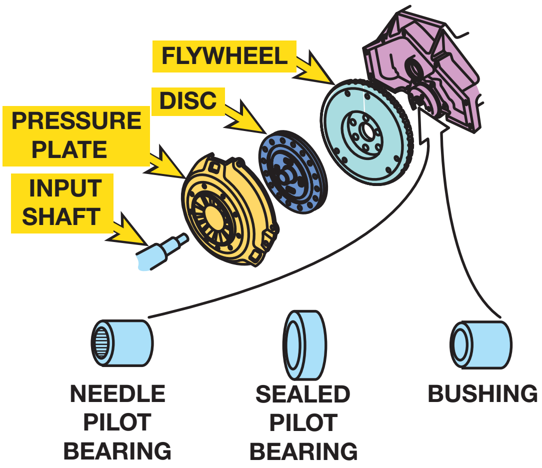


FIGURE 121–15 Pilot bearings (bushings) are made in several different designs depending on the application.

CLUTCH PEDAL LINKAGE

PURPOSE AND FUNCTION

The purpose and function of the clutch pedal linkage are to transfer the force the driver exerts on the clutch pedal to the release bearing.

TYPES OF CLUTCH LINKAGE

There are three methods of transferring the force of the driver's foot to the release (throwout) bearing, including

1. **Levers and rods.** Mechanical linkage uses a series of levers and rods, to move the release fork against the throwout bearing. This method was commonly used on many older vehicles, including the muscle cars of the 1960s and early 1970s. The force applied to the clutch pedal is directed to an equalizer bar (also known as a Z-bar) that is mounted on pivot shafts to reverse the direction of the force. This type of linkage ends at the **clutch fork** after it passes through an equalizer shaft that pivots from both the engine/bell housing and the vehicle body. Mechanical linkage includes an adjustment at some point so that free travel can be adjusted. Free travel (also called free play) is the slight clearance exists (about 1 in. [25 mm] measured at the pedal, or about 1/16 in. [2 mm] measured at the clutch fork).
2. **Cable operation.** A cable is used similar to a brake cable on a bicycle. Cable linkage consists of a steel cable attached to the clutch pedal. The clutch cable is routed to the engine/bell housing, where it can pull on the clutch fork/lever. Much of the cable is enclosed in a housing or conduit so that it can be routed around corners or obstacles. Although simple and inexpensive, cables have a drawback in that they develop internal friction through time, which makes them harder to operate. Older vehicles include a method of manual adjustment at the end of either the cable or cable housing.

   Many vehicles include a self-adjuster mechanism at the clutch pedal and some are adjusted by pulling up on the clutch pedal. The self-adjuster is usually a spring-loaded cam that is mounted onto the pedal when a spring-loaded pawl engages it. The pawl is lifted each time the clutch is disengaged so that the cam's spring can rotate and remove any slack or clearance in the cable. When the pedal is depressed, the pawl's spring returns it to lock the cam to the pedal. ● **SEE FIGURE 121–16.**

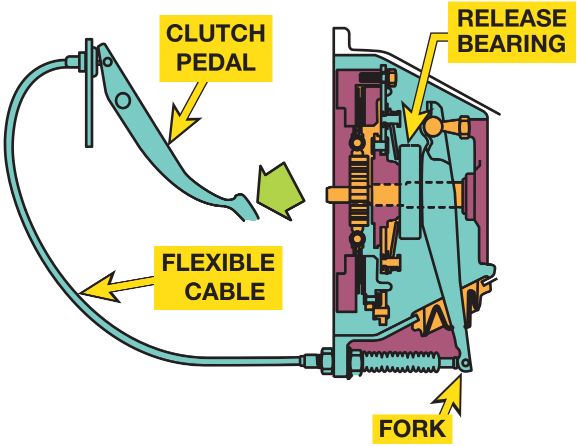


FIGURE 121–16 A typical cable clutch linkage uses a cable to transmit motion from the pedal to the release bearing.

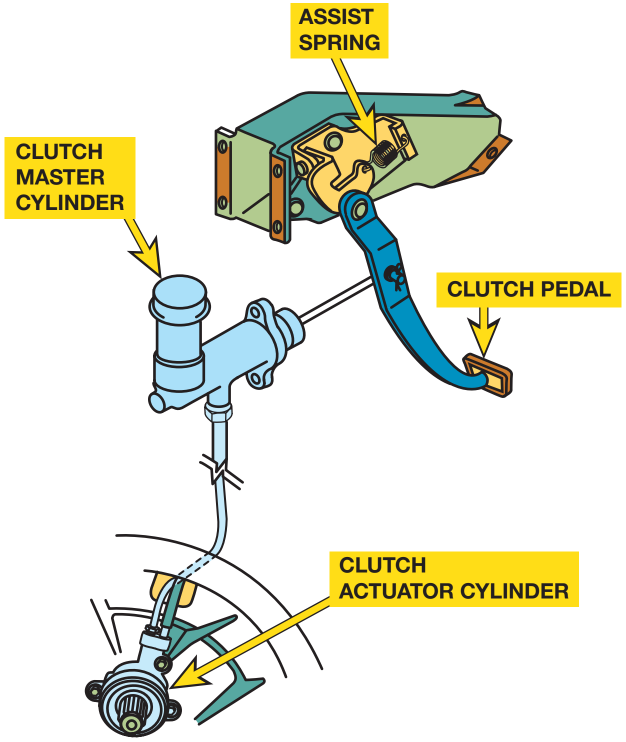


FIGURE 121–17 The actuator cylinder of some systems is concentric to the transmission input bearing retainer. When the clutch pedal is depressed, pressurized fluid is forced from the clutch master cylinder to the actuator cylinder to release the clutch.

3. **Hydraulic.** The most commonly used clutch operating system is hydraulic. A small **master cylinder** is located on the bulkhead and operated by the clutch pedal. This is connected by tubing to an **actuator cylinder** located near the release (throwout) bearing. ● **SEE FIGURE 121–17.**

HYDRAULIC CLUTCH OPERATION A hydraulic system transmits force using a fluid. Liquids cannot be compressed, and if a force is put on liquid at one end of a passage, liquid at the other end of the passage will exert the same force. In a hydraulic clutch system, the input piston in the clutch master cylinder is connected to the clutch pedal.

The output piston is located in the actuator cylinder, and it will operate the release bearing directly or through a clutch fork/lever. The master cylinder and actuator cylinder pistons are connected by metal, reinforced rubber, or plastic tubing.

- When the clutch pedal is depressed, the master cylinder piston forces fluid through the tubing to the actuator cylinder, where the pressure forces the actuator cylinder piston to move the clutch fork/lever.
- When the clutch pedal is up, the pressure plate forces the actuator cylinder piston to return the fluid to the master cylinder.
- When the clutch pedal is up, a compensating port in the master cylinder is opened up between the cylinder bore and the fluid reservoir.
- This port allows for fluid expansion or contraction due to temperature changes, for any air to leave the fluid, and in many cases, for self-adjustment for disc wear.
- Because air can be compressed, any air trapped in a hydraulic system will cause mushy, spongy pedal, or incomplete operation. DOT 3 brake fluid is generally used in clutch hydraulic systems.
- Many systems use an actuator cylinder that is concentric to the bearing retainer and has the release bearing connected directly to it. Some vehicles use an actuator cylinder that is mounted on the exterior of the bell housing.

RELEASE (THROWOUT) BEARING

PURPOSE AND FUNCTION The release (throwout) bearing rides on the transmission front bearing retainer. The clutch operating system moves the clutch release bearing when the driver presses or releases the clutch pedal. Most systems move the release bearing toward the flywheel to disengage the clutch.

OPERATION The release bearing presses against the diaphragm spring fingers or coil spring levers. This takes spring force off the pressure plate so that it no longer clamps the friction disc against the flywheel. The diaphragm spring fingers or coil spring levers rotate at crankshaft speed, but the clutch operating system is mounted on the transmission housing and does not rotate. The release bearing is the point where the fixed, stationary clutch operating system meets the rotating clutch assembly.

RELEASE BEARING CONSTRUCTION Most clutch release bearings are ball bearings. The bearing absorbs a thrust load when its outer race presses against the diaphragm spring fingers or coil spring levers. When the outer race contacts the spring fingers or levers, it must rotate with them at engine crankshaft speed. The inner bearing race is pressed onto an iron hub or sleeve. In some designs, the inner bearing race and sleeve are machined as one piece. The inner bearing race and sleeve are stationary and do not spin when the outer race spins.

RELEASE BEARING LOCATION The transmission front bearing retainer has a long, hollow tube extending toward the engine. The release bearing sleeve slides on the outer surface of this tube, which is also commonly called (slang):

- Quill
- Quill shaft
- Candlestick

In a typical system, the outside of the release bearing sleeve has grooves or raised flat surfaces that fit into the clutch release fork. A snap ring, spring clips, or lock pins secure the release bearing to the release fork. The clutch operating system pivots the release fork back and forth when the driver presses and releases the clutch pedal. The pivoting motion of the fork slides the release bearing away from or toward the engine to engage or disengage the clutch.

TYPES OF RELEASE BEARINGS If the clutch operating system self-adjusting, then there is no clearance between the release bearing outer race and the diaphragm spring fingers or coil spring levers.

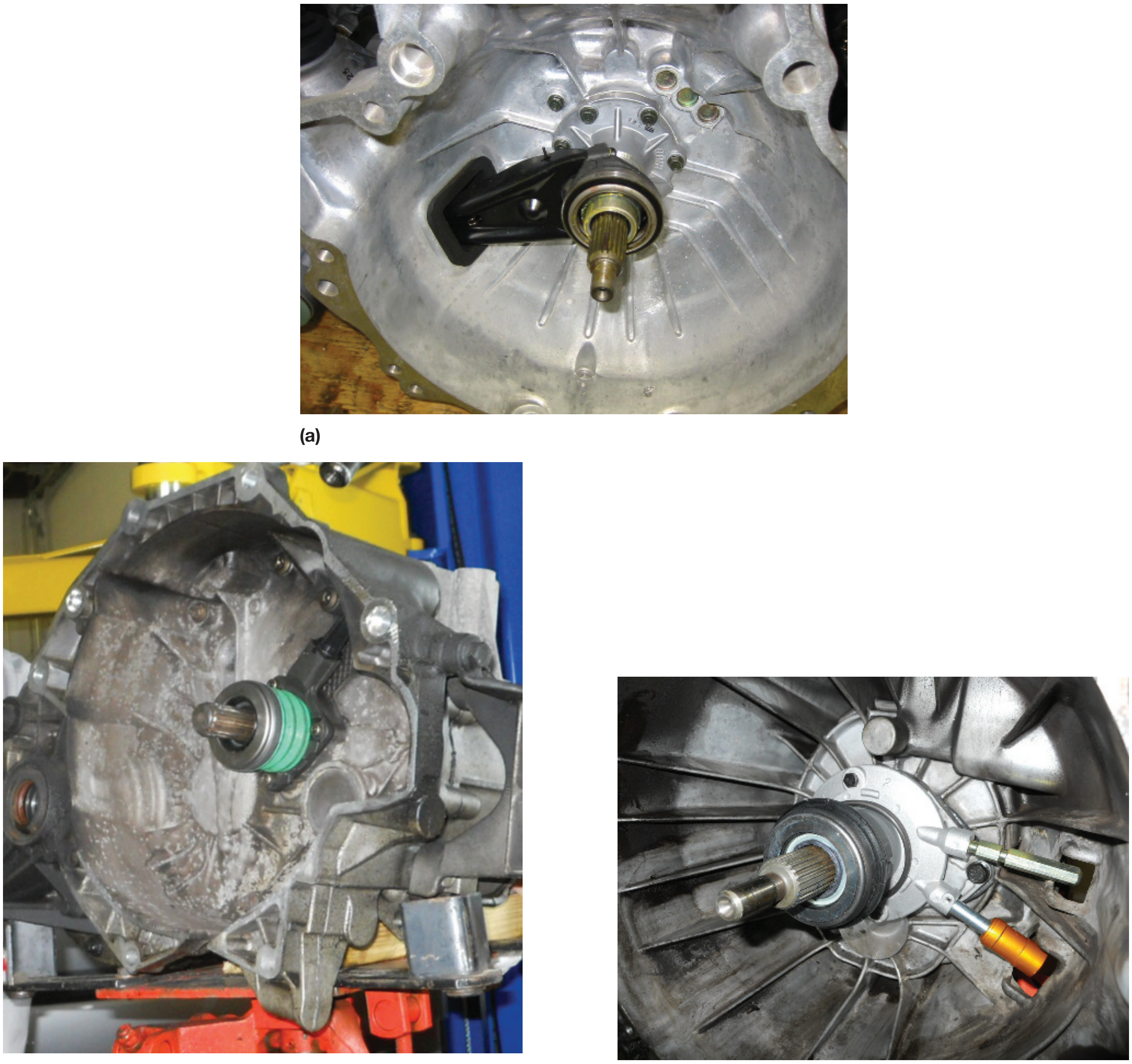
- The release bearing outer race constantly turns at engine crankshaft speed. This is called a constant-running release bearing. In some self-adjusting systems, a snap ring holds the outer race to the spring fingers. This design is typical of pull-type clutch operating systems that move away from the flywheel to disengage the clutch.

- If the clutch operating system does not self-adjust, then there must be some clearance between the release bearing outer race and the spring fingers when the clutch is engaged. The outer race does not contact the spring fingers and so it does not turn. As the driver depresses the clutch pedal, the release bearing moves into contact with the fingers and the outer race begins to rotate with them. This type of release bearing is not designed to rotate constantly. If the clutch is not adjusted properly and there is no clearance, the release bearing spins constantly and wears out quickly. ● **SEE FIGURE 121–18.**

CLUTCH PEDAL SWITCH

PURPOSE AND FUNCTION A **clutch pedal position switch** is used to signal the starter circuit that the clutch is disengaged, which prevents starter operation unless the clutch pedal is depressed. Some vehicles will have a clutch pedal position switch at the pedal stop that is normally closed in addition to a **safety switch**. This is for disengaging the cruise control.

OPERATION The switch is normally electrically open, and it closes when the pedal is completely depressed. This completes the circuit from the ignition switch to the starter relay, and when the circuit is completed, the starter relay energizes the starter, cranking the engine. This safety feature prevents the vehicle from moving accidentally when the starter is engaged.


(a)

(b)

(c)

FIGURE 121–18 (a) A release (throwout) bearing on a transmission that uses a clutch fork and a mechanical or cable-operated linkage. (b) A style of release bearing that includes the actuator cylinder, sometimes called a *concentric cylinder*. (c) A combination release bearing and actuator cylinder showing the two hydraulic lines. The lower line is from the master clutch cylinder, and the upper line is used to bleed air from the hydraulic system.

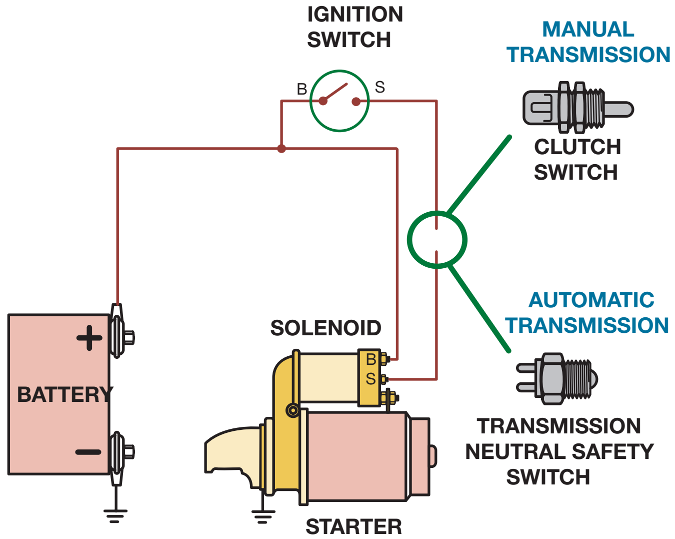


FIGURE 121–19 The clutch pedal switch is used to prevent the engine from cranking unless the clutch pedal is depressed.

CAUTION: Not all vehicles are equipped with a clutch safety switch, so it is very important that the transmission be placed in neutral and/or the clutch fully depressed before starting the engine.

● **SEE FIGURE 121–19.**

CLUTCH DIAGNOSIS AND REPLACEMENT

SYMPTOMS OF A DEFECTIVE CLUTCH The following symptoms will occur if there is a fault in the clutch or in the linkage or hydraulic system that could prevent the clutch from being fully disengaged:

- The transmission will be difficult (or impossible) to shift into reverse.
- The transmission will be difficult (or impossible) to shift between forward gears.

LEAK DETECTION A drop in fluid level at the reservoir indicates a fluid leak. Normally, facing wear will cause an increase, or rise, in the fluid level, so topping off the reservoir is not necessary or recommended. The cause of a fluid leak is usually found through visual inspection of the cylinders and lines to locate the wetness. Fluid leak repair is done by correcting the fault, which could include

- Tightening a loose line fitting.
- Replacing an O-ring, fluid line or hose.
- Replacing the clutch master cylinder or actuator cylinder.

ACTUATOR CYLINDER TRAVEL Inability to release the clutch completely can be checked by observing actuator cylinder travel as the clutch pedal is depressed. The actuator cylinder should begin moving immediately and travel in a smooth, steady manner. Some manufacturers provide actuator cylinder travel or extension specifications. For example, one manufacturer specifies 0.5 inch (13 mm) of actuator cylinder motion for one complete stroke of the clutch pedal. Insufficient actuator cylinder travel indicates air in the system or a faulty actuator or master cylinder.

CLUTCH SLIPPAGE DIAGNOSIS **Clutch slippage** can be checked easily in a shop; however, a more thorough check can be made during a road test.

To check for slippage in a shop, perform the following steps:

STEP 1 Check and adjust clutch pedal free travel.

STEP 2 Warm up the engine to operating temperature, block the wheels, and apply the parking brake completely.

STEP 3 Shift the transmission into a high gear and let out the clutch pedal smoothly. The engine should stall immediately. A delay indicates slow engagement and slipping.

To check for slippage on a road test, perform the following steps:

STEP 1 Check and adjust clutch pedal free travel.

STEP 2 Drive to an area with very little traffic. Accelerate slowly and drive at 15 to 20 mph (24 to 32 km/h) in the highest transmission gear. Use the lowest speed at which the vehicle will operate smoothly.

STEP 3 Depress the accelerator completely to wide-open throttle and listen to the engine RPM or watch the tachometer. The engine speed should increase steadily as the vehicle accelerates. If the engine speed flares upward, the clutch is slipping and needs service. Slipping becomes even more evident if this test is made while driving up a hill.

CLUTCH SPIN-DOWN TEST Hard shifting into gear from neutral, sometimes accompanied by gear clash, can be caused by a clutch that is not releasing completely. This is called **drag** and is easily checked by a spin-down test. **Clutch spin-down** is the time it takes for the clutch disc and transmission gears to spin to a stop when the clutch is released.

To check clutch spin-down, perform the following steps:

STEP 1 Check and adjust clutch pedal free travel.

STEP 2 Warm up the engine and transmission to operating temperatures.

TECH TIP

Take Precautions

Whenever working on a clutch assembly, most vehicle manufacturers recommend the use of personal protective equipment (PPE) to protect the technician against possible hazards. The items needed include the following:

1. Safety glasses
2. Protective gloves

Because clutch disc material may contain asbestos, precautions should include avoid causing any clutch friction material from becoming airborne by wetting the area.

Check service information for specific precautions recommended by the vehicle manufacturer for the vehicle being serviced.

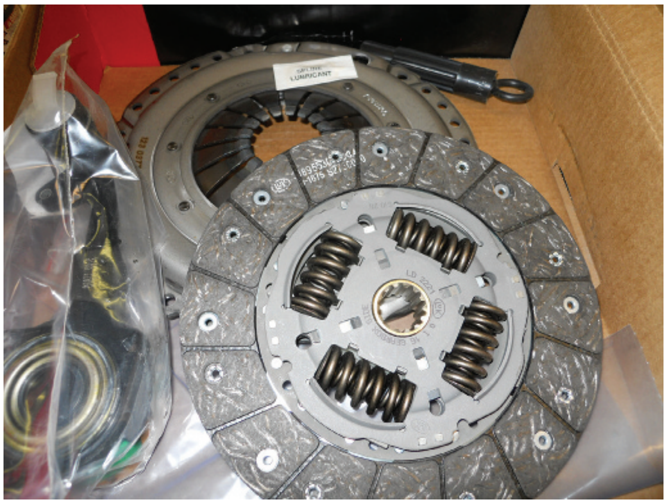


FIGURE 121–20 A typical clutch kit, which includes the clutch disc, pressure plate, and release (throwout) bearing as well as grease for the spline and a clutch disc alignment tool.

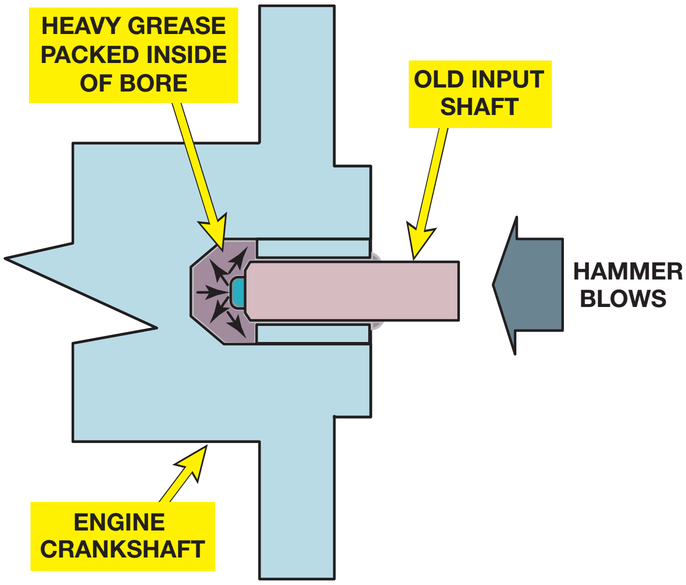


FIGURE 121–21 An old input shaft obtained from a disassembled transmission can be used to force the old pilot bushing out.

STEP 3 With the engine running at idle speed and the transmission in neutral, push in the clutch pedal, wait two seconds, and shift the transmission into reverse (a nonsynchronized gear). The shift should occur silently. **Gear clash** or grinding indicates a dragging clutch that has not released completely. If a clutch fails the spin-down check, it likely needs to be replaced.

CLUTCH REPLACEMENT Clutch replacement, commonly called a *clutch job*, is a fairly expensive and labor intensive repair. During disassembly, each part should be checked to determine if it is the cause of the failure and if it is suitable for reuse. During reassembly, each phase is normally accompanied by checks for proper clearances or operation so that any faulty parts or assemblies can be corrected as early in the assembly as possible.

Clutch replacement normally involves replacing four items:

1. Pressure plate assembly
2. Clutch disc
3. Release bearing
4. Pilot bearing ● **SEE FIGURE 121–20**.

CLUTCH REMOVAL The clutch replacement for a typical rear-wheel-drive vehicle includes the following steps:

1. Hoist the vehicle safely and mark and remove the driveshaft. This step ensures that the driveshaft will be reinstalled correctly and in phase.
2. Disconnect the shift linkage, speedometer connections, and reverse light switch connection as well as the clutch linkage or cable or actuator cylinder.
3. Support the transmission with a transmission jack and then remove the rear cross member and bell housing bolts.
4. Carefully move the transmission toward the rear. Try to keep the transmission level to avoid causing damage to the pilot bearing or clutch components. A slight wiggling of the transmission is usually necessary to allow the input shaft to slide over the spline of the clutch disc.
5. After the transmission has cleared the clutch, it can be lowered and inspected before being reinstalled after the clutch assembly has been replaced.
6. Mark the pressure plate and flywheel if they are to be reused to allow them to be reinstalled in the same location to maintain assembly balance.
7. Remove the clutch pressure plate retaining bolts, and remove the clutch assembly including the release bearing, pressure plate, and clutch disc.

PILOT BEARING A commonly used pilot bushing removal method is to thread a coarse bolt into the bushing so it bottoms against the crankshaft. Further tightening will move the bushing outward. Some vehicle manufactures recommend the use of a special puller. A somewhat messy alternative method to remove a pilot bearing is to fill the cavity behind the bearing with chassis grease and drive a close-fitting round rod or **dowel** into the grease. This will create a hydraulic force behind the bearing, forcing it outward. Soap or wet tissue can also be used. ● **SEE FIGURE 121–21**.

IMPORTANCE OF INSPECTION Technicians should check each part as it is disassembled to determine if it is reusable or why it failed. This identifies any condition that needs special attention before the clutch is reassembled. If the clutch is slipping, the disc and the pressure plate should be replaced. The following sections explain the normal checks to be made during a clutch job.

⚠ WARNING

The clutch driven disc may contain asbestos, which is known to be a cancer-causing agent. Never clean clutch surfaces with compressed air. Avoid inhaling any dust from any clutch surface. When cleaning the clutch surfaces, use a commercially available brake cleaning fluid.

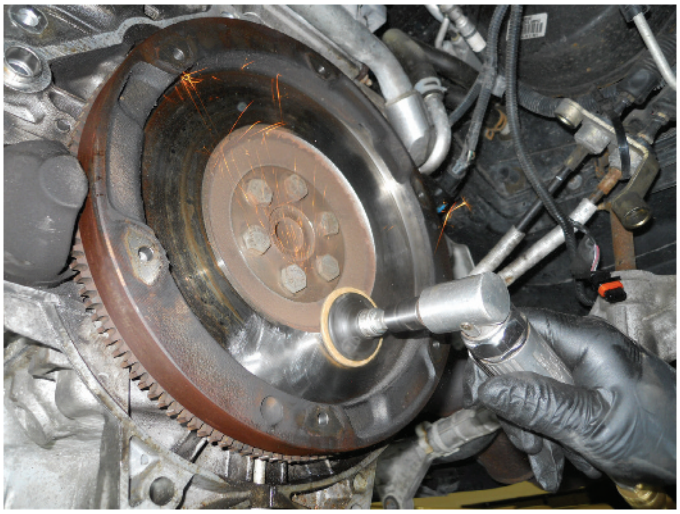


FIGURE 121–22 Using an abrasive disc to remove the glaze and to restore the proper surface finish to a flywheel.

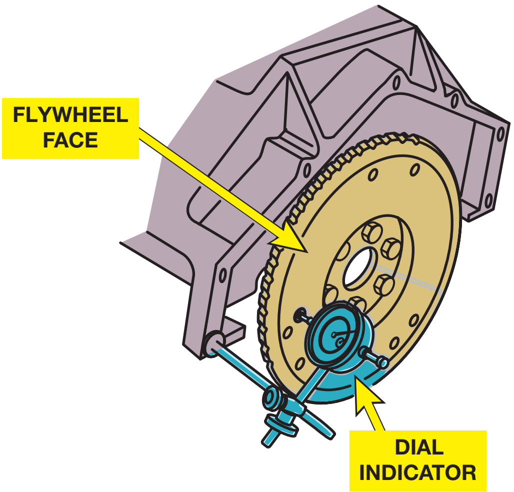


FIGURE 121–23 A dial indicator set up to measure flywheel face or axial runout.

FLYWHEEL INSPECTION The friction surface of the flywheel should be checked for the following:

- Grooves
- Nicks
- Heat damage (discoloration or cracks caused by excessive heat)

Any of these indicates that the flywheel needs to be resurfaced or replaced.

FLYWHEEL RESURFACING Blanchard grinding moves a spinning grinding stone around the flywheel surface. This is the recommended method of resurfacing because it leaves a truly flat surface with a circular, nondirectional pattern. A nondirectional finish promotes rapid disc facing-to-flywheel break-in.

If the friction surface is flat and smooth but highly polished or glazed, some technicians will sand the friction surface using a disc sander with 80- to 120-grit paper. When doing this, the sander is kept in motion while attempting to duplicate the ground finish of a new unit without cutting grooves. ● **SEE FIGURE 121–22**.

FLYWHEEL AXIAL RUNOUT Many flywheels are forged steel, which tends to warp (potato chip shape) or dish if overheated. This is checked by placing a straightedge across the flywheel in several locations. Over 0.0005 inch (0.013 mm) of warpage per inch of diameter is considered excessive. This means that a 12-inch-diameter flywheel can have 0.006 inch (12 × 0.0005) of warpage error.

If there is a vibration concern or an odd wear pattern at the hub of the disc or pressure plate release levers, the flywheel should be checked for excessive runout. Face or axial runout is checked by positioning a dial indicator with the indicating stylus at the outer edge of the flywheel face. ● **SEE FIGURE 121–23**.

To measure flywheel axial runout, perform the following steps:

STEP 1 Mount the dial indicator so the measuring stem is parallel to the crankshaft and pointing directly toward the flywheel contacting the disc friction area, and adjust the indicator to read zero.

STEP 2 Rotate the flywheel while watching the dial indicator. Maintain an even pressure, either inward or outward, to maintain zero crankshaft end play. The variation in reading is the amount of axial runout.

STEP 3 Set up the dial indicator to measure lengthwise flywheel/crankshaft motion, and push and pull on the flywheel and crankshaft in a direction that is parallel to the crankshaft. The dial indicator is measuring crankshaft end play. Normal crankshaft end play should be about 0.002 to 0.010 inch (0.05 to 0.25 mm). Movement greater than specified indicates worn engine crankshaft thrust bearings.

To measure flywheel radial runout, perform the following steps:

STEP 1 Mount the dial indicator so it is at the edge of the flywheel, pointing directly toward the center of the flywheel.

STEP 2 Adjust the dial indicator to read zero.

STEP 3 Rotate the flywheel while watching the dial indicator.

STEP 4 The variation in reading is the amount of radial runout.

Radial runout has a greater effect on balance and vibration than on clutch operation. Runout in either direction greater than 0.010 inch (0.25 mm) is considered excessive axial runout, as little as 0.005 inch (0.1 mm) can cause chatter. If the flywheel is to be removed, place index marks at the crankshaft flange for faster alignment during reassembly. Also inspect the starter ring gear teeth. If they are damaged, replace either the starter gear or the flywheel.

PRESSURE PLATE ASSEMBLY INSPECTION A used pressure plate assembly should be inspected visually for all of the following.

- Friction surface damage
- Release lever wear
- Lever pivot wear
- Cover distortion

Like the flywheel, the friction surface will tend to polish or glaze from normal use. If there is excessive slippage, grooves, heat checks, and warping can occur. Warpage can be checked by placing a straightedge across the friction surface and will show up as a gap between the straightedge and the inner portion of the pressure plate ring. Set the pressure plate on the flywheel without the clutch disc in place. All of the mounting points should meet the flywheel evenly and completely. Any air gaps indicate a distorted clutch cover. Release lever height should be checked after the pressure plate and disc are bolted to the flywheel. Soft reddish-brown rust and highly polished or shiny rough areas around the lever pivots are indications of wear at these points. If any problems are noticed, the pressure plate assembly should be replaced.

CLUTCH DISC INSPECTION If installing a used disc, it should be checked for all of the following:

- Facing thickness
- Damper spring condition
- Wear of the hub splines
- Contaminated or oil soaked facing material (oil or grease on the friction surface can cause clutch grab or chatter)
- Warpage or axial runout

The thickness of the facing can be checked by two different methods:

Method 1. The first method is to place cardboard or a shop cloth over the facing to keep it clean and squeeze the facings together to compress the marcel spring. If specifications are not available, the minimum thickness of the compressed disc should be 0.280 inch (7.1 mm). ● **SEE FIGURE 121–24**.

Method 2. The most popular method is to measure the height of the facing surface above the rivets, which is also called *rivet head depth*. With a new disc, rivet head depth will be about 0.050 inch (1.2 mm). A disc with less than 0.015 to 0.020 inch (0.38 to 0.5 mm) should be replaced. ● **SEE FIGURE 121–25**.

The damper springs and hub splines are checked visually for reddish rust, often called "rust dust" and shiny worn areas as well as loose, broken, or missing springs. **Disc runout** warpage is checked by making an axial runout check. This usually requires a pair of tapered centers or an expanding arbor at true center to the hub splines. The disc is rotated while watching for runout or wobbling of the facing surfaces. More than 0.020 inch (0.5 mm) is excessive, and the disc should be replaced.

A quick check for warpage is to set the disc against the flywheel. The facing should contact the flywheel evenly all around the disc.

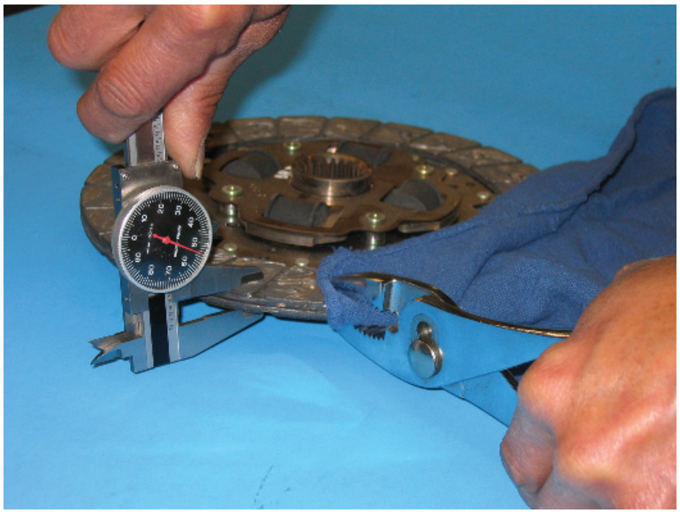


FIGURE 121–24 The thickness of the clutch disc facing can be measured using a dial caliper.

CLUTCH/BELL HOUSING INSPECTION There should not be any oil or grease residue inside the bell housing. If oil is present, check for a leaking front bearing retainer seal or oil galleys plugs or back of the intake manifold. If there has been early failure of the pilot or release bearings, clutch pedal vibration, or the transmission is jumping out of gear, the face and bore surfaces of the bell housing should be checked for excessive runout. Check for excessive runout with a dial indicator attached to the crankshaft, flywheel, pressure plate, or disc, depending on the equipment available and how far the clutch is disassembled.

HOUSING BORE RUNOUT To check clutch housing bore runout, perform the following steps:

STEP 1 Reposition the dial indicator so the measuring stem is inside the bore and pointing outward.

STEP 2 Adjust the dial indicator to read zero.

STEP 3 Rotate the crankshaft while watching the indicator reading.

STEP 4 Any variation in reading is the amount of bore runout.

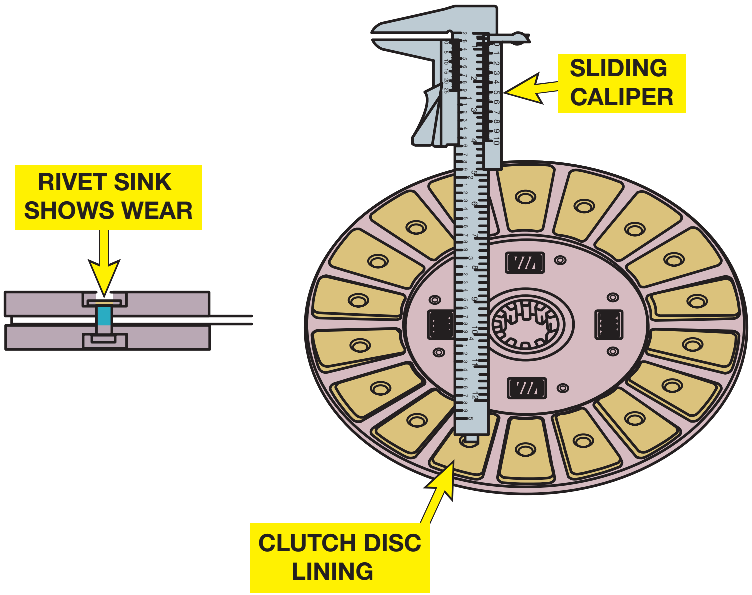


FIGURE 121–25 The overall disc thickness can be measured using a vernier caliper by first compressing the marcel spring using pliers.

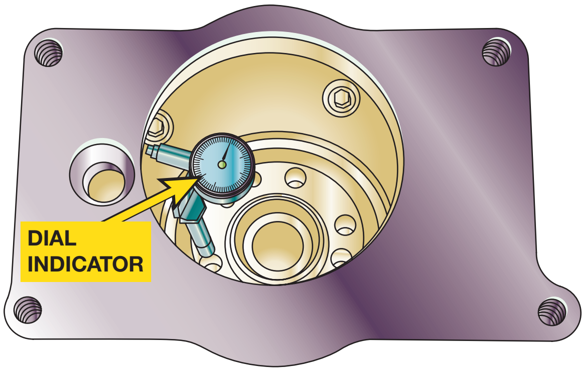


FIGURE 121–26 The dial indicator has a lever added to check clutch housing bore runout. Excessive runout can be caused by damaged or missing dowels in the engine block. If the dowels are okay, excessive runout can be corrected by installing eccentric dowels.

If the runout cannot be corrected, the bell housing is usually replaced, but it is possible to put shims between the bell housing and the engine block to correct excessive runout. The limit for bore runout is about 0.010 inch (0.25 mm). Bore runout can be corrected by using eccentric dowel pins to reposition the bell housing. These are available in different sizes. Position the bell housing so it is centered with the crankshaft. ● **SEE FIGURE 121–26**.

RELEASE BEARING INSPECTION Other than feeling for roughness or seeing obvious wear or discoloration, there are no effective bench checks for **release bearings**. This is one reason why they are normally replaced with the disc and pressure plate.

CLUTCH ASSEMBLY REPLACEMENT To replace a clutch assembly, perform the following steps:

STEP 1 Check the flywheel bolts to make sure that they are tight and torqued to specifications.

STEP 2 Check the pilot bearing recess to ensure that it is clean, and drive the new pilot bearing into place. The best tool for this is a commercial or shop-made driver with a stem the same size as the bearing bore and a face that is larger than the diameter of the bearing. The new pilot bearing is driven in until it is fully seated or has entered completely into the crankshaft. Most pilot bearings do not require lubrication. Roller bearings with exposed rollers should be lubricated with a thin film of grease or a few drops of engine oil is all that is needed on a sintered bushing.

STEP 3 Place the new clutch disc over the transmission clutch shaft and make sure that it slides freely over the splines. Determine which side of the disc goes against the flywheel which will often be marked *flywheel side*. If not marked, the damper assembly normally faces the pressure plate.

NOTE: To determine the correct clutch disc position, place each side of the disc against the flywheel and rotate it. The side that contacts the flywheel bolts or does not let the clutch facing contact the flywheel is the wrong side.

STEP 4 Position the **disc alignment** tool or an old transmission shaft or a plastic dummy transmission shaft through the disc and into the pilot bearing to center the disc.

STEP 5 Install the pressure plate over the disc, making sure that it is properly aligned with the dowel pins and mounting bolt holes, and install the mounting bolts.

CAUTION: Use only the bolts that were used originally or if replacement bolts are used, be sure that they are grade 8 (high tensile strength) fasteners.

STEP 6 Tighten the mounting bolts two turns at a time alternating back and forth across the pressure plate. Tighten the bolts to the correct torque.

STEP 7 Remove the alignment device and check to make sure that the pilot bearing is in the exact center of the disc. The height variation of the release levers can be checked after the pressure plate is installed. Using a vernier or dial caliper, measure from the contact face for the release bearing to the clutch disc. All of the heights should be within 0.020 inch (0.5 mm). The readings will be more accurate after the clutch has been applied a few times.

STEP 8 Check the clutch linkage to make sure that it operates smoothly. On cable-operated clutches, this is a good time to remove, clean, and lubricate the cable.

STEP 9 Fill the groove inside the bore of the release bearing with grease, apply a thin film of the specified high-temperature grease on the fork contact areas, and slide the release bearing onto the transmission quill, making sure that the bearing collar slides smoothly. The quill portion of the transmission bearing retainer should be smooth and unworn. On clutch forks that use pivot balls, a thin film of grease should be put on the ball. On forks mounted on pivot shafts, the pivot bushings should be lubricated.

STEP 10 Replace the transmission/transaxle, being sure to observe the following:

- Place a very thin film of grease on the clutch splines.
- Never let the transmission hang on the clutch disc splines.
- The transmission should be completely seated against the clutch housing or engine before the mounting bolts are tightened.
- Tighten the transmission mounting bolts two turns at a time, working back and forth across the transmission until they are tightened to the correct torque. It should not be necessary to force the transmission into place.
- Adjust the free travel before operating the clutch.

HYDRAULIC CLUTCH BLEEDING In many cases, a clutch hydraulic system can be bled by **gravity bleeding**, while in others, a helper may be needed. To bleed a clutch hydraulic system using the gravity method, perform the following steps:

STEP 1 Clean the bleeder valve at the actuator cylinder and place a shop cloth under it to catch escaping fluid. ● **SEE FIGURE 121–27**.

STEP 2 Open the bleeder valve by loosening the bleeder screw and observe the flow. If no flow occurs, have a helper depress the clutch pedal in a smooth, slow manner. Air bubbles coming from the bleed valve indicate that the system needed bleeding. After the air bubbles stop and a constant flow of fluid occurs, close the bleed valve. An alternative method is reverse, or back-bleeding. This is done by forcing fluid through the actuator cylinder bleed valve and upward to the reservoir.

STEP 3 Check the fluid level and correct it, if necessary.

Some master and actuator cylinders are mounted so that the cylinder portion is above the line connection, which makes it extremely difficult to bleed air from them.

- In some cases, it is possible to bench bleed them to remove all the air before installing on the vehicle. An alternative bleeding method is to have a helper partially apply the clutch while reverse bleeding using pressure surges from the fluid injector.
- Some clutch hydraulic systems will partially self-bleed if the clutch pedal is held completely depressed overnight using a brake pedal depressing tool.
- Another bleeding method is to construct an adapter to the fluid reservoir so a vacuum can be applied to the fluid using a hand, electric, or air-powered vacuum pump. Reducing the air pressure on the fluid will cause the air bubble to expand and move upward to the reservoir.

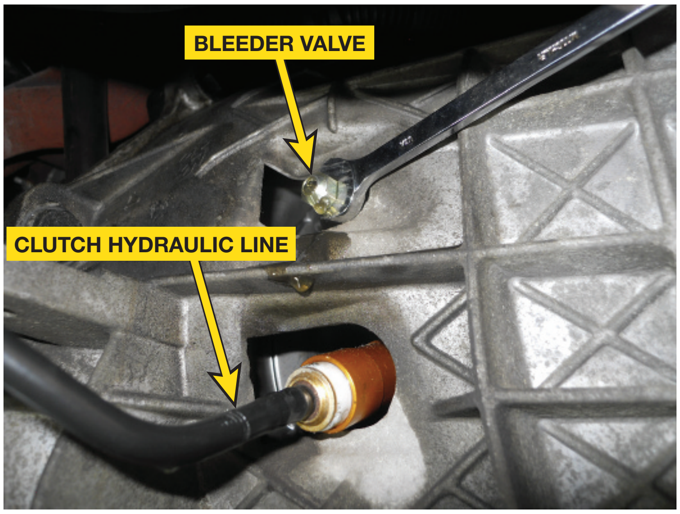


FIGURE 121–27 Gravity bleeding a hydraulic clutch. Opening the bleeder valve should allow air to escape and then fluid should flow.

REVIEW QUESTIONS

1. What parts are included in a typical clutch assembly?
2. What happens when the driver depresses the clutch pedal?
3. Why is a dual-mass flywheel used on some vehicles?
4. What parts are normally replaced as part of a clutch job?
5. What should be lubricated during clutch replacement?

CHAPTER QUIZ

1. Which part does *not* rotate when the engine is running and the clutch pedal is depressed?
  a. Pilot bearing (bushing)
  b. Pressure plate
  c. Input shaft
  d. Flywheel

2. A clutch disc is being installed. Technician A says the damper assembly of the clutch disc normally faces the pressure plate. Technician B says that the disc splines should be lightly lubricated. Which technician is correct?
  a. Technician A only
  b. Technician B only
  c. Both Technicians A and B
  d. Neither Technician A nor B

3. A dual-mass flywheel is used to ______________.
  a. reduce clutch effort
  b. reduce vibration
  c. increase torque holding ability of a clutch
  d. decrease vehicle weight

4. Most hydraulic clutch systems use what hydraulic fluid?
  a. DOT 3 brake fluid
  b. Mineral (hydraulic) oil
  c. SAE 80W-90 gear oil
  d. ATF

5. Flywheels are constructed of cast iron because ______________.
  a. they contain about 3% carbon, which acts as a lubricant for the clutch
  b. they have a lot of inertia
  c. they can be resurfaced
  d. All of the above

6. The most commonly used clutch linkage is ______________.
  a. mechanical (rods and levers)
  b. hydraulic
  c. cable
  d. electrically controlled

7. The release bearing sleeve slides on the outer surface of a tube, which is commonly called the ______________.
  a. quill
  b. quill shaft
  c. candlestick
  d. Any of the above

8. A clutch switch is used to ______________.
  a. disengage the clutch
  b. engage the clutch
  c. prevent the engine from starting unless the clutch pedal is depressed
  d. provide an input signal for the PCM to disengage the clutch

9. Springs are mounted at the center of a clutch disc. Technician A says they help cushion clutch engagement. Technician B says they absorb engine torsional vibrations. Which technician is correct?
  a. Technician A only
  b. Technician B only
  c. Both Technicians A and B
  d. Neither Technician A nor B

10. When the clutch is disengaged (clutch pedal down) ______________.
  a. springs force the pressure ring toward the clutch cover
  b. springs force the pressure ring toward the flywheel
  c. the release (throwout) bearing is used to move the pressure ring toward the clutch cover
  d. the pilot bearing is pressed toward the engine

Chapter

122

MANUAL TRANSMISSIONS/ TRANSAXLES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the need for a transmission.
- Explain the different types of gears.
- Discuss gear ratios.
- Describe the relationship between torque, speed, and power.
- Describe the construction of a transmission/transaxle.
- Describe speed gears.
- Explain the construction and operation of a synchronizer.
- Describe the torque flow through a five-speed manual transmission.
- Describe the procedure to diagnose, remove, disassemble, assemble, and install a manual transmission/transaxle.
- Discuss manual transmission/transaxle lubricants.

KEY TERMS:

Axis 1529 • Back taper 1537 • Bell housing 1533 • Bevel gear 1531 • Blocker ring 1535 • Cluster gears 1533 • Cluster shaft 1533 • Clutch 1533 • Constant-mesh gear 1539 • Counter gears 1533 • Countershaft 1533 • Direct drive 1531 • Drive gear 1531 • Driven gear 1531 • Extension housing 1533 • External gears 1530 • Fifth gear 1539 • Final drive assembly 1540 • First gear 1538 • Fourth gear 1538 • Front bearing retainers 1533 • Gear reduction 1531 • Helical gear 1530 • Hub 1535 • Input shaft 1533 • Internal ring gears 1530 • Keys 1535 • Lay shaft 1533 • Main drive pinion assembly 1533 • Main gear 1533 • Main shaft 1533 • Neutral 1537 • Output shaft 1533 • Overdrive 1532 • Pinion gear 1530 • Quill 1533 • Reverse 1539 • Second gear 1538 • Sliding reverse gear 1539 • Sliding sleeve 1535 • Springs 1535 • Spur gear 1529 • Stop ring 1535 • Synchronizer assemblies 1535 • Synchronizer keys 1535 • Synchronizer ring 1535 • Third gear 1538 • Transmission case 1533

THE NEED FOR A TRANSMISSION

A vehicle requires a lot of torque to start off and to climb hills, yet it does not require as much torque to move on level ground. The source of the torque is the engine. Torque is a twisting or turning force that is exerted on the input shaft of a transmission/transaxle. An engine produces increasing torque as its speed increases up to a certain point where the torque output starts to decrease. Therefore, to get a vehicle moving or to accelerate up a hill, it is desirable to use a transmission that allows the engine speed to be increased even though the vehicle speed may be low. Using gears allows the engine speed to increase at low vehicle speeds yet still permits the engine speed to drop at higher speeds to save fuel and reduce exhaust emissions.

For example,

- First gear: Vehicle speed is low, engine speed is high.
- Second gear: Vehicle speed increases, engine speed decreases as shift is made.
- Third gear: Vehicle speed continues to increase, engine speed is kept in a narrow range.
- Fourth gear: Again, the vehicle speed is increasing, yet engine speed is about the same as in third gear.

GEAR TYPES

The simplest type of gear is the **spur gear**. ● **SEE FIGURE 122–1**. A spur gear consists of a gear blank with straight-cut teeth around its entire circumference. All gear teeth lie parallel to the centerline, or **axis**, of the gear. The teeth are shaped so they can mesh without slippage with a second spur gear's teeth positioned along a parallel axis.

Spur gear design permits 1.5 to 2.5 gear teeth to mesh at a time. The gear teeth make contact with each other over their full width at the same instant. The fact that the gear teeth are in full contact increases the strength of the gear, but also causes spur gear operation to be noisy. Due to their strength, most heavy-duty truck transmissions use spur gears.

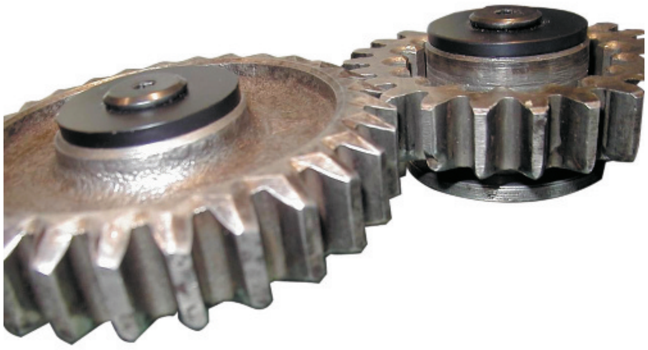


FIGURE 122–1 Spur gears have straight-cut teeth.

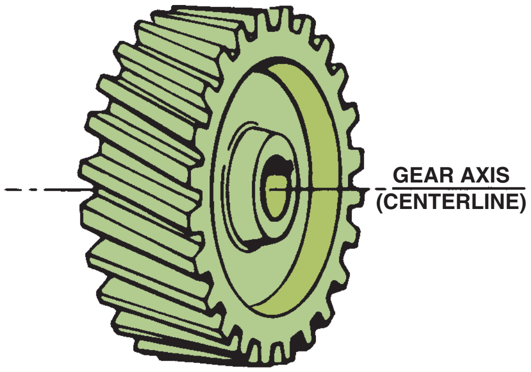


FIGURE 122–2 The teeth of a helical gear are cut at an angle to the gear axis.

A **helical gear**, although similar to a spur gear, has its teeth cut at an angle to the axis of the gear. ● **SEE FIGURE 122–2**. This enables more teeth, 2.5 to 3.5, to mesh at a time than the spur gear. Additionally, the angle allows the teeth to mesh gradually, rather than all at once. As a result, helical gears run quieter than spur gears. Helical gears, however, have two disadvantages. Each gear pushes against its shaft parallel to its axis. Special bearings are needed to protect the gearbox from this type of axial, or thrust, loading. Furthermore, because of the increased contact area, helical gears create more friction than spur gears. ● **SEE FIGURE 122–3**.

Spur and helical gears have gear teeth on their outside circumference and, for this reason, are called **external gears**. This type of gear is the most commonly used in manual transmissions and transaxles.

Gears having teeth along the inside circumference are called **internal ring gears**. ● **SEE FIGURE 122–4**. The teeth of an internal ring gear may be spur or helical teeth. An internal ring gear may mesh with a smaller external gear designed to rotate as it travels around the inside of the internal ring gear. This type of external gear is called a **pinion gear** because of its smaller diameter.

FREQUENTLY ASKED QUESTION

What Is the Difference between a Transmission and a Transaxle?

A transmission is used on rear-wheel-drive vehicles, whereas a transaxle is usually used on front-wheel-drive vehicles. A vehicle equipped with a transmission uses a separate differential to split the torque equally to the drive wheels. A transaxle includes a differential assembly. In a transaxle, the differential, sometimes called the *final drive unit,* is incorporated in the construction of the transmission.

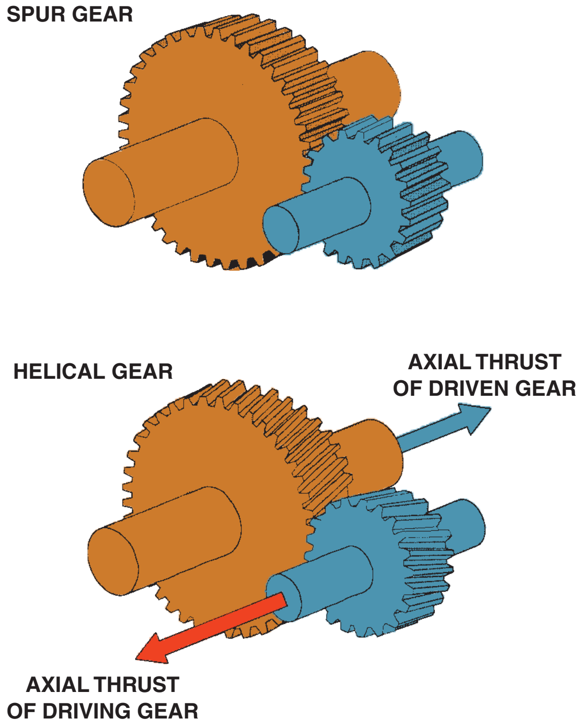


FIGURE 122–3 A spur gear has straight-cut teeth. This design is very strong and is used where strength is important. Spur gears are noisy during operation. Helical-cut gears, on the other hand, operate quietly but create a force in line with the axis of the gears due to the angle of the gear teeth.

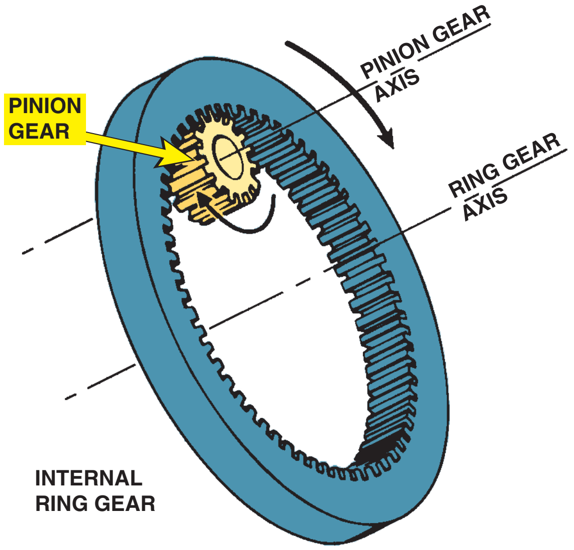


FIGURE 122–4 A pinion gear meshed with an internal ring gear rotates in the same direction around a parallel axis of rotation.

When an external gear meshes with an internal ring gear, both gears rotate in the same direction, but when an external gear meshes with another external gear, the gears rotate in opposite directions as shown in ● **SEE FIGURE 122–5**.

BEVEL GEARS The teeth of a **bevel gear** are cut at an angle to the outside gear surface. Simple bevel gears have straight-cut teeth similar to those on a spur gear. ● **SEE FIGURE 122–6**.

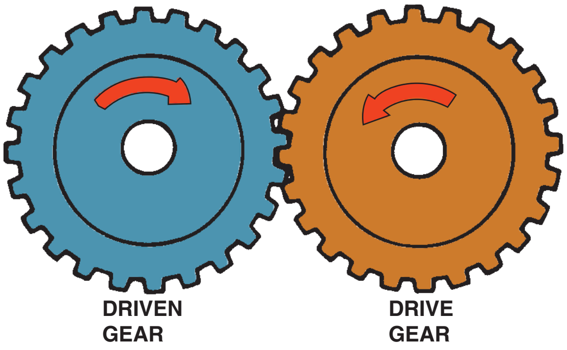


FIGURE 122–5 When two external gears mesh, they rotate in opposite directions.

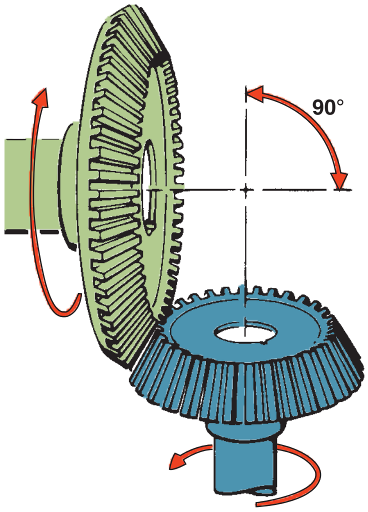


FIGURE 122–6 Bevel gears are often used to change the direction of rotation and are typically used in differentials.

Special gears used in a differential, called spider gears, are a common example of the simple bevel gear.

GEAR RATIOS

When one gear turns another, the speed that the two gears turn in relation to each other is the gear ratio. Gear ratio is expressed as the number of rotations the **drive gear** must make in order to rotate the **driven gear** through one revolution. To obtain a gear ratio, simply divide the number of teeth on the driven gear by the number of teeth on the drive gear. Gear ratios, which are expressed relative to the number one, fall into three categories:

- Direct drive
- Gear reduction
- Overdrive

A gear ratio is determined by dividing the number of teeth on the driven gear (output) by the number of teeth on the driving gear (input). ● **SEE FIGURE 122–7**.

$$\frac{\textbf{Number of teeth on the driven gear (24)}}{\textbf{Number of teeth on the driving gear (12)}} = \textbf{2:1}$$

The gear ratio represents the number of turns of the input gear to one turn of the output gear. A transmission/transaxle usually uses two pairs of gears to achieve each gear ratio, and there may be four, five, or six forward gears plus reverse. When two pairs of gears are used to create a gear, simply multiply the two ratios together to get the gear ratio.

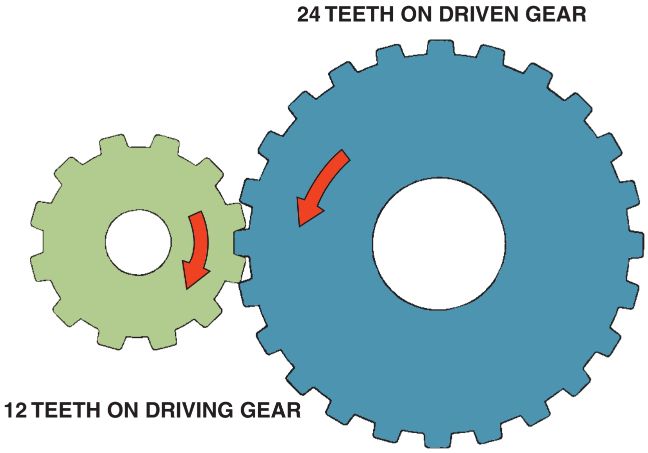


FIGURE 122–7 Gear ratio is determined by dividing the number of teeth of the driven (output) gear (24 teeth) by the number of teeth on the driving (input) gear (12 teeth). The ratio illustrated is 2:1.

A low first-gear (high numerical) ratio creates a high amount of torque applied to the drive wheels to get the vehicle moving. To summarize what is occurring if the engine speed is constant:

First gear:

- Output shaft speed is a lot lower than engine speed.
- Output torque is a lot higher than the engine is producing.

Fifth gear:

- Output shaft speed is faster than the engine speed.
- Output torque is lower than the engine is producing.

DIRECT DRIVE

If two meshed gears are the same size and have the same number of teeth, they will turn at the same speed. Since the drive gear turns once for each revolution of the driven gear, the gear ratio is 1:1; this is called a **direct drive**. When a transmission is in direct drive, the engine and transmission turn at the same speed.

GEAR REDUCTION

If one gear drives a second gear that has three times the number of teeth, the smaller drive gear must travel three complete revolutions in order to drive the larger gear through one rotation. ● **SEE FIGURE 122–8**. Divide the number of teeth on the driven gear by the number of teeth on the drive gear and you get a 3:1 gear ratio (pronounced three to one). This type of gear arrangement, where driven gear speed is slower than drive gear speed, provides **gear reduction**. Gear reduction may also be called underdrive as drive speed is less than, or under, driven speed. Both terms mean the same thing and use is a matter of preference.

Gear reduction is used for the lower gears in a transmission. First gear in a transmission is called "low" gear because output speed, not gear ratio, is low. Low gears have numerically high gear ratios. That is, a 3:1 gear ratio is a lower gear than those with a 2:1 or 1:1 gear ratio. These three ratios taken in order represent a typical upshift pattern from low gear (3:1), to second gear (2:1), to third gear (1:1).

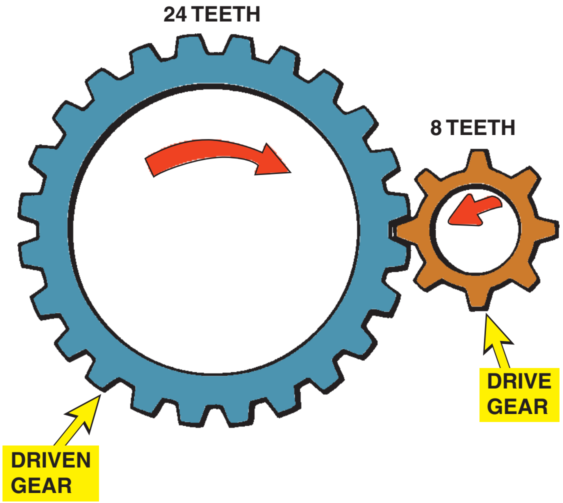


FIGURE 122–8 This gear combination provides a gear reduction of 3:1.

OVERDRIVE **Overdrive** is the opposite of a gear reduction condition and occurs when a driven gear turns faster than its drive gear. For the gears shown in ● **FIGURE 122–9**, the driven gear turns three times for each turn of the drive gear. The driven gear is said to overdrive the drive gear. For this example, the gear ratio is 0.33:1. Overdrive ratios of 0.65:1 and 0.70:1 are typical of those used in automotive applications.

NOTE: Ratios always end in one with a colon in between. Therefore, the first number is less than one if it is an overdrive ratio and greater than one if it is a gear reduction ratio.

IDLER GEARS A gear that operates between the drive and driven gears is called a floating gear, or idler gear. ● **SEE FIGURE 122–10**. Idler gears do not affect the speed relationship between the drive and driven gears, although they do affect the direction of rotation. Reverse gear on a manual transmission often uses an idler gear to change the direction of rotation.

When a drive and driven gear mesh directly, they rotate in opposite directions. When an idler gear is installed between the drive and driven gears, both drive and driven gears rotate in the same direction.

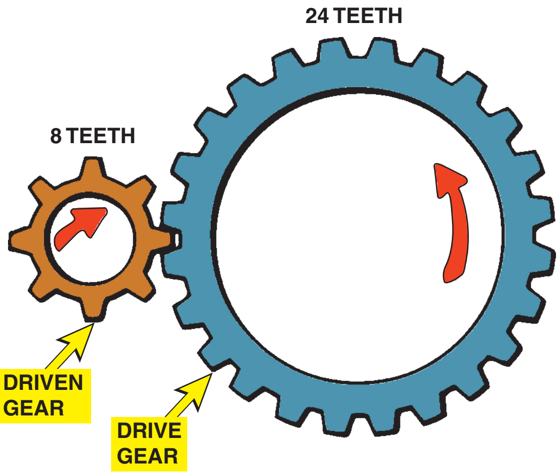


FIGURE 122–9 This gear combination provides an overdrive ratio of 0.33:1.

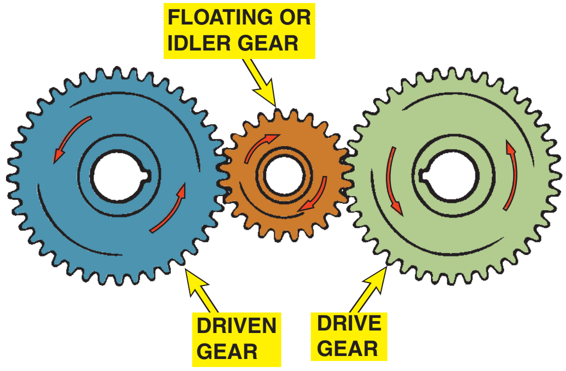


FIGURE 122–10 Idler gears affect the direction of rotation in a gear train, but not the final drive ratio.

TORQUE, SPEED, AND POWER

Torque is a twisting force commonly expressed in pound-feet (lb-ft) or Newton-meters (N-m). Gears apply torque much like a wrench does; each tooth of a gear is actually a lever. On a gear with a 2-foot radius, applying a force of 10 pounds to one gear tooth exerts 20 lb-ft of torque on the center of the shaft to which the gear attaches. ● **SEE FIGURE 122–11**.

TORQUE AND SPEED RELATIONSHIP Torque and speed have an inverse relationship: as one goes up, the other goes down. With a constant input speed, transmission torque decreases as output speed increases. The opposite also applies assuming a constant input speed, transmission torque increases as output speed decreases.

TORQUE MULTIPLICATION Levers can be used to increase or multiply torque. For example, a wheel that is too heavy for a person to turn by muscle power alone turns easily when that same person uses a lever and fulcrum to multiply the applied force. ● **SEE FIGURE 122–12**. The force, or torque, increases at one end, but the lever must be moved a greater distance at the opposite end to obtain the increase in force. Either distance or speed must always be given up in order to increase, or multiply, torque.

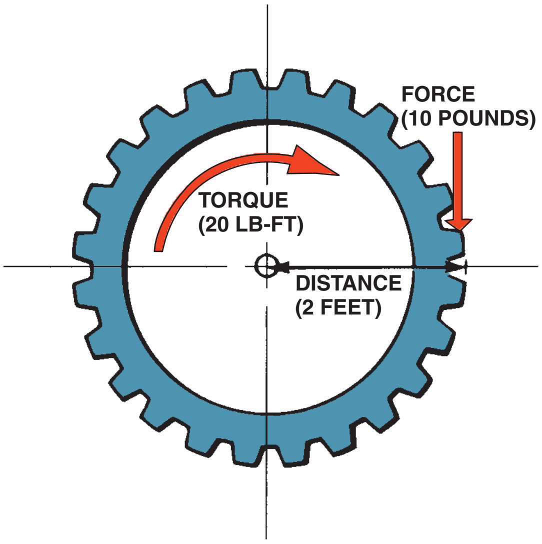


FIGURE 122–11 Gears apply torque in the same way a wrench applies torque—the force applied multiplied by the distance from the center of the gear equals the torque.

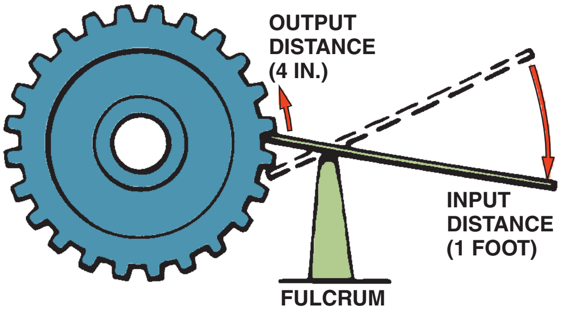


FIGURE 122–12 A lever can be used to multiply torque, but it does so at the expense of distance or speed.

When two gears of the same diameter are meshed, the driven gear will turn at the same speed as the drive gear. Since there is no difference in speed, there is no difference in torque between the two gears.

If the drive gear is one-third the diameter of the driven gear, it must rotate three times for each rotation of the larger gear. This means that the larger gear will turn three times slower than the smaller gear. At the same time, the larger gear will exert three times the torque of the smaller gear. When speed decreases, torque increases. Torque multiplication and gear ratios are directly related. When a gear system is in reduction, there is more torque available at the driven gear, but less speed. When the gear system is in overdrive, there is less torque available at the driven gear, but greater speed.

ENGINE TORQUE CHARACTERISTICS The torque curve of an engine shows how much torque is available at different points within a range of engine speeds.

Because of these characteristics, torque multiplication must be provided between the crankshaft and drive axles to enable a vehicle to begin moving from a standstill and to accelerate at low speeds. Once engine RPM rises beyond the torque peak, a change in gear ratio brings engine speed back within the most efficient torque producing range.

TRANSMISSION CONSTRUCTION

A transmission is usually constructed of cast aluminum machined to accept the internal parts and strong enough to be a structural member of the drive train. The front of the transmission attaches to a separate **bell housing** or includes the bell housing as part of the casting of the transmission itself. At the front of the transmission (toward the engine) is the **front bearing retainer** (sometimes called the **quill**) that supports the clutch throwout (release) bearing and usually houses the front grease seal. The rear of the transmission usually includes a separate casting called the **extension housing**. The center housing is usually referred to as the **transmission case**. ● **SEE FIGURE 122–13**.

The **input shaft** is splined to the clutch disc and is also referred to as the **main gear**, **clutch gear**, or **main drive pinion assembly**. The **main shaft**, also called the **output shaft**, is splined at the end and transmits engine torque to the drive shaft (propeller shaft) through a yoke and universal shaft.

All manual transmissions/transaxles use a **countershaft** (also called a **lay shaft** or **cluster shaft**) to provide the other set of gears necessary to achieve the changes in gear ratios. The gears on the countershaft are called **cluster gears** or **counter gears**.

FREQUENTLY ASKED QUESTION

What Is Meant by a 77 mm Transmission?

The size (77 mm or about 3 inches) is the distance between the center of the input shaft and the center of the countershaft. The greater this distance, the larger the transmission and the more torque it is capable of handling due to the larger gears. ● **SEE FIGURE 122–14**.

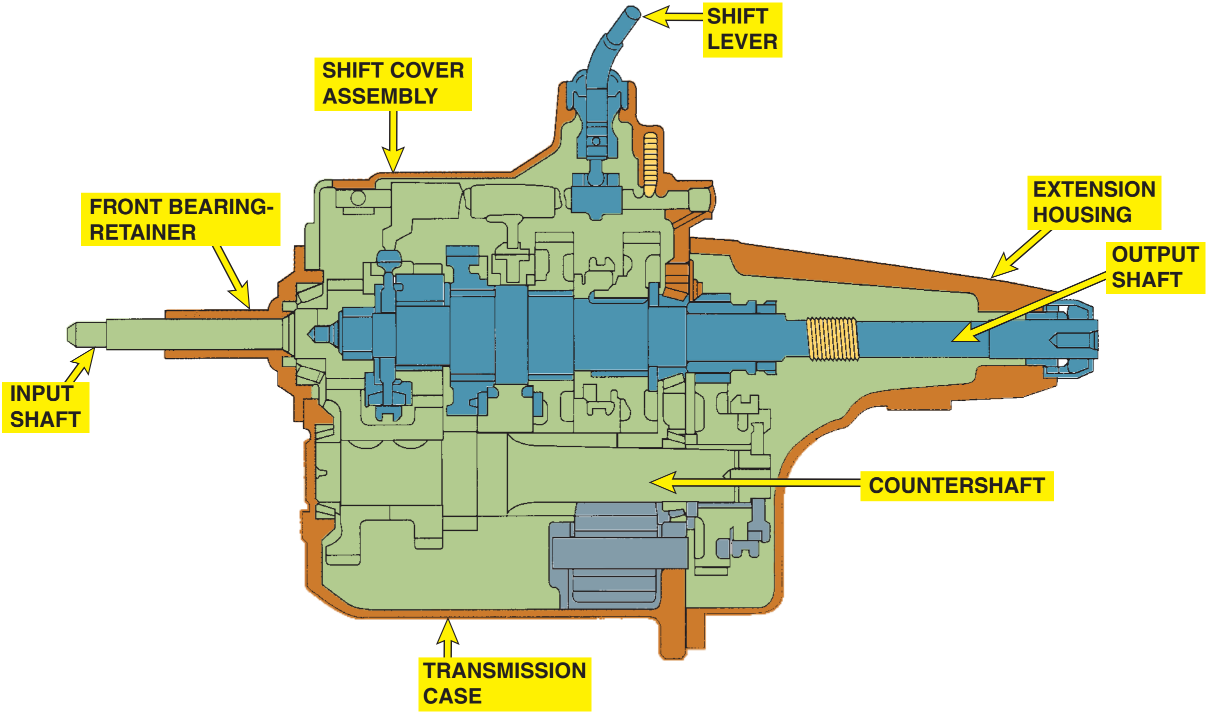


FIGURE 122–13 Cross section of a five-speed manual transmission showing the main parts.

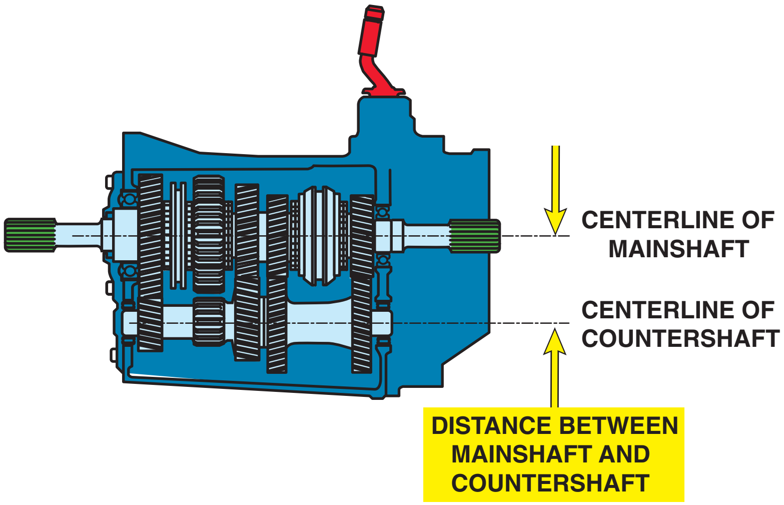

CENTERLINE OF MAINSHAFT
CENTERLINE OF COUNTERSHAFT
DISTANCE BETWEEN MAINSHAFT AND COUNTERSHAFT

FIGURE 122–14 The torque capacity of a transmission is determined by the size of the gear and bearings used. The greater the distance, usually measured in millimeters such as 77 mm, between the main shaft and the countershaft, the greater the torque capacity.

TORQUE FLOW THROUGH A MANUAL TRANSMISSION The engine torque is applied to the input shaft when the clutch is engaged (clutch pedal up). This torque is applied to the main gear, which is in constant mesh with the countershaft gear.

HINT: The fact that the countershaft is revolving any time the clutch is engaged makes transmission noise diagnosis easier.

The engine torque is multiplied by the ratio difference between the main gear and the cluster gear. The engine torque is then transferred and multiplied again when first gear is in mesh with the corresponding first gear on the main (output) shaft. Again, the torque is multiplied by the ratio difference between the two gears. The engine torque then is applied to the drive wheels through the driveshaft, differential, and drive axles.

SPEED GEARS

All gears on the countershaft are permanently attached to the shaft. When the countershaft rotates, all gears on the countershaft rotate. The input shaft gear is also part of the input shaft. However, the gears on the main shaft are free to move on the shaft and are connected to the main shaft through the synchronizer hub when a shift is made. The gears that rotate on the main shaft are called *speed gears* and are free to rotate on a film of oil or on bearings.

HINT: When assembling the main shaft and the countershaft, just remember that each shaft should look like a fir tree (tapered downward from the top). When installed in the transmission, these two "fir trees" are meshed together with the small gear end of one shaft meshing with the large gear end of the other shaft. ● **SEE FIGURE 122–15.**

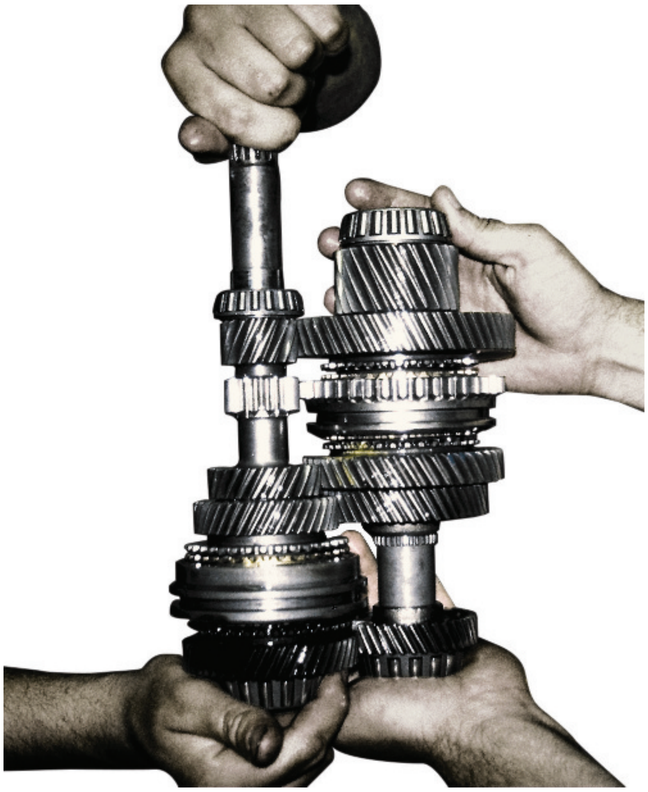


FIGURE 122–15 Notice that the countershaft and the main shaft both use gears of increasing size that mesh together.

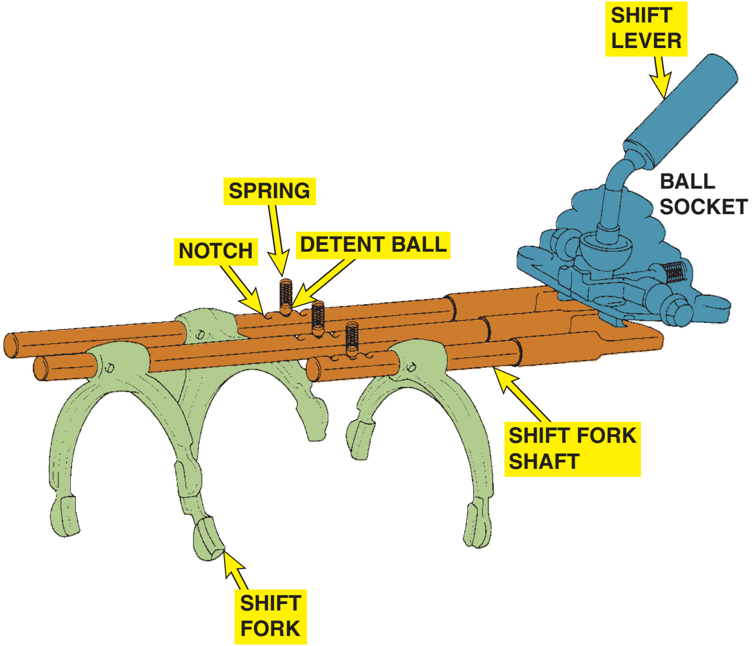


FIGURE 122–16 A typical shift mechanism is designed to not only give the driver a solid feel when shifting, but also prevents shifting into reverse except from the neutral position.

SYNCHRONIZER PARTS AND OPERATION

Most vehicles today in a manually shifted transmission use a floor-mounted shifter to change gears. The shifting lever either moves cables that transfer the shifting motion to the transmission or transaxle or move the shift forks directly. Inside the transmission/transaxle are shift forks that control shifts between two gears, such as first and second or second and third. Interlocks either in the shifter linkage itself or inside the transmission/transaxle prevent the accidental selection of reverse except when shifting from neutral and also prevent selecting two gears at the same time. ● **SEE FIGURE 122–16.**

Synchronizers are used in manual transmissions/transaxles to make shifting easier. To synchronize means to make two or more events occur at the same time. When the driver depresses the clutch pedal, torque is no longer being transmitted to the input shaft and the drive wheels are "driving" the main shaft of the transmission/ transaxle. To achieve a clash-free (no grinding sound) shift, the two gears to be meshed must be rotating at the same speed. The detents and interlocks hold the shift mechanism in position.

The real "shifting" in a synchromesh transmission takes place in the **synchronizer assemblies**, not the gears. Most synchronizer assemblies ride on the output shaft between two gears. A synchronizer assembly is named for the gears on either side of it, which are the two speeds that it engages. For example, a five-speed transmission with constant-mesh reverse uses a 1–2 synchronizer, 3–4 synchronizer, and a 5-reverse synchronizer.

SYNCHRONIZER CONSTRUCTION Although there are a number of design variations, all are similar and include a hub, a **sliding sleeve**, a **blocker ring** (or **stop ring** or **synchronizer ring**), **keys**, and **springs**. In addition, the tapered cone and coupling teeth machined on the speed gear are part of the synchronizer assembly. ● **SEE FIGURE 122–17**. In a typical synchronizer:

- Splines attach the center **hub** of the synchronizer to the output shaft, so the hub and output shaft rotate together. There are also splines machined on the outer circumference of the hub.
- An outer sliding sleeve rides on the external hub splines with enough clearance so that it slides freely. The splines on the sleeve also match the small coupling teeth of the stop ring and speed gear. Coupling teeth are also called engagement or clutch teeth. The sleeve is splined to the hub, so it rotates with the output shaft.
- A **stop ring** sits between the speed gear and the sleeve. The coupling teeth on the stop ring match those on both the sleeve and the speed gear. The stop ring also has a tapered cone to match the cone machined on the speed gear.
- Small, spring-loaded detent keys, also called **synchronizer keys** or **struts,** ride in slots on the outer sleeve. The stop ring has slots to match these keys. This allows the stop ring to rotate slightly, relative to the sleeve, before the keys hit the sides of their slots and stop the stop ring. As the sleeve moves, the synchronizer keys move with it, which pushes the blocking ring onto the tapered cone of the speed gear.

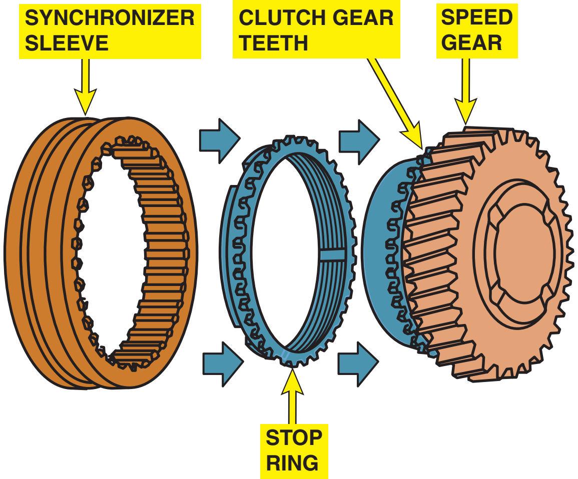


FIGURE 122–17 The shifter fork fits into the groove of the synchronizer sleeve. When a shift is made, the sleeve is moved toward the speed gear. The sleeve presses the stop ring (synchronizer ring) against the cone area of the speed gear. The friction between the stop ring and the speed gear causes the speed of the two to become equal, permitting the sleeve to engage the gear clutch teeth of the speed gear. When this engagement occurs, the shift is complete.

SYNCHRONIZER OPERATION When the outer sliding sleeve is centered on the hub, the synchronizer is in its neutral position—it does not contact either of the speed gears. ● **SEE FIGURE 122–18**. To shift into gear, the driver disengages the clutch and moves the shift linkage. The shift linkage, which is described later in this chapter, pushes the sleeve toward one of the speed gears. As the sleeve moves, the detent keys help guide the stop ring toward the speed gear. This causes the ring cone to slide onto the tapered cone of the speed gear.

The speed gear is turning because it is in constant mesh with a countershaft gear. However, the gear may not be turning at the same speed as the synchronizer assembly even though both are on the same shaft. When the clutch is disengaged, the engine is no longer driving the transmission, so there is no torque applied to the input shaft, and the countershaft, or cluster gear, simply freewheels. As the shift is made, the stop ring acts as a brake to slow down the gear so that its speed matches the speed of the synchronizer assembly. That is, it synchronizes the shift. This matched speed allows the internal hub splines to easily engage the coupling teeth on the stop ring and speed gear. When the clutch disengages, the crankshaft drives the input shaft, which drives the countershaft, which drives the output shaft through the selected gear.

The synchronizer goes through three stages during a shift:

1. As the shift is selected, the sliding sleeve moves toward the speed gear. If the speeds of the sliding sleeve (main shaft) and the speed gear (counter shaft) are not identical, the speed difference will cause the tapered cone to "mis-align" the teeth of the sleeve, the stop ring, and the speed gear. This "blocks" the shift. Now, the tapered teeth of the sliding sleeve push against the teeth of the stop ring, which in turn pushes the stop ring tapered surface up against the tapered surface of the speed gear. This causes the speed gear to either speed up or slow down based on the difference between the main shaft speed (hub) and the counter gear speed (speed gear). When the speeds are equal, the

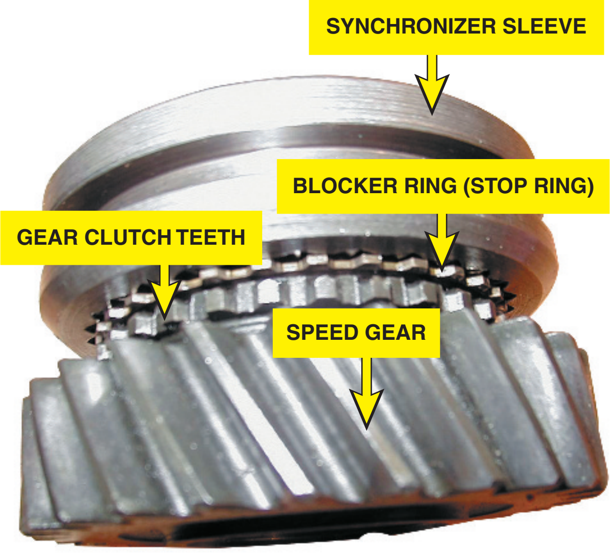


FIGURE 122–18 Typical synchronizer assembly.

thrust is released on the tapered surface, which now allows the "alignment" of the sliding sleeve teeth, the stop ring teeth, and the speed gear teeth that allows the shift to be completed. ● **SEE FIGURE 122–19**.

2. The sleeve overcomes the force of the detent key springs as the shift linkage continues to move it toward the gear. This allows the stop ring to relax and move slightly so that the sleeve splines begin to engage the coupling teeth on the stop ring. At this point, the coupling teeth on the stop ring and the speed gear may not line up with each other. However, friction continues to build between the ring and the cone, so the gear continues to slow down.
3. Once the sleeve, stop ring, and gear are all turning at the same speed, it takes just a small movement between the stop ring and gear to align the coupling teeth and allow the sleeve to slip completely over both sets. The speed gear is now locked to the output shaft through the synchronizer stop ring and sleeve. ● **SEE FIGURE 122–20**.

Synchronizer stop rings are a simple type of clutch, called a cone clutch for the shape of the mating surfaces. Some manufacturers refer to the synchronizer action as "clutching."

Synchronizer sleeves and hubs are gear-quality steel. Stop rings are a softer metal—usually brass, copper, or a sintered metal—to absorb the friction of synchronizer operation.

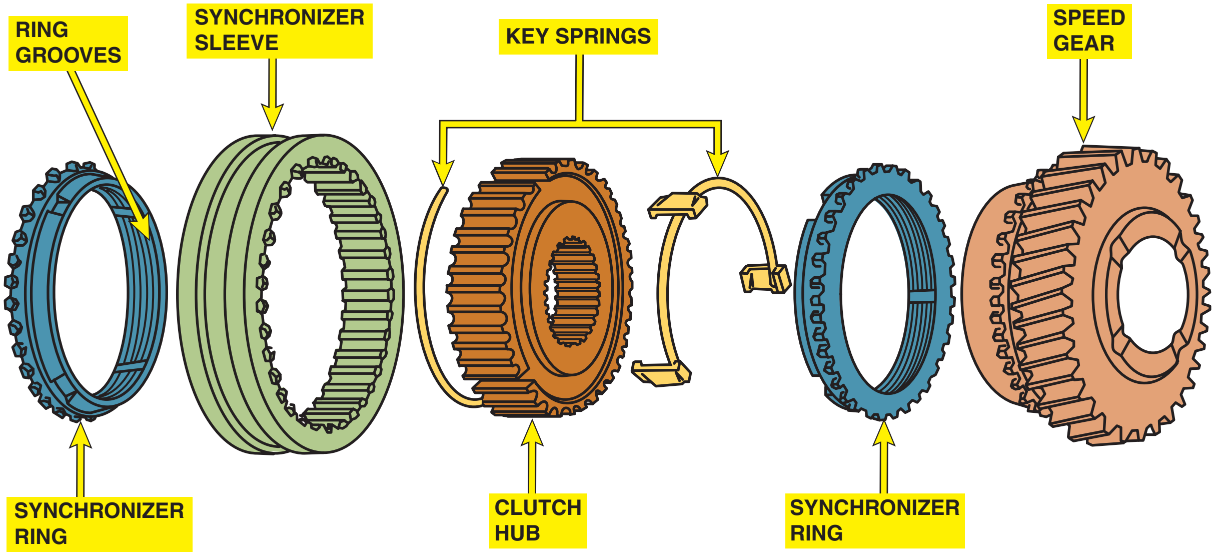


FIGURE 122–19 Synchronizer keys are attached to the clutch hub and push against the synchronizer ring when the sleeve is being moved during a shift. Notice the grooves on the synchronizer ring. These grooves prevent lubricating oil from becoming trapped between the ring and the cone surface of the speed gear. The grooves also help the ring release from the cone surface when a shift is made out of a gear.

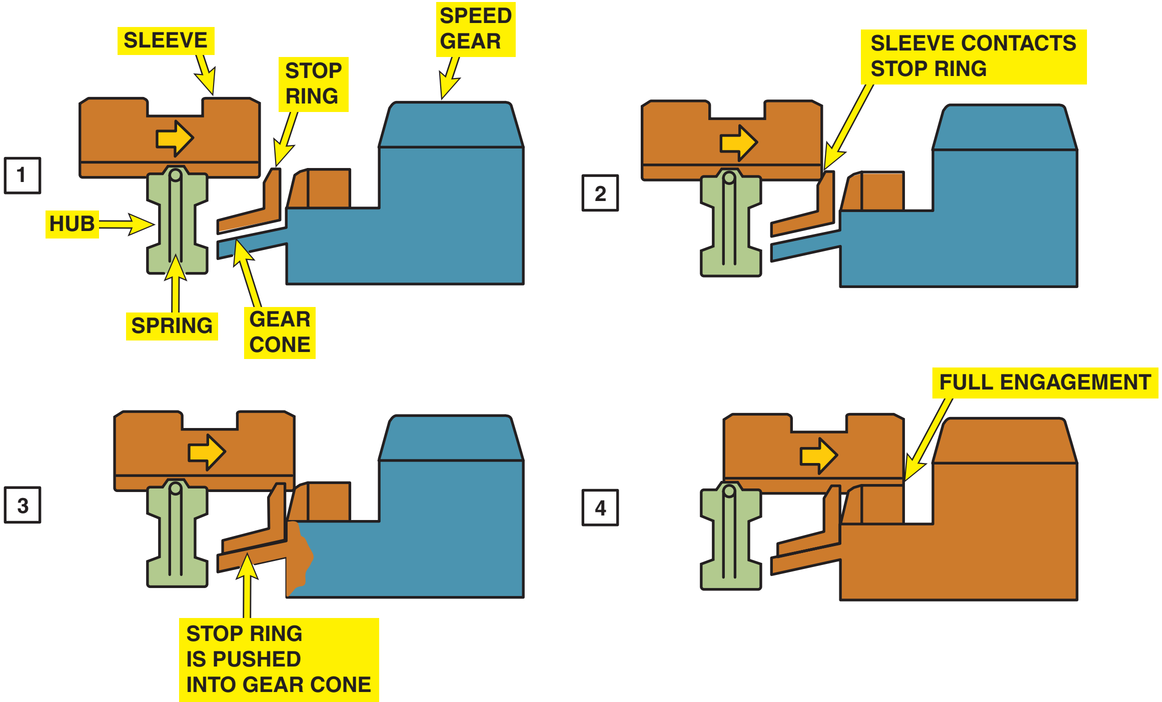


FIGURE 122–20 A shift sequence starts when the shift fork is moved by the driver, (1) applying a force on the sleeve that moves it toward the speed gear. (2) The sleeve and the inserts contact the stop ring (blocking ring). (3) The synchronizer ring (stop ring) engages the cone on the speed gear, causing both assemblies to reach the same speed. (4) The shift is completed when the internal teeth of the sleeve mesh with the gear clutch teeth of the speed gear.

FREQUENTLY ASKED QUESTION

What Do the Keys Do?

The keys are there to limit the amount of rotation of the ring from 1/2 tooth misaligned in the forward direction, to 1/2 tooth misaligned in the "coast" direction so that both upshifts and downshifts can be made. The detent key springs are designed to "push up" on the keys that have a "bump" on them that aligns with a notch in the inside center of the sliding sleeve. This upward pressure tends to keep the sliding sleeve in the neutral position and prevents unwanted movement toward another unwanted gear.

The tapered cone is relieved, that is, grooves are machined into its contact surface. These grooves serve two purposes; they

- Channel excess lubricant out from between the two pieces for better contact.
- Retain a small amount of lubricant. This decreases wear when the cone clutch must slip slightly during coupling tooth alignment.

The internal splines on the synchronizer sleeve and the coupling gear teeth on stop rings and speed gears have a special shape that works to hold the gear engaged once the driver releases the shift lever. The ends of the gear teeth are chamfered, giving them a triangular shape. These pointed ends allow easier sleeve-to-gear alignment as the angles tend to center the splines between the teeth. Once aligned, a back taper machined behind the chamfered end of the teeth and splines tends to keep the sleeve in place until the linkage pushes the sleeve away for another shift. **Back taper** is an angle cut opposite to the chamfer so that spline or tooth narrows just behind the chamfered end. ● **SEE FIGURE 122–21**. The back taper creates resistance to motion to keep the splines from sliding off the coupling teeth. This is especially important when there is no torque load, such as coasting, to help keep the parts meshed. Worn back taper may cause the transmission to jump out of gear, usually when the throttle is released.

Some synchronizer stop rings have friction material on the cone surface. This paper friction material is the same as used on automatic transmission clutch plates and provides a smoother synchronizing action than metal-to-metal contact. A manual transmission with paper stop rings must use automatic transmission fluid (ATF). Other lubricants damage the paper ring surface. ● **SEE FIGURE 122–22**.

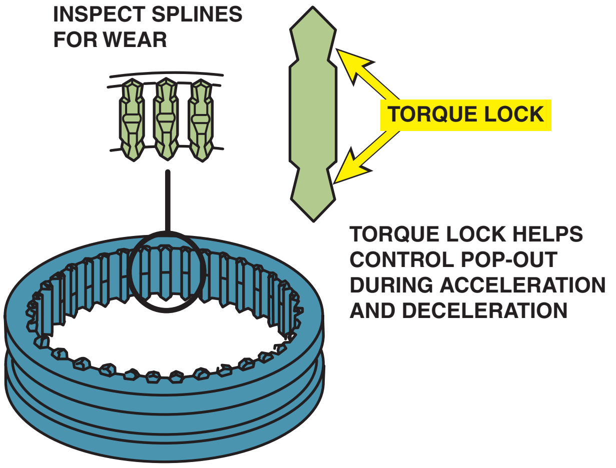

INSPECT SPLINES FOR WEAR
TORQUE LOCK
TORQUE LOCK HELPS CONTROL POP-OUT DURING ACCELERATION AND DECELERATION

FIGURE 122–21 Before reassembling the transmission/transaxle, carefully inspect the splines on the synchronizer sleeves for wear. The shape of the splines helps prevent the transmission/transaxle from jumping out of gear during acceleration and deceleration.

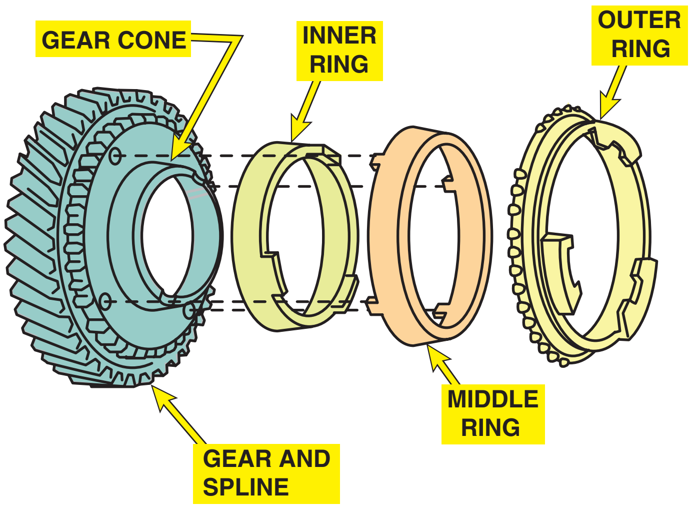


FIGURE 122–22 Exploded view of a triple-cone synchronizer. The inner and outer rings rotate with the synchronizer sleeve while the middle ring rotates with the speed gear.

FIVE-SPEED TRANSMISSION TORQUE FLOW

FIVE-SPEED TRANSMISSION A five-speed transmission has six gear sets that provide five forward speeds and one reverse speed. Either a sliding gear or constant-mesh gears may be used for reverse. All forward gears are the constant-mesh type. The Borg-Warner T5 manual transmission serves as an example of a contemporary five-speed design. In addition to reverse, the T5 provides three gear reduction ratios (first, second, and third), direct drive (fourth), and an overdriven ratio (fifth). A sliding idler gear is used to change output shaft direction and provide reverse.

NEUTRAL In **neutral**, all of the synchronizer sleeves are centered on their hubs as shown in ● **SEE FIGURE 122–23**. Note that in this

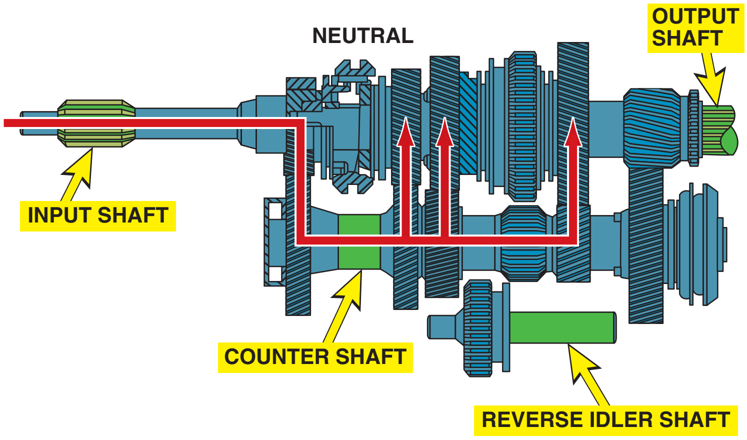


FIGURE 122–23 In neutral, the input shaft and the countershaft are rotating if the clutch is engaged (clutch pedal up), but no torque is being transmitted through the transmission.

and the following illustrations the reverse idler shaft and sliding gear have been repositioned for clarity. In actuality, the assembly is positioned so it meshes with the reverse gears of the countershaft and output shaft simultaneously.

With the clutch engaged, the drive gear of the input shaft turns the cluster gear, or countershaft. The speed gears are driven by the cluster gears, but rotate freely, on the output shaft. The output shaft may turn if the vehicle is moving or coasting, but no engine torque being transferred through the transmission.

FIRST GEAR In **first gear**, the shift linkage slides the 1–2 synchronizer sleeve rearward toward the first speed gear. ● **SEE FIGURE 122–24**. The synchronizer assembly locks the speed gear to the output shaft.

With the clutch engaged, the input shaft drives the countershaft, delivering engine torque to the gearbox. Torque transfers from the first counter gear to the first speed gear, which drives the output shaft through the 1–2 synchronizer hub splines. Torque flows through the transmission in gear reduction at the first gear ratio.

SECOND GEAR In **second gear**, the shift linkage slides the 1–2 synchronizer sleeve forward, away from the first speed gear and toward the second speed gear. ● **SEE FIGURE 122–25**. The synchronizer assembly releases first gear, then locks the second speed gear to the output shaft.

With the clutch engaged, the input shaft is driven at crankshaft speed and turns the countershaft. Engine torque transfers from the second counter gear to the second speed gear, which drives the output shaft through the 1–2 synchronizer hub splines. Torque flows through the transmission in gear reduction at the second gear ratio.

THIRD GEAR In **third gear**, the shift linkage centers the 1–2 synchronizer sleeve and moves the 3–4 synchronizer sleeve back toward the third speed gear. ● **SEE FIGURE 122–26**. The synchronizer assembly locks the third speed gear to the output shaft.

With the clutch engaged and the input shaft driving the countershaft, the third counter gear transfers torque to the third speed gear. The speed gear drives the output shaft through the 3–4 synchronizer hub splines. Torque flows through the transmission in gear reduction at the third gear ratio.

FOURTH GEAR In **fourth gear**, the shift linkage moves the 3–4 synchronizer sleeve forward, away from the third speed gear and toward the input shaft drive gear. ● **SEE FIGURE 122–27**. The synchronizer assembly locks the input shaft drive gear to the output shaft.

With the clutch engaged, the input shaft drives the output shaft through the 3–4 synchronizer hub splines and both shafts rotate at crankshaft speed. Torque flows straight through the transmission

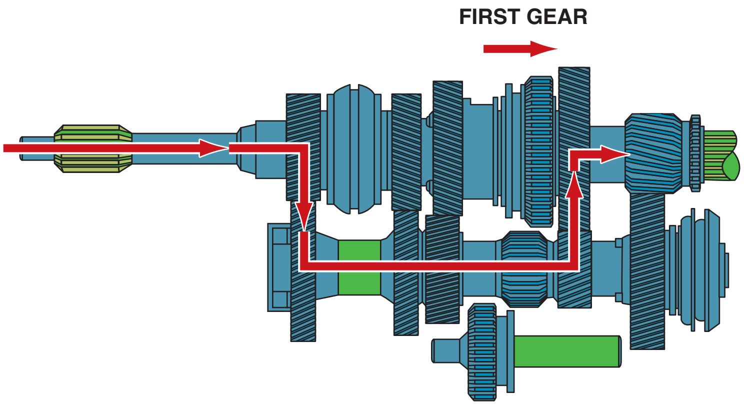


FIGURE 122–24 In first gear, the 1–2 synchronizer sleeve is moved rearward, locking the first speed gear to the output shaft. Torque is transmitted from the input shaft to the countershaft and then to the output shaft.

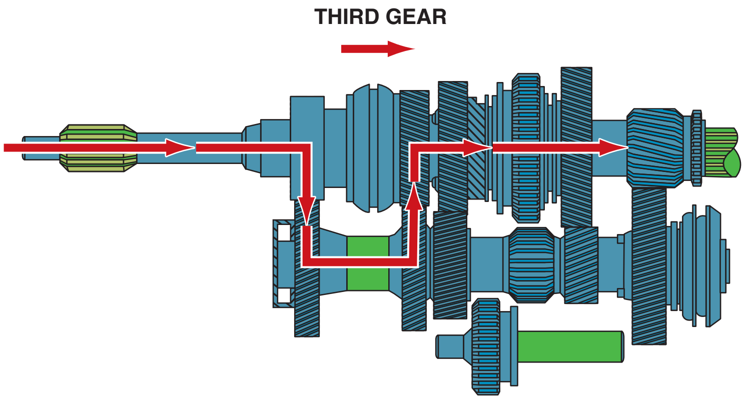


FIGURE 122–26 To achieve third gear, the shaft linkage first centers the 1–2 synchronizer sleeve and then moves the 3–4 synchronizer sleeve rearward, locking third speed gear to the output shaft.

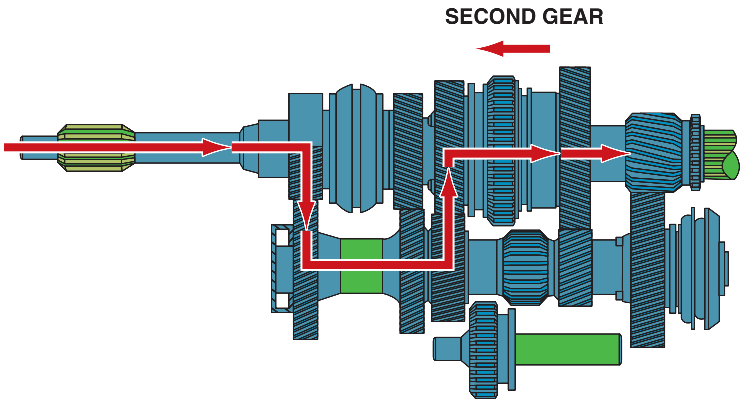


FIGURE 122–25 In second gear, the 1–2 synchronizer sleeve is moved forward, which locks the second speed gear to the output shaft.

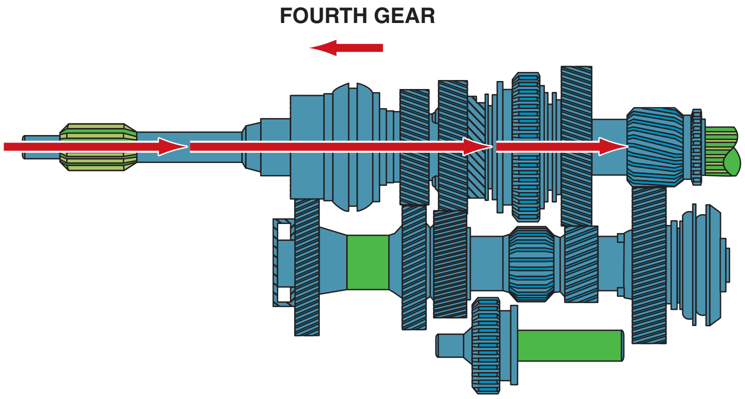


FIGURE 122–27 In fourth gear, the 3–4 synchronizer sleeve is moved forward, which locks the fourth speed gear to the output shaft.

at a 1:1 ratio, delivering engine torque to the drive shaft. This is called direct drive because there is no gear reduction through the transmission. The counter gears also turn because they are in constant mesh, but they do not affect torque flow because all of the speed gears are freewheeling on the output shaft.

FIFTH GEAR In **fifth gear**, the shift linkage centers the 3–4 synchronizer sleeve and moves the fifth synchronizer sleeve toward the fifth speed gear. ● **SEE FIGURE 122–28**. Note that on the T5 transmission the synchronizer assembly locks the fifth speed gear to the countershaft. The speed gear drives a fixed gear on the output shaft.

With the clutch engaged, the input shaft drives the countershaft. The fifth synchronizer hub is splined to the countershaft, so it is driven and driving the fifth speed gear when fifth gear is engaged. This transfers engine torque to the output shaft through the fixed fifth gear. Note the countershaft gear is larger than the output shaft gear. Therefore, fifth gear is overdriven. Torque flows through the transmission at the fifth gear, or overdrive, ratio. Typical overdrive gear ratios are between 0.6:1 and 0.8:1. This lowers engine speed for economical highway cruising.

On some five-speed transmissions, the fifth speed gear is on the output shaft with the other speed gears. This type of arrangement is typically used with constant-mesh reverse gears. In these designs, fifth and reverse gears share a synchronizer assembly. The fixed countershaft gear drives the speed gear, which drives the output shaft through the hub splines when the sliding sleeve is engaged. Torque flow through the transmission is similar to any of the gear reduction forward speeds detailed above, but the fifth speed gear is generally overdriven.

REVERSE There are two common **reverse** gear designs used on transmissions:

1. Sliding gear.
2. Constant-mesh gear.

With a **sliding reverse gear** design, such as on the Borg-Warner T5, the shift linkage slides the reverse idler gear on its shaft until it engages the reverse gears on the countershaft and output shaft gear. Both gears are fixed to their respective shafts. This design uses spur gears for reverse, not helical gears, because the gear teeth must move into and out of mesh. On some gearboxes, the sliding gear splines to the output shaft. The linkage moves the gear along the output shaft splines to engage the reverse idler gear.

An unusual feature of the Borg-Warner T5 is that it does not have a separate reverse output shaft gear. ● **SEE FIGURE 122–29**. Instead, spur teeth machined around the outside of the 1–2 synchronizer sleeve act as the reverse output gear. When the T5 is shifted into reverse, the linkage moves the reverse idler gear rearward so it simultaneously meshes with the countershaft reverse gear and the gear on the synchronizer sleeve.

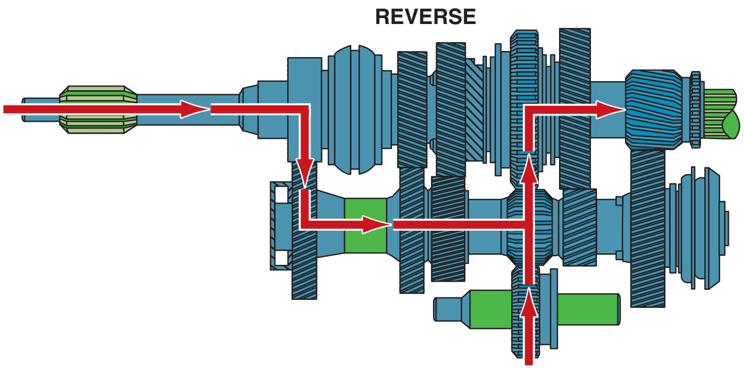


FIGURE 122–29 Torque flows through the transmission in reverse gear. Note that the idler gear drives the 1–2 synchronizer sleeve gear, which is splined to the output shaft.

When the clutch is engaged, the countershaft is driven and the reverse gear drives the idler gear, which rotates in the opposite direction of the countershaft. The idler gear drives the 1–2 synchronizer sleeve, so there is another directional change in rotation. Although the sleeve is not engaged to a speed gear, it remains splined to the output shaft, so the sleeve drives the output shaft when the idler gear is engaged. The output shaft rotates in the opposite direction of the input shaft because the idler gear is between them.

With **constant-mesh gears**, the shift linkage moves the 5-reverse synchronizer sleeve away from the fifth speed gear and toward the reverse speed gear when reverse is selected. Typically, no stop ring is used between the synchronizer sleeve and the reverse gear, so the output shaft must be stopped to engage reverse without grinding the sleeve splines against the coupling teeth of the reverse gear. The synchronizer assembly locks the reverse speed gear to the output shaft.

With the clutch engaged, the input shaft drives the countershaft. The reverse counter gear drives the reverse idler gear, which drives the reverse speed gear in the direction opposite normal rotation. The reverse speed gear drives the output shaft through the 5-reverse synchronizer hub splines. Torque flows through the transmission in gear reduction at the reverse gear ratio. The output shaft turns opposite its normal direction of rotation, so the vehicle moves to the rear. ● **SEE FIGURE 122–30**.

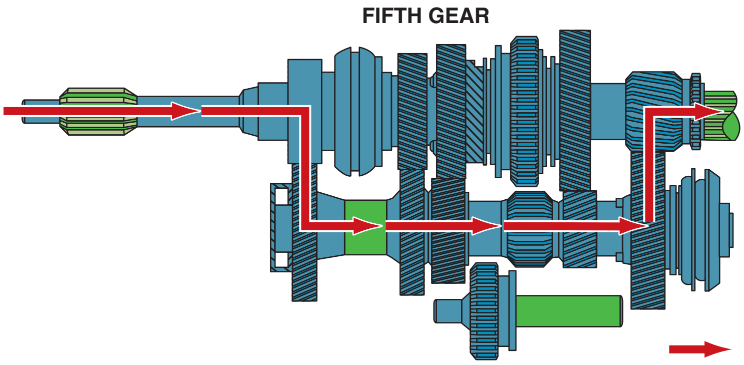


FIGURE 122–28 To achieve fifth gear, the shift linkage first centers the 3–4 synchronizer sleeve and then moves the fifth synchronizer sleeve toward the fifth speed gear, locking it to the output shaft.

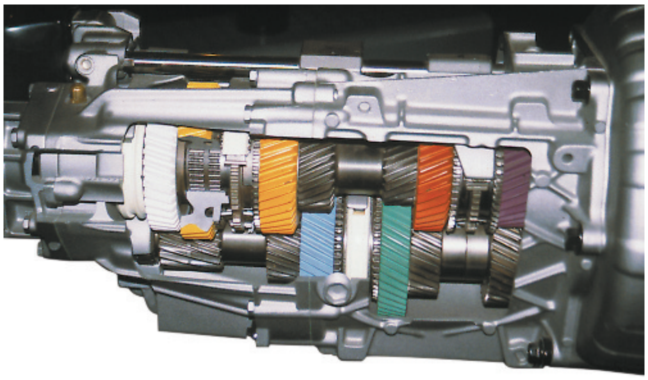


FIGURE 122–30 Cutaway of a T56 six-speed transmission showing all of its internal parts.

MANUAL TRANSMISSION/ TRANSAXLE CONSTRUCTION AND SERVICE

MANUAL TRANSAXLE CONSTRUCTION A manually shifted transaxle includes an input shaft, an output shaft, and a differential assembly all in one case. The input shaft is attached to the clutch, which transfers engine torque from the engine flywheel to the input shaft when the clutch is engaged. Most transaxles use speed gears and synchronizers on both the input and output shafts, as shown in ● **SEE FIGURE 122–31**. The differential assembly, also called a **final drive assembly**, attaches to the output shaft and splits the torque to both front drive axles. ● **SEE FIGURE 122–32**.

HARD-TO-SHIFT DIAGNOSIS Several items that could be worn or defective can cause a manual transmission/transaxle to be difficult to shift, including

- Clutch not fully disengaging. If the clutch linkage is not properly adjusted or if there is a leak in the hydraulic clutch linkage, the clutch may not be fully disengaged. A shift is very difficult, if not impossible, if engine torque is being transferred through the transmission/transaxle as a shift is being attempted.
- Worn synchronizer. If the synchronizer rings are worn, the rings will be unable to properly match the speed gear speed, making the shift difficult and/or creating gear clash (noise) when shifting.
- Worn, cracked, or loose shift forks. If there is any problem with the shift forks, the synchronizer cannot be properly moved during a shift attempt, making shifting difficult, if not impossible. If only one fork is worn or defective, usually engaging two gears instead of one is likely.
- Excessive input- or main-shaft end play. Excessive end play in the input or main shaft will cause the gears to move away from the synchronizer assembly, resulting in grinding during shifts or shifts that are difficult or impossible to complete.
- Improper lubrication. Many of today's manual transmissions use synchronizer rings (blocking rings) that are lined with compounds, paper, or other friction material. All of these transmissions/transaxles must be filled with the proper fluid formulated for proper shifting.

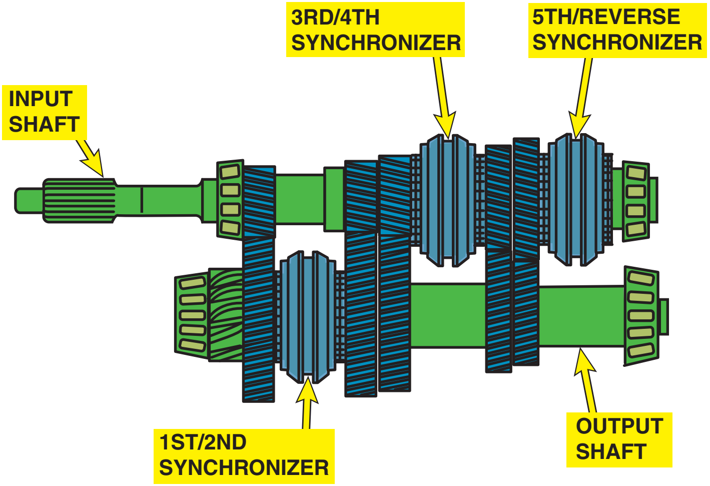


FIGURE 122–31 Notice that this five-speed transaxle from a Dodge/Plymouth Neon uses synchronizers on both the input and output shafts.

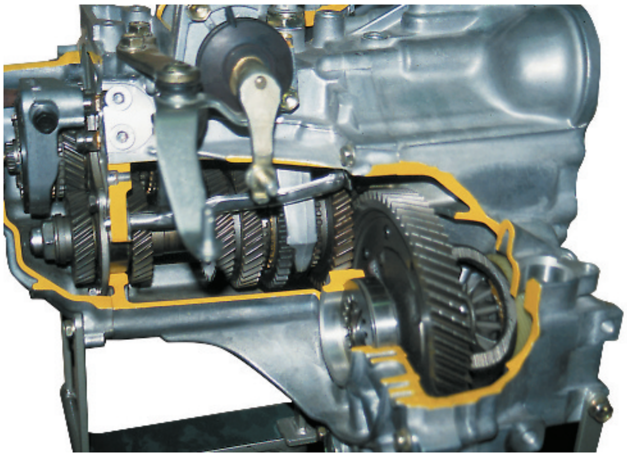


FIGURE 122–32 Cutaway of a typical manual transaxle showing all of its internal parts including the final drive assembly.

NOTE: A worn synchronizer sleeve and/or blocking ring can cause the transmission/transaxle to pop out of gear while accelerating or decelerating.

TRANSMISSION/TRANSAXLE REMOVAL Before removing the transmission/transaxle for service, double-check that the problem is not due to any malfunction of the clutch or shift linkage. To remove a transmission or transaxle, always follow the procedure in the service manual to be assured of doing no harm to either the vehicle or to yourself. Steps typically involved in the removal and disassembly include

- Disconnecting the negative battery cable.
- Safely hoisting and supporting the vehicle.
- Supporting the engine with a holding fixture or other support (front-wheel-drive). ● **SEE FIGURES 122–33 AND 122–34**.
- Removing the drive axle shafts or drive shaft (rear-wheel-drive).
- Removing the clutch linkage and shift linkage. ● **SEE FIGURE 122–35**.

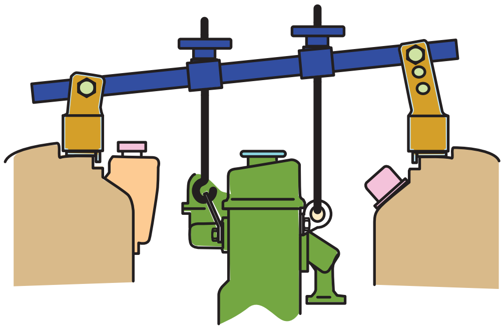


FIGURE 122–33 Most front-wheel-drive (FWD) vehicles require the use of a fixture to support the engine before removing the transaxle.

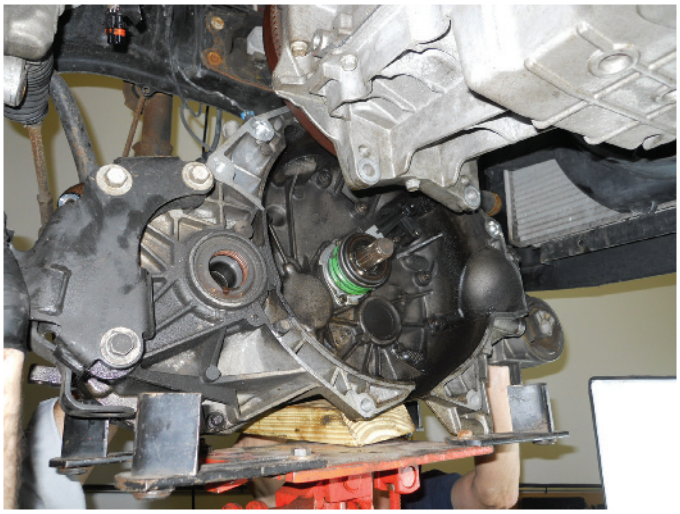


FIGURE 122–34 A transaxle being removed from underneath a vehicle and being supported by a transmission jack.

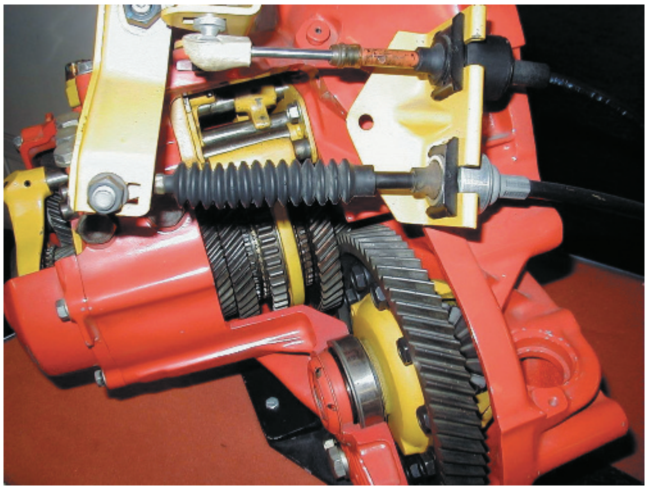


FIGURE 122–35 Typical cable-operated shift linkage used on a front-wheel-drive transaxle.

- Disconnecting the vehicle speed sensor and reverse (backup) light connectors.
- Removing the attaching bolts/nuts from the engine and transmission/transaxle mounts and then removing the unit from the vehicle.

Sometimes it is easier to remove the entire power train (engine and transaxle as an assembly) from the vehicle. When the entire assembly has been removed from the vehicle, often the transaxle can then be removed from the engine.

TRANSMISSION/TRANSAXLE DISASSEMBLY Before disassembling the transmission/transaxle, drain any remaining gear lubricant from the unit and dispose of it properly. ● **SEE FIGURE 122–36**.

CAUTION: Most extreme pressure (EP) lubricants contain sulfur compounds that can cause skin irritation. Either wear protective gloves or wash your hands thoroughly using soap and water after exposure to used gear lubricant.

Mount the transmission/transaxle on a holding fixture or place it on a large, clean work surface. Many vehicle manufacturers recommend removing the shift housing before further disassembly. The removal of the shifter housing allows the technician to see any obvious damage as well as providing the opportunity to check the shift forks, which are frequently worn in manually shifted transmissions/transaxles. ● **SEE FIGURES 122–37 AND 122–38**.

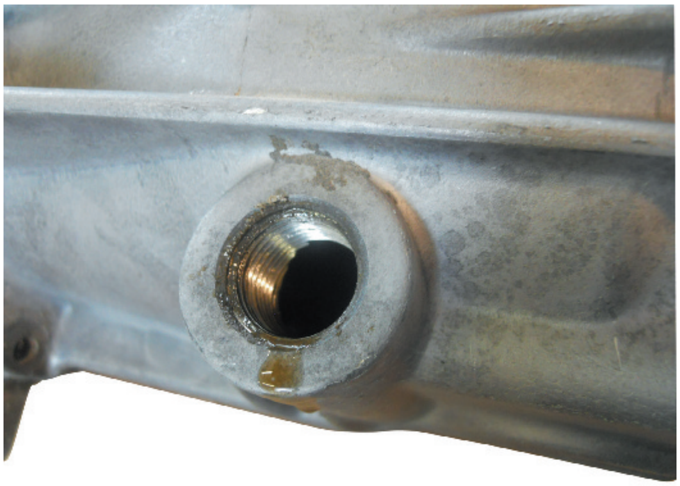


FIGURE 122–36 Drain the fluid into a suitable container and dispose of the old fluid according to local, state, and federal regulations.

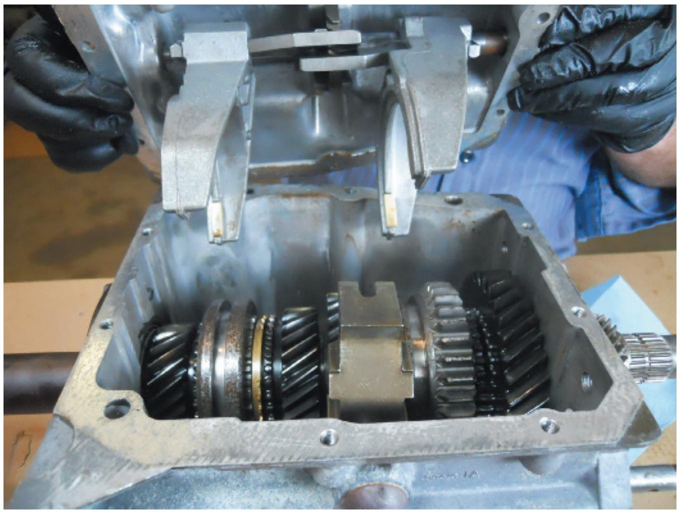


FIGURE 122–37 A Borg-Warner T5 five-speed transmission shown with the shifter cover removed.

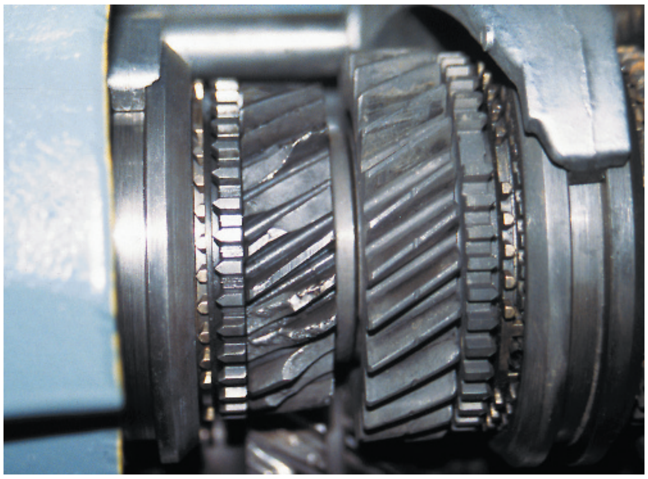


FIGURE 122–38 The cost to replace these gears may exceed the cost of a replacement transmission.

TECH TIP

Manual Transmission Service Tips

A wise technician once told a beginning technician to remember these items when working with transmissions:

- Always use a *brass* or *plastic* hammer when pounding on a steel or aluminum component.
- If using a steel hammer, always use a *brass* or *aluminum* punch or place wood between the steel components and the hammer.
- Many parts can be installed in either direction but usually only one way is correct.
- If you are exerting a lot of force, you are probably doing something wrong.
- Many drive train parts are pulled or pressed off and pressed or driven on.

The disassembly and reassembly of a manual transaxle is similar to that for a manual transmission except for the addition of the final drive unit. Some transaxles require two people for disassembly and reassembly because often the shift linkage has to be held in place while assembled components are placed into the case, as shown in ● **FIGURE 122–39**.

Check the service manual for the exact disassembly procedures to follow for the unit being serviced. Sometimes the main shaft is removed through the rear of the transmission and sometimes it is removed through the top of the case. Also look for hidden snap rings. ● **SEE FIGURES 122–40 AND 122–41**. Also see the Tech Tip titled “Manual Transmission Service Tips.”

END PLAY/PRELOAD CHECKS During the reassembly of a transaxle/transmission that uses tapered roller bearings, the preload or end play of each shaft should be checked. A selective shim is located at a bearing at one end of each shaft, and the thickness of this shim controls the amount of preload or end play.

- Preload causes a slight drag as a shaft is rotated, and it is usually measured using a torque wrench or spring scale.
- End play is a free, lengthwise movement of the shaft and is usually measured using a dial indicator or feeler gauge. ● **SEE FIGURE 122–42**.

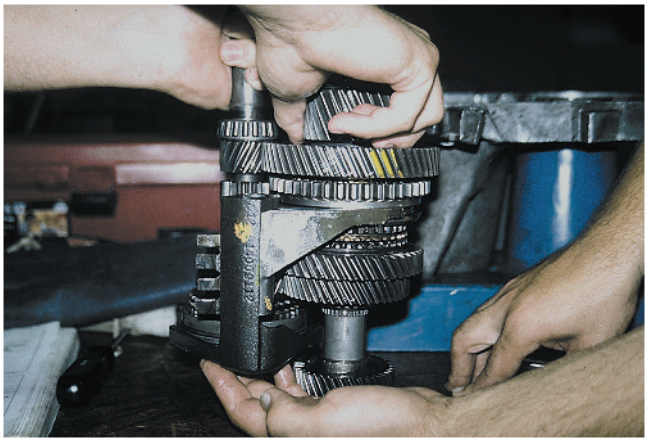


FIGURE 122–39 It often requires two people to assemble a transaxle because the shaft with the shifter forks needs to be placed into the case as an assembly, as on this unit.

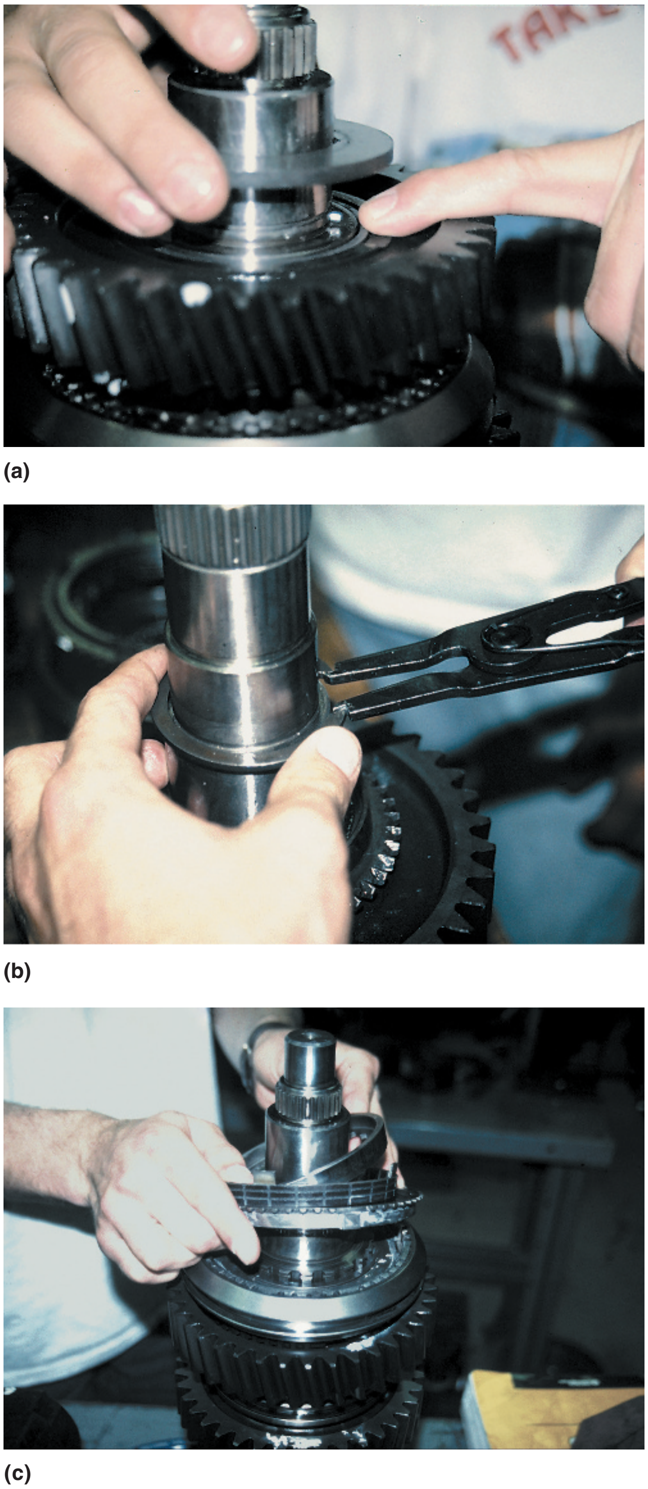


FIGURE 122–40 (a) During the disassembly of any manual transmission/transaxle, carefully check for the location of the snap rings. Often they are hidden. Consult the factory service manual or unit repair manual for information and procedures for the unit being serviced. (b) Using snap-ring pliers to remove a snap ring. Many snap rings have an “up” side. Be sure to reinstall any snap rings in the correct direction. (c) After the snap ring is removed, some components can be simply lifted off the main shaft, while other gears may require the use of a press.

MANUAL TRANSMISSION INSTALLATION When installing a repaired or replacement transmission/transaxle, the clutch should be carefully inspected and replaced as necessary. The clutch friction disc must be held in position using an alignment tool that is secured in the pilot bearing. This holds the disc in

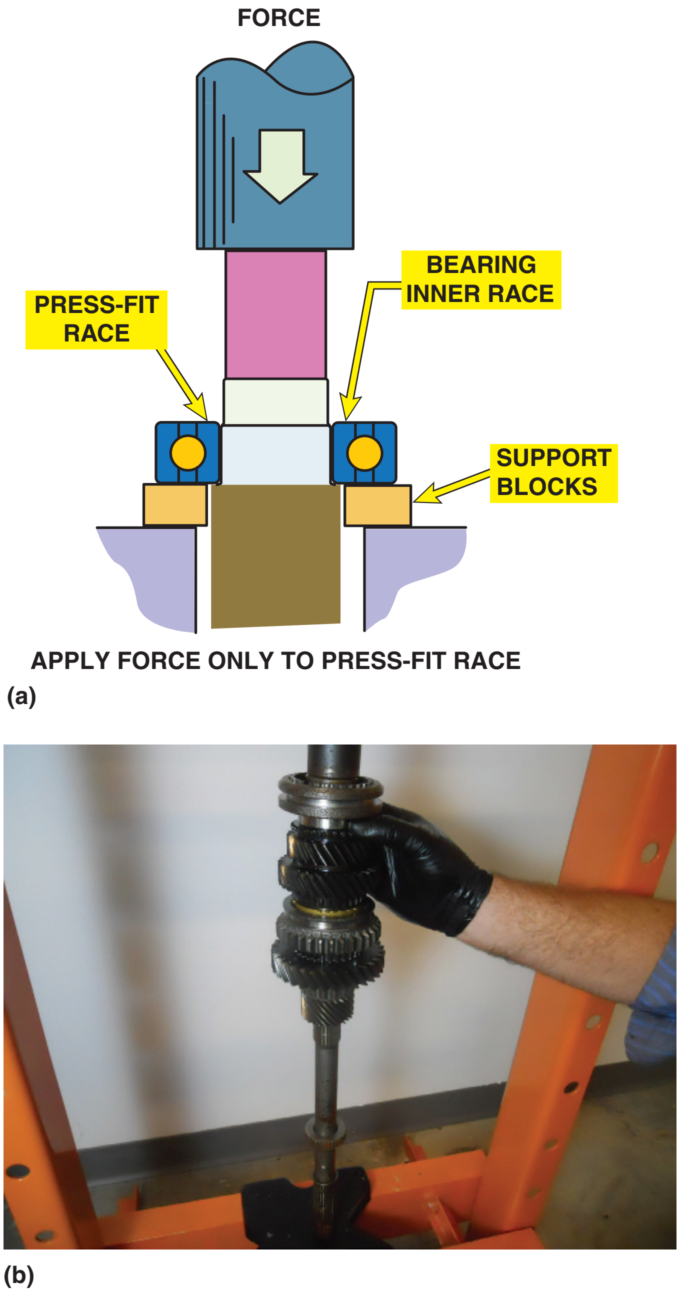


FIGURE 122–41 (a) When a ball bearing is pressed off a shaft, the bearing should be supported by the inner race (if possible) so the force is not exerted on the outer race by the balls. (b) Use caution when pressing parts onto the main shaft. Always follow the specified assembly procedures as found in service information.

position while the pressure plate is being installed. Finally, the engine bell housing is put on the engine, if it was not installed before. The alignment of this type of bell housing is then checked.

CAUTION: Perfectly round cylinders can be distorted whenever another part of the engine is bolted and torqued to the engine block. For example, it has been determined that after the cylinders are machined, the rear cylinder bore can be distorted as much as 0.006 inch (0.15 millimeter) out-of-round after the bell housing is bolted onto the block! To help prevent this distortion, always apply the specified torque to all fasteners going into the engine block and tighten in the recommended sequence.

CASE STUDY

The Worn Shift Fork Mystery

A vehicle equipped with a manual transmission had to be repaired several times for worn shift forks. Even though the vehicle warranty paid for the repair, both the customer and the service department personnel were concerned about the repeated failures. All technical service bulletins (TSBs) were checked to see if there was an updated, improved shift fork. No luck. Even the manufacturer's technical assistance personnel were unable to determine why the shift forks were wearing out. After the third repair, the service technician rode with the customer to see if the cause could be determined. As the driver got into the driver's seat, she placed the handle of her purse over the shifter on the floor and allowed the purse to hang from the shifter. The technician asked the owner if she always placed her purse on the shifter and when she said yes, the technician knew immediately the cause of the worn shift forks. The purse exerted a force on the shifter all the time. This force pushed the shift forks against the synchronizer sleeve. Because the sleeve rotates all the time the vehicle is in motion, the shift forks were quickly worn. The service technician should have determined the root cause of the problem after the *first* repair. The customer agreed to find another location for her purse so that the transmission problem would not reoccur.

Summary:

Complaint—Driver complained of repeated transmission failures.
Cause—The root cause was found to be that the driver was hanging their purse over the floor shifter causing wear to occur to the shift forks.
Correction—The driver found another location for her purse.

The clutch release yoke should be checked for free movement. Usually, the clutch release bearing is replaced, ensuring that the new bearing is securely attached to the clutch release yoke. The transmission can then be installed.

The transmission clutch shaft must be guided straight into the clutch disc and pilot bearing. The transmission clutch shaft is rotated, as required, to engage in the splines of the clutch disc. The assembly bolts are secured when the transmission fully mates with the bell housing.

CAUTION: Always adjust the clutch free play *before* starting the engine to help prevent thrust bearing damage.

Complete the installation by attaching the transmission/transaxle mount, driveshaft (drive axle shafts), vehicle speed sensor, and reverse (backup) light switch.

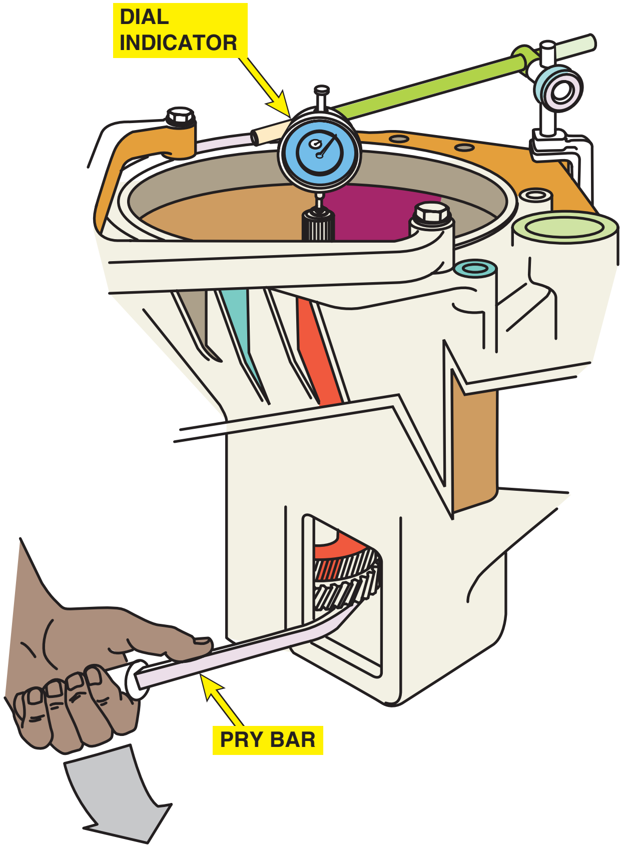

DIAL INDICATOR
PRY BAR

FIGURE 122–42 The dial indicator is set up to measure input shaft endplay as it is lifted and dropped using the pry bar.

GEAR LUBRICATION

After the installation of the transmission/transaxle, the unit should be filled with the correct lubricant. The various lubricants, their general use, and their American Petroleum Institute (API) rating include

GL-1 Straight mineral oil
GL-2 Worm-type gear lubricant
GL-3 Mild-type EP lubricant (will not protect hypoid gears)
GL-4 EP-type lubricant (okay for manual transmissions/transaxles)
GL-5 EP-type okay for hypoid gears and for Mil-L2150B (military)

Goodwrench
Synchromesh
Transmission Fluid
SAE 75W, API GL3
CAUTION
MAY CAUSE EYE IRRITATION
Read Cautionary Statement on Back Panel
NET CONTENTS: ONE QUART

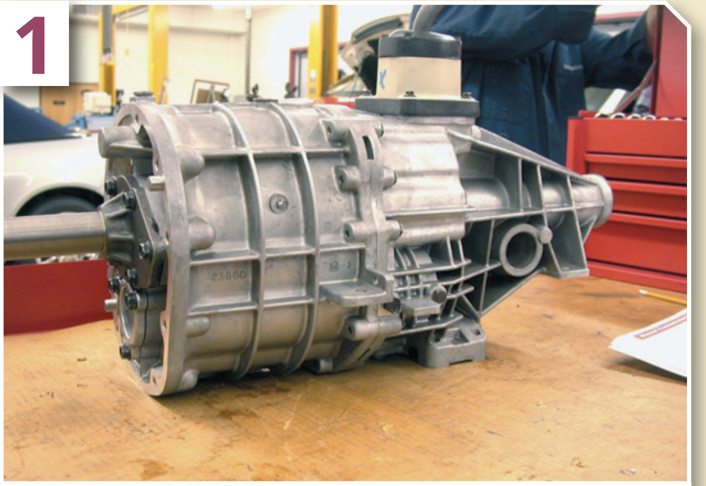
FIGURE 122–43 Some manual transmissions/transaxles require synchromesh transmission fluid.

Manual transmissions/transaxles require one of the following lubricants:

- SAE 80W-90 (GL-4) gear lube.
- STF (synchromesh transmission fluid), but with friction characteristics designed for manual transmissions. ● **SEE FIGURE 122–43**.
- ATF (automatic transmission fluid).
- Engine oil (usually SAE 5W-30).

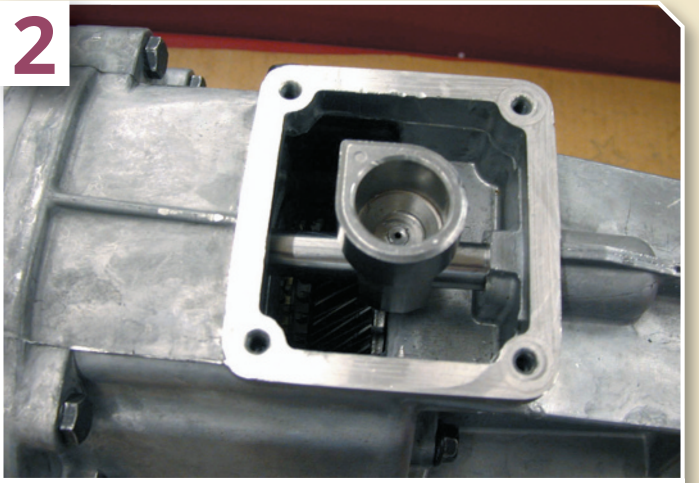
CAUTION: Failure to use the specified manual transmission/transaxle lubricant could cause hard shifting and possible severe transmission damage.

1



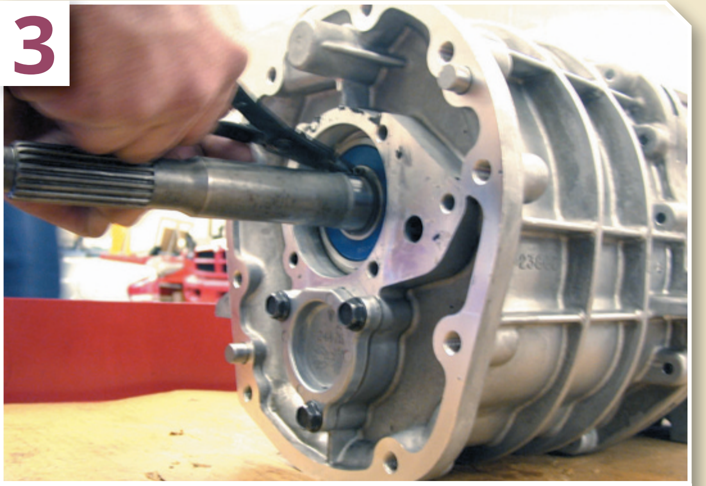
A NV-1500 five-speed manual transmission is used in two-wheel drive applications only.

2



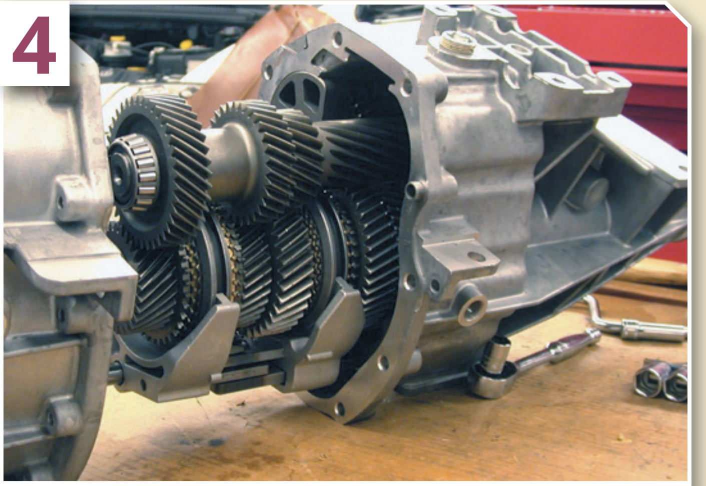
The shifter assembly has been removed. Note the roll pin in the center of the shift lever socket.

3



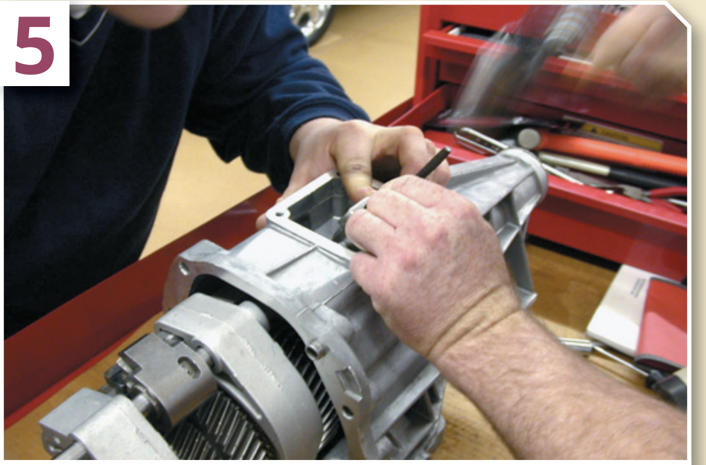
Snap-ring pliers are being used to remove the snap ring retaining the input shaft bearing.

4



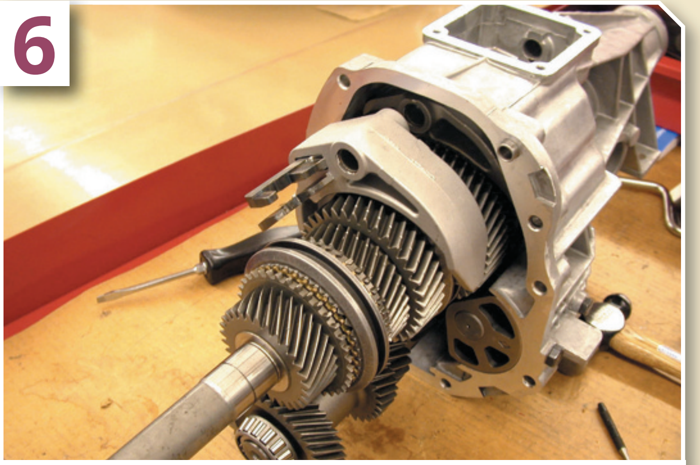
The upside down case is being separated showing the countershaft (top) and shift forks.

5



Before further disassembly can be accomplished, the shift lever socket roll pin must be driven out using a punch and a hammer.

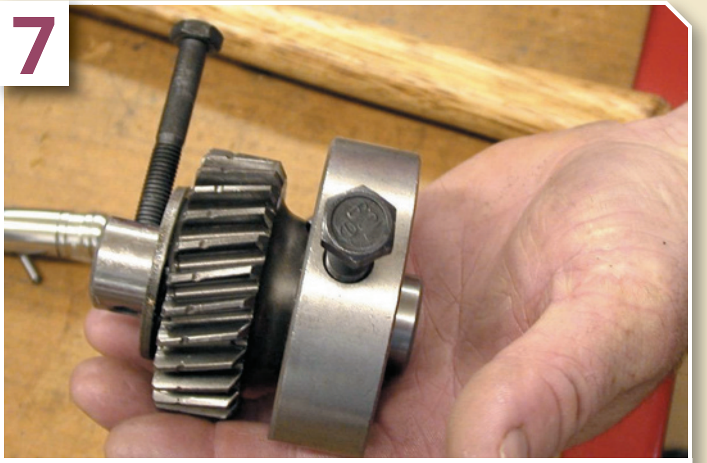
6



The shift shaft and forks can now be removed.

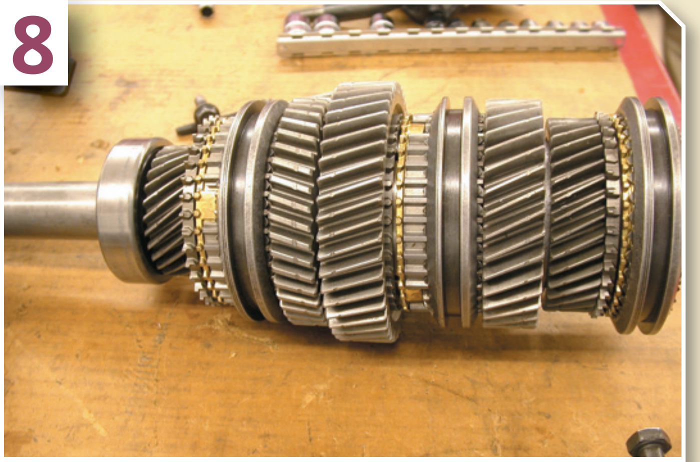
NV-1500 MANUAL TRANSMISSION SERVICE

7



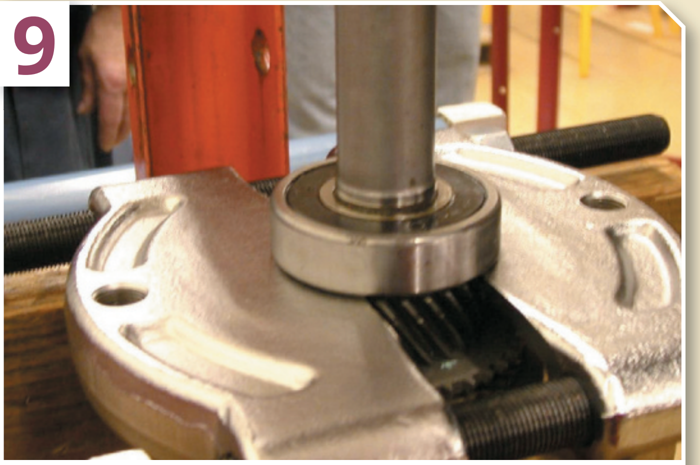
The reverse idle gear is unbolted from the case and removed.

8



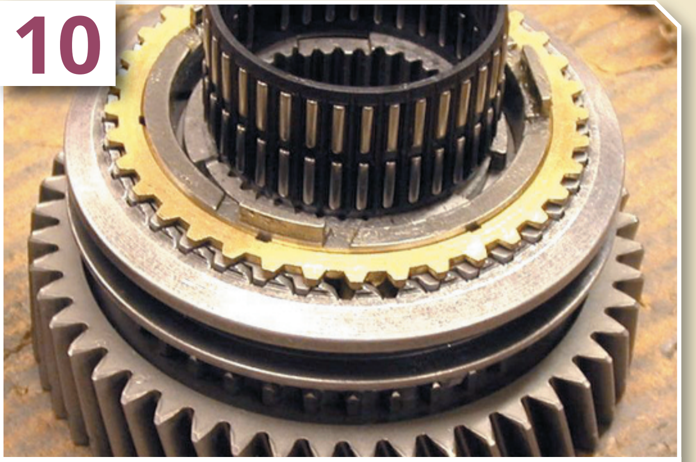
The output shaft assembly fifth gear (far left) and the synchronizer assemblies.

9



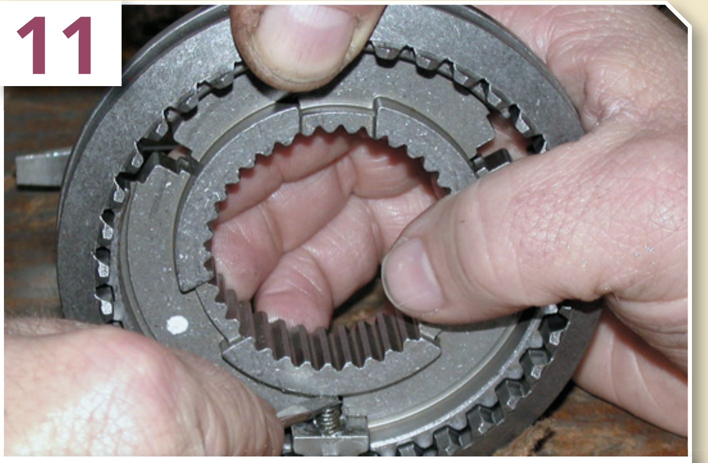
The bearing is being removed using a bearing splitter and a hydraulic press.

10



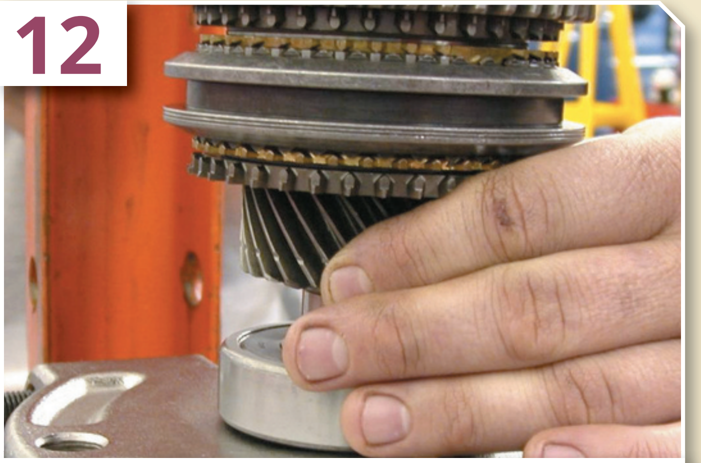
A speed gear (bottom) along with the double row needle bearing used between the shaft and the speed gear. The hub (center) is splined and rotates with the output shaft.

11



A synchronizer assembly being reassembled. It often takes several hands to hold the hub (center) and the sleeve (outer ring).

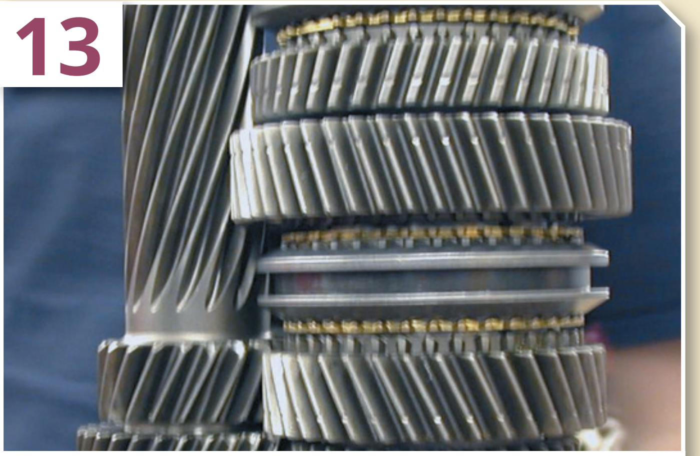
12



A hydraulic press is used to reassemble output shaft and bearing.

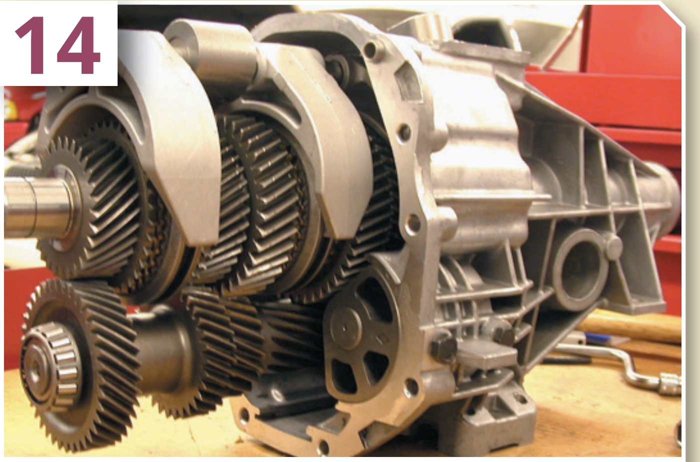
STEP BY STEP

13



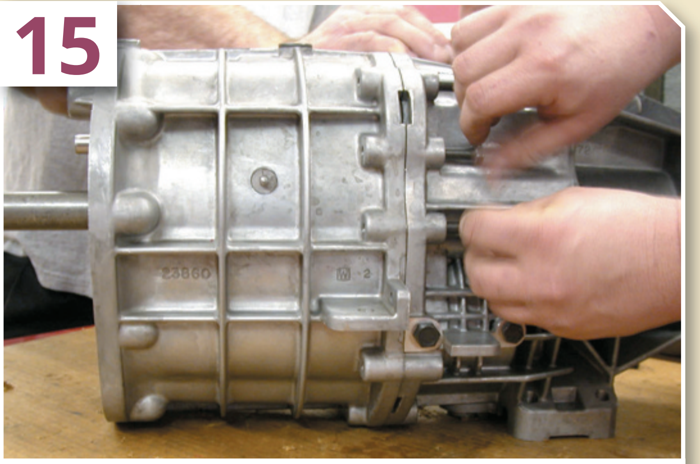
The assembled output shaft is held against the counter shaft to double check that all of the gears have been correctly assembled.

14



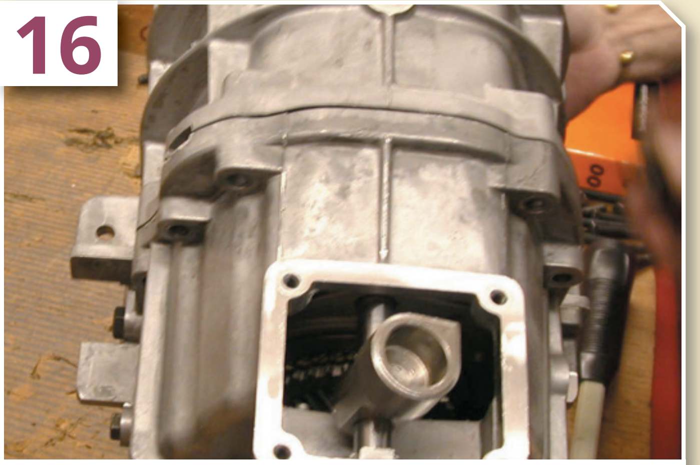
The assembled output shaft and counter shaft are being reinstalled in the transmission case.

15



The case halves are bolted together.

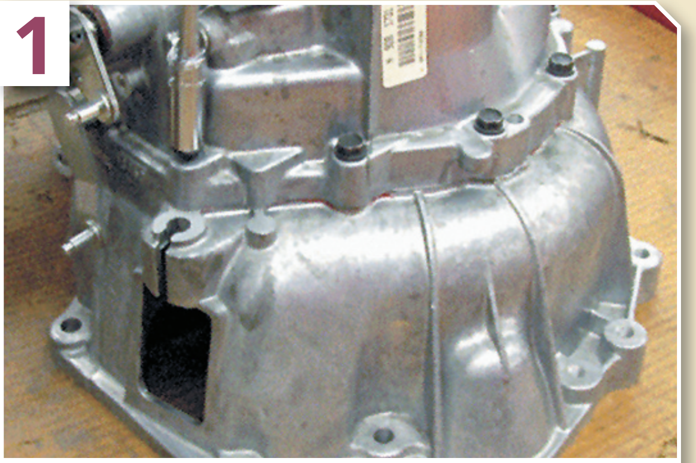
16



The last step is to assembly the shift lever and check for proper operation in all gear positions.

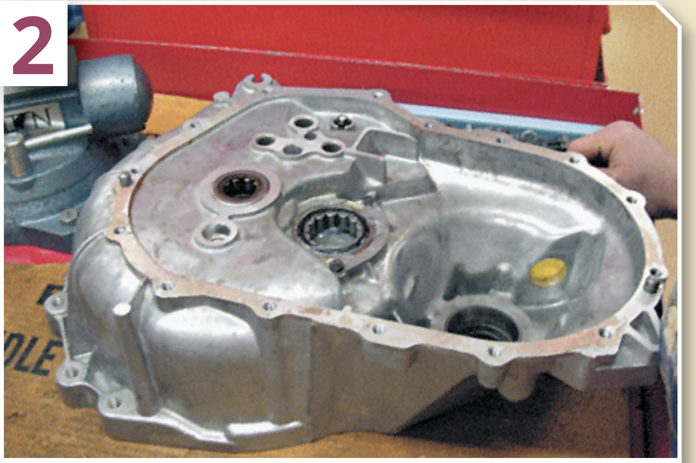
NV-350 TRANSAXLE SERVICE

1



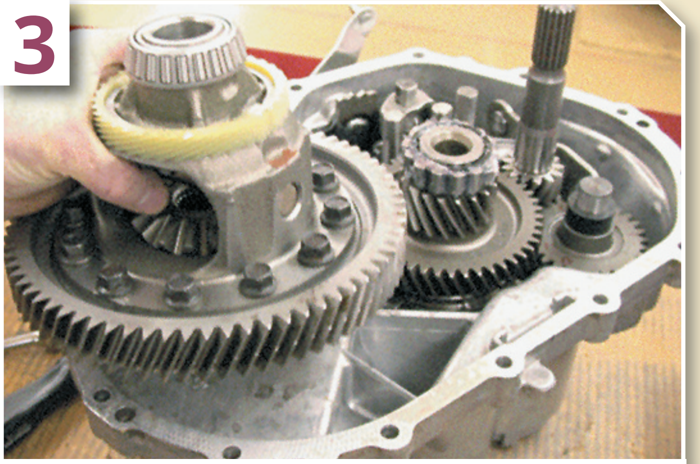
After the transaxle has been removed from the vehicle and the fluid drained, place the transaxle on a work surface.

2



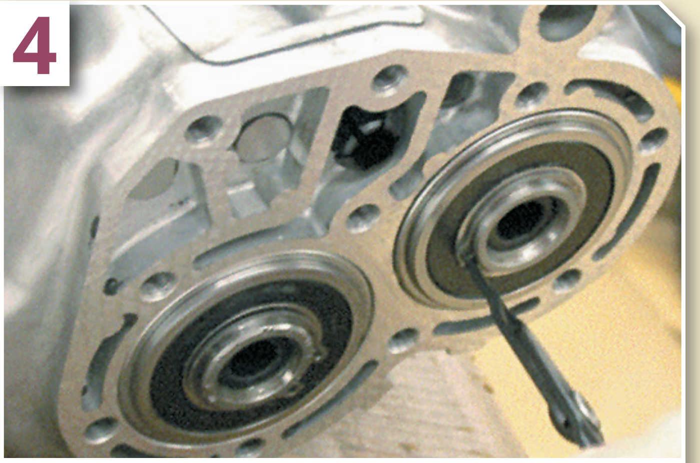
The bell housing case half containing the large output shaft front bearing (center) and the input shaft front bearing (smaller bearing on the left).

3



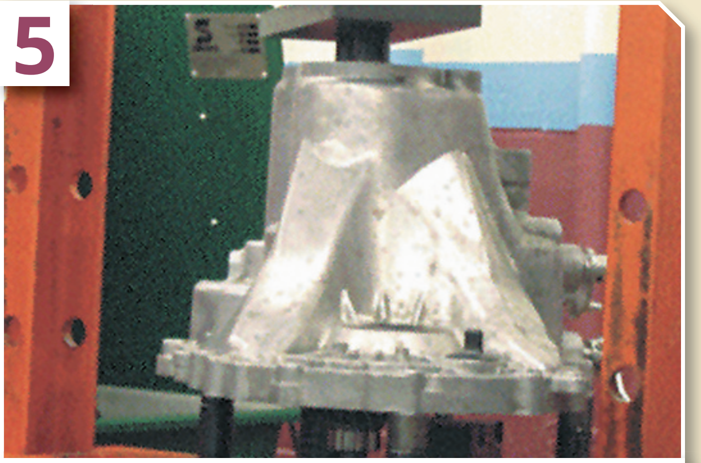
The differential assembly is simply lifted out of half of the case.

4



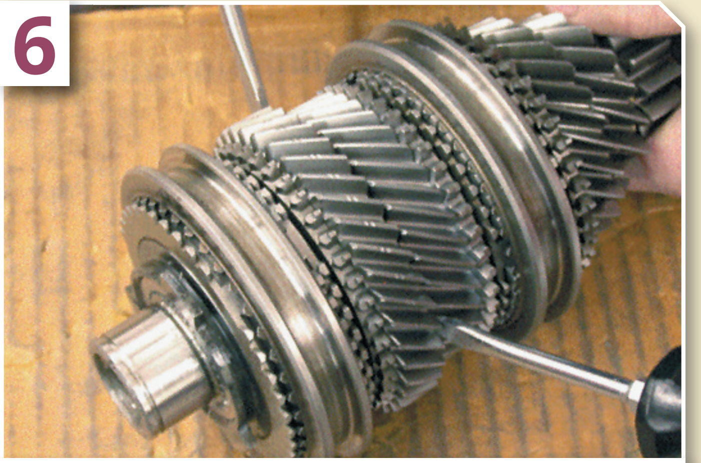
The input and output shafts are a press fit into the bearings and are also retained with a snap ring, which must be removed.

5



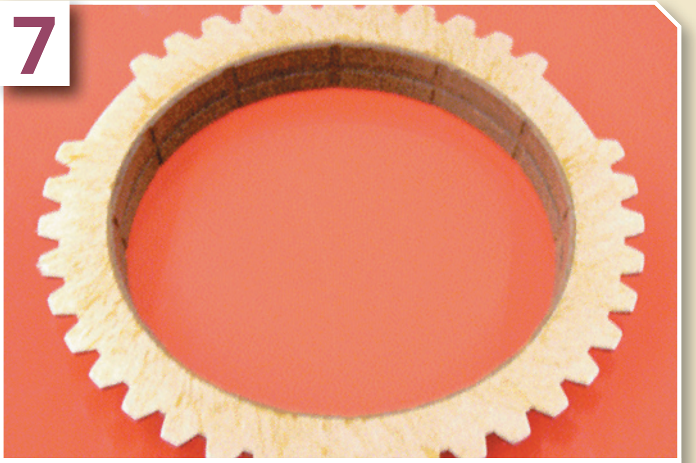
Using a special tool, the input and output shafts are pressed out of the housing using a hydraulic press.

6



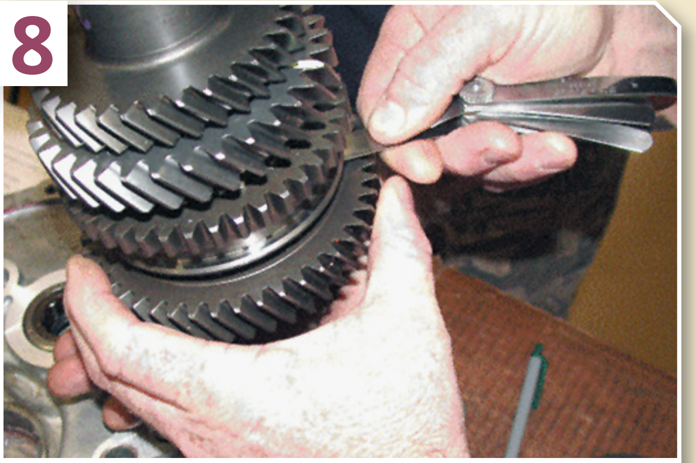
The input shaft can be disassembled using a bearing splitter and a press, or two screwdrivers to pry the gears off the shaft.

7



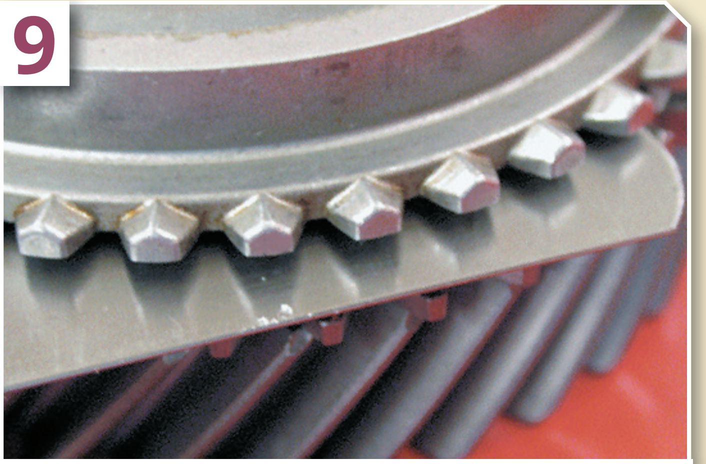
This transaxle uses both brass and powdered metal synchronizer rings with a fiber (paper) inner cone surface.

8



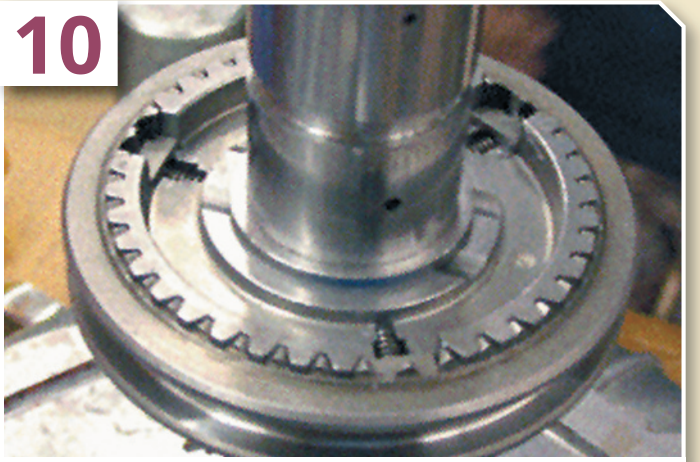
Synchronizer ring gaps are being measured using a feeler (thickness) gauge. The factory specifications are usually 0.040 to 0.069 inches.

9



The gear clutch teeth should be inspected for wear.

10



An assembled synchronizer assembly containing a sleeve, keys, springs, and detent.

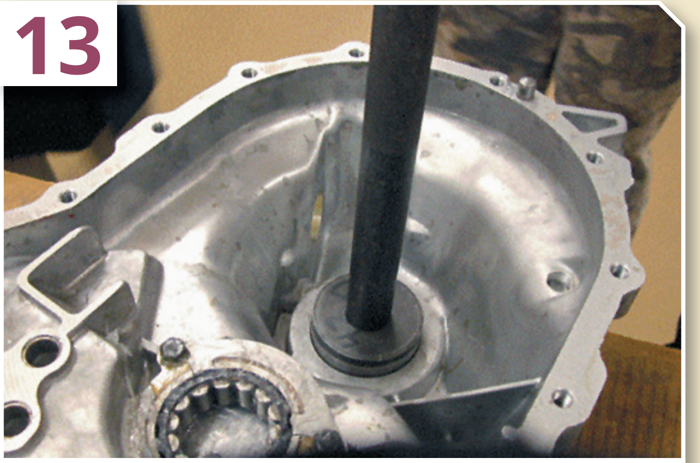
11

The input shaft (left) and the output shaft (right) are checked for proper assembly before being installed into the case.

12

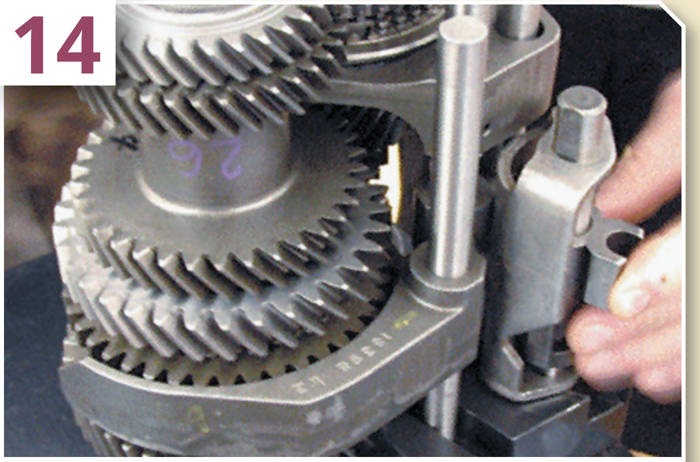
The differential bearing preload is determined by measuring for zero end play; then adding the thickness shim under the bearing cup.

13



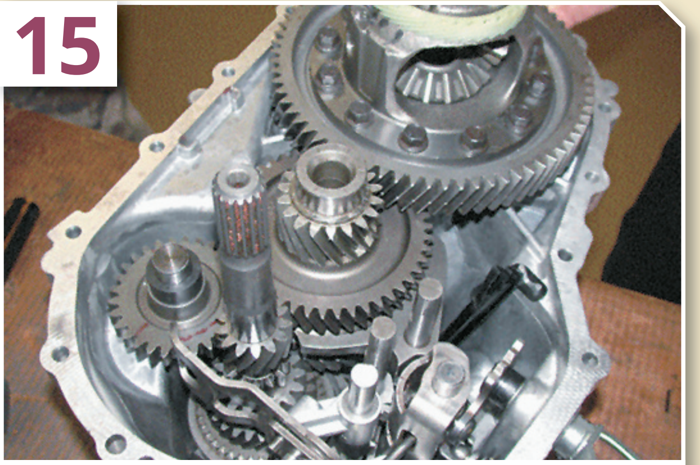
The bearing cup is being installed using an installation tool and a hammer.

14



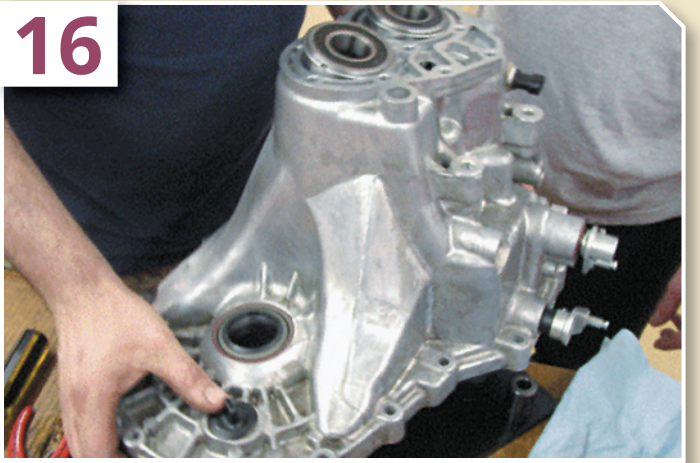
All of the shift forks and shift arms must be aligned properly before installing the components into the case.

15



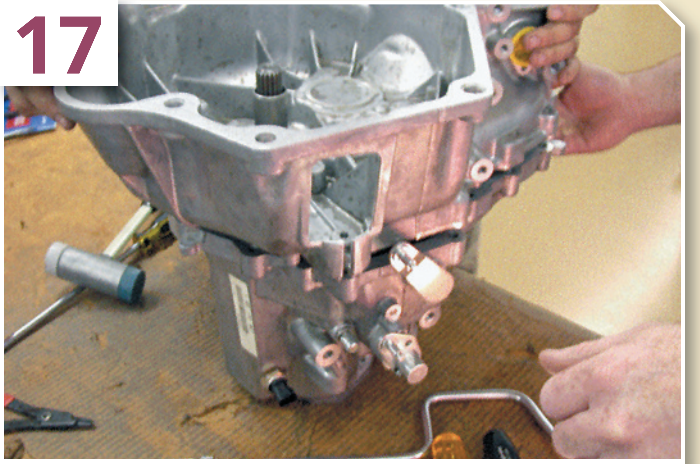
All of the components, including the differential (right), the output shaft (center), and the input shaft (left), plus the shift linkage are installed and checked for proper positioning.

16



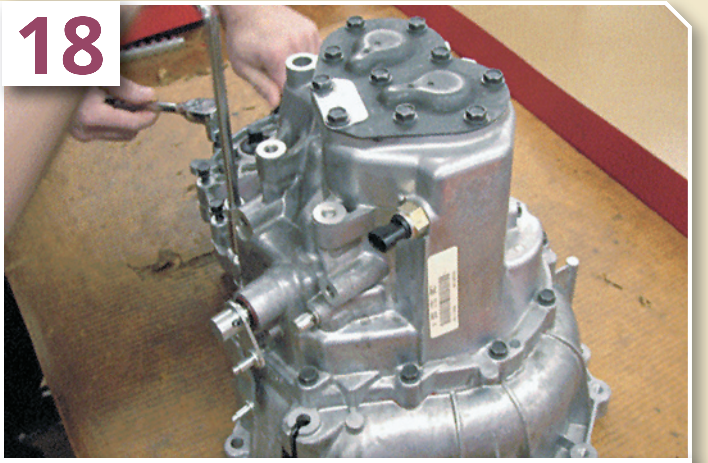
The case halves being reinstalled. The bearings (top) must be pressed back onto the input and output shafts using a press.

17



The bell housing case being reattached.

18



The completed assembly. Notice the bearing cover (top) has already been installed.

REVIEW QUESTIONS

1. Calculate the gear ratio if the driven gear has 36 teeth and the driving gear has 12 teeth.
2. Explain what is meant by an overdrive ratio.
3. List the parts of a manual transmission.
4. Explain how a synchronizer assembly is able to allow a clash-free shift.
5. List the possible lubricants that a manual transmission/transaxle may require.

CHAPTER QUIZ

1. What is the purpose and function of a transmission?
   - **a.** Allows the engine to accelerate the vehicle
   - **b.** Allows the engine speed to be reduced at higher speeds to save fuel
   - **c.** Allows the vehicle to accelerate up a hill
   - **d.** All of the above
2. The type of gears used in a transmission include __________.
   - **a.** spur gear
   - **b.** helical gear
   - **c.** external gears
   - **d.** All of the above
3. What is the relationship between speed, torque, and power?
   - **a.** Torque and speed have an inverse relationship
   - **b.** As speed increases, torque increases
   - **c.** With a constant input speed, transmission torque decreases as output speed increases
   - **d.** Both a and c
4. Which part is splined to the clutch disc?
   - **a.** Main shaft
   - **b.** Countershaft (lay shaft)
   - **c.** Cluster shaft
   - **d.** Main gear
5. In a manual transmission, engine torque is applied to the ______________ when the engine is running and the clutch is engaged.
   - **a.** input shaft
   - **b.** main gear
   - **c.** cluster gear
   - **d.** All of the above
6. The free rotating gears on the main shaft of an RWD manual transmission are called ______________ gears.
   - **a.** floating
   - **b.** fixed
   - **c.** hypoid
   - **d.** speed
7. Which part of a synchronizer is splined to a shaft?
   - **a.** Synchronizer sleeve
   - **b.** Hub
   - **c.** Synchronizer ring (blocking ring)
   - **d.** Speed gear
8. A rear-wheel-drive 5-speed manual transmission is being discussed. What is the gear ratio when the transmission is in 4th gear?
   - **a.** 1.5 to 1
   - **b.** 1 to 1
   - **c.** 3 to 1
   - **d.** 8 to 1
9. A customer complained of hard shifting particularly into first gear and reverse. Technician A says that the blocking ring may be worn. Technician B says that the clutch may be defective or out of adjustment. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. A manual transmission is difficult to shift but only when the outside temperature is below freezing (32°F or 0°C). Technician A says that the brass blocking ring could be defective. Technician B says that incorrect gear lubricant could be the cause. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter 123

DRIVESHAFTS AND HALF SHAFTS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe driveshaft design.
- Describe driveshaft balance.
- Describe the function and operation of U-joints.
- Discuss double-Cardan joints.
- Discuss the two types of CV joints and how they work.

KEY TERMS:

Cardan joints 1554 • Center support bearing 1552 • CV joint boot 1559 • Double-Cardan joints 1556 • Driveshaft 1552 • Fixed joint 1557 • Half shaft 1558 • Plunge joint 1558 • Propeller shaft 1552 • Rzeppa joint 1556 • Spider 1554 • Trunnions 1554 • Universal joints 1554

DRIVESHAFTS

PURPOSE AND FUNCTION A driveshaft transmits engine torque from the transmission or transaxle (if front-wheel drive) to the rear axle assembly or drive wheels. ● **SEE FIGURES 123–1 AND 123–2**.

Driveshaft is the term used by the Society of Automotive Engineers (SAE) to describe the shaft between the transmission and the rear axle assembly on a rear-wheel-drive vehicle. General Motors and some other manufacturers use the term **propeller shaft** or *prop shaft* to describe this same part. The SAE term will be used throughout this textbook.

A typical driveshaft is a hollow steel tube. A splined end yoke is welded onto one end that slips over the splines of the output shaft of the transmission. ● **SEE FIGURE 123–3**. An end yoke is welded onto the other end of the driveshaft. Some driveshafts use a center support bearing.

DRIVESHAFT DESIGN Most driveshafts are constructed of hollow steel tubing. *The forces are transmitted through the surface of the driveshaft tubing.* The surface is therefore in tension, and cracks can develop on the outside surface of the driveshaft due to metal fatigue. Driveshaft tubing can bend and, if dented, collapse. A dented driveshaft should be replaced and no attempt should be made to repair the dent. ● **SEE FIGURE 123–4**.

Most rear-wheel-drive cars and light trucks use a one- or two-piece driveshaft. A steel tube driveshaft has a maximum *length of about 65 inches (165 cm)*. Beyond this critical length, a **center support bearing** must be used, as shown in ● **FIGURE 123–5**. A center support bearing is also called a steady bearing or hanger bearing.

Some vehicle manufacturers use aluminum driveshafts; these can be as long as 90 inches (230 cm) with no problem. Many extended-cab pickup trucks and certain vans use aluminum driveshafts to eliminate the need (and expense) of a center support bearing. Composite-material driveshafts are also used in some vehicles. These carbon-fiber-plastic driveshafts are very strong yet lightweight and can be made in extended lengths without the need for a center support bearing.

To dampen driveshaft noise, it is common to line the inside of the hollow driveshaft with cardboard or rubber. This helps eliminate the tinny sound whenever shifting between drive and reverse in a vehicle equipped with an automatic transmission. ● **SEE FIGURE 123–6**.

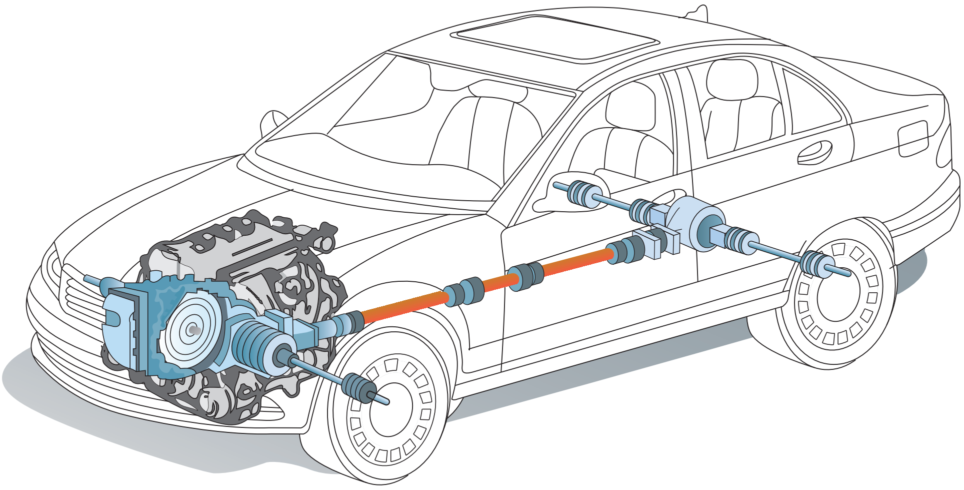


FIGURE 123–1 A vehicle equipped with all-wheel drive using a transaxle uses many different driveshafts. From the transaxle to the front wheels, two "half shafts" are used. In this example, the multi-piece driveshaft is used to transmit engine torque to the drive axle at the rear of the vehicle. From the drive axle, two more half-shafts (drive axle shafts) are used to transmit torque to the rear wheels.

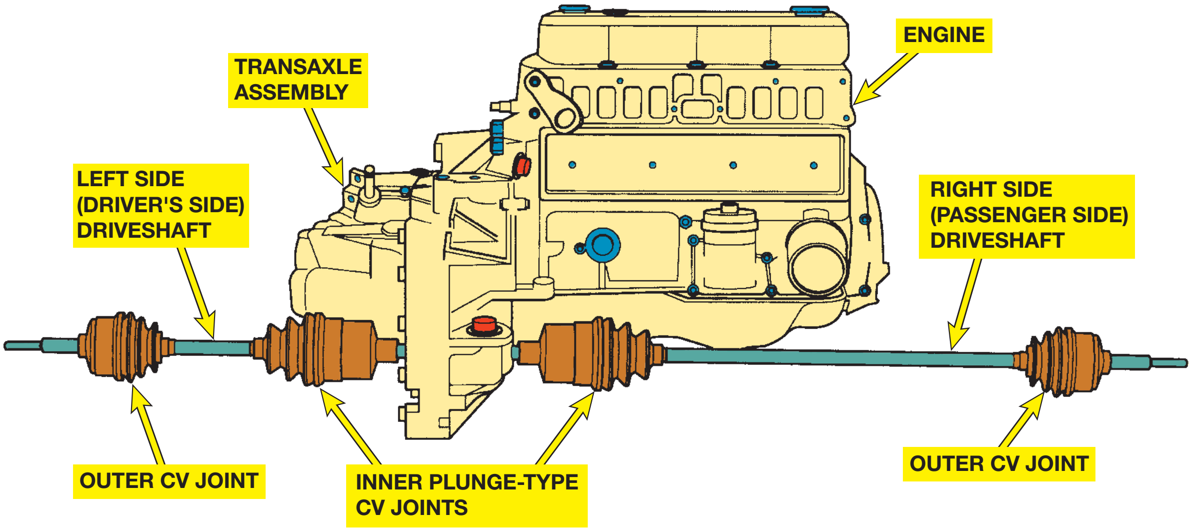

TRANSAXLE ASSEMBLY
ENGINE
LEFT SIDE (DRIVER'S SIDE) DRIVESHAFT
RIGHT SIDE (PASSENGER SIDE) DRIVESHAFT
OUTER CV JOINT
INNER PLUNGE-TYPE CV JOINTS
OUTER CV JOINT

FIGURE 123–2 On a rear-wheel-drive vehicle, the driveshaft transmits engine torque from the transmission to the rear axle assembly and drive wheels. On a front-wheel-drive vehicle, driveshafts (also called axle shafts) transmit torque from the transaxle to each of the front drive wheels.

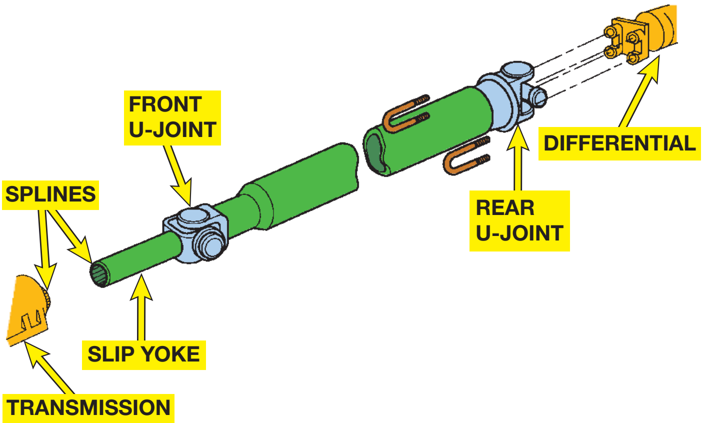

FRONT U-JOINT
SPLINES
DIFFERENTIAL
REAR U-JOINT
SLIP YOKE
TRANSMISSION

FIGURE 123–3 Typical driveshaft (also called a *propeller shaft*). The driveshaft transfers engine power from the transmission to the differential.

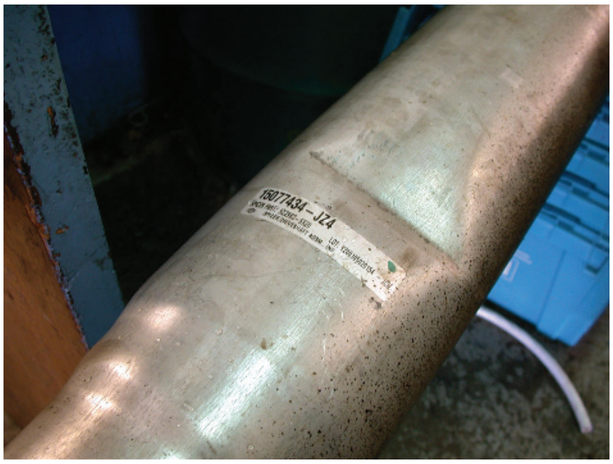

15077434 – JZ4

FIGURE 123–4 This driveshaft was found to be dented during a visual inspection and has to be replaced.

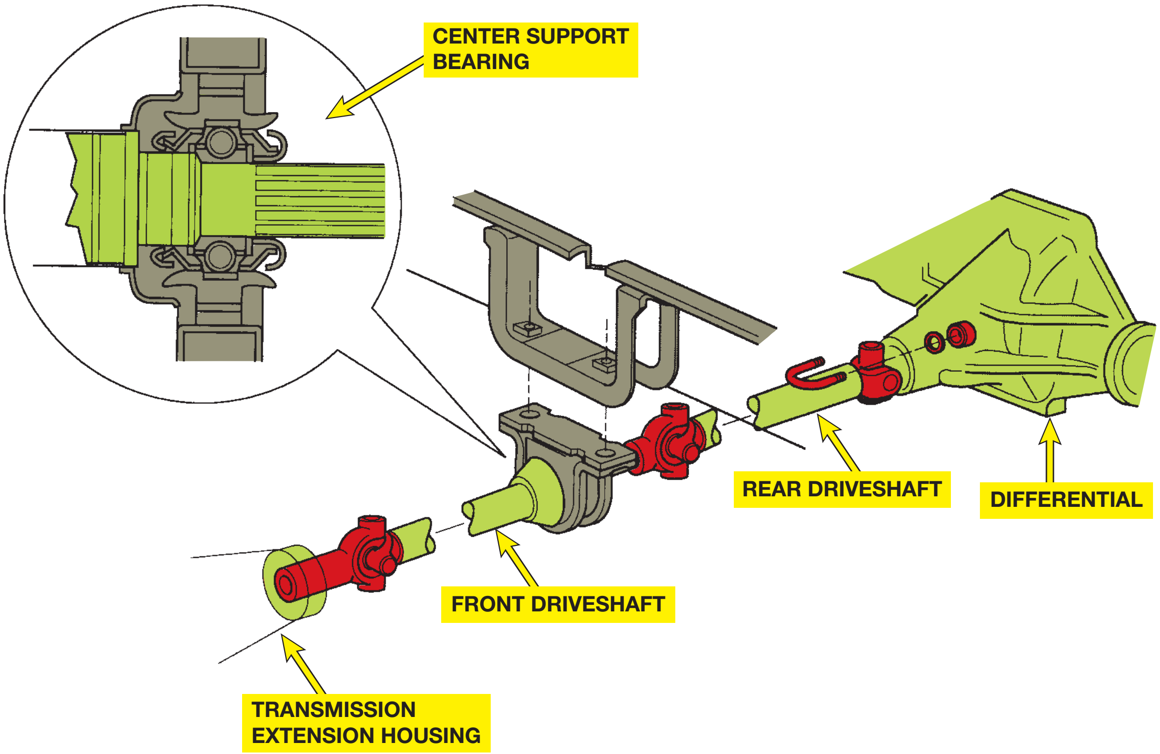


FIGURE 123–5 A center support bearing is used on many vehicles with long two-part driveshafts.

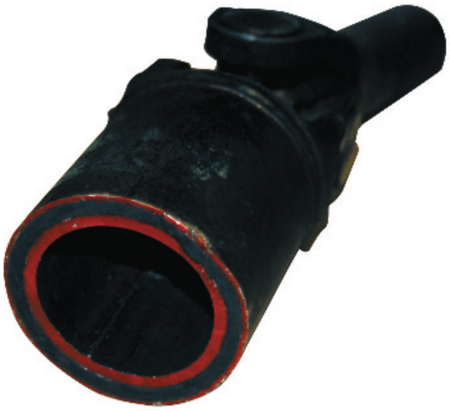


FIGURE 123–6 Some driveshafts use rubber between an inner and outer housing to absorb vibrations and shocks to the driveline.

DRIVESHAFT BALANCE

All driveshafts are balanced. Generally, any driveshaft whose rotational speed is greater than 1000 RPM must be balanced. Driveshaft balance should be within 0.5% of the driveshaft weight. One of the reasons why aluminum or composite driveshafts can be longer is because of their light weight.

Driveshafts are often not available by make, model, and year of the vehicle. There are too many variations at the factory, such as transmission type, differential, or U-joint type. To get a replacement driveshaft, it is usually necessary to know the series of U-joints (type or style of U-joint) and the center-to-center distance between the U-joints.

U-JOINT DESIGN AND OPERATION

Universal joints (U-joints) are used at both ends of a driveshaft. U-joints allow the wheels and the rear axle to move up and down, remain flexible, and still transfer torque to the drive wheels. A simple universal joint can be made from two Y-shaped yokes connected by a crossmember called a cross or **spider**. The four arms of the cross are called **trunnions**. ● **SEE FIGURE 123–7** for a line drawing of a simple U-joint with all part names identified. A similar design is the common U-joint used with a socket wrench set.

Most U-joints are called cross-yoke joints or **Cardan joints**. *Cardan* is named for a sixteenth-century Italian mathematician who worked with objects that moved freely in any direction. Torque from the engine is transferred through the U-joint. The engine drives the

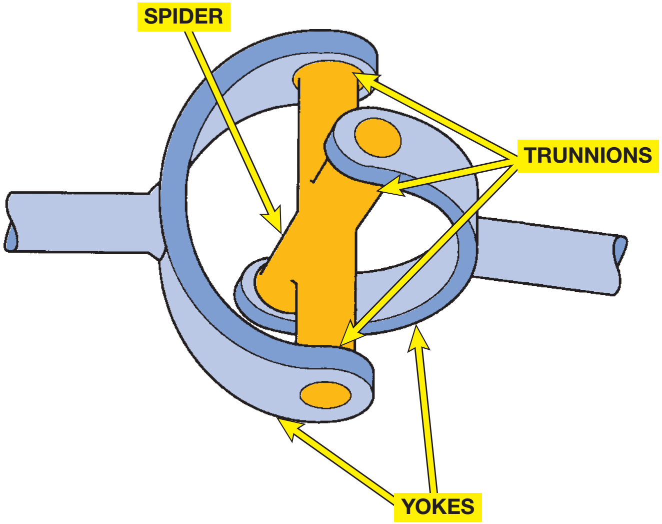


FIGURE 123–7 A simple universal joint (U-joint).

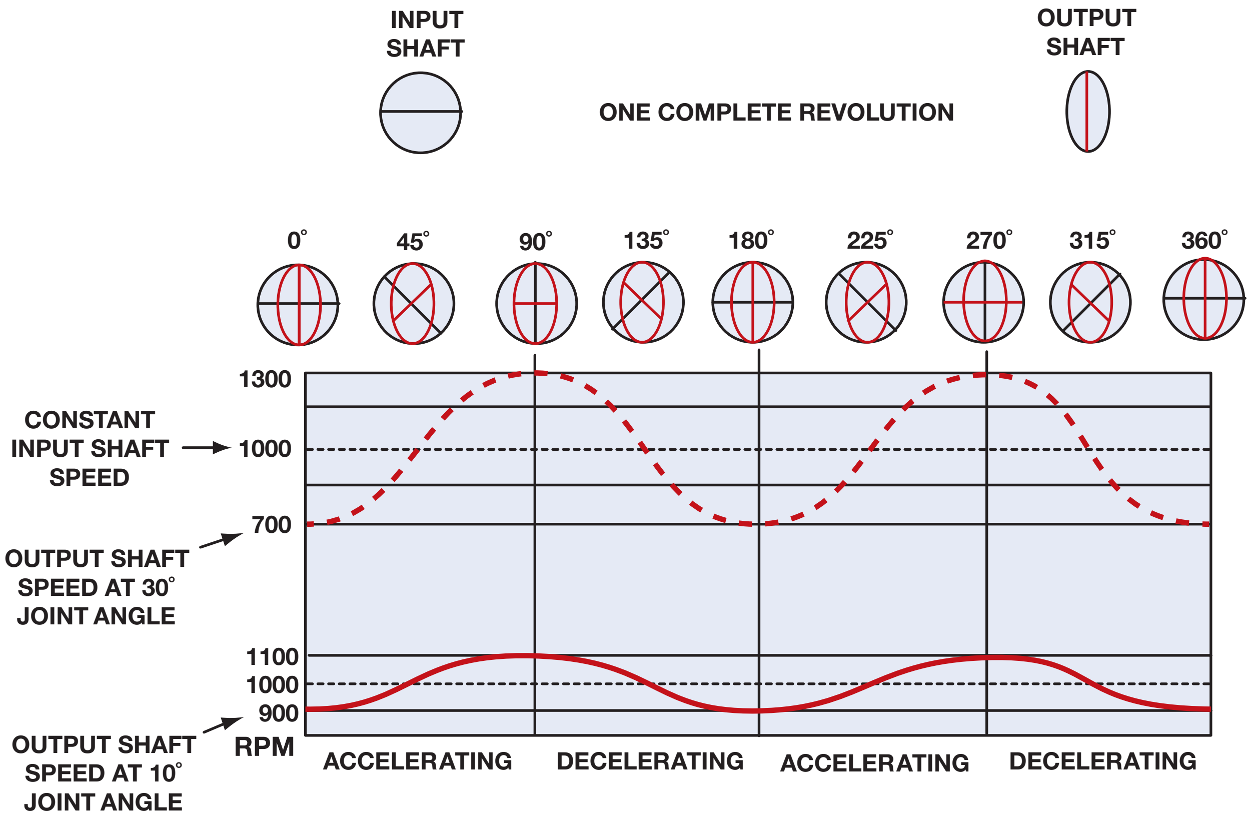


FIGURE 123–8 How the speed difference on the output of a typical U-joint varies with the speed and the angle of the U-joint. At the bottom of the chart, the input speed is a constant 1000 RPM, while the output speed varies from 900 to 1100 RPM when the angle difference in the joint is only 10 degrees. At the top of the chart, the input speed is a constant 1000 RPM, yet the output speed varies from 700 to 1200 RPM when the angle difference in the joint is changed to 30 degrees.

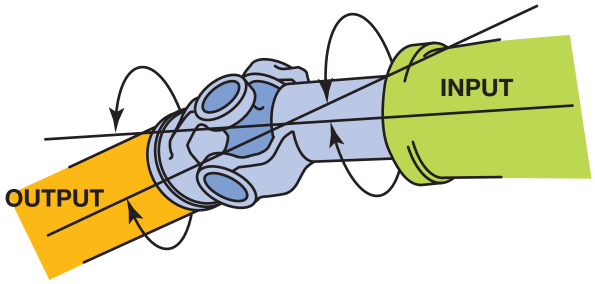


FIGURE 123–9 The joint angle is the difference between the angles of the joint.

U-joint at a constant speed, but the output speed of the U-joint changes because of the angle of the joint. The speed changes twice per revolution. *The greater the angle, the greater the change in speed (velocity)*. ● **SEE FIGURE 123–8**.

If only one U-joint were used in a driveline, this change in speed of the driven side (output end) would generate vibrations in the driveline. To help reduce vibration, another U-joint is used at the other end of the driveshaft. If the angles of both joints are nearly equal, the acceleration and deceleration of one joint is offset by the alternate deceleration and acceleration of the second joint. *It is very important that both U-joints operate at about the same angle to prevent excessive driveline vibration*. ● **SEE FIGURE 123–9**.

ACCEPTABLE WORKING ANGLES Universal joints used in a typical driveshaft should have a *working angle* of 1/2 to 3 degrees. ● **SEE FIGURE 123–10**. The working angle is the angle between the driving end and the driven end of the joint.

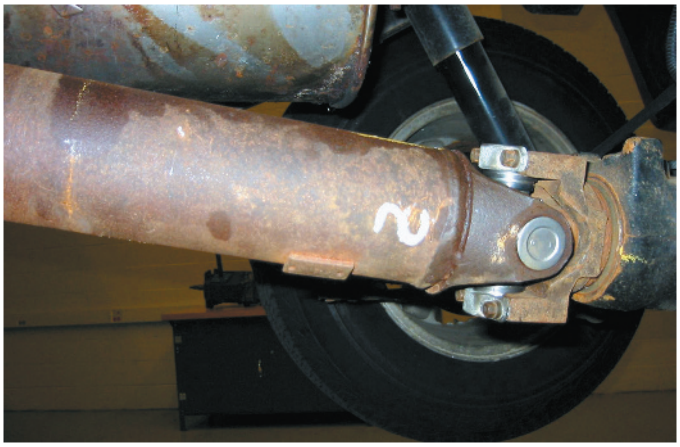


FIGURE 123–10 The angle of this rear-Cardan U-joint is noticeable.

If the driveshaft is perfectly straight (0 degree working angle), then the needle bearings inside the bearing cap are not revolving because there is no force (no difference in angles) to cause the rotation of the needle bearings. If the needle bearings do not rotate, they can exert a constant pressure in one place and damage the bearing journal. If a two-piece driveshaft is used, one U-joint (usually the front) runs at a small working angle of about 1/2 degree, just enough to keep the needle bearings rotating. The other two U-joints (from the center support bearing and rear U-joint at the differential) operate at typical working angles of a single-piece driveshaft.

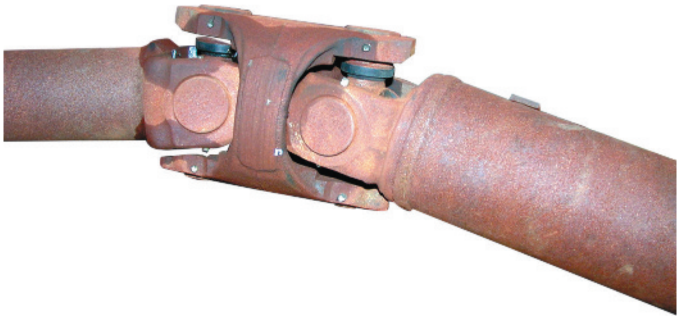


FIGURE 123–11 A double-Cardan U-joint.

If the U-joint working angles differ by more than a 1/2 degree between the front and the rear joint, a vibration is usually produced that is *torque sensitive.* As the vehicle is first accelerated from a stop, engine torque can create unequal driveshaft angles by causing the differential to rotate on its suspension support arms. This vibration is most noticeable when the vehicle is heavily loaded and being accelerated at lower speeds. The vibration usually diminishes at higher speeds due to decrease in the torque being transmitted. If the driveshaft angles are excessive (over 3 degrees), a vibration is usually produced that increases as the speed of the vehicle (and driveshaft) increases.

DOUBLE-CARDAN JOINTS

Regular U-joints are usually designed to work up to 12 degrees of angularity. If two Cardan-style U-joints are joined together, the angle at which this **double-Cardan joint** can function is about 18 to 20 degrees. ● **SEE FIGURE 123–11**.

Double-Cardan U-joints were first used on large rear-wheel-drive vehicles to help reduce drive line-induced vibrations, especially when the rear of the vehicle was fully loaded and driveshaft angles were at their greatest. As long as a U-joint (either single or double Cardan) operates in a straight line, the driven shaft will rotate at the same constant speed (velocity) as the driving shaft. As the angle increases, the driven shaft speed or velocity varies during each revolution. This produces pulsations and a noticeable vibration or surge.

NOTE: Many four-wheel-drive light trucks use standard Cardan-style U-joints in the front drive axles. If the front wheels are turned sharply and then accelerated, the entire truck often shakes due to the pulsations created by the speed variations through the U-joints. This vibration is normal and cannot be corrected. It is characteristic of this type of design and is usually not noticeable in normal driving.

CONSTANT VELOCITY JOINTS

PURPOSE AND FUNCTION Constant velocity joints, commonly called CV joints, are designed to rotate without changing speed.

RZEPPA JOINTS The first constant velocity joint was designed by Alfred H. Rzeppa (pronounced shep'pa) in the mid-1920s. The **Rzeppa joint** transfers torque through six round balls that are held in position midway between the two shafts. This design causes the angle between the shafts to be equally split regardless of the angle. ● **SEE FIGURE 123–12**. Because the angle is always split equally, torque is transferred equally without the change in speed (velocity) that occurs in Cardan-style U-joints. This style of joint results in a constant velocity between driving and driven shafts. It can also function at angles greater than simple U-joints can, up to 40 degrees.

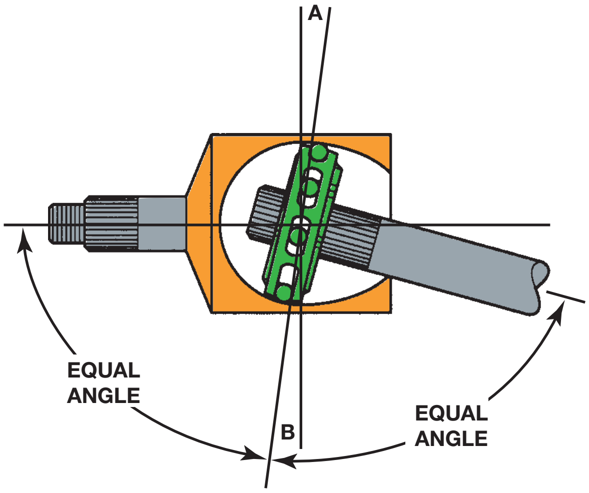


FIGURE 123–12 A constant velocity (CV) joint can operate at high angles without a change in velocity (speed) because the joint design results in equal angles between input and output.

NOTE: CV joints are also called LOBRÖ joints, the brand name of an original equipment manufacturer.

While commonly used today in all front-wheel-drive vehicles and many four-wheel-drive vehicles, its first use was on the

FREQUENTLY ASKED QUESTION

What Is a 1350-Series U-Joint?

Most universal joints are available in sizes to best match the torque that they transmit. The larger the U-joint, the higher the amount of torque. Most U-joints are sized and rated by series numbers. See the accompanying chart for series numbers and sizes.

Series Number	Cap Diameter (in.)	Overall Length (in.)	Trunnion Diameter (in.)
1000	15/16	2 5/64	1/2
1100	15/16	2 13/64	1/2
1260/1270	1 1/16	2 31/32	19/32
1280	1 1/16	2 31/32	39/64
1310	1 1/16	2 31/32	21/32
1330	1 1/16	3 3/8	21/32
1350	1 3/16	3 3/8	49/64
1410	1 3/16	3 15/16	49/64
1480	1 3/8	3 7/8	57/64

front-wheel-drive 1929 Cord. Built in Auburn, Indiana, the Cord was the first front-wheel-drive car to use a CV-type drive axle joint.

OUTER CV JOINTS The Rzeppa-type CV joint is most commonly used as an outer joint on most front-wheel-drive vehicles. ● **SEE FIGURE 123–13**. The outer joint must do the following:

1. Allow up to 40 degrees or more of movement to allow the front wheels to turn.
2. Allow the front wheels to move up and down through normal suspension travel in order to provide a smooth ride over rough surfaces.
3. Be able to transmit engine torque to drive the front wheels.

Outer CV joints are called **fixed joints**. The outer joints are also attached to the front wheels. They are more likely to suffer from road hazards that often can cut through the protective outer flexible boot. ● **SEE FIGURE 123–14**. Once this boot has been split open, the special high-quality grease is thrown out and contaminants such as dirt and water can enter. Some joints cannot be replaced individually if worn. ● **SEE FIGURE 123–15**.

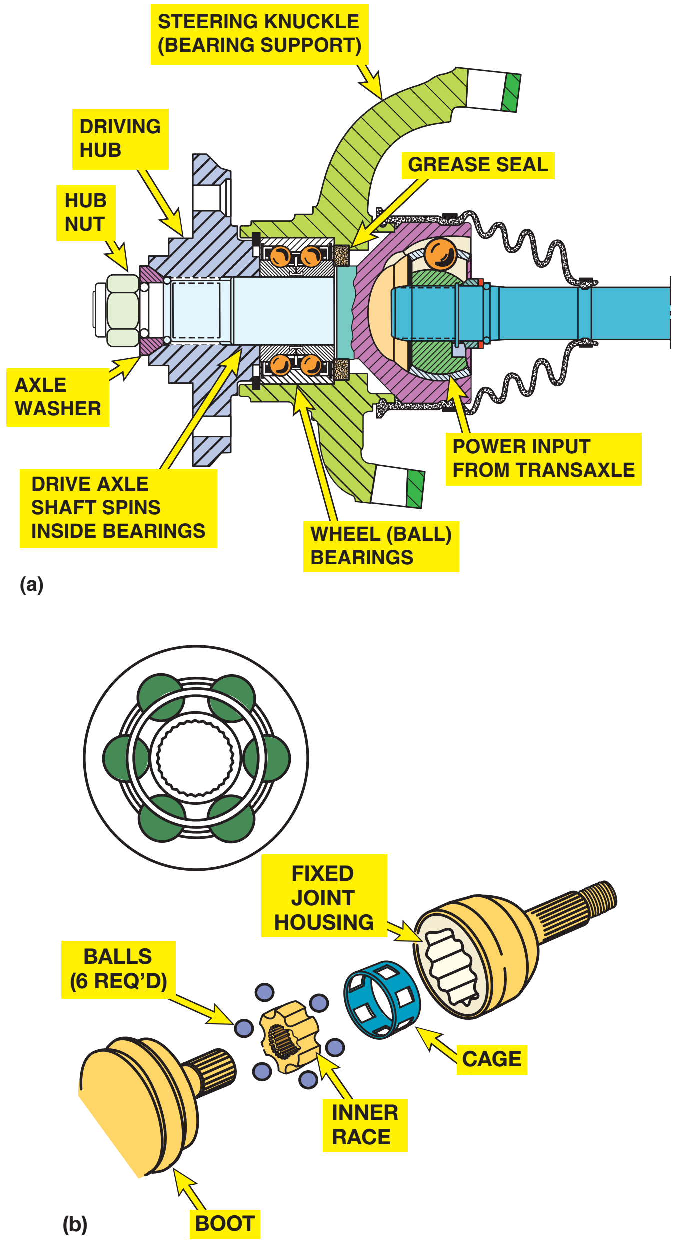

STEERING KNUCKLE (BEARING SUPPORT)
DRIVING HUB
HUB NUT
GREASE SEAL
AXLE WASHER
POWER INPUT FROM TRANSAXLE
DRIVE AXLE SHAFT SPINS INSIDE BEARINGS
WHEEL (BALL) BEARINGS
(a)
FIXED JOINT HOUSING
BALLS (6 REQ'D)
CAGE
INNER RACE
BOOT
(b)

FIGURE 123–13 (a) A cutaway view of the outer CV joint with a double-row ball bearing assembly that shows the relations of the parts involved. (b) A Rzeppa fixed joint. This type of CV joint is commonly used at the wheel side of the drive axle shaft. This joint can operate at high angles to compensate for suspension travel and steering angle changes.

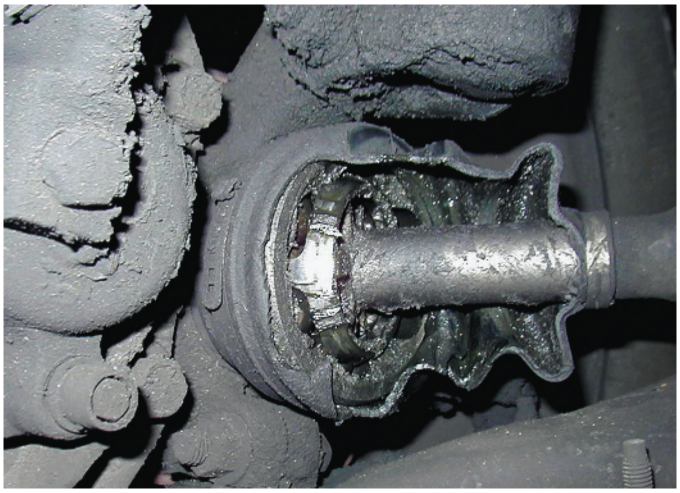


FIGURE 123–14 The protective CV joint boot has been torn away on this vehicle and all of the grease has been thrown outward onto the brake and suspension parts. The driver of this vehicle noticed a "clicking" noise, especially when turning.

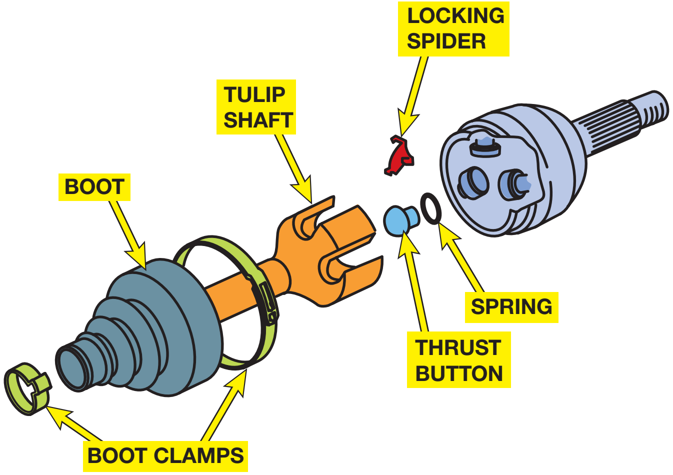

LOCKING SPIDER
TULIP SHAFT
BOOT
SPRING
THRUST BUTTON
BOOT CLAMPS

FIGURE 123–15 A tripod fixed joint. This type of joint is found on some Japanese vehicles. If the joint wears out, it is to be replaced with an entire drive axle shaft assembly.

NOTE: Research has shown that in as few as eight hours of driving time, a CV joint can be destroyed by dirt, moisture, and a lack of lubrication if the boot is torn. The technician should warn the owner as to the possible cost involved in replacing the CV joint itself whenever a torn CV boot is found.

INNER CV JOINTS Inner CV joints attach the output of the transaxle to the drive axle shaft. Inner CV joints are therefore inboard, or toward the center of the vehicle. ● **SEE FIGURE 123–16**.

Inner CV joints have to be able to perform two very important movements:

1. Allow the drive axle shaft to move up and down as the wheels travel over bumps.
2. Allow the drive axle shaft to change length as required during vehicle suspension travel movements (lengthening and

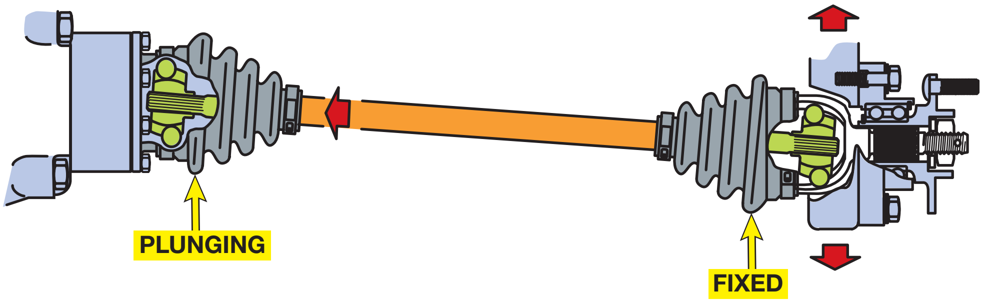


FIGURE 123–16 The fixed outer joint is required to move in all directions because the wheels must turn for steering as well as move up and down during suspension movement. The inner joint has to be able to not only move up and down but also plunge in and out as the suspension moves up and down.

shortening as the vehicle moves up and down; same as the slip yoke on a conventional RWD driveshaft). CV joints are also called **plunge joints**.

Typical types of inner CV joints that are designed to move axially, or *plunge,* include the following:

1. Tripod. ● **SEE FIGURE 123–17**.
2. Cross-groove. ● **SEE FIGURE 123–18**.
3. Double offset. ● **SEE FIGURE 123–19**.

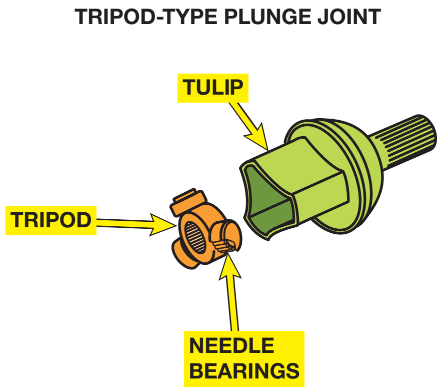


FIGURE 123–17 A tripod joint is also called a tripot, tripode, or tulip design.

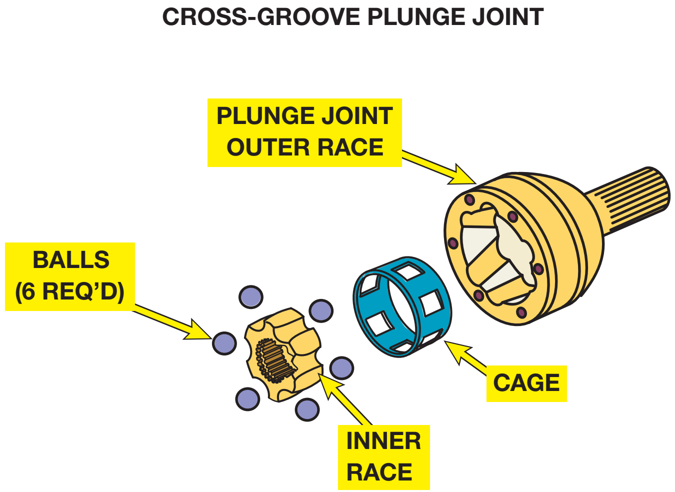


FIGURE 123–18 A cross-groove plunge joint is used on many German front-wheel-drive vehicles and as both inner and outer joints on the rear of vehicles that use an independent-type rear suspension.

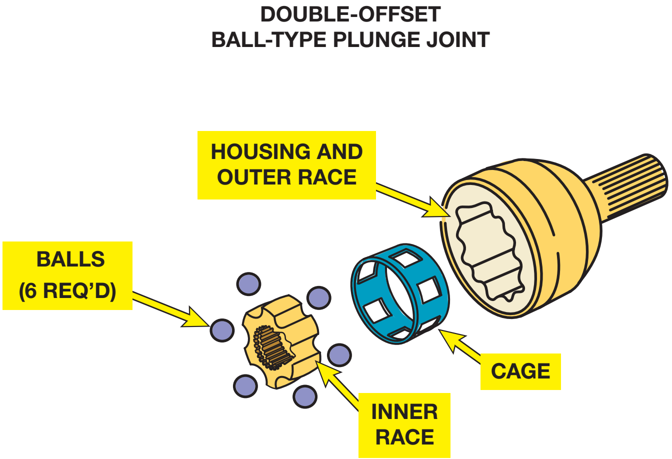


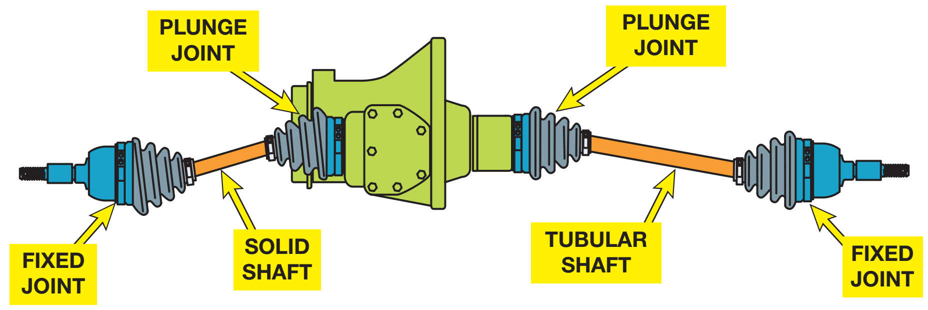
FIGURE 123–19 Double-offset ball-type plunge joint.

HALF SHAFTS Unequal-length **half shafts** result in unequal drive axle shaft angles to the front drive wheels. ● **SEE FIGURE 123–20**. This unequal angle often results in a pull on the steering wheel during acceleration. This pulling to one side during acceleration due to unequal engine torque being applied to the front drive wheels is called torque steer. To help reduce the effect of torque steer, some vehicles are manufactured with an intermediate shaft that results in equal drive axle shaft angles. Both designs use fixed outer CV joints with plunge-type inner joints.

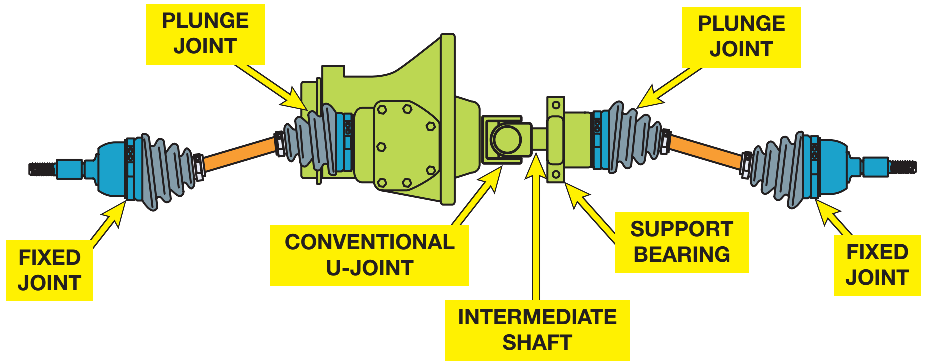
FREQUENTLY ASKED QUESTION

What Is That Weight for on the Drive Axle Shaft?

Some drive axle shafts are equipped with what looks like a balance weight. ● **SEE FIGURE 123–21**. It is actually a dampener weight used to dampen out certain drive line vibrations. The weight is not used on all vehicles and may or may not appear on the same vehicle depending on engine, transmission, and other options. The service technician should always try to replace a defective or worn drive axle shaft with the exact replacement. When replacing an entire drive axle shaft, the technician should always follow the manufacturer's instructions regarding either transferring or not transferring the weight to the new shaft.


PLUNGE JOINT
PLUNGE JOINT
FIXED JOINT
SOLID SHAFT
TUBULAR SHAFT
FIXED JOINT

UNEQUAL-LENGTH HALF SHAFTS


PLUNGE JOINT
PLUNGE JOINT
FIXED JOINT
CONVENTIONAL U-JOINT
INTERMEDIATE SHAFT
SUPPORT BEARING
FIXED JOINT

EQUAL-LENGTH HALF SHAFTS

FIGURE 123–20 Unequal-length driveshafts result in unequal drive axle shaft angles to the front drive wheels. This unequal angle side to side often results in a steering of the vehicle during acceleration called torque steer. By using an intermediate shaft, both drive axles are the same angle and the torque steer effect is reduced.

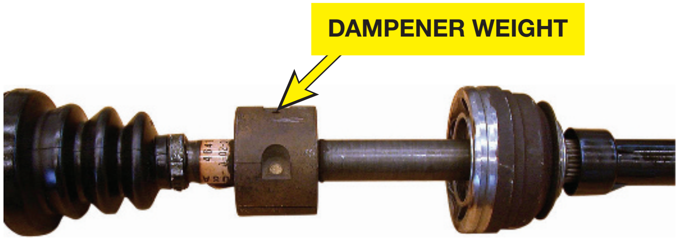

DAMPENER WEIGHT

FIGURE 123–21 A typical drive axle shaft with dampener weight.

CV JOINT BOOT MATERIALS The pliable boot surrounding the CV joint, or **CV joint boot**, must be able to remain flexible under all weather conditions and still be strong enough to avoid being punctured by road debris. There are four basic types of boot materials used over CV joints:

1. *Natural rubber* (black) uses a bridge-type stainless steel clamp to retain.
2. *Silicone rubber* (gray) is a high-temperature-resistant material that is usually used only in places that need heat protection, such as the inner CV joint of a front-wheel-drive vehicle.
3. *Hard thermoplastic* (black) is a hard plastic material requiring heavy-duty clamps and a lot of torque to tighten (about 100 lb-ft!).
4. *Urethane* (usually blue) is a type of boot material usually found in an aftermarket part. ● **SEE FIGURE 123–22**.

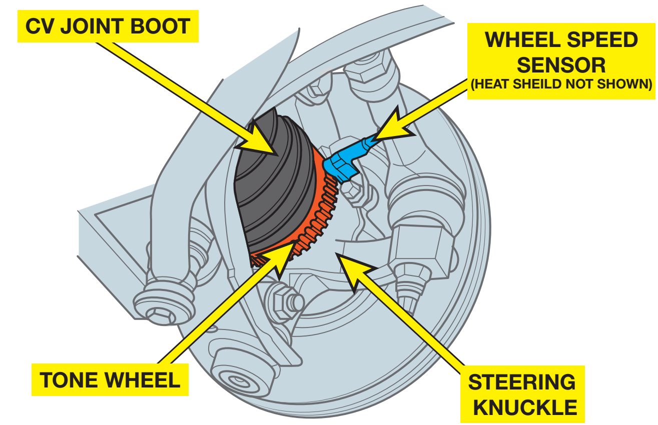

CV JOINT BOOT
WHEEL SPEED SENSOR
(HEAT SHEILD NOT SHOWN)
TONE WHEEL
STEERING KNUCKLE

FIGURE 123–22 Many outer CV joints include the tone wheel for the wheel speed sensor used by the anti-lock and stability control systems.

NOTE: Some aftermarket companies offer a split-style replacement CV joint boot. Being split means that the boot can be replaced without having to remove the drive axle shaft. Vehicle manufacturers usually do *not* recommend this type of replacement boot because the joint cannot be disassembled and properly cleaned with the drive axle still in the vehicle. The split boots must also be kept perfectly clean (a hard job to do with all the grease in the joint) in order to properly seal the seam on the split boot.

It is important that boot seals be inspected regularly and replaced if damaged. The inboard (plunging joint) can often pump water into the joint around the seals or through small holes in the boot material itself because the joint moves in and out. Seal retainers are used to provide a leakproof connection between the boot seal and the housing or axle shaft.

CV JOINT GREASE CV joints require special greases. Grease is an oil with thickening agents. Greases are named for the thickening agents used.

Most CV joint grease is molybdenum-disulfide-type grease, commonly referred to as *moly* grease. The exact composition of grease can vary depending on the CV joint manufacturer. *The grease supplied with a replacement CV joint or boot kit should be the only grease used*.

The exact mix of chemicals, viscosity (thickness), wear, and corrosion-resistant properties varies from one CV joint application to another. Some technicians mistakenly think that the *color* of the grease determines in which CV joint it is used. The color—such as black, blue, red, or tan—is used to identify the grease during manufacturing and packaging as well as to give the grease a consistent, even color (due to blending of various ingredients in the grease).

The exact grease to use depends on many factors, including the following:

1. The type (style) of CV joint. For example, outer (fixed) and inner (plunging) joints have different lubricating needs.
2. The location of the joint on the vehicle. For example, inner CV joints are usually exposed to the greatest amount of heat.
3. The type of boot. The grease has to be compatible with the boot material.

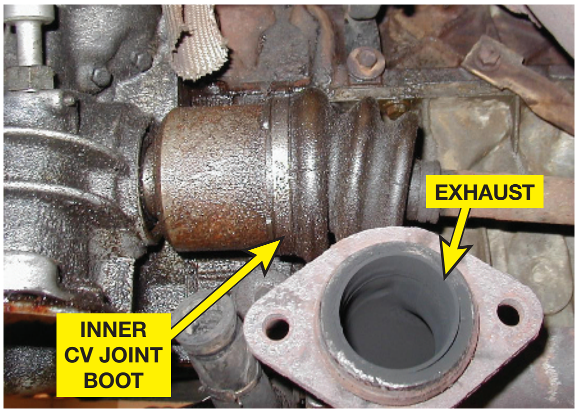


FIGURE 123–23 Many CV joints are close to the exhaust system where they are exposed to higher than normal temperatures.

TECH TIP

CV Joint Boots Are in a Hot Place

While the outer CV boots move when the front wheels are steered, the inner boots are also subjected to possible damage because they are often near the exhaust system where the high temperatures can damage the boot material. Then, if there is an engine oil leak, the engine oil could harm the CV boot too. Try to fix all leaks to help prevent premature CV boot failure. ● **SEE FIGURE 123–23**.

REVIEW QUESTIONS

1. Explain why Cardan-type U-joints on a driveshaft must be within 1/2 degree working angles.
2. What makes a constant velocity joint able to transmit engine torque through an angle at a constant velocity?
3. What type of grease must be used in CV joints?
4. Why is it necessary to replace a dented driveshaft?
5. What is the purpose of the weight found on some drive axle shafts?

CHAPTER QUIZ

1. Two technicians are discussing a dented driveshaft. Technician A says that it should be repaired. Technician B says that it should be replaced. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. All driveshafts are balanced to within ________________.
   - **a.** 1 ounce
   - **b.** 10 ounces
   - **c.** 15 ounces
   - **d.** 0.5% of the driveshaft weight
3. Drive axle shafts are also called ________________.
   - **a.** double-Cardan shafts
   - **b.** half shafts
   - **c.** driveshafts
   - **d.** propeller shafts
4. The name most often used to describe the universal joints on a conventional rear-wheel-drive vehicle driveshaft is ________________.
   - **a.** trunnion
   - **b.** Cardan
   - **c.** CV
   - **d.** spider
5. A rear-wheel-drive vehicle vibrates when first accelerating from a stop. The vibration is less noticeable at higher speeds. The most likely cause is ________________.
   - **a.** driveshaft unbalance
   - **b.** excessive U-joint working angles
   - **c.** unequal U-joint working angles
   - **d.** brinelling of the U-joint
6. The maximum difference between the front and rear working angle of a driveshaft is ________________.
   - **a.** 1/4 degree
   - **b.** 1/2 degree
   - **c.** 1 degree
   - **d.** 3 degrees

7. Which series U-joint has the greatest torque capacity?
   - **a.** 1260
   - **b.** 1310
   - **c.** 1350
   - **d.** 1480

8. Two technicians are discussing torque steer on a front-wheel-drive vehicle. Technician A says that equal-length drive axle shafts help reduce torque steer. Technician B says that equal drive axle shaft angles help reduce torque steer. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B

9. The outer CV joints used on front-wheel-drive vehicles are ________________.
   - **a.** fixed type
   - **b.** plunge type
   - **c.** double Cardan
   - **d.** Either b or c depending on the vehicle

10. The proper grease to use with a CV joint is ________________.
   - **a.** black chassis grease
   - **b.** dark blue EP grease
   - **c.** red moly grease
   - **d.** the grease that is supplied with the boot kit

Chapter

124

DRIVESHAFT AND HALF SHAFTS SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain how to diagnose a U-joint.
- Explain how to inspect a driveshaft and U-joint.
- List the steps necessary to replace a U-joint.
- Explain how to measure U-joint working angles.
- Discuss CV joint diagnosis and replacement shaft assemblies.
- Describe the service procedures for replacing CV joints.

KEY TERMS:

Inclinometer 1566 • Pin bushings 1565 • Pinch bolt 1567 • Spline bind 1570 • Synthetic retainers 1565 • Prevailing torque nut 1569 • U-joints 1563

U-JOINT DIAGNOSIS

BACKGROUND The driveshaft of a typical rear-wheel-drive (RWD) vehicle rotates about three times faster than the wheels. This is due to the gear reduction that occurs in the differential. The differential not only provides gear reduction but also allows for a difference in the speed of the rear wheels that is necessary whenever turning a corner.

The driveshaft rotates at the same speed as the engine if the transmission ratio is 1 to 1 (1:1). The engine speed, in revolutions per minute (RPM), is transmitted through the transmission at the same speed. In lower gears, the engine speed is many times faster than the output of the transmission. Most transmissions today, both manual and automatic, have an overdrive gear. This means that at highway speeds, the driveshaft is rotating faster than the engine.

SYMPTOMS OF DEFECTIVE U-JOINTS The driveshaft must travel up and down as the vehicle moves over bumps and dips in the road while rotating and transmitting engine power to the drive wheels. The driveshaft and universal joints should be carefully inspected whenever any of the following problems or symptoms occur:

1. Vibration or harshness at highway speed
2. A clicking sound whenever the vehicle is moving either forward or in reverse
3. A clunking sound whenever changing gears, such as moving from drive to reverse

DRIVESHAFT AND U-JOINT INSPECTION

The driveshaft should be inspected for the following:

1. Any dents or creases caused by incorrect hoisting of the vehicle or by road debris.

CAUTION: A dented or creased driveshaft can collapse, especially when the vehicle is under load. This collapse of the driveshaft can cause severe damage to the vehicle and may cause an accident.

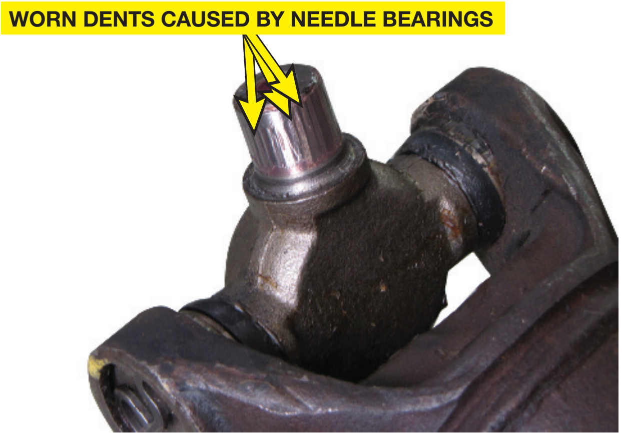


FIGURE 124–1 Notice how the needle bearings have worn grooves, called Brinelling, into the bearing surface of the U-joint.

CASE STUDY

The Squeaking Pickup Truck

The owner of a pickup truck complained that a squeaking noise occurred while driving in reverse. The "eeee eeee eeee" sound increased in frequency as the truck increased in speed, yet the noise did not occur when driving forward.

Because there was no apparent looseness in the U-joints, the service technician at first thought that the problem was inside either the transmission or the rear axle. When the driveshaft was removed to further investigate the problem, it became obvious where the noise was coming from. The U-joint needle bearing had worn the cross-shaft bearing surface of the U-joint. ● **SEE FIGURE 124–1**. The noise occurred only in reverse because the wear had occurred in the forward direction, and therefore only when the torque was applied in the opposite direction did the needle bearing become bound up and start to make noise. A replacement U-joint solved the squeaking noise in reverse.

Summary:

Complaint—Customer complained of squeaking sound but only while driving in reverse.
Cause—A worn U-joint was found to be the cause.
Correction—The worn U-joint was replaced and the noise issue was corrected.

2. Undercoating, grease, or dirt buildup on the driveshaft can cause vibrations.
3. Undercoating should be removed using a suitable solvent and a rag. Always dispose of used rags properly.

The **U-joints** should be inspected every time the vehicle chassis is lubricated, or four times a year. Original equipment (OE) U-joints are permanently lubricated and have no provision for greasing. If there is a grease fitting, the U-joint should be lubricated by applying grease with a grease gun. ● **SEE FIGURES 124–2 AND 124–3**.

In addition to periodic lubrication, the driveshaft should be grabbed and moved to see if there is any movement of the U-joints. If *any* movement is noticed when the driveshaft is moved, the U-joint is worn and must be replaced.

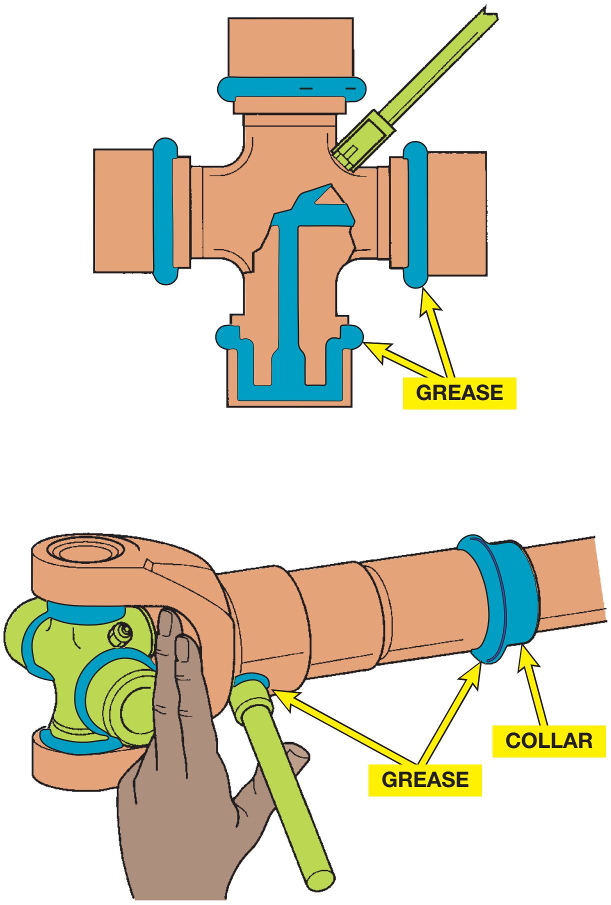


FIGURE 124–2 All U-joints and spline collars equipped with a grease fitting should be greased four times a year as part of a regular lubrication service.

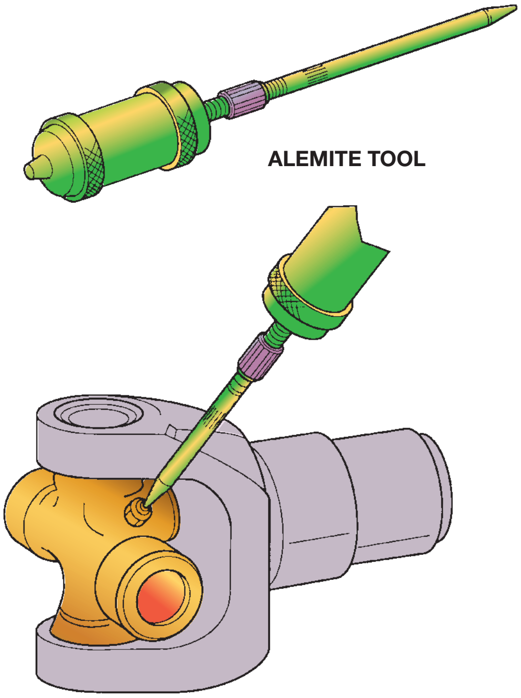


FIGURE 124–3 Many U-joints require a special grease gun tool to reach the grease fittings.

NOTE: U-joints are not serviceable items and cannot be repaired. If worn or defective, they must be replaced.

U-joints can be defective and still not show noticeable free movement. *A proper U-joint inspection can be performed only by removing the driveshaft from the vehicle*.

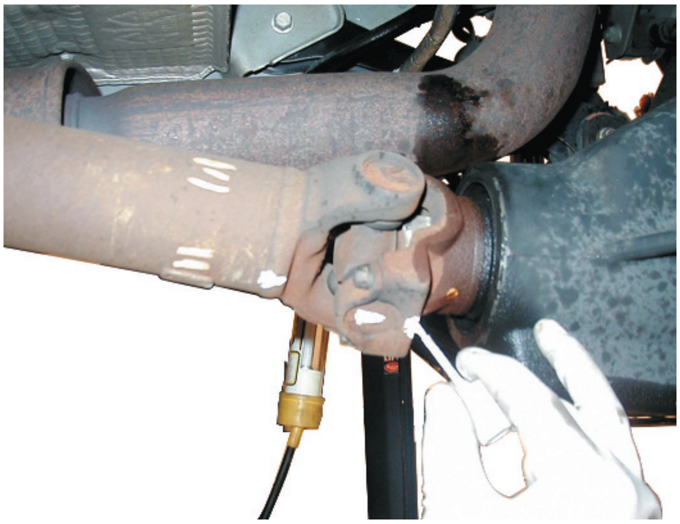


FIGURE 124–4 Always mark the original location of U-joints before disassembly.

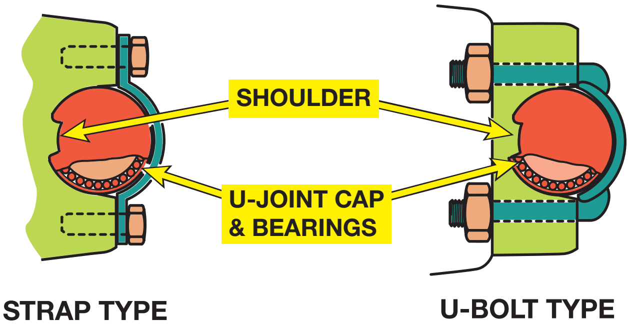


FIGURE 124–5 Two types of retaining methods that are commonly used at the rear U-joint at the differential.

Before removing the driveshaft, always mark the position of all mating parts to ensure proper reassembly. White correction fluid, also known as “White Out” or “Liquid Paper,” is an easy and fast-drying marking material. ● **SEE FIGURE 124–4**.

To remove the driveshaft from a rear-wheel-drive vehicle, remove the four fasteners at the rear U-joint at the differential. ● **SEE FIGURE 124–5**.

Push the driveshaft forward toward the transmission and then down and toward the rear of the vehicle. The driveshaft should slip out of the transmission spline and can be removed from underneath the vehicle.

NOTE: With the driveshaft removed, transmission lubricant can leak out of the rear extension housing. To prevent a mess, use an old spline the same size as the one being removed or place a plastic bag over the extension housing to hold any escaping lubricant. A rubber band can be used to hold the bag onto the extension housing.

To inspect U-joints, move each joint through its full travel, making sure it can move (articulate) freely and equally in all directions. ● **SEE FIGURE 124–6**.

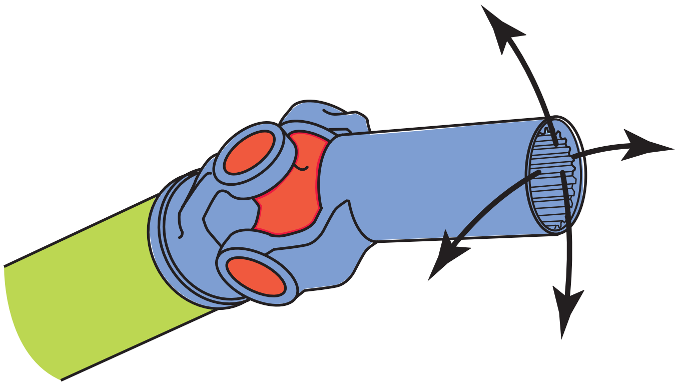


FIGURE 124–6 The best way to check any U-joint is to remove the driveshaft from the vehicle and move each joint in all directions. A good U-joint should be free to move without binding.

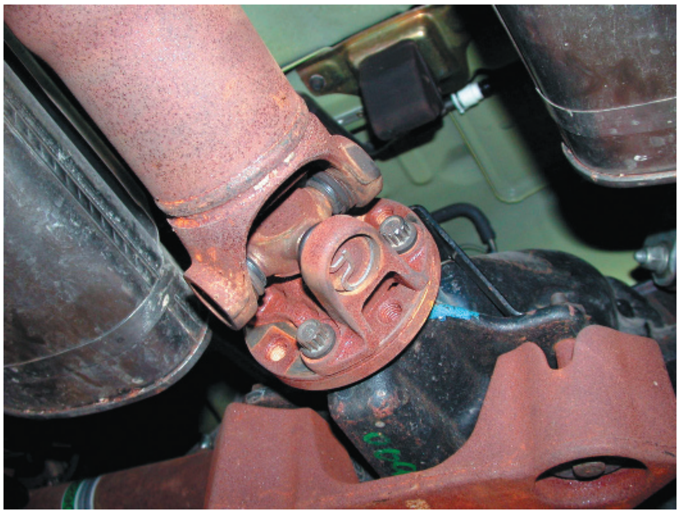


FIGURE 124–7 Typical U-joint that uses an outside snap ring. This style of joint bolts directly to the companion flange that is attached to the pinion gear in the differential.

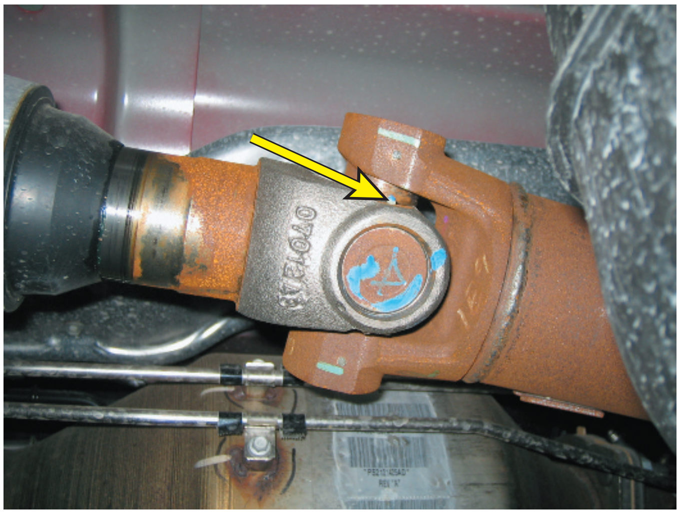


FIGURE 124–8 A U-joint that is held together by nylon and usually requires that heat be applied to remove from the yoke.

U-JOINT REPLACEMENT

All movement in a U-joint should occur between the trunnions and the needle bearings in the end caps. The end caps are press-fit to the yokes, which are welded to the driveshaft. Three types of retainers are used to keep the bearing caps on the U-joints: the outside snap ring (● **SEE FIGURE 124–7**), the inside retaining ring, and injected synthetic (usually nylon). ● **SEE FIGURE 124–8**.

After removing the retainers, use a press or a vise to separate the U-joint from the yoke. ● **SEE FIGURE 124–9**.

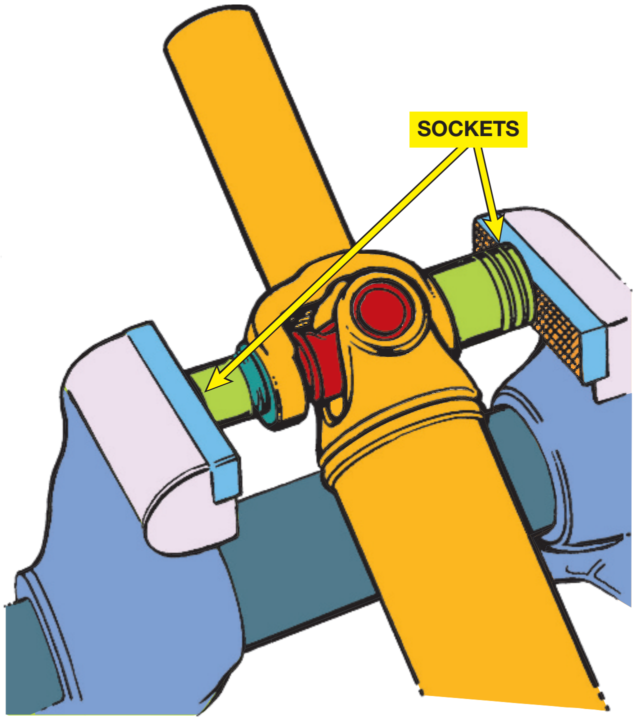


FIGURE 124–9 Use a vise and two sockets to remove a U-joint. One socket fits over the bearing cup and the other fits on the bearing to press-fit the cups from the crosspiece.

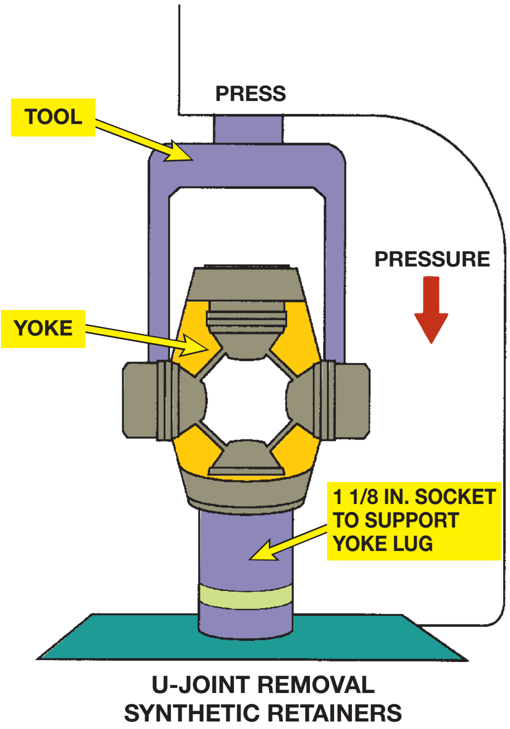


FIGURE 124–11 A special tool being used to press apart a U-joint that is retained by injected plastic. Heat from a propane torch may be necessary to soften the plastic to avoid exerting too much force on the U-joint.

TECH TIP

Use Tape to Be Safe

When removing a driveshaft, use tape to prevent the rear U-joint caps from falling off. If the caps fall off the U-joint, all of the needle bearings will fall out and scatter over the floor. ● **SEE FIGURE 124–10**.

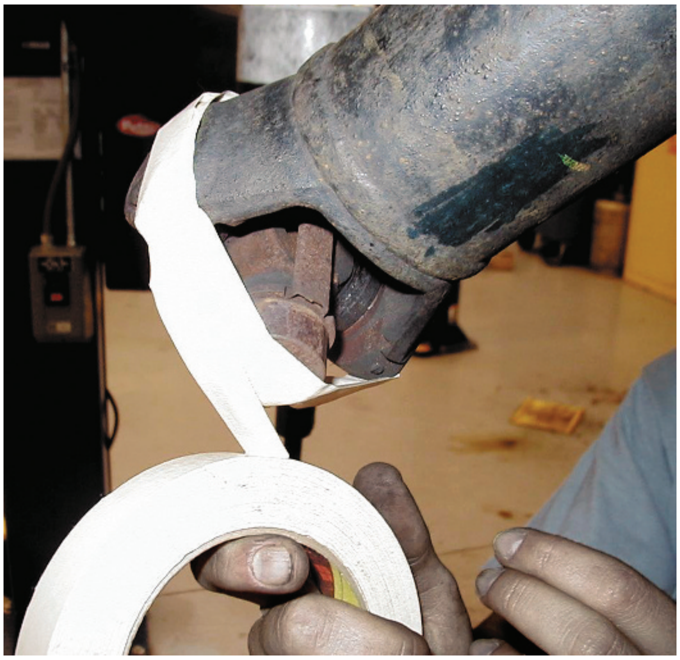


FIGURE 124–10 Taping the U-joint to prevent the caps from coming off.

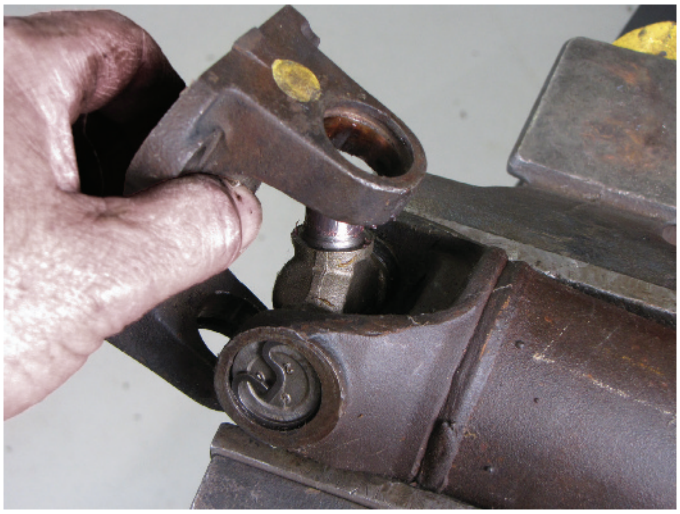


FIGURE 124–12 Removing the worn cross from the yoke.

U-joints that use **synthetic retainers** must be separated using a press and a special tool to press onto both sides of the joint in order to shear the plastic retainer, as shown in ● **FIGURE 124–11**.

Replacement U-joints use spring clips instead of injected plastic. Remove the old U-joint from the yoke, as shown in ● **FIGURE 124–12**, and replace with a new U-joint. Replacement U-joints should be *forged* (never cast) and use up to 32 needle bearings (also called **pin bushings**) instead of just 24 needle bearings, as used in lower-quality U-joints. Replacement U-joints usually have a grease fitting so that the new replacement U-joint can be properly lubricated. ● **SEE FIGURE 124–13**.

After removing any dirt or burrs from the yoke, press in a new U-joint. Rotate the new joint after installation to make sure it moves freely, without binding or stiffness. If a U-joint is stiff, it can cause a vibration.

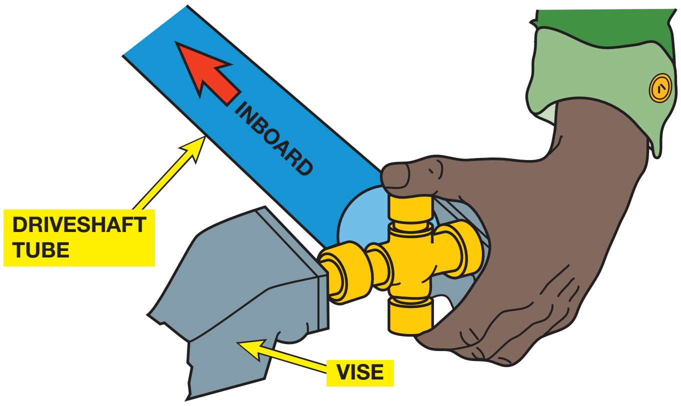


FIGURE 124–13 When installing a new U-joint, position the grease fitting on the inboard side (toward the driveshaft tube) and in alignment with the grease fitting of the U-joint at the other end.

NOTE: If a U-joint is slightly stiff after being installed, strike the U-joint using a brass punch and a light hammer. This often frees a stiff joint and is often called "relieving the joint." The shock aligns the needle bearings in the end caps.

U-JOINT WORKING ANGLES

Unequal or incorrect U-joint working angles can cause severe vibrations. Driveshaft and U-joint angles may change from the original factory setting due to one or more of the following:

1. Defective or collapsed engine or transmission mounts
2. Defective or sagging springs, especially the rear springs due to overloading or other causes
3. Accident damage or other changes to the chassis of the vehicle
4. Vehicle modification that raises or lowers the ride height

Replace any engine or transmission mount that is cracked or collapsed. When a mount collapses, the engine drops from its original location. Now the driveshaft angles are changed and a vibration may be felt.

Rear springs often sag after many years of service or after being overloaded. This is especially true of pickup trucks. Many people carry as much as the cargo bed can hold, often exceeding the factory-recommended carry capacity or gross vehicle weight (GVW) of the vehicle.

To measure U-joint and driveshaft angles, the vehicle must be hoisted using an axle contact or drive-on-type lift so as to maintain the same driveshaft angles as the vehicle has while being driven.

The working angles of the two U-joints on a driveshaft should be within 1/2 degree of each other in order to cancel out speed changes. ● **SEE FIGURE 124–14**.

To measure the working angle of a U-joint, follow these steps:

STEP 1 Place an **inclinometer** (a tool used to measure angles) on the rear U-joint bearing cap. Level the bubble and read the angle. ● **SEE FIGURE 124–15**; the pictured reading is 19.5 degrees.

STEP 2 Rotate the driveshaft 90 degrees and read the angle of the rear yoke. For example, this reading is 17 degrees.

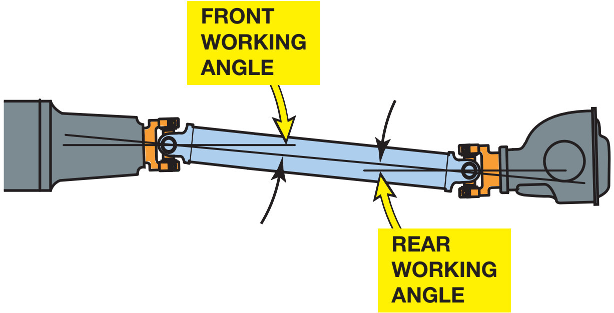


FIGURE 124–14 The working angle of most U-joints should be at least 1/2 degree (to permit the needle bearing to rotate in the U-joints) and should not exceed 3 degrees or a vibration can occur in the driveshaft, especially at higher speeds. The difference between the front and rear working angles should be within 1/2 degree of each other.

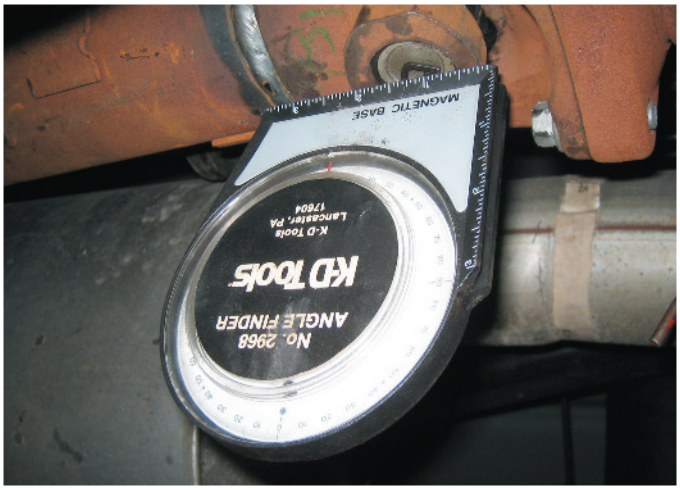


FIGURE 124–15 An inclinometer with a magnetic base is being used to measure the angle of the driveshaft at the rear U-joint.

STEP 3 Subtract the smaller reading from the larger reading to obtain the working angle of the joint. In this example, it is 2.5 degrees (19.5 degrees − 17 degrees = 2.5 degrees).

Repeat the same procedure for the front U-joint. The front and rear working angles should be within 0.5 degrees. If the two working angles are not within 0.5 degrees, shims can be added to bring the two angles closer together. The angle of the rear joint is changed by installing a tapered shim between the leaf spring and the axle, as shown in ● **FIGURE 124–16**.

CAUTION: Use caution whenever using wedges between the differential and the rear leaf spring to restore the correct U-joint working angle. Even though wedges are made to raise the front of the differential, the tilt often prevents rear-end lubricant from reaching the pinion bearing, resulting in pinion bearing noise and eventual failure.

The angle of the front joint is changed by adding or removing shims from the mount under the transmission. Sometimes the driveshaft working angles can change due to wear or failure of the engine or transmission mounts. ● **SEE FIGURE 124–17**.

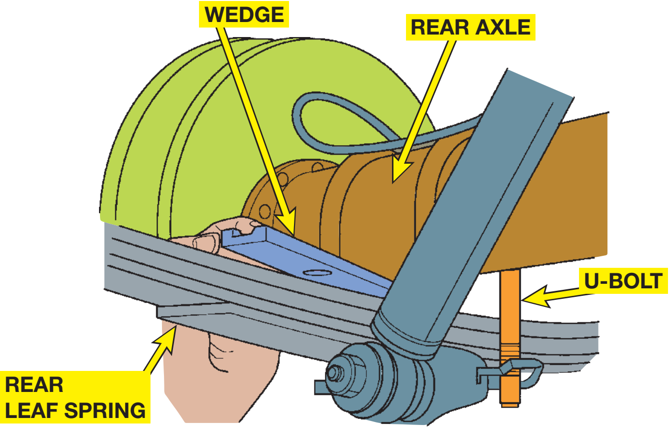


FIGURE 124–16 Placing a tapered metal wedge between the rear leaf spring and the rear axle pedestal to correct rear U-joint working angles.

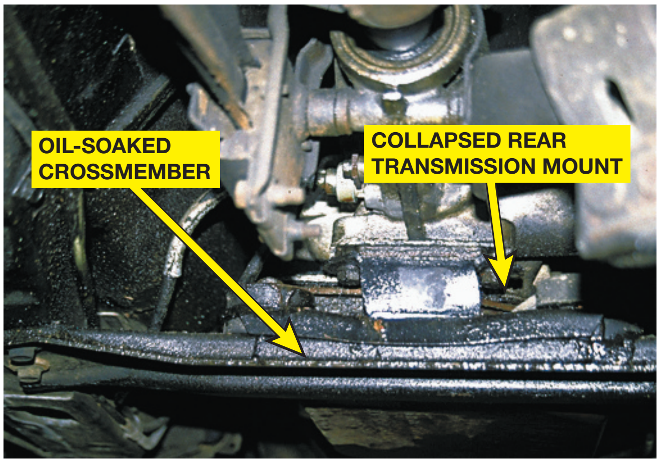


FIGURE 124–17 A transmission oil pan gasket leak allowed automatic transmission fluid (ATF) to saturate the rear transmission mount rubber, causing it to collapse. After replacing the defective mount, proper driveshaft angles were restored and the driveline vibration was corrected.

CV JOINT DIAGNOSIS

When a CV joint wears or fails, the most common symptom is noise while driving. An outer fixed CV joint will most likely be heard when turning sharply and accelerating at the same time. This noise is usually a clicking sound. While inner joint failure is less common, a defective inner CV joint often creates a loud clunk while accelerating from rest. To help verify a defective joint, drive the vehicle in reverse while turning and accelerating. This almost always will reveal a defective outer joint.

REPLACEMENT SHAFT ASSEMBLIES Front-wheel-drive vehicles were widely used in Europe and Japan long before they became popular in North America. The standard repair procedure used in these countries is the replacement of the entire drive assembly if there is a CV joint failure. Replacement boot kits are rarely seen in Europe because it is felt that even a slight amount of dirt or water inside a CV joint is unacceptable. Vehicle owners simply wait until the joint wear causes severe noise, and then the entire assembly is replaced.

The entire drive axle shaft assembly can easily be replaced and the defective unit can be sent to a company for remanufacturing. Even though cost to the customer is higher, the parts and repair shop does not have to inventory every type, size, and style of boot kit and CV joint. Service procedures and practices therefore vary according to location and the availability of parts. For example, some service technicians use replacement drive axle assemblies from salvage yards with good success.

NOTE: Some drive axle shafts have a weight attached between the inner and outer CV joints. This is a dampener weight. It is not a balance weight, and it need not be transferred to the replacement drive axle shaft (half shaft) unless instructed to do so in the directions that accompany the replacement shaft assembly.

TECH TIP

Quick and Easy Backlash Test

Whenever a driveline clunk is being diagnosed, one possible cause is excessive backlash (clearance) between the ring gear teeth and differential pinion teeth in the differential. Another common cause of excessive differential backlash is too much clearance between differential carrier pinion teeth and side gear teeth. A quick test to check backlash involves three easy steps:

STEP 1 Hoist the vehicle on a frame contact lift, allowing the drive wheels to be rotated.

STEP 2 Have an assistant hold one drive wheel and the driveshaft to keep them from turning.

STEP 3 Move the other drive wheel, observing how far the tire can rotate. This is the amount of backlash in the differential; it should be less than 1 inch (25 mm), of movement measured *at the tire.*

If the tire can move more than 1 inch (25 mm), then the differential should be inspected for wear and parts should be replaced as necessary. If the tire moves *less* than 1 inch (25 mm), then the backlash between the ring gear and pinion is probably *not* the cause of the noise.

CV JOINT SERVICE

The hub nut must be removed whenever servicing a CV joint or shaft assembly on a front-wheel-drive vehicle. Since these nuts are usually torqued to almost 200 lb-ft (260 N-m), keep the vehicle on the ground until the hub nut is loosened and then follow these steps (● **SEE FIGURE 124–18**):

STEP 1 Remove the front wheel and hub nut.

NOTE: Most manufacturers warn against using an air impact wrench to remove the hub nut. The impacting force can damage the hub bearing.

STEP 2 To allow the knuckle room to move outward enough to remove the drive axle shaft, some or all of the following will have to be disconnected:

a. Lower ball joint or **pinch bolt** (● **SEE FIGURE 124–19**).

b. Tie rod end (● **SEE FIGURE 124–20**).

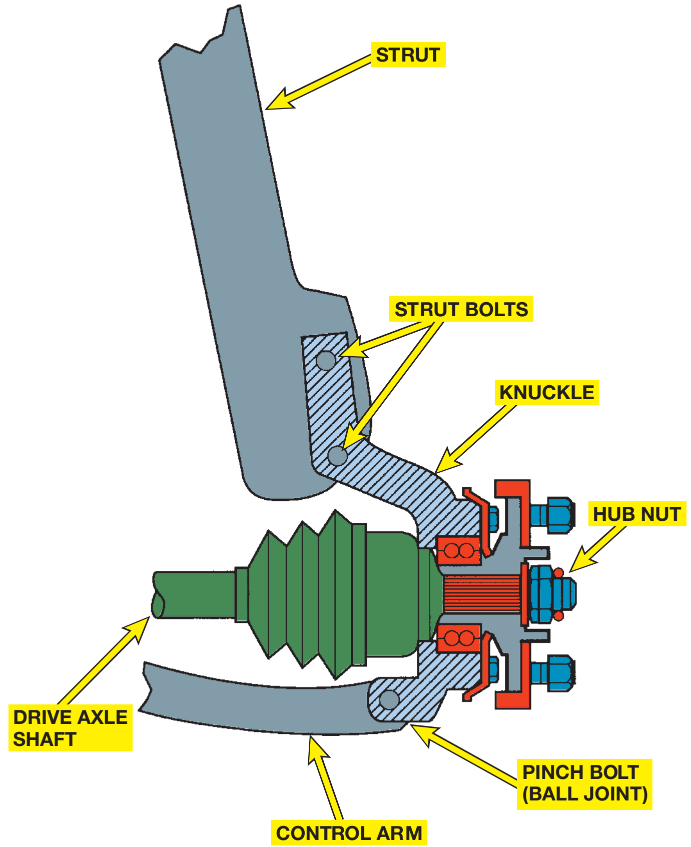

STRUT
STRUT BOLTS
KNUCKLE
HUB NUT
DRIVE AXLE SHAFT
PINCH BOLT (BALL JOINT)
CONTROL ARM

FIGURE 124–18 The hub nut must be removed before the hub bearing assembly or drive axle shaft can be removed from the vehicle.

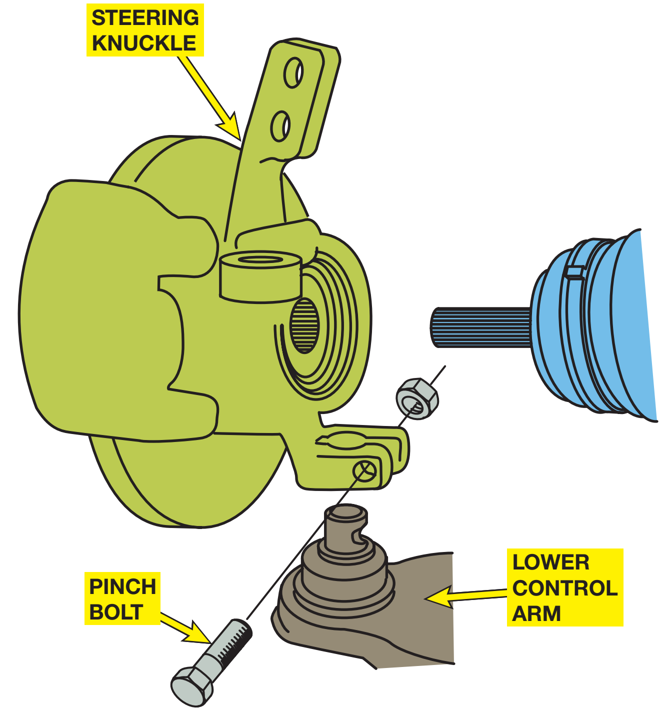

STEERING KNUCKLE
PINCH BOLT
LOWER CONTROL ARM

FIGURE 124–19 Many knuckles are attached to the ball joint on the lower control arm by a pinch bolt.

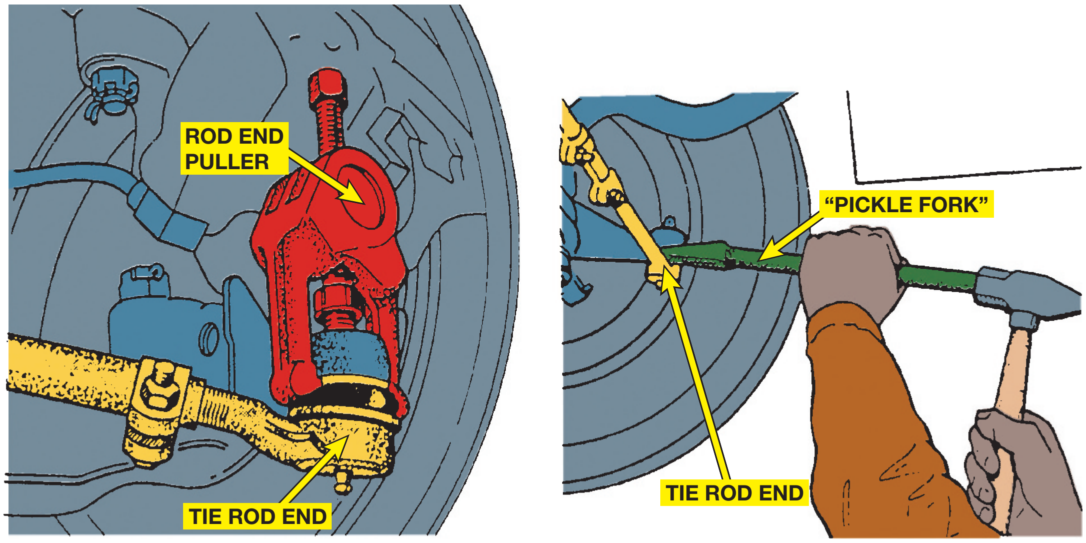

ROD END PULLER
TIE ROD END
"PICKLE FORK"
TIE ROD END

FIGURE 124–20 The preferred method for separating the tie rod end from the steering knuckle is to use a puller such as the one shown. A "pickle-fork"-type tool should be used only if the tie rod is going to be replaced. A pickle-fork-type tool can damage or tear the rubber grease boot. Striking the tie rod end with a hammer while holding another hammer behind the joint to shock and break the taper from the steering knuckle can also be used.

c. Stabilizer bar link.

d. Front disc brake caliper.

STEP 3 Remove the splined end of the axle from the hub bearing. Sometimes a special puller may be necessary, but in most cases the shaft can be tapped inward through the hub bearing with a light hammer and a brass punch can be used. To protect the threads of the drive axle shaft, install the hub nut temporarily. ● **SEE FIGURES 124–21 AND 124–22**.

STEP 4 Use a prybar or special tool with a slide hammer, as shown in ● **FIGURE 124–23**, and remove the inner joint from the transaxle.

STEP 5 Remove the drive axle shaft from the vehicle. ● **SEE FIGURES 124–24 AND 124–25**.

STEP 6 Reinstall the drive axle shaft in the reverse order of removal, and torque the drive axle nut to factory specifications. ● **SEE FIGURE 124–26**.

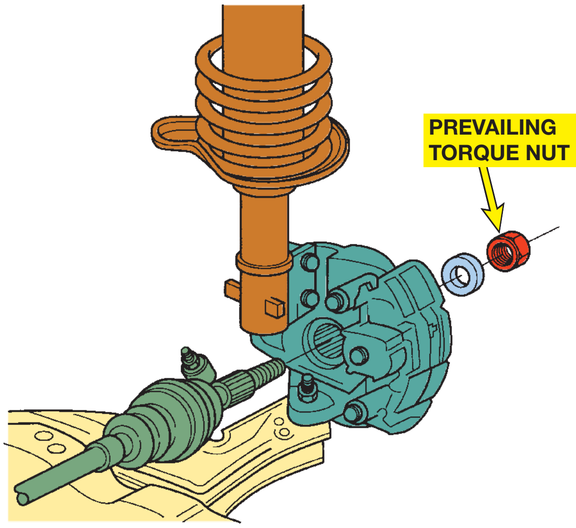


FIGURE 124–21 Many drive axles are retained by **prevailing torque nut** that must not be reused. Prevailing torque nuts are slightly deformed or contain a plastic insert that holds the nut tight (retains the torque) to the shaft without loosening.

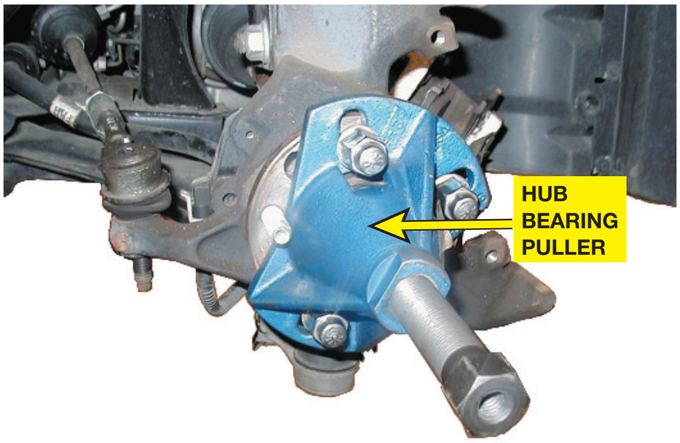


FIGURE 124–22 A special General Motors tool is being used to separate the drive axle shaft from the wheel hub bearing.

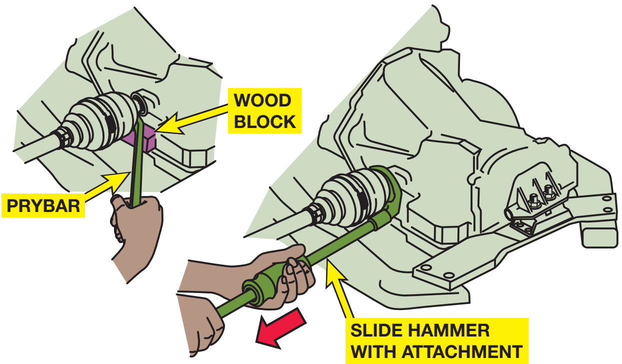


FIGURE 124–23 Most inner CV joints can be separated from the transaxle with a prybar.

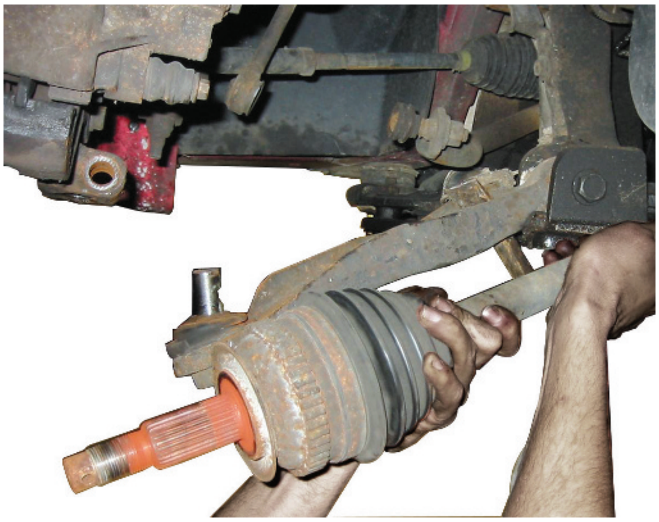


FIGURE 124–24 When removing a drive axle shaft assembly, use care to avoid pulling the plunge joint apart.

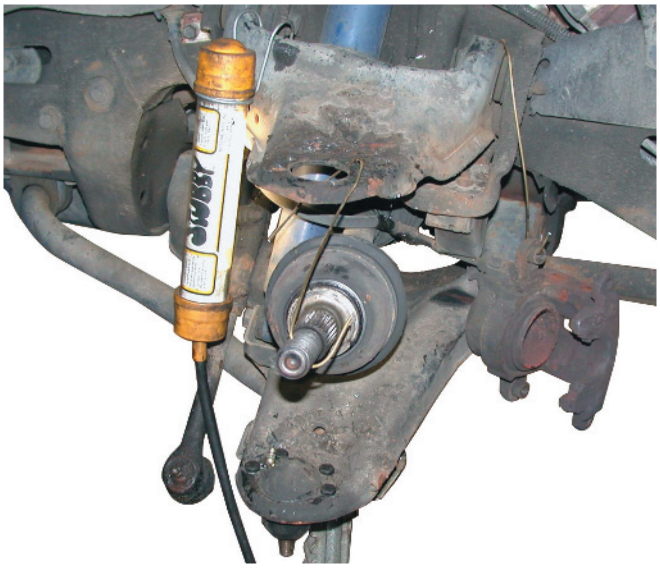


FIGURE 124–25 If other service work requires that just one end of the drive axle shaft be disconnected from the vehicle, be sure that the free end is supported to prevent damage to the protective boots or allowing the joint to separate.

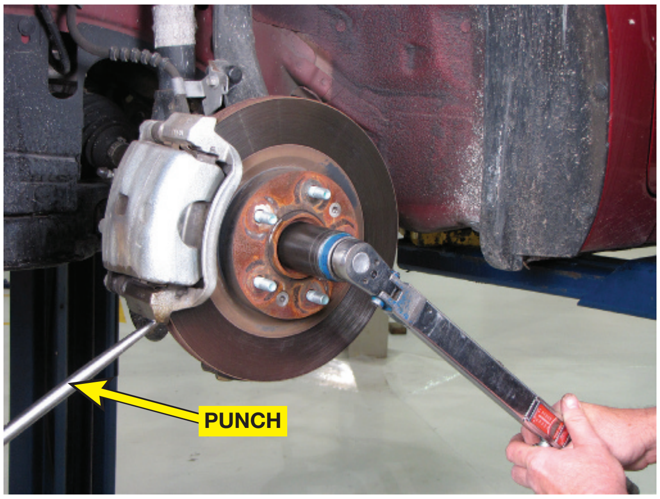


FIGURE 124–26 A punch being used to keep the rotor from rotating while torquing the axle shaft spindle nut.

TECH TIP

Spline Bind Cure

Driveline "clunk" often occurs in rear-wheel-drive vehicles when shifting between drive and reverse or when accelerating from a stop. Often the cause of this noise is excessive clearance in the differential. Another cause is called **spline bind**, where the changing rear pinion angle creates a binding in the spline when the rear springs change in height. For example, when a pickup truck stops, the weight transfers toward the front and unloads the rear springs. The front of the differential noses downward and forward as the rear springs unload. When the driver accelerates forward, the rear of the truck squats downward, causing the driveshaft to be pulled rearward when the front of the differential rotates upward. This upward movement on the spline often causes the spline to bind and make a loud clunk when the bind is finally released.

The method recommended by vehicle manufacturers to eliminate this noise is to follow these steps:

1. Remove the driveshaft.
2. Clean the splines on both the driveshaft yoke and the transmission output shaft.
3. Remove any burrs on the splines with a small metal file (remove all filings).
4. Apply a high-temperature grease to the spline teeth of the yoke. Apply grease to each spline, but do not fill the splines. Synthetic chassis grease is preferred because of its high temperature resistance.
5. Reinstall the driveshaft.

CASE STUDY

The Vibrating Buick

The owner of a front-wheel-drive Buick complained that it vibrated during acceleration only. The vehicle would also pull toward one side during acceleration. An inspection discovered a worn (cracked) engine mount. After replacing the mount, the CV joint angles were restored and both the vibration and the pulling to one side during acceleration were solved. ● **SEE FIGURE 124–27**.

Summary:

Complaint—Owner complained about a vibration and a pull to one side during acceleration.
Cause—A defective engine mount which caused the CV joint angles to be unequal, causing the vibration and pulling during acceleration.
Correction—The engine mount was replaced and the customer concern was solved.

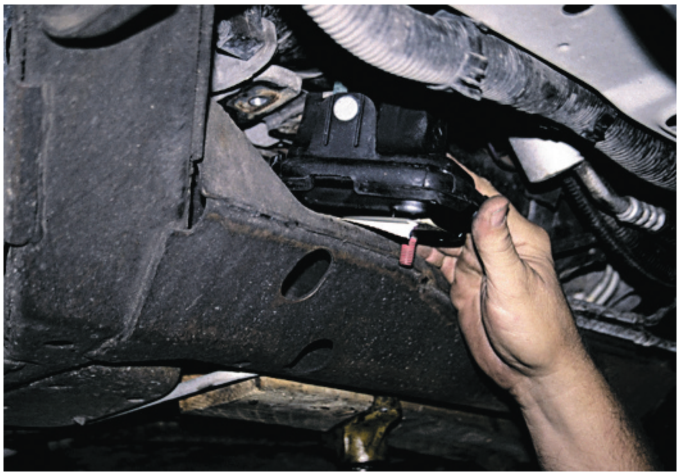
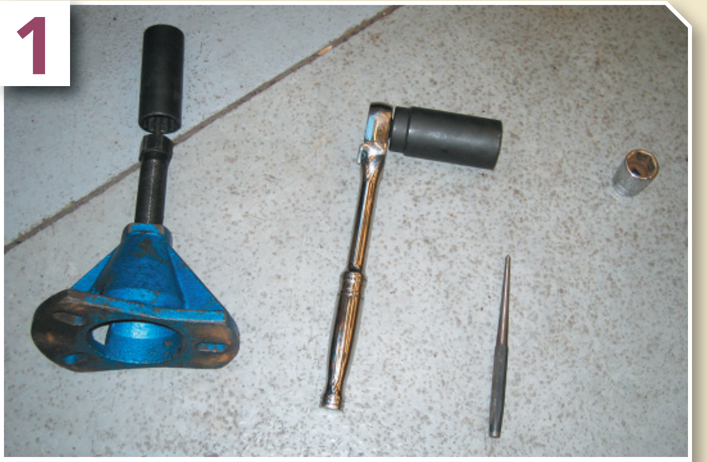


FIGURE 124–27 The engine had to be raised higher to get the new (non-collapsed) engine mount installed.

DRIVE AXLE SHAFT REPLACEMENT

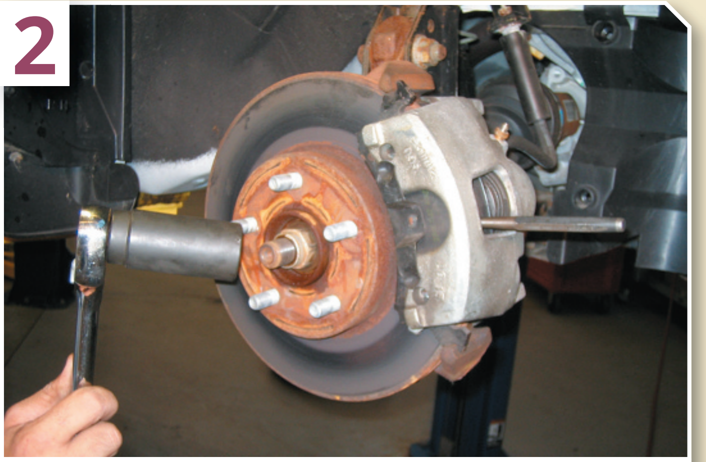
STEP BY STEP

1



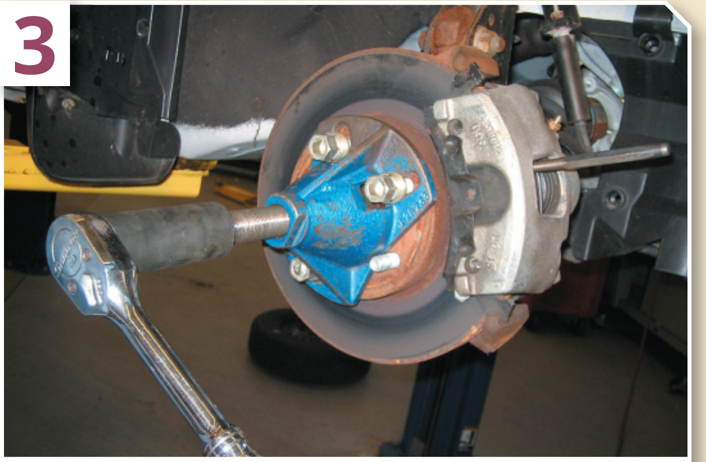
Tools needed to replace a drive axle shaft on a General Motors vehicle include a drift, sockets, plus a prybar bearing/axle shaft special tool.

2



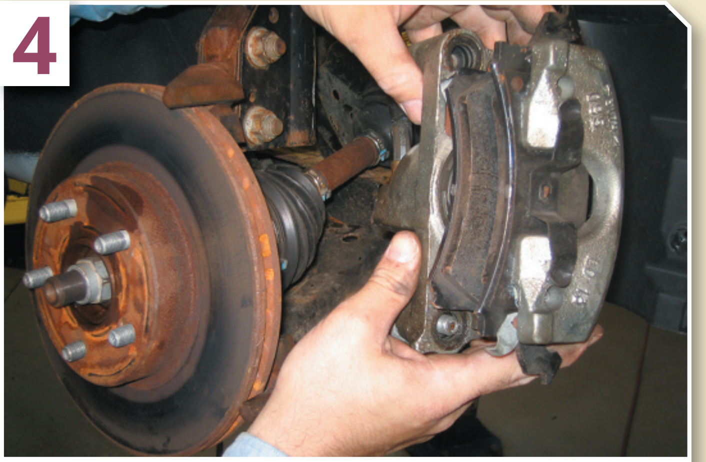
The drive axle shaft retaining nut can be loosened with the tire on the ground, or use a drift inserted into the rotor cooling fins before removing the nut.

3



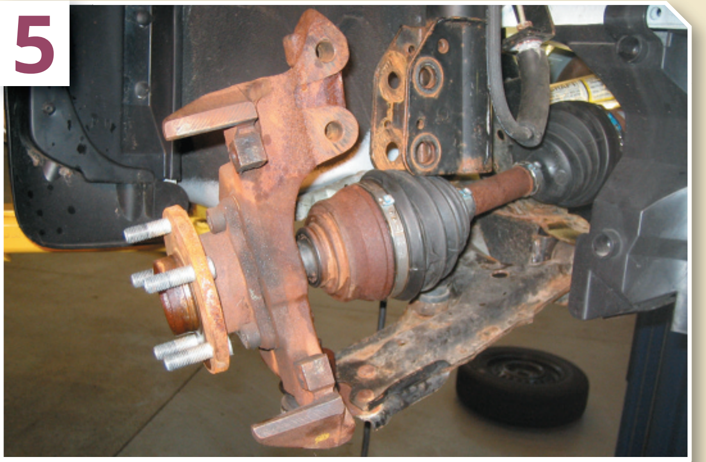
Using a special tool to push the drive axle splines from the bearing assembly.

4



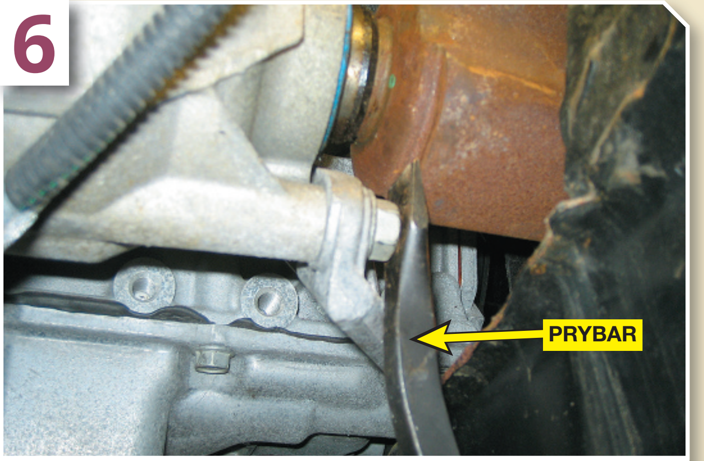
Remove the disc brake caliper and support it out of the way. Then, remove the disc brake rotor.

5



The lower ball joint could have been removed instead of disconnecting the strut from the knuckle so that the alignment could be retained.

6



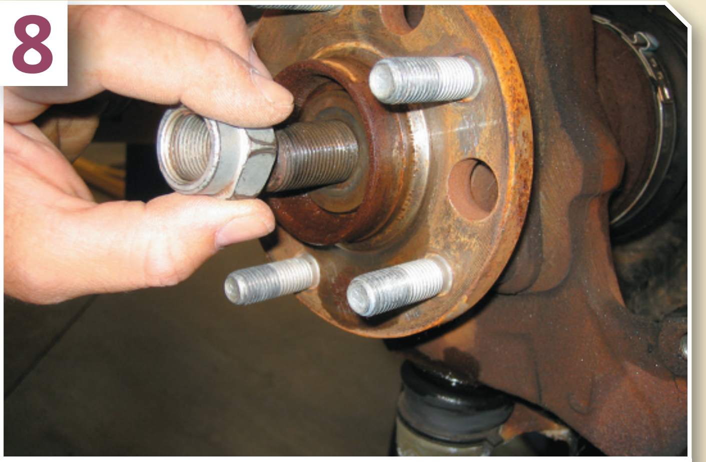
A prybar is used to separate the inner drive axle shaft joint from the transaxle.

DRIVE AXLE SHAFT REPLACEMENT

7

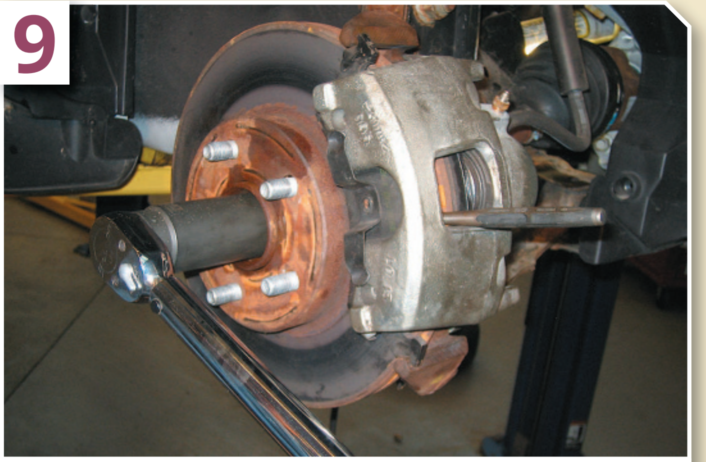
After the inner joint splines have been released from the transaxle, carefully remove the drive axle shaft assembly from the vehicle.

8



To install, reverse the disassembly procedure and be sure to install the washer under the retainer-nut, and always use a new prevailing torque nut.

9



Reinstall the disc brake rotor and caliper and then torque the drive axle shaft retaining nut to factory specifications.

REVIEW QUESTIONS

1. What two items should be checked when inspecting a driveshaft?
2. What steps are necessary to measure driveshaft U-joint working angles?
3. What is the procedure for replacing a Cardan-type U-joint?
4. How is a CV joint replaced?
5. What is a prevailing torque nut?

CHAPTER QUIZ

1. Two technicians are discussing U-joints. Technician A says that a defective U-joint could cause a loud clunk when the transmission is shifted between drive and reverse. Technician B says a worn U-joint can cause a clicking sound only when driving the vehicle in reverse. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. A Cardan-type U-joint may require what tool(s) to replace?
   - **a.** A special tool
   - **b.** A torch
   - **c.** A press or a vise
   - **d.** May require any of the above
3. Incorrect or unequal U-joint working angles are most likely to be caused by _____________.
   - **a.** a bent driveshaft
   - **b.** a collapsed engine or transmission mount
   - **c.** a dry output shaft spline
   - **d.** defective or damaged U-joints
4. Front and rear driveshaft U-joint working angles should be within _____________ degrees of each other.
   - **a.** 0.5
   - **b.** 1.0
   - **c.** 3.0
   - **d.** 4.0
5. What could be a symptom of a defective U-joint?
   - **a.** A vibration at highway speed
   - **b.** A clicking sound
   - **c.** A clunking sound
   - **d.** Any of the above
6. A defective outer CV joint will usually make a _____________.
   - **a.** rumbling noise
   - **b.** growling noise
   - **c.** clicking noise
   - **d.** clunking noise
7. What can be used to correct U-joint working angles?
   - **a.** A turnbuckle
   - **b.** A wedge
   - **c.** An adjustable shock absorber
   - **d.** Welded spring mounts
8. What needs to be removed to replace a drive axle shaft from a front-wheel-drive vehicle?
   - **a.** Tie rod end
   - **b.** Lower control arm or ball joint
   - **c.** Hub nut
   - **d.** All of the above
9. The splines of the driveshaft yoke should be lubricated to prevent _____________.
   - **a.** a vibration
   - **b.** spline bind
   - **c.** rust
   - **d.** transmission fluid leaking from the extension housing
10. What is recommended to install the drive axle shaft to avoid damage to the hub bearing?
    - **a.** Torque wrench
    - **b.** Cordless impact wrench
    - **c.** Pickle fork
    - **d.** Hub bearing puller

Chapter 125

DRIVE AXLES AND DIFFERENTIALS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the purpose and function of a drive axle.
- Describe the parts of a drive axle.
- Describe drive axle gear ratios.
- Discuss open differentials.
- Discuss limited slip differentials.
- Describe the components of a drive axle.
- Describe rear axle bearings.
- Explain how to identify drive axles.
- Explain how to determine the axle ratio.
- Discuss rear-end noise diagnosis.
- Discuss drive axle inspection.
- Discuss drive axle disassembly.
- Explain how to replace the pinion shaft bearing.
- Explain how to set the drive pinion depth.
- Discuss how to set the preload for pinion gears.
- Describe the procedure to check and correct backlash.
- Discuss how to set the preload for side bearings.
- Discuss drive axle reassembly.
- Discuss drive axle lubricants.

KEY TERMS:

Axle ratio 1576 • Coast (or concave) side 1576 • Companion flange 1579 • Crown 1576 • Diff 1575 • Differential case 1575 • Drive (or convex) side 1576 • Drive pinion gear 1575 • Floating position 1576 • Heel 1576 • Hunting gear sets 1576 • Hypoid gear set 1575 • Lap 1577 • Nonhunting gear sets 1577 • Partially nonhunting gear sets 1577 • Pinion gear 1575 • Pinion shaft 1575 • Preloaded clutch 1578 • Rear end 1575 • Ring gear 1575 • Ring gear runout 1583 • Root 1576 • Side gears 1575 • Spider gears 1575 • Straddle-mounted pinion 1580 • Toe 1576 • Turning torque 1585 • Viscous coupling 1579

DRIVE AXLES

TERMINOLOGY All rear-wheel-drive (RWD) vehicles use a drive axle assembly to transfer power from the drive shaft to the drive wheels. Because it is powered, it is sometimes called a **live axle**.

Front-wheel-drive (FWD) cars use a dead axle or non-powered rear axle. The major parts of a drive axle include

- Ring and pinion gears
- Differential
- Axle shafts

PURPOSE AND FUNCTION The purpose and function of a drive axle assembly include the following:

- To change the direction of engine torque (● **SEE FIGURE 125–1**.)
- To allow the drive wheels to rotate at different speeds (● **SEE FIGURE 125–2**.)

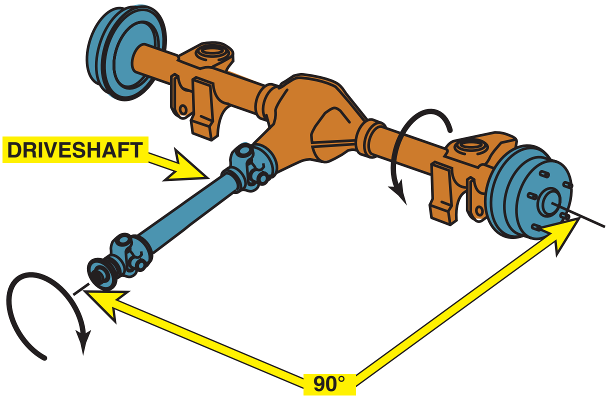


FIGURE 125–1 The differential assembly changes the direction of engine torque and increases the torque to the drive wheels.

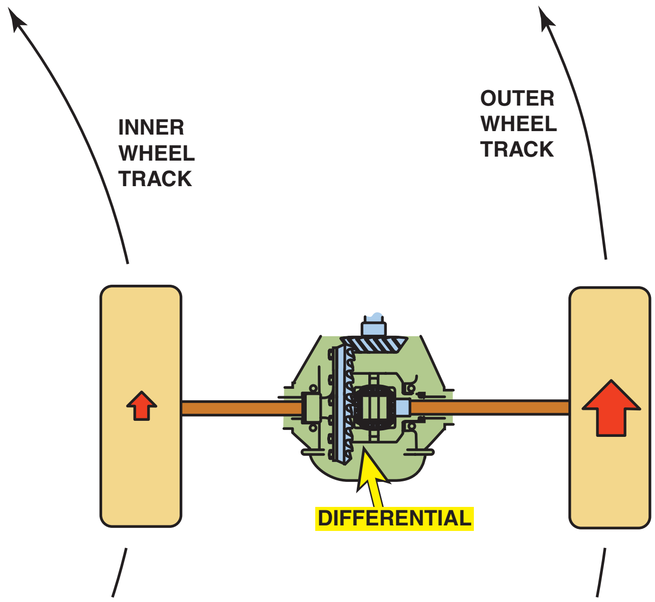

INNER WHEEL TRACK
OUTER WHEEL TRACK
DIFFERENTIAL

FIGURE 125–2 The difference between the travel distance of the drive wheels is controlled by the differential.

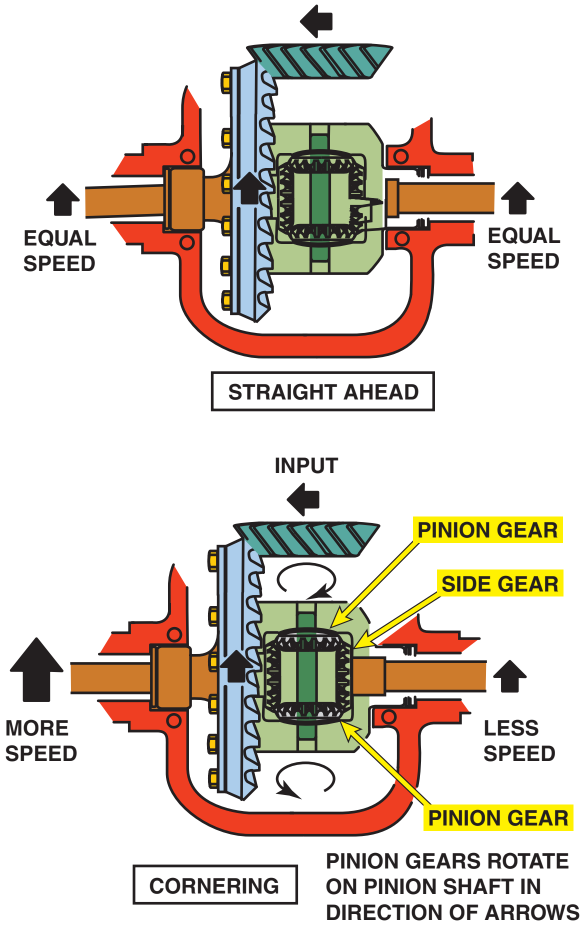

EQUAL SPEED
EQUAL SPEED
STRAIGHT AHEAD
INPUT
PINION GEAR
SIDE GEAR
MORE SPEED
LESS SPEED
PINION GEAR
CORNERING
PINION GEARS ROTATE ON PINION SHAFT IN DIRECTION OF ARROWS

FIGURE 125–3 When the vehicle turns a corner, the inner wheel slows and the outer wheel increases in speed to compensate. This difference in rotational speed causes the pinion gears to "walk" around the slower side gear.

A differential is a mechanical addition and subtraction assembly. By splitting the engine torque to the drive wheels when the vehicle is turning a corner, the torque forces cause the side gear and pinion gears to subtract torque from one side and add torque to the opposite side. ● **SEE FIGURE 125–3.**

NOTE: The differential used in most front-wheel-drive vehicles is incorporated into the transaxle assembly and is called the final drive assembly. The purpose and function of this final drive assembly is similar to the differential assembly used in rear-wheel-drive vehicles.

PARTS OF A DRIVE AXLE

A drive axle is also called a **rear end** or abbreviated simply as a **diff**. Whenever any vehicle makes a turn, the outside wheel must travel a greater distance than the inside wheel. The driveshaft applies torque to the **drive pinion gear** that meshes below the center line of a **ring gear** as shown in ● **FIGURE 125–4**. This type of gear set is called a **hypoid gear set** and requires gear lubrication specifically designed for this type of service. The ring gear is attached to a **differential case** that also contains small beveled **spider gears** or **pinion gears**. A **pinion shaft** passes through the two pinion gears in the case. In mesh with the pinion gears are two **side gears** that are splined to the inner ends of the axles. ● **SEE FIGURE 125–5.**

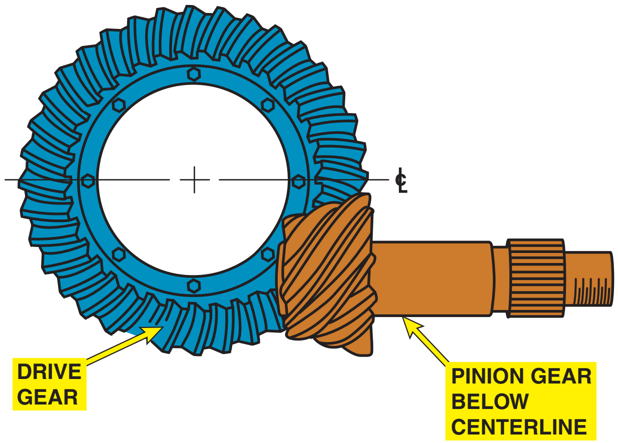

℄
DRIVE GEAR
PINION GEAR BELOW CENTERLINE

FIGURE 125–4 A hypoid gear set uses a drive pinion that meshes with the ring gear below the center line of the ring gear.

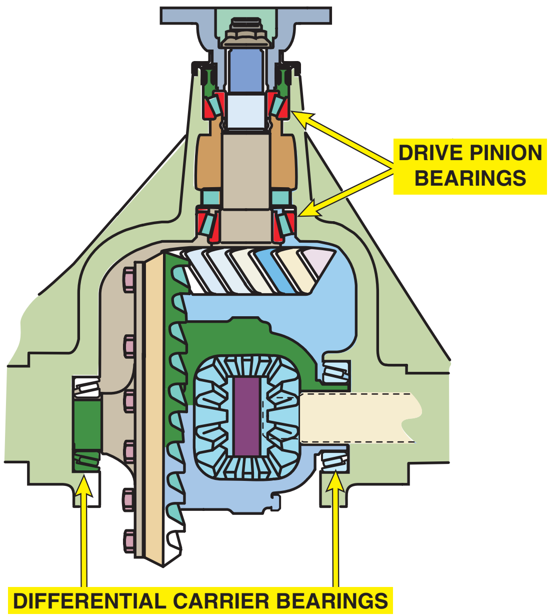

DRIVE PINION BEARINGS
DIFFERENTIAL CARRIER BEARINGS

FIGURE 125–5 A pair of tapered roller bearings called carrier bearings is used to locate the drive pinion gear and the differential case and ring gear. Another pair of bearings locates the drive pinion gear.

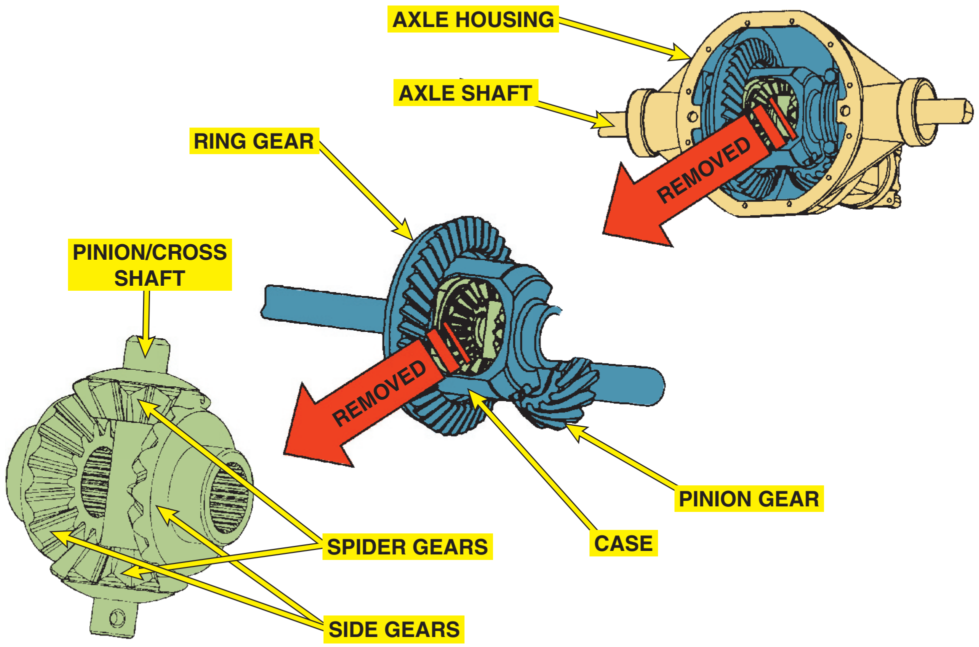


FIGURE 125–6 The relationship among the ring gear and drive pinion as well as the side and spider gears.

THE PINION AND RING GEARS DURING OPERATION During operation, the position of the drive pinion gear on the ring gear changes. The ring gear mounts onto the differential case as shown in ● **FIGURE 125–6**. Each slanted ring gear tooth has two ends. Its **toe** is closest to the ring gear center; its **heel**, closest to the outside circumference. The tooth **root** is the depression lying between two teeth, and the **crown** is the very top of each tooth.

While a vehicle accelerates, the drive pinion contacts the ring teeth on its **drive, or convex side**. While decelerating, the drive pinion contacts the ring teeth on its **coast, or concave side**. ● **SEE FIGURE 125–7**. The intermediate position between drive and coast, when neither the ring gear nor the pinion is driving each other, is called the **"floating" position**.

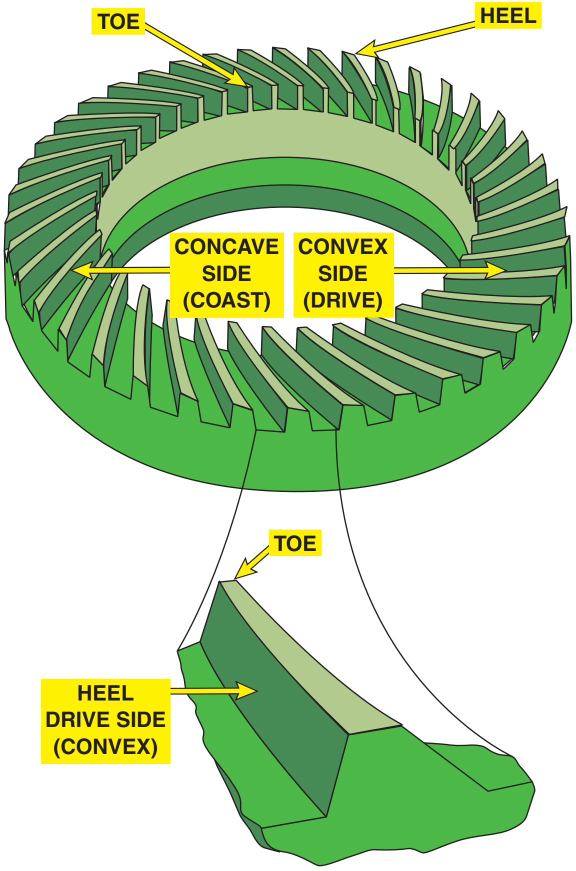


FIGURE 125–7 The drive side is the convex side of the ring gear except for some front axles used in four-wheel vehicles, and they often use the concave side on the drive side.

DRIVE AXLE GEAR RATIOS

The final gear reduction in the drive train occurs in the drive axle assembly. The amount of torque a gear set delivers depends on the gear ratio between the drive pinion gear and the driven ring gear. The gear ratio of the final drive (differential) is called the **axle ratio**. To determine the axle ratio, divide the number of teeth of the ring gear (driven gear) by the number of teeth of the drive pinion gear (driving gear):

$$\frac{\textbf{Ring gear (41 teeth)}}{\textbf{Pinion gear (10 teeth)}} = \textbf{4.10 (Axle ratio)}$$

The higher the axle ratio number, the faster the engine rotates for each rotation of the drive wheels. See the High-Performance Tip "Change the Axle Ratio."

RING AND PINION GEAR SET TYPES The final drive gear ratio determines how many times a drive pinion tooth will make contact with a particular ring gear tooth during one revolution. This affects final drive gear set manufacture and service.

Final drive gear sets may be divided into three types, depending on the final drive gear ratio.

1. **Hunting gear sets** are gear sets with final drive ratios expressible in a fraction that cannot be reduced to any lower terms. An example of a hunting gear set is one that has 41 teeth on the ring gear and 11 teeth on the drive pinion. This combination creates a 3.73:1 axle ratio. This type of gear set requires no timing marks or alignment during assembly. As the pinion gear drives the ring gear, each pinion tooth will hunt for, or seek, contact with every ring gear tooth.

2. **Nonhunting gear sets** are gear sets with final drive ratios expressible as a whole number. An example of a nonhunting gearset is a differential that uses 39 teeth on the ring gear and 13 teeth on the pinion gear, which gives a 3.00:1 gear ratio. Nonhunting gear sets require timing marks. As the pinion gear drives the ring gear, each pinion tooth contacts only a few ring gear teeth during each revolution.
3. **Partially nonhunting gear sets** are gear sets with final drive ratios expressible as a reducible fraction not equaling a whole number. An example of a partial nonhunting gearset is an axle ratio of 3.50:1.

Partially nonhunting gear sets also require timing marks. During final drive operation, each pinion tooth contacts only some of the ring pinion teeth. For the pinion teeth to make contact with the highest number of ring gear teeth, the pinion gear must drive the ring gear more than one revolution.

On nonhunting and partially nonhunting gears, manufacturers **lap** the contacting gear teeth to decrease wear. For this reason, these gear sets are marked to ensure proper alignment during assembly procedures. To preserve the wear patterns, the gear sets should be reassembled using the same alignment. This prolongs the life of the gear set and decreases operational noise.

HIGH PERFORMANCE TIP

Change the Axle Ratio

To increase vehicle performance, replace a high ratio (lower number) rear axle ratio with a lower ratio (higher number) rear axle. For example,

Stock rear end = 3.23:1 (drive pinion has 13 teeth and the ring gear has 42 teeth)

Replacement rear end = 3.73:1 (drive pinion has 11 teeth and the ring gear has 41 teeth)

The high-performance axle ratio (3.73:1) allows the engine to rotate faster than the stock 3.23:1 ratio. Because most engines produce greater torque with increasing RPM (up to a point), this allows more torque to be applied to the drive wheels. Not only is the engine producing more torque, but the higher-number gear ratio also multiplies the available torque times 3.73 instead of the original 3.23. However, there are several disadvantages associated with changing the rear end ratio:

- Decreased fuel economy
- Incorrect speedometer and odometer readings that can affect the shifting of the automatic transmission unless changes are made to the computer or vehicle speed sensors
- Increased engine noise due to the higher engine speed
- Increased engine wear, again due to the increased engine speed

If you can live with these disadvantages, a change in the rear end ratio generates a real performance gain.

OPEN DIFFERENTIALS

PURPOSE AND FUNCTION While a vehicle travels straight ahead, the speed of each driven wheel must be allowed to vary slightly as they go over bumps, potholes, railroad tracks, and other road surface irregularities. While cornering, the wheels must be able to turn at much greater differences in speed. Without some mechanism to allow for a difference in speed between the wheels, the left wheel would skid through the turn.

Inside the differential gear housing four to six bevel gears help drive the axles. In most differentials, there are two bevel gears called pinions that are constantly meshed with a beveled axle side gear on each axle. The pinion and axle side gears are contained in a housing called the carrier or case.

TORQUE FLOW THROUGH A STANDARD OPEN DIFFERENTIAL

Open differentials deliver equal torque to both wheels at all times. As the case rotates (driven by the engine through the ring and pinion gears), the cross-shaft applies a drive force to the spider gears. The two side gears apply reaction forces that counter this drive force. ● **SEE FIGURE 125–8**. Because the spider gear is free to rotate about the cross-shaft, the two reaction forces are equal. As the side gear applies a force to the spider gear, the spider gear applies an equal and opposite force to the side gear. It is this force, on the side gear, that supplies the torque to the axle that drives the wheel. Because the force on each side gear is equal, the torque supplied to each wheel is also equal. This is true regardless of whether one wheel is rotating faster than the other or at the same speed.

TRAVELING STRAIGHT-AHEAD Assuming that a vehicle has equal traction at both wheels, differential action does not occur. In other words, when traveling straight on smooth road surfaces the ring gear, carrier, and the drive axles are traveling at the same speed; they rotate as a unit and the spider gears are not rotating on the cross shaft.

TRAVELING AROUND CORNERS The ability of the differential pinion gears to spin on their shafts allows each axle to rotate at a different speed.

Case speed is always equal to the average speed of the two side gears. Since the ring gear rotates with the case and each

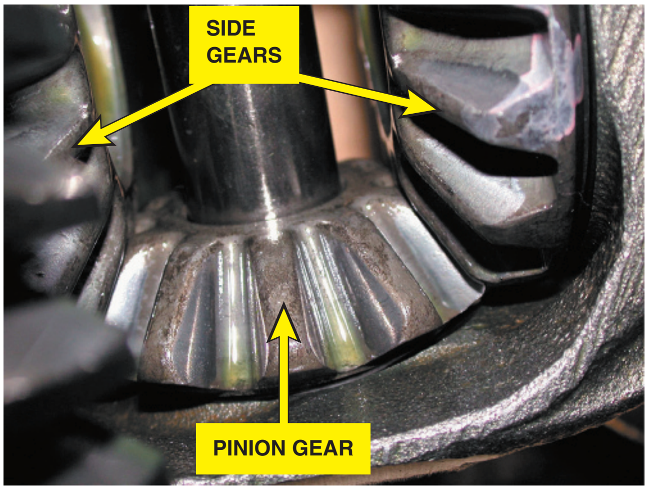


FIGURE 125–8 A close-up view of the side gears and spider (pinion) gear. Note the ridges on the gear teeth. These ridges are manufactured into the gear teeth to help retain lubricant so that no metal-to-metal contact occurs.

side gear rotates with its axle, when a vehicle corners, the outside wheel gains the same number of RPMs that the wheel on the inside loses, while ring gear RPM remains constant.

LIMITED SLIP DIFFERENTIALS

PURPOSE AND FUNCTION When a vehicle equipped with a standard differential spins a tire, the opposite wheel does not receive enough torque to move the vehicle. To solve this problem, most manufacturers use differentials that direct more power to the side gear attached to the spinning axle. Many differentials do this by forcing the side gear against the revolving case. This bypasses differential action, allowing the case to drive the side gear directly.

A limited-slip differential distributes torque to both wheels equally or unequally, allowing the wheels to turn at the same or at different speeds. ● **SEE FIGURE 125–9**.

The only means of having the standard differential apply different amounts of torque to each axle is to have the case drive the side gear directly, bypassing the pinion gears. One means of accomplishing this is to literally "push" the side gear out of mesh with the pinion gears against the rotating case.

PARTS AND OPERATION **Preloaded clutches** use two mechanisms to accomplish this action. First, a coil, Belleville, or leaf spring applies a force against the two side gears. ● **SEE FIGURE 125–10**. Second, a multidisc clutch pack or cones lie behind one or both of the side gears. Vehicle manufacturers refer to these differentials using various brand names, such as Positive Traction, Sure-Grip, Anti-Spin, and Traction-Lok.

When forces inside the differential push the side gear against the case, the clutch pack allows the gear to lock smoothly without jerking. The pack, lying between at least one of the backs of the side gears and the case, consists of two types of alternatively stacked steel discs with holes through their middle sections. The first is coated with friction material and the second is not. The interior splines of the friction disc holes mesh with the splines on the center hub protruding from the backside of the side gear. The holes of the steel discs are not splined. Instead, they have two or three tabs along their outside diameter that fit into slots machined into the differential case.

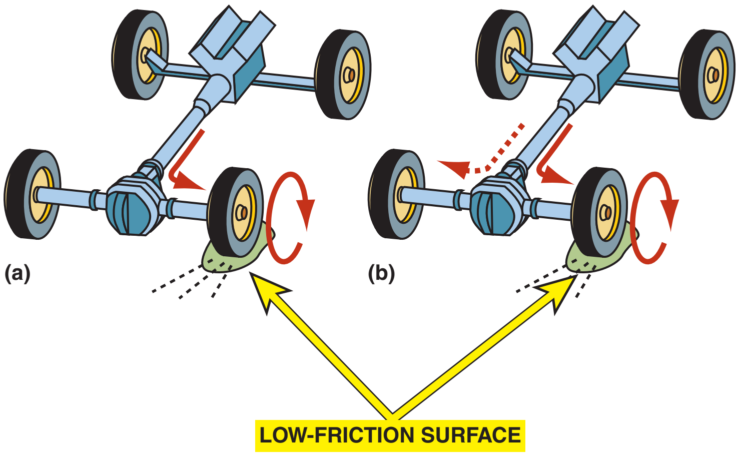


FIGURE 125–9 (a) A two-wheel-drive vehicle equipped with an open differential. (b) A two-wheel-drive vehicle equipped with a limited-slip differential.

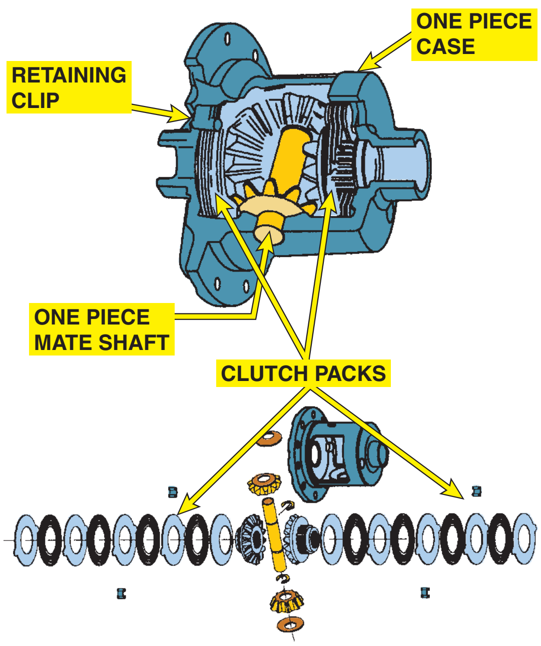


FIGURE 125–10 Trac-loc limited-slip differential. This type of limited-slip differential uses the preload force from a spring and the torque generated by the side gears as the two axles rotate at different rates to apply the clutches and limit the amount of difference in the speed of two axles.

As the side gear is pushed farther against the case, each friction plate rubs against the steel plate in front of and behind it, gradually slowing the side gear's rotation until it smoothly locks against the case.

1. The rotating differential pinions apply pressure against the side gear. The amount of pressure depends on the traction beneath the tire connected to the side gear.
2. The spring applies the second force that allows the preloaded clutch to work. This spring, whether a coil, leaf, or Belleville, preloads the clutch discs, narrowing the clearances between them. Tighter springs cause the differential to lock up sooner than looser springs.

To vary the amount of traction a tire must have before its axle's side gear locks up, many differentials use adjustment shims. Available in different thicknesses, manufacturers install them between the rear of the clutch packs and the differential case. The thicker the shims, the sooner the differential locks up. Some differentials rely on the preload spring alone to determine when the side gear locks up. They use no shims.

During operation, the clutch discs slide against each other every time the vehicle turns and corners. This action creates friction, making it important to add the manufacturer-recommended lubricant that contains a friction modifier. This lubricant may already be included in the gear oil or may be a special additive. Using improper lubricants may cause the discs to wear prematurely and vibrate during turns.

CONE-TYPE The second type of preloading clutch differential uses two tapered cones instead of multidisc clutch packs. Positioned between the side gears and the case, the cone's tapered end fits inside a dished receptacle machined into the case. The same forces that push the side gears against the case in the clutch pack differential push the side gears against the case in the tapered-cone differential. When these forces press the cones into their dished receptacles, they come to a stop smoothly, locking the side gears to the case.

VISCOUS COUPLED LIMITED-SLIP UNITS Differentials can be designed to work on the principle of a **viscous coupling**. This design uses a series of closely positioned plates, which do not physically touch one another. Half of the plates are splined to the case, and the other half are alternately splined to each side gear. The plates are housed in a sealed chamber, which is filled with a thick and viscous silicone-based fluid. The silicone allows normal speed differences between two shafts, resisting high-speed differences associated with wheel spin on one shaft.

This type of viscous-coupled differential is used in the front differentials of some Japanese front-wheel-drive vehicles and in four-wheel-drive vehicles.

THE EATON "LOCKER" DIFFERENTIAL The Eaton locker's sturdier design makes it more efficient in transferring torque from the driveline to the axles while in the locked position than the clutch-type multidisc differential.

When a vehicle spins a rear wheel, both the preloaded multidisc differential and the Eaton "locker" compress their clutch packs lying between the side gears and the case. This allows the case to directly drive the axles, bypassing the effect of the rotating differential pinions.

The Eaton and preloaded multidisc differentials differ in how they compress their clutch packs. The preloaded multidisc uses either a coil, leaf, or Belleville spring to apply initial pressure against the side gears and the clutch pack. As the rotating pinion gears push against a slower moving side gear, it is forced against the case, thereby compressing the discs in the clutch pack together.

The Eaton differential, on the other hand, uses a unique mechanism to collapse the clutch packs. ● **SEE FIGURE 125–11**. It has four parts:

- A governor with two flyweights
- A cam plate and cam side gear on the left side
- A latching bracket
- A thrust block

These parts allow the Eaton to momentarily shift into the locked mode when side gear and case rotational speeds differ by more than 100 RPM.

TORSEN DIFFERENTIALS The Torsen differential is a torque sensing, locking design that uses a set of worm side gears in mesh with individual worm wheel pinions that are supported by the differential case. ● **SEE FIGURE 125–13**. The pinions have spur gear sections machined on them at each end, which form the connection between left- and right-side pinions. Because of the worm and worm wheel configurations, the side gears can turn the pinions, but the pinions cannot turn the side gears. The result is a complex operation, which meets all drive requirements without excessive wheel slip.

This unit has been available as original equipment on several vehicles as well as for many aftermarket applications.

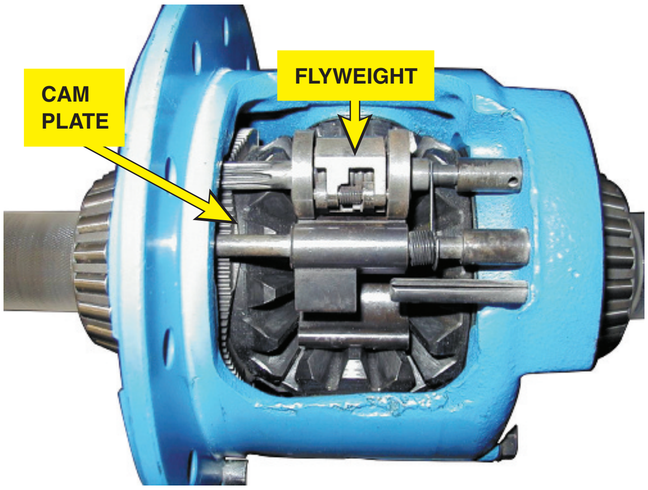


FIGURE 125–11 An Eaton locker differential.

CASE STUDY

I Used to Have a Limited-Slip Differential

An owner of a Chevrolet S-10 pickup truck equipped with a V-6 and five-speed manual transmission complained that he used to be able to spin both rear tires on dry pavement, but lately only one tire spins. The service technician assigned to the repair order was very familiar with what might have occurred. Many General Motors pickup trucks are equipped with an Eaton locking differential that uses a torque-limiting disc. The teeth of this disc are designed to shear to prevent the possibility of breaking an axle. ● **SEE FIGURE 125–12**.

The service procedure to correct the customer's concern is to replace the left-hand clutch plates. Usually, the shearing of the torque-linking teeth is associated with a loud bang in the rear axle. The differential will continue to operate normally as a standard (open) differential.

Summary:

Complaint—Customer complained that the truck used to spin both rear tires when accelerating rapidly from a stop, but now only one tire spins.
Cause—The torque-limiting disc in the differential had sheared.
Correction—The left-hand clutch discs were replaced, which restored proper limited-slip differential operation.

DRIVE AXLE COMPONENTS

DRIVE PINIONS The drive pinion gear of the drive axle is driven by a flange often called a **companion flange**. The heavy bulk of the companion flange helps dampen vibrations and absorb shocks in the driveline. ● **SEE FIGURE 125–14**. The final drive pinion shaft may be supported by bearings using one of two methods.

1. The first method, and most common, uses two opposed taper roller bearings, with a collapsible (compressible) spacer separating the two inner races to support an overhung pinion. ● **SEE FIGURE 125–15**. The term "overhung" means all of the bearings supporting the pinion shaft lie on one side of the pinion gear. The bearings are preloaded, a state that minimizes wobble and endwise movement while the drive pinion shaft rotates.

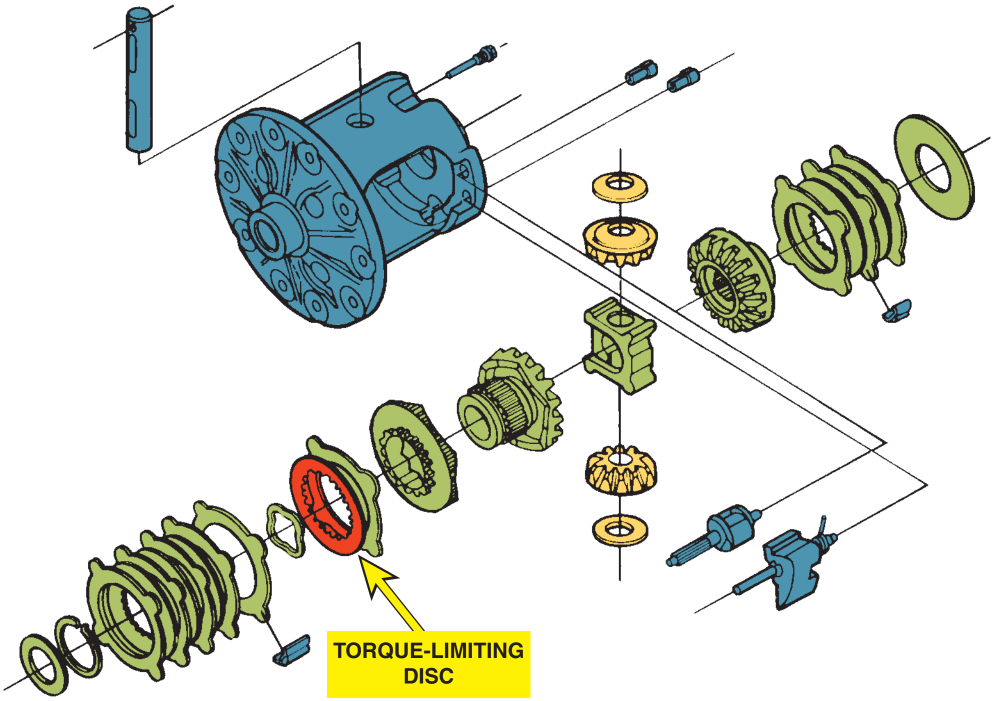


FIGURE 125–12 This Eaton design differential uses a torque-limiting disc to prevent the possibility of breaking an axle in the event of a high-torque demand. When the disc tangs shear, the differential will continue to function but as an open rather than as a limited-slip differential.

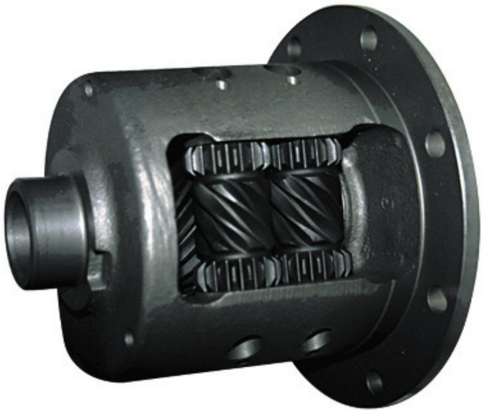


FIGURE 125–13 A Torsen differential. This type of differential provides torque to both drive wheels even if one tire is on ice. The complex system of gears allows this smooth transfer of torque without the use of clutches.

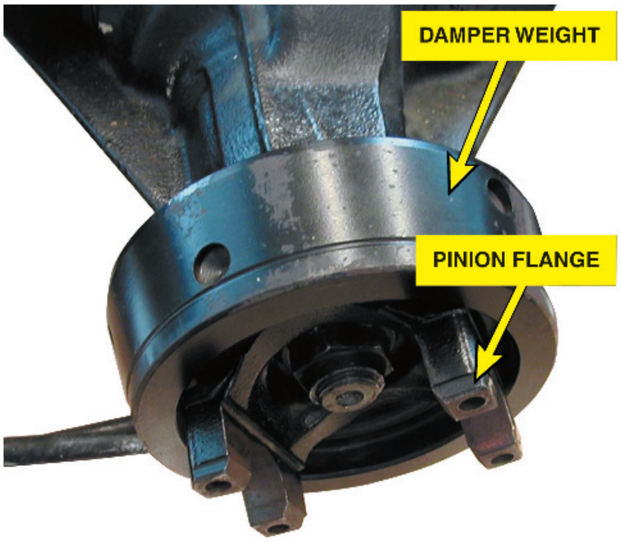


FIGURE 125–14 This pinion flange is equipped with a damper weight to help dampen driveline vibrations.

2. The second method uses two opposed taper roller bearings to support a **straddle-mounted pinion**, but the distance between them is smaller than in the overhung design. Most noticeably, a third smaller bearing attaches to a stemlike machined pilot protruding from the gear-end of the drive pinion shaft. This third bearing, usually a straight roller type, fits into a bore in the carrier. Unlike the overhung design, bearings supporting a straddle-mounted pinion lie on both sides of the pinion gear. Like the overhung design, a straddle-mounted pinion shaft usually has a compressible preloaded spacer positioned between the two larger differential case bearings. Straddle-mounted pinions are usually mounted in a pinion housing that can be removed from the carrier.

DRIVE PINION GEAR DEPTH The pinion shaft mounting method also determines how deeply the pinion gear meshes into the ring gear. This is called pinion depth and helps adjust the precise gear tooth relationship between the ring and pinion gears. You can vary the pinion depth adjustment by changing the thickness of a shim (spacer). This shim is located between the rear preloaded bearing and the pinion gear, or between the removable pinion housing and the carrier.

SIDE BEARINGS The differential case is supported by two side bearings pressed onto its sides. ● **SEE FIGURE 125–16**. These are usually tapered roller bearings and are preloaded to ensure case rotation without axial or radial movement.

Side bearing preload is adjusted either by threaded adjusting nuts as shown in ● **FIGURE 125–17** or by placement of adjusting shims (spacers) on either side of the case between the bearing outer races and the inside of the carrier. The method used to adjust side bearing preload is also used to adjust ring

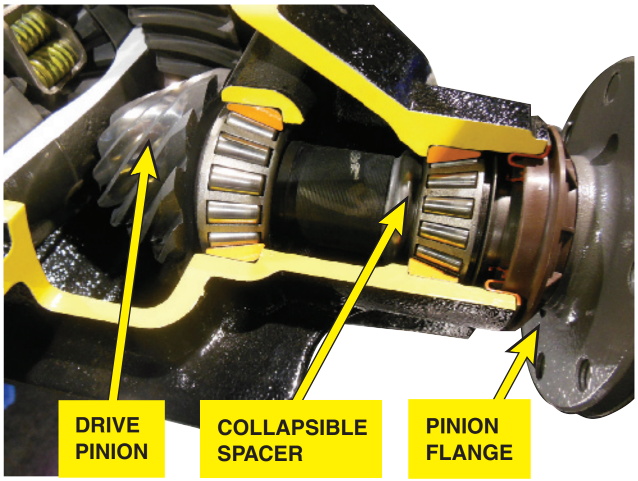


FIGURE 125–15 A collapsible spacer-type drive pinion shaft.

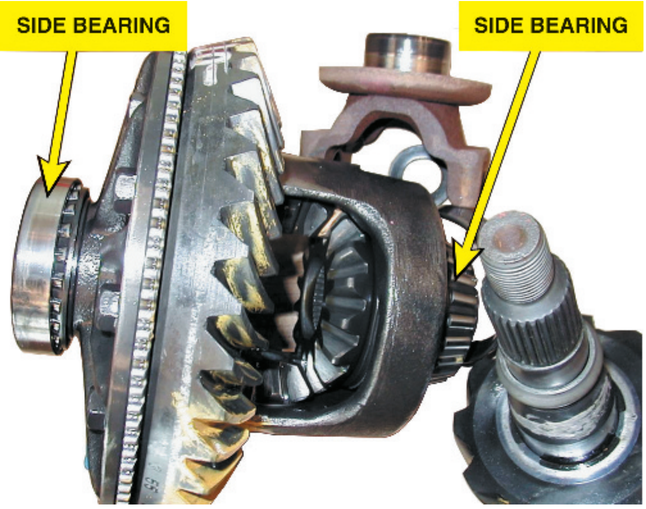


FIGURE 125–16 Side bearings are press fit on the differential case.

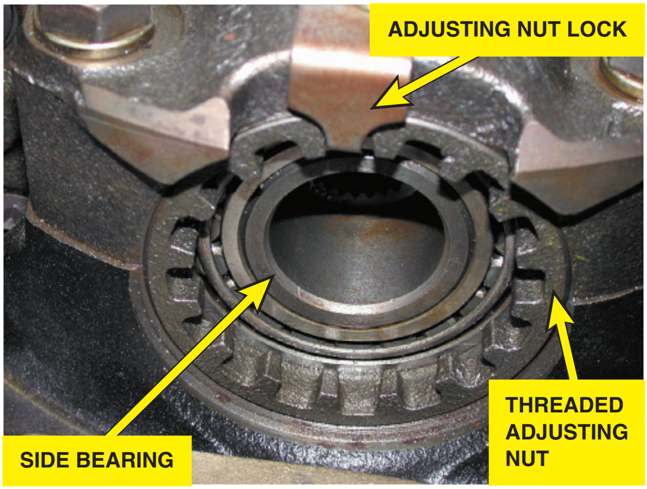


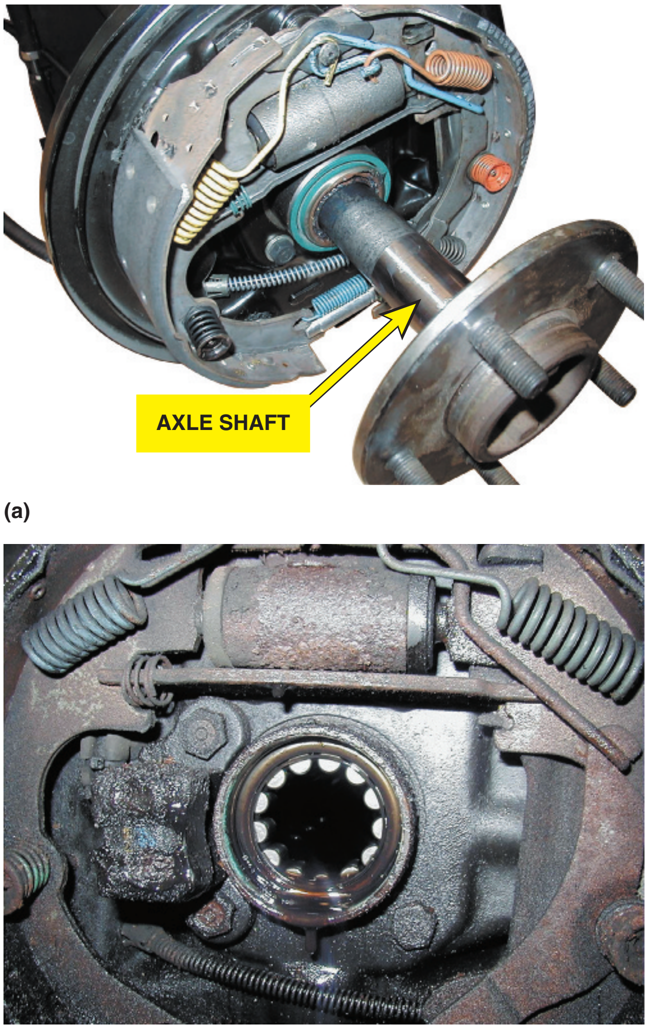
FIGURE 125–17 Some side bearings use threaded adjusters to adjust preload.

gear-to-pinion backlash (tooth clearance between one gear and the other). This is necessary to ensure enough space between the teeth of the two gears to allow for expansion of the gear tooth dimensions as the unit warms up to operating temperature. When the unit is warm, there must be just enough space between the gear teeth to allow adequate lubrication of the tooth surfaces and still allow full tooth contact for good transfer of torque from one gear to the other. Too much clearance between the gears will allow one to travel too far before contacting the other when the powertrain goes from drive to coast and back again. Excess clearance can result in final drive noise and gear tooth damage.

REAL AXLE BEARINGS

BALL BEARINGS/REAR AXLES If ball bearings are used, the bearing itself absorbs the radial forces. The bearing is placed on the axle and retained by a pressed-on collar. A stamped steel plate bolts to the axle housing and keeps the axle in place. The bearing is prelubricated when it is manufactured. An oil seal is located on the inboard side of the bearing retainer collar, and keeps the hypoid lubricant from reaching the bearing or the brake assembly. In this design, there is no axle shaft end play (thrust) adjustment.

STRAIGHT ROLLER BEARINGS/REAR AXLES If a straight roller bearing is used, the axle surface serves as the inner race. ● **SEE FIGURE 125–18**. The outer race is pressed into the housing, and a grease seal is pressed in afterward. The bearing is lubricated by the hypoid lubricant. This design uses a C-washer



(a)

(b)

FIGURE 125–18 (a) The axle shaft itself is the inner race if a straight roller bearing is used. (b) The straight roller bearings are lubricated by the rear axle fluid, and a leak at the rear axle seal can cause this fluid to get onto brake components.

on the inboard end of the axle, which prevents the axle from moving outward. Outward thrust forces are taken by the C-washer through the axle's side gear and thrust washer, to the differential case and side bearing. Inward thrust forces are taken by the axle shaft inner end pushing on the spider pinion shaft, and passed on to the differential case and the opposite side bearing. There is no axle shaft end play adjustment with this design.

TAPERED ROLLER BEARINGS/REAR AXLES If a tapered roller bearing is used, axle shaft end play is adjustable. The bearing is pre-lubricated before it is installed and is held by a press fit on the axle shaft. A retaining ring is then pressed on the shaft next to the bearing to secure it in place. The axle is prevented from moving outward by a stamped steel retainer plate that bolts to the axle housing. The inner diameter of the plate is threaded to accept a bearing-adjusting nut, which is similar in appearance and function to a differential side bearing adjuster. A variation of this design has the end play adjustment made by shims between the axle housing and the brake backing plate. Thrust is taken from the inner end of the axle by a thrust block mounted on the spider pinion shaft, and passed on to the opposite axle, through its length to the opposite wheel bearing.

DRIVE AXLE IDENTIFICATION

Before any service work is performed on a drive axle assembly, the *exact* axle specification must be determined. Vehicle manufacturers often use axles from more than one axle manufacturer, and each manufacturer has its own individual ratios, parts, service procedures, and specifications. Differential assembly identification includes

- **Visual identification**—usually identifies the manufacturer and size only
- **Axle assembly number**—usually stamped in the axle tube of the differential assembly and identifies the gear ratio and other information
- **Limited-slip identification tag**—often the only external identification whether or not the axle assembly is an open design or limited-slip design
- **Differential cover shape**—and number of bolts used to retain the cover

TECH TIP

Don't Spin Those Wheels!

While driving on ice or snow-covered roads, it is common to see drivers moving slowly up a hill by simply spinning one drive wheel. However, when one wheel is spinning and the other wheel is stationary (or close to stationary), the pinion gears are spinning twice as fast as the drive wheel. This spinning of the drive wheel has been known to completely wear down the pinion gear thrust washers in less than one minute! ● **SEE FIGURE 125–19**. The same wear can occur if different-size tires are used on the same drive axle. Therefore, to prevent expensive repairs, avoid unnecessary tire spinning and check that both tires on the same axle are the same size, brand name, and condition.

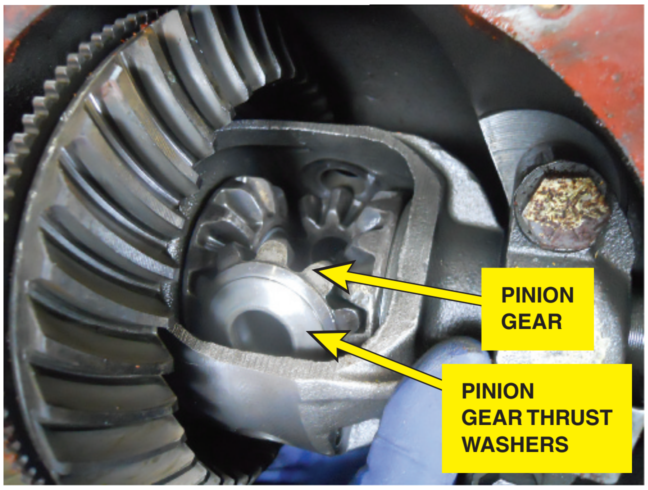


FIGURE 125–19 The pinion gear thrust washers can be destroyed by spinning one wheel for an extended period of time.

DETERMINING THE AXLE RATIO

To determine the axle ratio of a differential without having to remove the axle housing cover, simply follow these steps:

STEP 1 Hoist the vehicle safely.

STEP 2 Mark the rear tires with masking tape at 12 o'clock position.

STEP 3 Mark the driveshaft with masking tape.

STEP 4 Have an assistant hold one drive tire to keep it from moving and slowly rotate the other drive tire exactly 10 times while the assistant counts the driveshaft revolutions.

STEP 5 Multiply the driveshaft revolutions by 2 (except for a limited-slip differential), and then move the decimal point one place to the left. For example, if 10 turns of the tire result in 18.5 turns of the driveshaft, that multiplied by 2 equals 37.0; then, moving the decimal point to the left one place equals a 3.70:1 gear ratio.

TECH TIP

A Quick-and-Easy Backlash Test

Excessive clearance (lash) between the drive pinion and the ring gear can cause driveline clash noise during a gear selector change. To check if the cause is due to the differential, simply hoist the vehicle and, while one wheel and the driveshaft are being held stationary, use your hand to move the opposite wheel. The maximum amount the tire should move is 1 inch (2.5 cm) measured at the tread of the tire. If backlash is greater than this, then further inspection of the differential assembly is required. Beside excessive clearance between the drive pinion and the ring gear, the wear may also be between the pinion and the side gears.

REAR-END NOISE DIAGNOSIS

One of the major reasons why differentials are serviced is to correct a noise problem. Knowing when and under what conditions the noise is noticeable is a big help in identifying which bearing or component is the likely cause. Typical noise and its sources include

- **Grinding or growling noise while turning**—usual cause is a defective axle bearing.
- **Whine noise during cruise**—drive pinion bearings are the likely causes of this type of noise.

DRIVE AXLE INSPECTION

Carefully inspect the drive axle for obvious damage or wear. ● **SEE FIGURE 125–20**. Check the backlash. The backlash is the amount of clearance between the drive pinion and the ring gear; excessive backlash could indicate excessive wear. Use a dial indicator as shown in ● **FIGURE 125–21** to check and compare the results with specifications.

Also use a dial indicator to check **ring gear runout** (● **SEE FIGURE 125–22**). If any of the visual measurement tests indicate a problem or a noise analysis indicates a bearing problem, the axle assembly should be disassembled for further analysis and service.

TOOTH CONTACT PATTERN TEST

A tooth contact pattern test is an excellent method for checking proper drive pinion depth as well as proper backlash between the drive pinion and the ring gear. Any faults in these areas will be reflected in the pattern. The pattern test involves the following steps:

STEP 1 Clean the gear teeth of the ring gear and the drive pinion.

STEP 2 Using a small brush, apply a light coating of iron oxide compound.

STEP 3 Use a small pry bar to apply a load to the ring gear to achieve a more accurate contact pattern. ● **SEE FIGURE 125–23**.

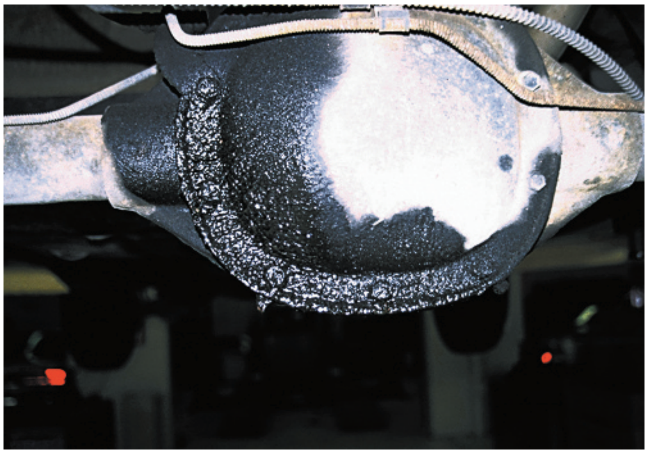


FIGURE 125–20 This differential has obviously been leaking. If the differential lubricant is low, wear may have occurred that would require further inspection.

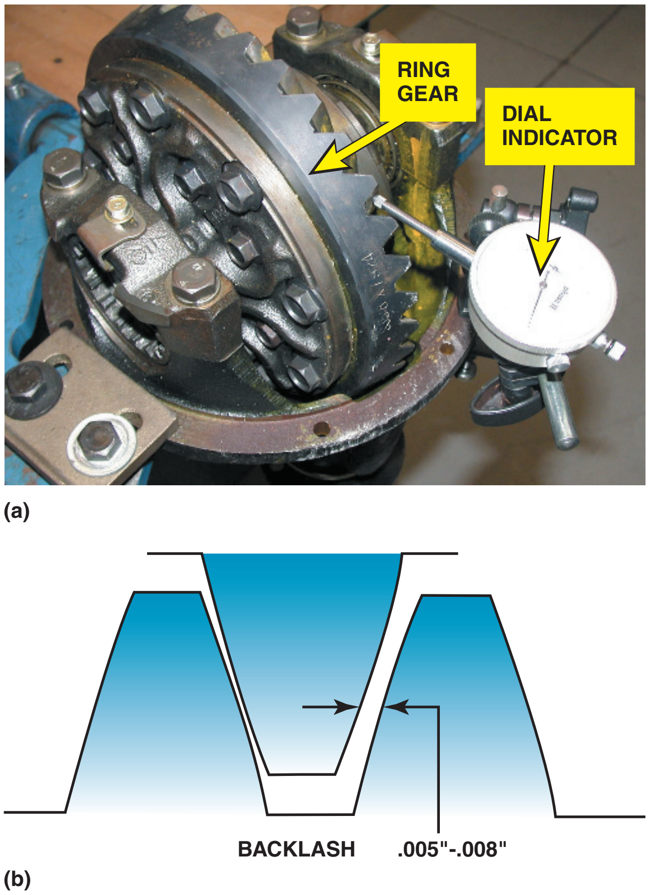


FIGURE 125–21 (a) Backlash is determined by mounting a dial indicator to the differential housing and placing the button of the gauge against a tooth of the ring gear. Moving the ring gear back and forth will indicate on the dial indicator the amount of backlash. (b) Backlash is the clearance between the drive pinion and the ring gear teeth.

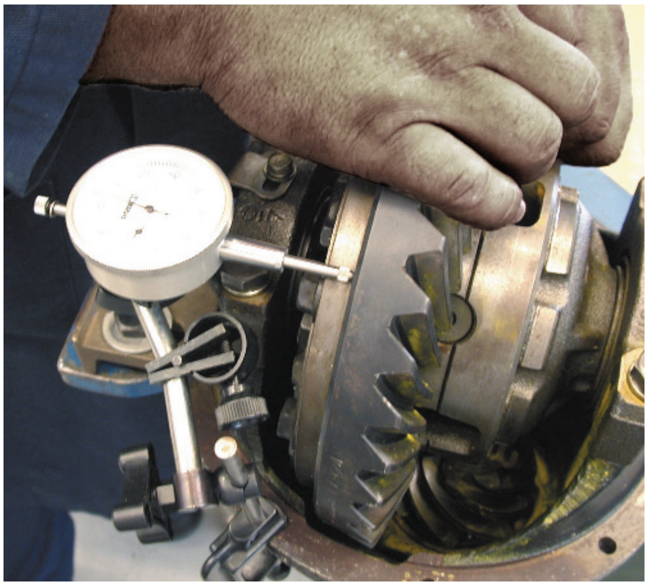


FIGURE 125–22 Ring gear runout should be less than 0.002 inch (0.05 mm) as measured by a dial indicator.

STEP 4 Rotate the drive pinion until the ring gear turns one revolution (about three revolutions of the drive pinion gear).

STEP 5 Repeat rotating the drive pinion in the opposite direction. This will create a contact pattern on both the drive side and the coast side of the ring gear.

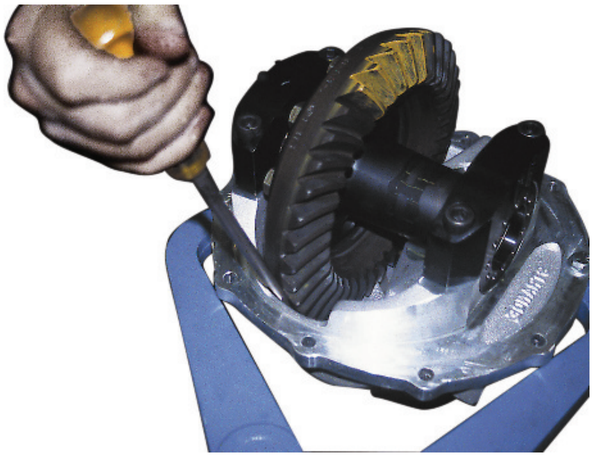


FIGURE 125–23 Force has to be applied to the ring gear to achieve a proper contact pattern.

NOTE: The drive side is the convex surface of the ring gear teeth. The coast side is the concave side of the ring gear. This is true except for many differentials used on the front of four-wheel-drive vehicles. In this case, the drive side in the front differential is the concave surface and the coast side is the convex surface of the ring gear teeth. Always check the service information for the vehicle being serviced for the correct interpretation of the pattern results.

● **SEE FIGURE 125–24** for good and bad tooth contact patterns and what could have caused them.

DRIVE AXLE DISASSEMBLY

Start the disassembly by removing the axle housing cover. Be sure that the old rear-end lubricant is drained into a disposal container according to local, state, provincial, and federal laws and regulations. After the cover has been removed, complete the disassembly by following these steps:

STEP 1 After the cover has been removed, remove pinion shaft lock bolt.

STEP 2 Remove pinion shaft.

STEP 3 Remove two spider gears and two axle side gears.

STEP 4 Push axles in and remove C-clips.

STEP 5 Remove axles.

STEP 6 Mark and remove case caps.

STEP 7 Using a case spreader or two pry bars, pry up and remove carrier case keeping the shims separate. ● **SEE FIGURE 125–25**.

STEP 8 Remove pinion shaft nut and washer. Discard the nut.

STEP 9 Mark and remove companion flange with suitable puller.

STEP 10 Remove front pinion seal and front pinion bearing.

STEP 11 Using suitable punch, drive pinion gear rearward until it is free of housing.

STEP 12 Remove crush collar (never re-use). ● **SEE FIGURE 125–26**.

CAUTION: Do not use an air impact wrench to remove or install the drive pinion nut. The hammer action of the impact wrench can cause the roller bearings to be pounded into the race. This denting of the race is called *brinelling* and can cause premature bearing failure.

PINION SHAFT BEARING REPLACEMENT

The pinion shaft usually has two tapered roller bearings; the small diameter of each bearing faces the other. This arrangement allows the two bearings to absorb thrust load in both directions. When tapered roller bearings are used in a differential, it is very important that they have the proper preload. If a tapered roller bearing is too loose (too little preload), then the bearing cannot properly support and position the pinion shaft. If the preload is too great, excessive heat will quickly destroy the bearing as it expands with heat during normal operation of the rear axle assembly. Two methods are used to ensure proper drive pinion gear preload (● **SEE FIGURE 125–27**):

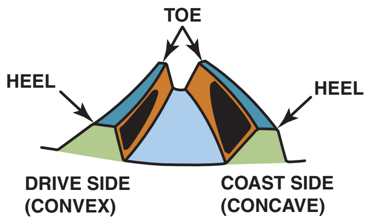
- Preload shims
- Collapsible spacer

The rear pinion shaft bearing (closest to the drive pinion gear) is usually pressed out the drive pinion. A shim is usually located between the drive pinion gear and the rear drive pinion bearing to properly position the drive pinion in relation to the ring gear. The ring gear and pinion are manufactured as a matched pair and must be installed correctly to be assured of quiet operation and long service life. ● **SEE FIGURE 125–28**. The drive pinion bearing must be pressed off using a hydraulic press or a special tool.

DRIVE PINION DEPTH

The drive pinion gear and ring gear are manufactured as a matched set and must be installed as a set. Due to variances in the production of these gears, it is often necessary to vary the thickness of a shim (thin metal spacer) between the rear pinion bearing and the pinion gear to provide the correct contact tooth pattern when the gears are assembled. Correct drive pinion depth measurement can be determined in several different ways:

- **Wear pattern analysis.** This method is useful as a first step and a last step to verify correct setup (discussed earlier in the chapter). It is time consuming to use this method to determine the thickness of the drive pinion shim because the rear pinion bearing must be pressed off and then back on for each shim change.
- **Plus (+) and minus (–) markings on the drive pinion.** The end of the pinion gear is usually marked as to the variance needed to create the proper ring gear-to-drive pinion pattern:
  A plus (+) sign means the gear is too long and removing a shim(s) is required when assembling the drive pinion into the axle housing.
  A minus (–) sign means that the gear is too short and a shim(s) will be needed when assembling the drive pinion into the axle housing.
- **A gauging set and depth micrometer.** This is a common method used to determine the correct shim thickness necessary to provide the proper gear pattern. ● **SEE FIGURE 125–29**.



CONDITION

PINION DEPTH CORRECT.

BACKLASH INCORRECT - TOO MUCH CLEARANCE BETWEEN THE PINION AND RING GEARS.

CORRECTION

INCREASE THE THICKNESS OF THE LEFT (RING GEAR SIDE) SHIM AND DECREASE THE THICKNESS OF THE RIGHT SHIM AN EQUAL AMOUNT.

SERVICE HINTS

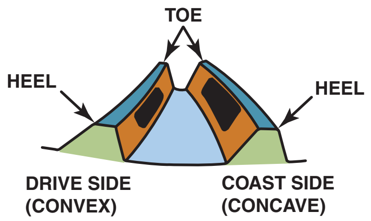
HOW TO CHECK PATTERNS:

BRUSH GEAR MARKING COMPOUND ON THE RING GEAR TEETH.

APPLY BRAKES SO THAT 50 LB. FT. IS NEEDED TO ROTATE THE PINION.

ROTATE THE PINION SIX TIMES CLOCKWISE AND SIX TIMES COUNTERCLOCKWISE.

OBSERVE THE TOOTH CONTACT PATTERN AND MAKE ANY NECESSARY CORRECTIONS.



CONDITION

PINION DEPTH CORRECT.

BACKLASH CORRECT.

CORRECTION

NONE.

SERVICE HINTS

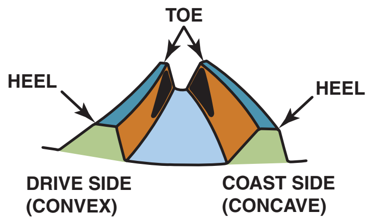
PATTERNS THAT VARY MAY BE CAUSED BY LOOSE BEARINGS ON THE PINION OR THE DIFFERENTIAL CASE. CHECK THESE BEARING PRELOAD SETTINGS:

TOTAL ASSEMBLY

DIFFERENTIAL CASE

PINION

IF THESE SETTINGS ARE GOOD, LOOK FOR DAMAGED OR INCORRECTLY ASSEMBLED PARTS.



CONDITION

PINION DEPTH CORRECT.

BACKLASH INCORRECT - TOO LITTLE CLEARANCE BETWEEN THE PINION AND RING GEARS.

CORRECTION

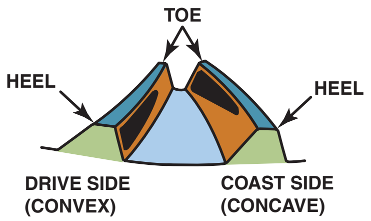
INCREASE THE THICKNESS OF THE RIGHT (RING GEAR SIDE) SHIM AND DECREASE THE THICKNESS OF THE LEFT (RING GEAR SIDE) SHIM.

SERVICE HINTS

SIDE BEARING GEAR LOCATIONS:

BETWEEN THE SIDE BEARING CONES AND THE DIFFERENTIAL CASE.

BETWEEN THE SIDE BEARING CUPS AND THE REAR AXLE HOUSING.



CONDITION

PINION DEPTH INCORRECT - PINION GEAR IS TOO FAR AWAY FROM THE RING GEAR.

BACKLASH CORRECT

CORRECTION

INCREASE THE PINION SHIM THICKNESS.

SERVICE HINTS

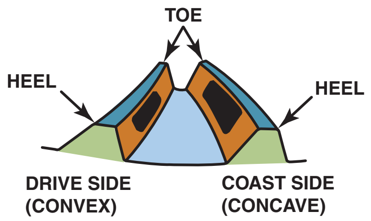
HOW TO CHECK PATTERNS:

BRUSH GEAR MARKING COMPOUND ON THE RING GEAR TEETH.

APPLY BRAKES SO THAT 50 LB. FT. IS NEEDED TO ROTATE THE PINION.

ROTATE THE PINION SIX TIMES CLOCKWISE AND SIX TIMES COUNTERCLOCKWISE.

OBSERVE THE TOOTH CONTACT PATTERN AND MAKE ANY NECESSARY CORRECTIONS.



CONDITION

PINION DEPTH CORRECT.

BACKLASH CORRECT.

CORRECTION

NONE.

SERVICE HINTS

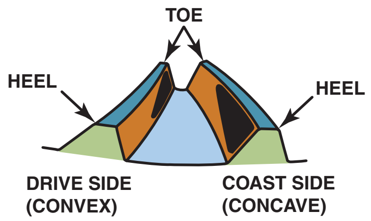
PATTERNS THAT VARY MAY BE CAUSED BY LOOSE BEARINGS ON THE PINION OR THE DIFFERENTIAL CASE. CHECK THESE BEARING PRELOAD SETTINGS:

TOTAL ASSEMBLY

DIFFERENTIAL CASE

PINION

IF THESE SETTINGS ARE GOOD, LOOK FOR DAMAGED OR INCORRECTLY ASSEMBLED PARTS.



CONDITION

PINION DEPTH INCORRECT - PINION GEAR IS TOO CLOSE TO RING GEAR.

BACKLASH CORRECT.

CORRECTION

DECREASE THE PINION SHIM THICKNESS.

SERVICE HINTS

PINION DEPTH SHIM LOCATIONS:

BETWEEN THE INNER PINION BEARING CONE AND THE HEAD OF THE PINION GEAR.

BETWEEN THE INNER PINION BEARING CUP AND THE REAR AXLE HOUSING.

FIGURE 125–24 Tooth contact pattern.

PINION GEAR PRELOAD

After the proper drive pinion depth has been determined, the correct size shim is installed and the rear drive pinion bearing is pressed onto the drive pinion. The outer races of the pinion bearing should be replaced in the axle housing and the pinion shaft placed in the housing. It is then necessary to apply the specified preload to the pinion bearings. A new drive pinion nut should be used and tightened to specifications. After the nut has been tightened, torque needed to rotate the drive pinion should be measured using a beam-type torque wrench. The drive pinion nut is then tightened farther until the **turning torque** is within specifications. ● **SEE FIGURE 125–30**.

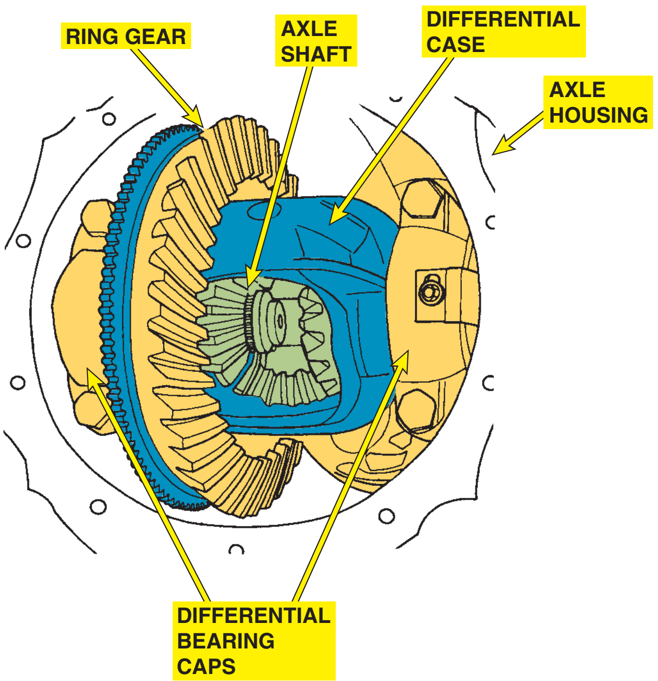

RING GEAR
AXLE SHAFT
DIFFERENTIAL CASE
AXLE HOUSING
DIFFERENTIAL BEARING CAPS

FIGURE 125–25 Mark the differential bearing caps before removing them to make sure that they are replaced in the same location.

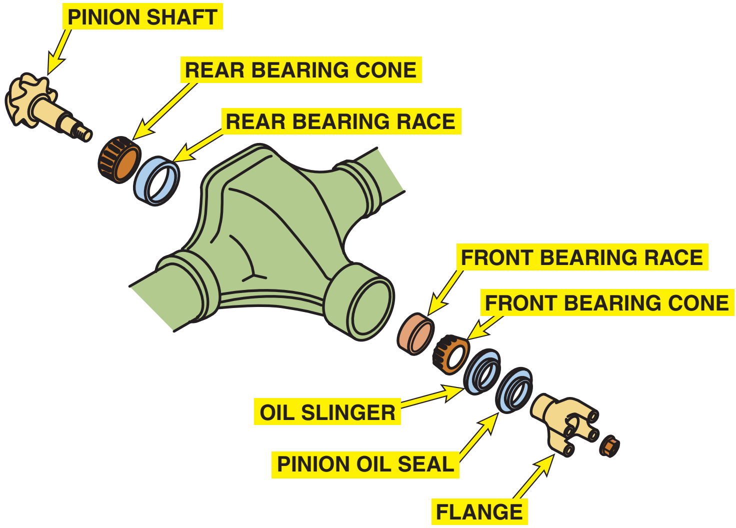

PINION SHAFT
REAR BEARING CONE
REAR BEARING RACE
FRONT BEARING RACE
FRONT BEARING CONE
OIL SLINGER
PINION OIL SEAL
FLANGE

FIGURE 125–26 Pinion gear and associated parts. The pinion end yoke is also called the pinion flange.

CHECKING AND CORRECTING BACKLASH

If the ring gear and pinion are being replaced, the bolts that hold the ring gear to the differential case *must* be replaced. ● **SEE FIGURE 125–31**. The differential case with the ring gear is then placed into the differential housing. Backlash is the clearance between the drive pinion gear and the ring gear. A dial indicator is used to measure backlash, as shown in ● **FIGURE 125–32**. The backlash should be checked at three or four points around the ring gear and the lash should not vary over 0.002 inch (0.05 mm). Backlash normally is between 0.005 and 0.008 inch (0.10 and 0.20 mm) for most axle assemblies. Always check the specifications for the differential being serviced. ● **SEE FIGURE 125–33**.

Backlash is corrected by moving the ring gear either closer or farther away from the drive pinion gear. The correction is made

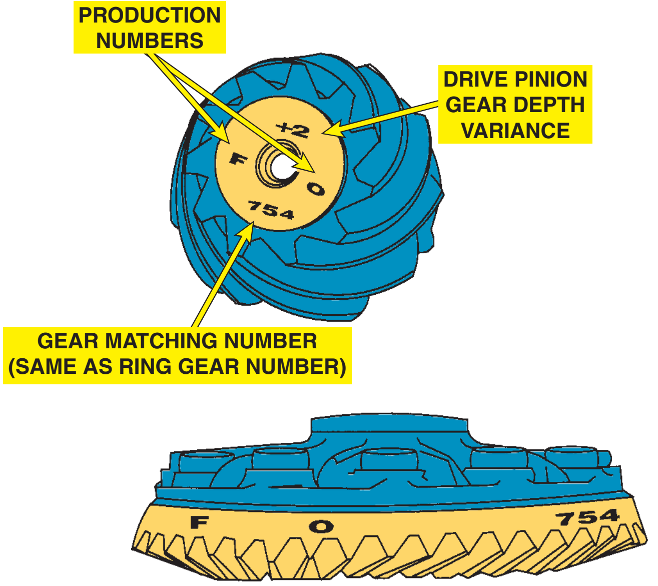

PRODUCTION NUMBERS
DRIVE PINION GEAR DEPTH VARIANCE
+2
F
O
754
GEAR MATCHING NUMBER (SAME AS RING GEAR NUMBER)
F
O
754

FIGURE 125–28 The ring and pinion gears are a matched set and are marked for correct pinion depth variance.

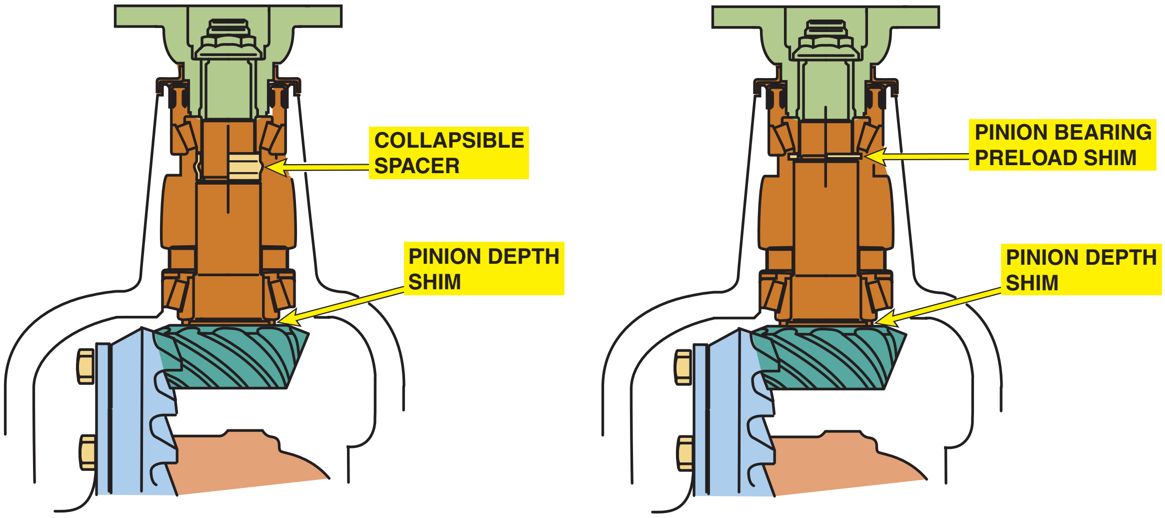

COLLAPSIBLE SPACER
PINION DEPTH SHIM
PINION BEARING PRELOAD SHIM
PINION DEPTH SHIM

FIGURE 125–27 The pinion on the left uses a collapsible spacer, and the pinion on the right uses shims to provide the necessary preload to the pinion shaft bearings.

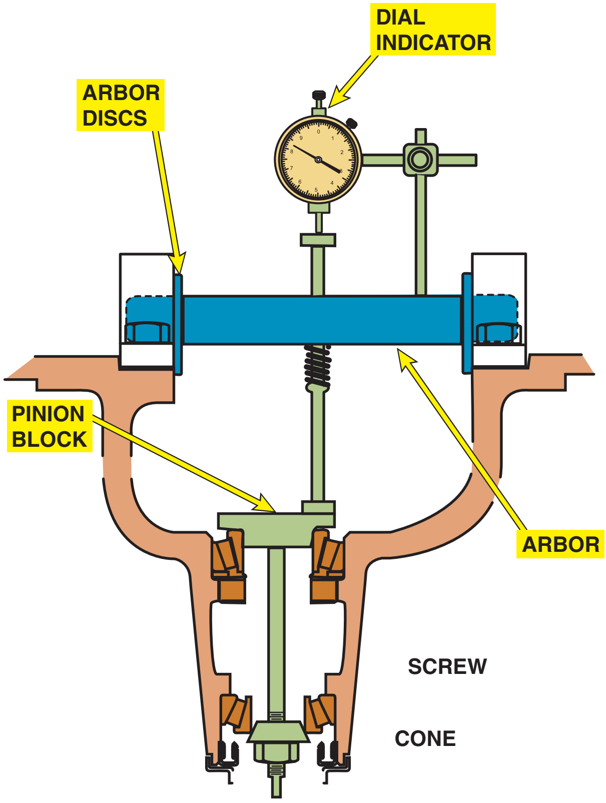


FIGURE 125–29 Special tool kit used for determining the correct pinion shaft shim thickness.

TECH TIP

"Click-Click" Is Okay-"Clunk-Clunk" Is Not

An experienced service technician was observed checking the backlash on a differential. The technician was simply turning the drive pinion by grasping the pinion flange and using wrist action to quickly rotate it first in one direction and then the other. The technician explained that if it made a "click-click" sound, the backlash was usually between 0.005 and 0.008 inch, which is usually within specifications for most differentials. If, however, the sound made was more like a "clunk-clunk," then the backlash was greater than 0.010 inch and had to be corrected. To summarize what the sounds mean when the drive pinion is moved back and forth:

- **No sound when moved back and forth**—too little or no backlash; backlash must be adjusted.
- **A "click-click" sound**—backlash is usually within specifications; double-check with a dial indicator and compare against specifications for the axle being serviced.
- **A "clunk-clunk" sound**—usually too much backlash; correction is required to restore proper backlash.

by either of two methods depending on the manufacturer and the type of differential:

- Transferring shims from one side of the axle housing to the other
- Turning threaded adjusters located in the differential housing bores, as shown in ● **FIGURE 125–34**.

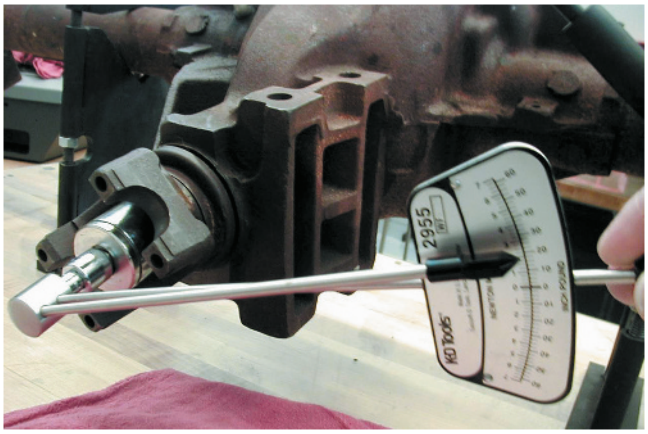


FIGURE 125–30 Using an inch-pound torque wrench to check the rotating torque of the drive pinion. This procedure is very important if the axle uses a collapsible spacer. The drive pinion nut should be gradually tightened and the rotating torque checked to prevent overtightening the nut. If the rotating torque is higher than specifications, the collapsible spacer will require replacement and the installation procedure must be repeated.

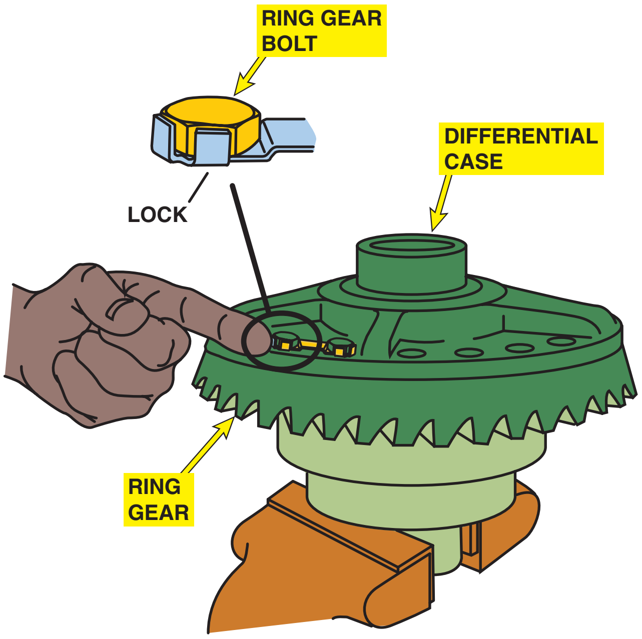


FIGURE 125–31 If the ring gear has been removed from the differential case or if a new ring gear is being installed, always replace the ring gear bolts.

SETTING SIDE BEARING PRELOAD

After the correct backlash has been determined, the side bearing must be correctly preloaded. To accomplish the proper preload, thicker shims than were used to set proper backlash are placed between the housing and the differential to provide for the proper preload on the side bearings. ● **SEE FIGURE 125–35**. Always follow the procedures specified for the axle being serviced. A typical axle may require the installation of a shim 0.004 thicker on both sides. After setting the preload, double-check that the backlash is within specification.

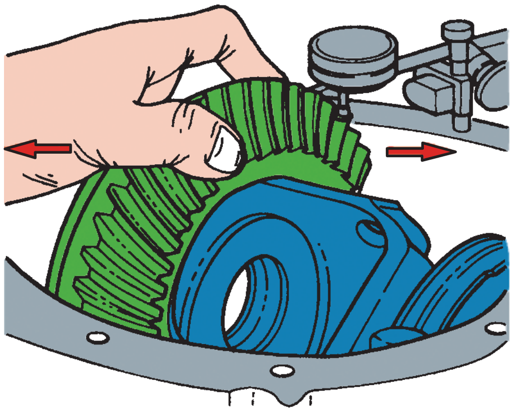


FIGURE 125–32 Backlash should be between 0.005 and 0.008 inch on most differentials. If the backlash is too great, add shim thickness to the ring gear side and subtract shim thickness from the opposite side.

FREQUENTLY ASKED QUESTION

What Is a Spool Rear End?

A spool is a solid piece of metal that takes the place of the side gears and pinion gears in a differential assembly (● **SEE FIGURE 125–36**). A spool used in drag racing is not suitable for street driving because the spool does not allow for any differences in the speeds of the drive wheel during cornering. Obviously, drag vehicles do not turn corners while racing and the spool rear end is one of the reasons they bounce when turning around at the end of the strip to return to the pits.

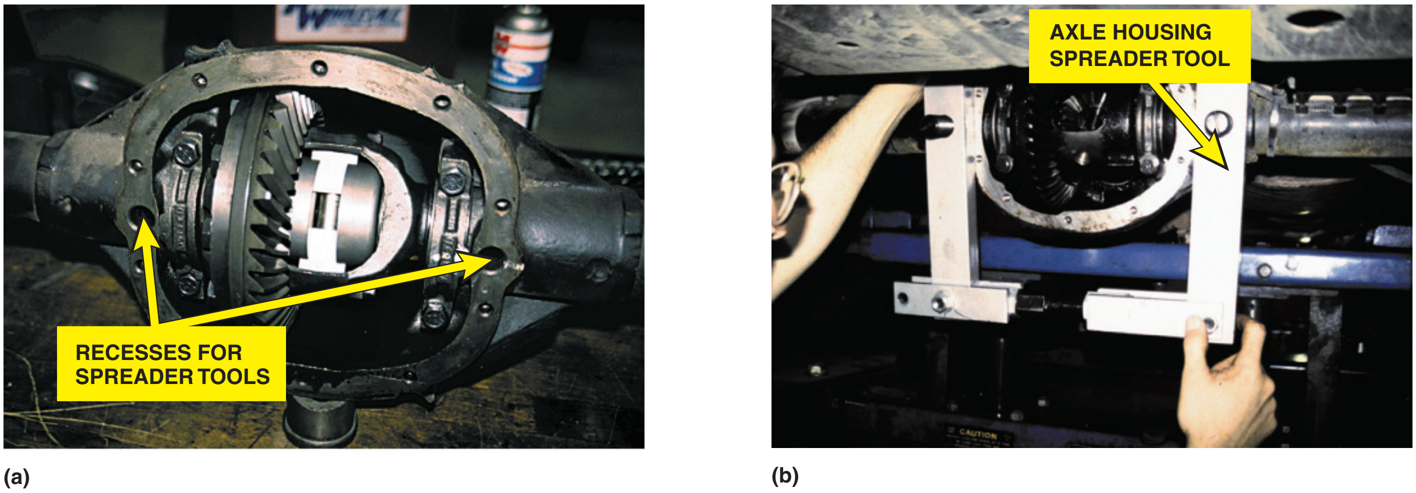


FIGURE 125–33 (a) Some vehicle manufacturers recommend using a housing spreader tool that fits into the round openings on both sides. (b) The spreader tool being installed. The housing is spread a specified amount and the differential is then installed into the housing.

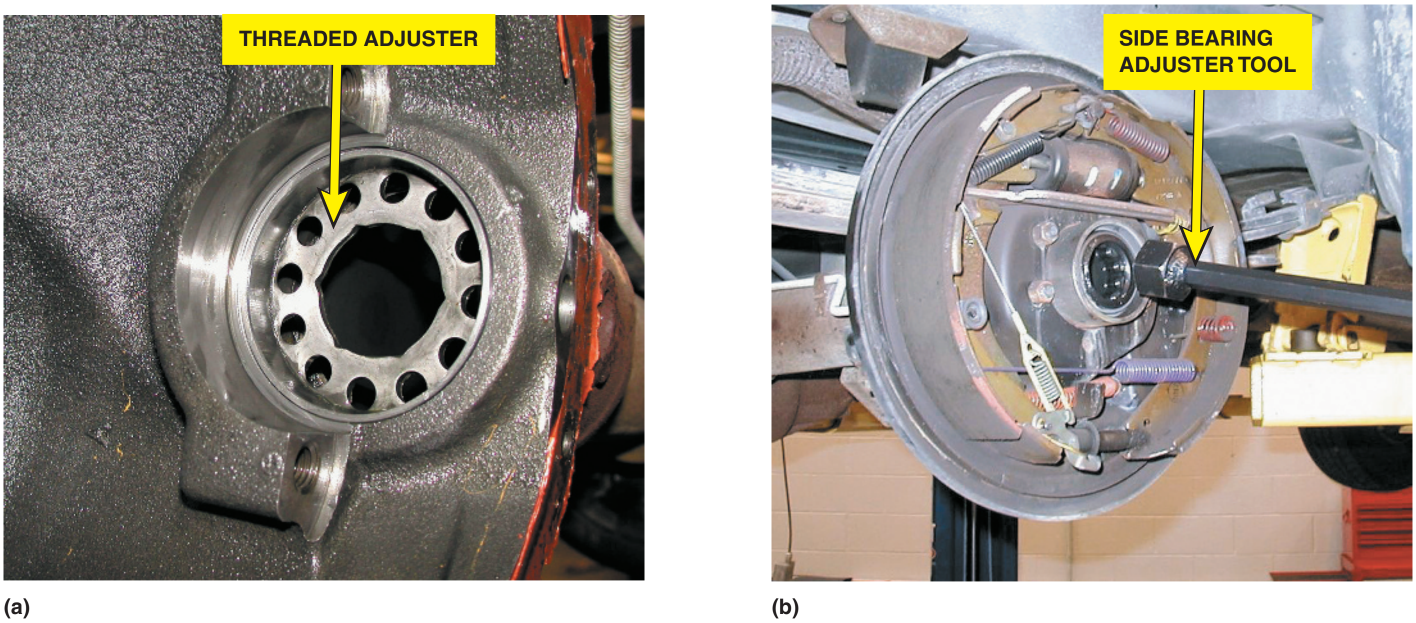


FIGURE 125–34 (a) Note the hex shape of the threaded adjuster used to adjust side bearing preload and ring gear backlash on a Dodge Dakota truck. (b) A long-handled adjuster tool is needed to turn the side bearing adjuster on this truck.

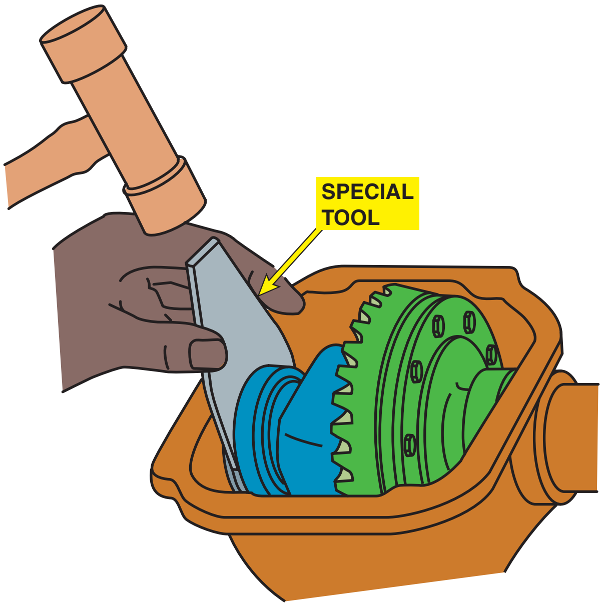


FIGURE 125–35 On many axles, it is necessary to use a special tool to install steel spacers (shims) to achieve the specified backlash and side bearing preload.

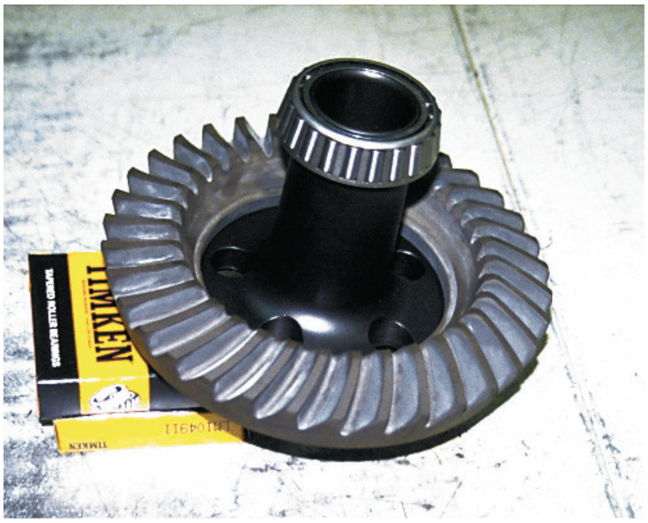


FIGURE 125–36 A spool used in a rear end for drag racing only.

REASSEMBLY OF THE DRIVE AXLE

After the backlash has been checked to be within factory specifications, the axle shafts can be installed. ● **SEE FIGURE 125–37.** Install the retaining "C" clip or bolt the retainer to the axle housing. Clean and install the differential cover and fill with the specified differential lubrication.

DRIVE AXLE LUBRICANT

Because all differentials use hypoid gear sets, a special lubricant is necessary because the gears both roll and slide between their meshed teeth. Gear lubes (GL) are specified by the American Petroleum Institute (API):

GL-1 Straight mineral oil

GL-2 Worm gear lubricant

GL-3 Mild EP lubricant (will *not* protect hypoid gears)

GL-4 Mild EP lubricant suitable for manual transmissions/ transaxles

GL-5 EP lubricant okay for hypoid gears (meets military Mil-L2150B requirements)

● **SEE FIGURE 125–38.**

NOTE: EP additives contain sulfurized esters and organic sulfur phosphorous compounds. These ingredients give the lubricant a very strong pungent smell. To avoid possible skin irritation, always wear protective gloves or wash your hands thoroughly with soap and water if exposed to differential lubricant.

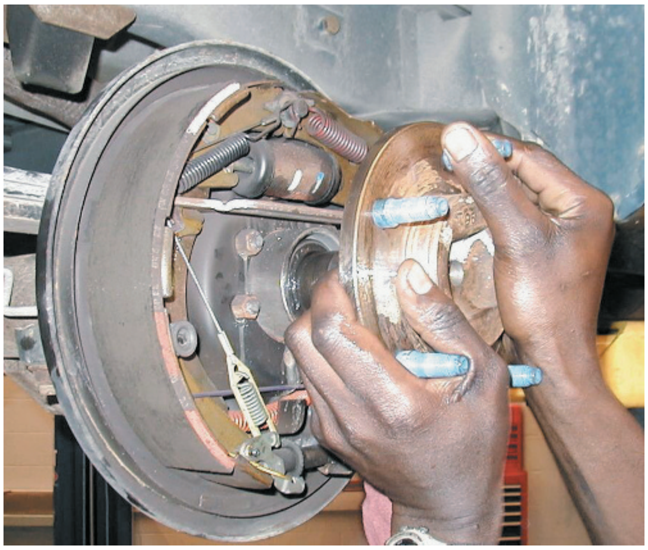


FIGURE 125–37 Install the axle shaft, being careful to not damage the seal.

FREQUENTLY ASKED QUESTION

What Do I Do about Drive Pinion Bearing Preload When I Replace Just the Pinion Seal?

To replace a pinion seal, the drive pinion nut and pinion flange must be removed.

CAUTION: Do not use an air impact wrench on the drive pinion nut. The pinion bearings can be damaged by the impact of the wrench.

Before the nut is removed, make a mark on the pinion nut and on the axle housing. After the new pinion seal is installed, tighten the pinion nut to the same position it was in before disassembly and then rotate the nut 1/16 inch (1.5 mm) farther. This extra rotation makes sure that the collapsible space (crush sleeve) is still able to maintain the proper preload on the pinion bearing. Another method is to measure the rotating torque of the drive pinion using an inch-pound beam-type torque wrench after removing both rear wheels and brake drums. After installing the replacement pinion shaft seal, tighten the drive pinion nut until the rotating torque is 3 to 5 in-lb more than the reading obtained before the pinion nut was removed.

FIGURE 125–38 A container of GL-5 SAE 80W-90 gear lubricant.

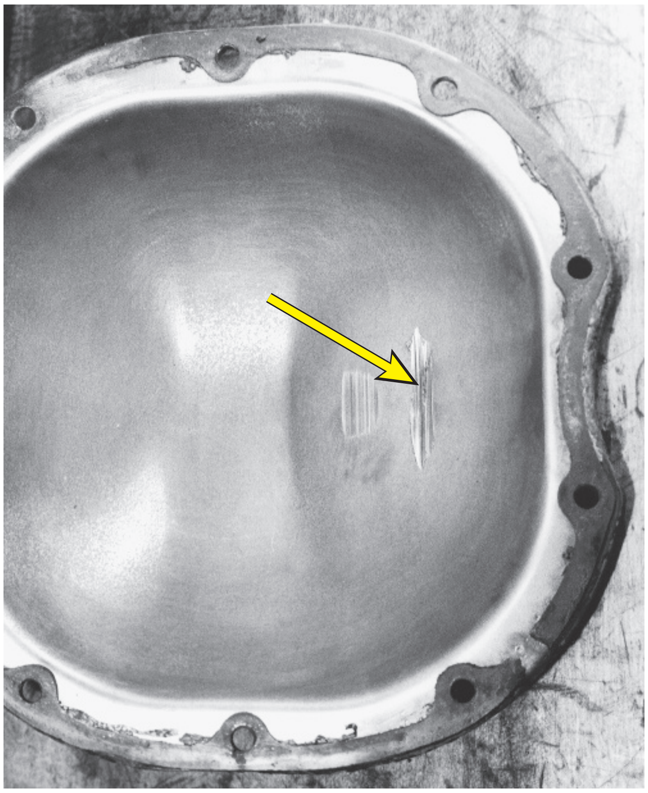


FIGURE 125–39 The beginning automotive student did not realize that the axle housing cover could fit the wrong way. The only problem was that the ring gear scraped against the cover.

CASE STUDY

I Didn't Know It Would Fit the Wrong Way!

An automotive student changed the differential lubricant by removing the housing cover. The cover was reinstalled and then filled with the correct lubricant. However, when the student drove the vehicle it made a grinding sound that was not there before the differential service. When the cover was removed, it was discovered that the cover had been installed with the raised area on the right side of the housing instead of on the left side and the ring gear had rubbed a groove in the cover, as shown in ● **FIGURE 125–39**. Installing the cover correctly stopped the grinding sound.

Summary:

Complaint—Vehicle made a grinding noise after a differential fluid service procedure was performed.
Cause—The drive axle hosing cover was installed incorrectly.
Correction—The cover was removed and installed correctly.

Most differentials require

1. SAE 80W-90 GL-5
2. SAE 75W-90 GL-5
3. SAE 80W GL-5

NOTE: Always check the *exact* specification before adding or replacing rear axle lubricant.

Limited-slip differentials (often abbreviated LSD) usually use an additive that modifies the friction characteristics of the rear axle lubricant to prevent chattering while cornering.

HINT: If chattering becomes noticeable while cornering, replace the old differential lubricant with the correct lubricant and add limited-slip additives if specified by the vehicle manufacturer. After refilling the differential, drive the vehicle in a figure-eight pattern at least four times to help all of the lubricant and additives get into the clutch plates. This usually stops the chattering-while-cornering problem.

REVIEW QUESTIONS

1. Explain how to determine the axle ratio without removing the housing cover.
2. Describe how to perform a ring gear tooth contact pattern test.
3. List three methods that may be used to determine the proper drive pinion gear depth.
4. Explain how to achieve proper drive pinion gear bearing preload.
5. Describe how to adjust the position of the ring gear to achieve the proper backlash.

CHAPTER QUIZ

1. Inside the drive axle of a rear-wheel-drive vehicle, the ring gear is attached to the _____________.

a. drive shaft
b. pinion gear
c. differential case
d. spider gears

2. A limited-slip differential has _____________ on the side gears that a standard (open) differential does not have.

a. sliders
b. clutch packs
c. slip teeth
d. slipper rings

3. A collapsible spacer is used in some differentials to provide _____________.

a. a lubrication path to the drive pinion bearing
b. the proper preload for the side bearings
c. the proper preload for the drive pinion bearings
d. the proper amount of slippage in a limited-slip differential

4. The shim used on a drive pinion gear is used to properly position the gear so that it can correctly mesh with the _____________.

a. ring gear
b. side gear
c. differential pinion gears
d. Both b and c

5. Technician A says that the convex side of the ring gear is the drive side on most rear axle assemblies. Technician B says that the convex side of the ring gear is the drive side on differentials used in the front of many four-wheel-drive vehicles. Which technician is correct?

a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

6. A growling sound is heard from the rear of a rear-wheel-drive vehicle during cornering only. Technician A says that defective rear axle bearings may be the cause. Technician B says that defective drive pinion bearings may be the cause. Which technician is correct?

a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

7. Technician A says that if the backlash is okay, then the side bearing preload is also okay. Technician B says that a ring gear tooth pattern check will indicate if the drive pinion depth is correct. Which technician is correct?

a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

8. The backlash exceeds specifications. The technician should position the ring gear _____________.

a. closer to the drive pinion gear
b. farther from the drive pinion gear
c. toward the heel
d. toward the toe

9. The backlash is less than specifications (too low). This will cause the ring gear tooth pattern to be too close to the _____________.

a. heel
b. flank
c. toe
d. face

10. Two technicians are discussing which lubricants are used in a limited-slip differential. Technician A says to use SAE 80W-140. Technician B says that most vehicle manufacturers usually specify SAE 80W-90 be used with or without special limited slip additives. Which technician is correct?

a. Technician A only
b. Technician B only
c. Both Technicians A and B
d. Neither Technician A nor B

Chapter

126

FOUR-WHEEL DRIVE AND ALL-WHEEL DRIVE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the operation of four-wheel-drive systems.
- Explain the operation of all-wheel-drive systems.
- Discuss front and rear differential axle ratios.
- Describe the components of a transfer case.
- Discuss the purpose and function of an interaxle differential.
- Describe the different types of four-wheel-drive axles and drive axle ratios.
- Describe the procedure to diagnose and service transfer cases.
- Describe the procedure to diagnose and service locking hubs.

KEY TERMS:

Annulus gear 1598 • Bevel gear differential 1599 • Electronically controlled clutch assembly 1594 • Input member 1598 • Interaxle differential (center differential) 1599 • Internal gear 1598 • Low range 1595 • Mode shift 1595 • Output member 1598 • Planet carrier 1597 • Planet pinions 1597 • Range shift 1595 • Reaction member 1598 • Ring gear 1598 • Sun gear 1597 • Viscous coupling 1594

FOUR-WHEEL-DRIVE SYSTEMS

PURPOSE AND FUNCTION Two-wheel-drive vehicles use engine torque to turn either the front or the rear wheels. A differential is required to allow the drive wheels to travel different distances and speeds while cornering or driving over bumps or dips in the road. A four-wheel-drive vehicle, therefore, requires two differentials—one for the front wheels and one for the rear wheels.

NOTE: The term 4 × 4 means a four-wheeled vehicle that has engine torque applied to all four wheels (four-wheel drive). A 4 × 2 means a four-wheeled vehicle that has engine torque applied to only two wheels (two-wheel drive).

Full-time four-wheel-drive vehicles require more than just two differentials. The front and the rear wheels of a four-wheel-drive vehicle also travel different distances and speeds whenever cornering or running over dips or rises in the road.

TRANSFER CASE Engine torque from the transmission is applied directly to the rear differential through the transfer case. ● **SEE FIGURE 126–1**.

The transfer case permits the driver to select different modes and ranges of operation.

These positions and their meanings include

- 4H four-wheel drive with no gear reduction in the transfer case.
- 4L four-wheel drive with gear reduction. Use of this position is usually restricted to low speeds on slippery surfaces.
- 2H two-wheel drive (rear wheels only) in high range, meaning no gear reduction in the transfer case.

To prevent driveling binding and stress when in four-wheel-drive, there must be a way to allow for differences in front-to-rear driveline speed variation. Three methods to do this are

METHOD 1—LOCKING HUBS In normal 4H driving on hard surfaces, the front hubs must be in the unlocked position. The front hubs are locked whenever driving on loose road surfaces to absorb and allow for tire slippage due to the different tire speeds front to back. ● **SEE FIGURE 126–2**.

CAUTION: Failure to unlock the front-wheel hubs while driving on a hard road surface can cause serious driveline vibrations and damage to driveshafts, U-joints, and bearings as well as to the transfer case, or transmission,

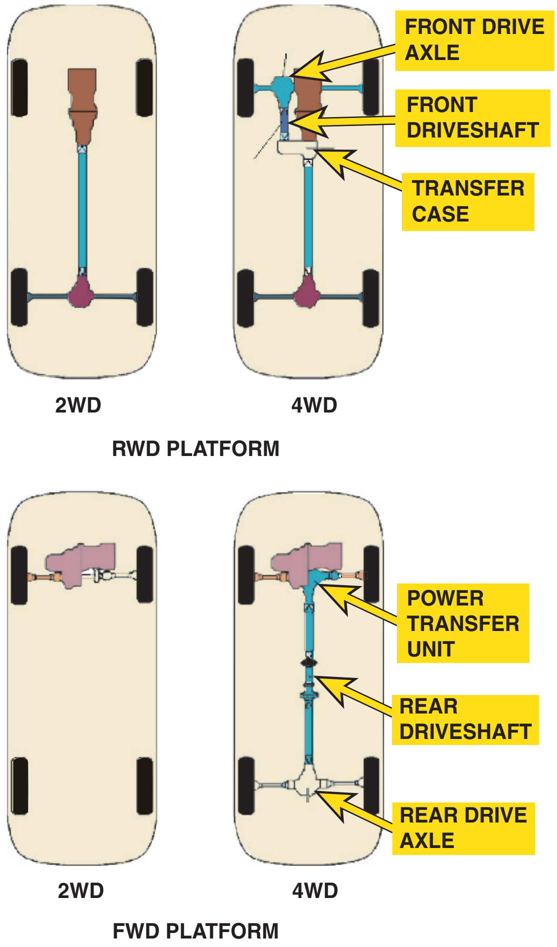


FIGURE 126–1 Four-wheel-drive vehicles can be achieved by using an existing rear-wheel-drive arrangement and adding a transfer case, or a front-wheel-drive arrangement with the addition of rear axle output shaft and center differential assembly.

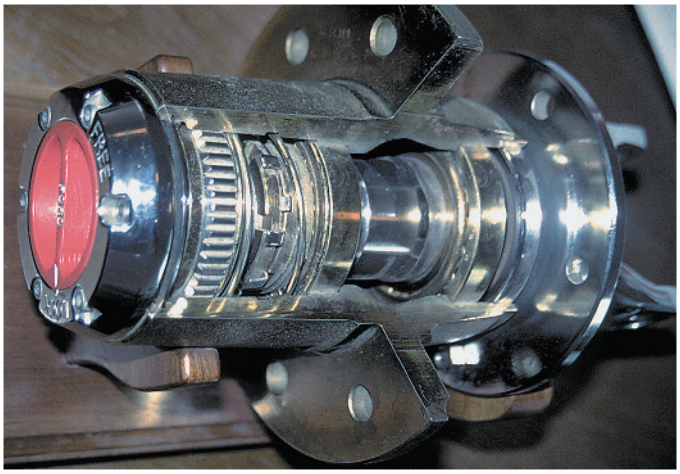


FIGURE 126–2 Cutaway of a manually operated locking hub.

METHOD 2—AUTOLOCKING HUBS Another method of locking the hubs on a part-time four-wheel-drive system is with a clutch arrangement built into the hub assembly. Whenever driving on smooth, hard road surfaces, the hubs "free wheel" and allow the front wheels to rotate at different speeds from the rear wheels. When the speed difference between the wheels and the front drive axle is great, the hubs will automatically lock and allow engine torque to be applied to the front wheels. ● **SEE FIGURE 126–3** shows an autolocking hub with the cover

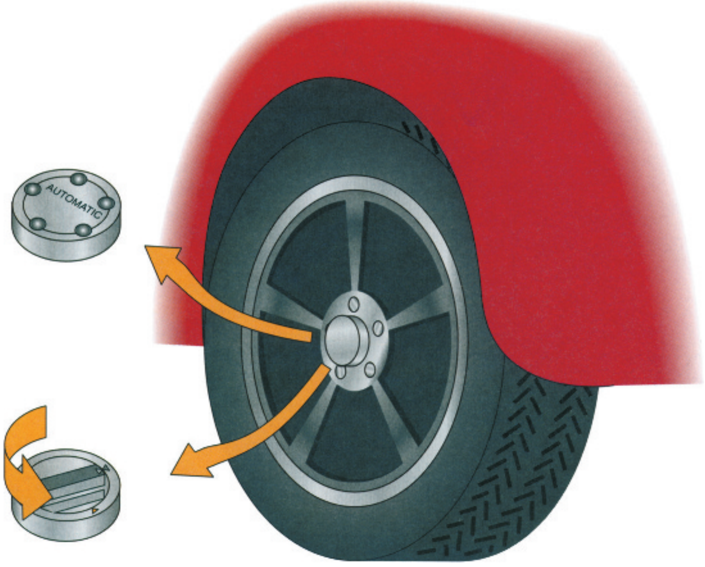


FIGURE 126–3 Manual locking hubs require that the hubs be rotated to the locked position by hand to allow torque to be applied to the front wheels. Automatic locking hubs enable the driver to shift into four-wheel drive from inside the vehicle.

FREQUENTLY ASKED QUESTION

What Is the Difference between Four-Wheel Drive (4WD) and All-Wheel Drive (AWD)?

The major difference between four-wheel drive and all-wheel drive is that four-wheel-drive units contain a transfer case with a low range. Most all-wheel-drive vehicles do not have low range and are in high four-wheel drive all the time. Both use a center (interaxle) differential and both usually use a viscous coupling or an electronically controlled clutch to control (lock) the center differential.

TECH TIP

How to Tow a Four-Wheel-Drive Vehicle without Doing Harm

If any of the drive wheels are on the ground, the wheels are turning the axles. Depending on the exact type of four-wheel-drive vehicle being towed, this rotation of the wheels can cause severe wear; therefore, most experts suggest the following options:

- **Placing the vehicle on a flatbed or trailer.** This keeps all four wheels off the ground and is the safest method for transporting a four-wheel-drive (or all-wheel-drive) vehicle without doing any harm.
- **Hoisting the front wheels off the ground and placing the rear wheels on a dolly.** This procedure also keeps all wheels off the ground and therefore prevents any damage being done to the powertrain as a result of towing. ● **SEE FIGURE 126–4.**

Always check with vehicle-specific information for exact towing procedures.

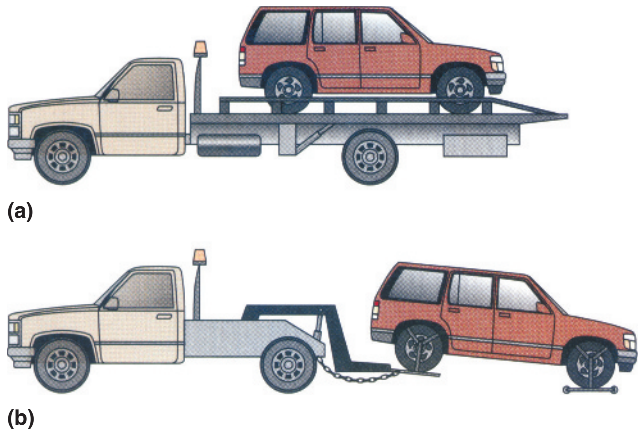


FIGURE 126–4 If a four-wheel-drive vehicle must be towed, it should be either on (a) a flatbed truck or (b) a dolly.

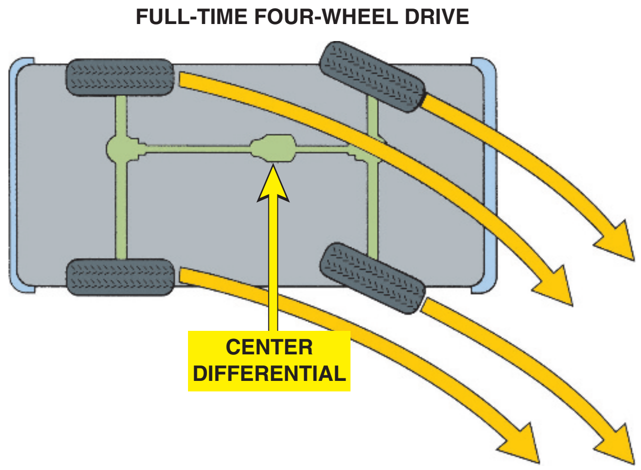


FIGURE 126–5 When turning a corner, each wheel takes a slightly different path and rotates at a slightly different speed. Unlike a part-time four-wheel-drive system, which when engaged locks the front and rear axles together, a full-time system uses a center differential that allows for any speed differences between the front and rear axles. It can therefore be activated on any surface—slippery or dry.

removed. Some automatic-locking hubs are unlocked by disengaging four-wheel drive and driving in reverse for several feet.

METHOD 3—FULL—TIME FOUR-WHEEL DRIVE This method uses a center differential to allow front and rear wheels to travel at different speeds under all operating conditions, as shown in ● **FIGURE 126–5**. Although this drive train design is the easiest to operate both on and off the road, the center differential can cause the vehicle to get stuck in mud or snow even though it is a four-wheel- drive vehicle.

All open-style differentials allow for speed differences and torque is applied equally, so if one wheel is on ice or mud, the other wheel receives the same low torque. This is why many vehicles spin just one wheel when stuck on ice or snow. But if one rear wheel starts to spin, the vehicle may not move forward at all!

There are two methods used to lock the center differential to prevent this from happening.

- A **viscous coupling** is commonly used on many four-wheel-drive vehicles to provide an "automatic" lockup of the center differential. A viscous coupling is a type of fluid clutch. When the speed difference between the front and rear wheels is high enough, the silicone fluid inside the coupling stiffens to reduce the speed difference between the front and rear drive shafts. ● **SEE FIGURES 126–6 AND 126–7**.
- An **electronically controlled clutch assembly** is actuated by the vehicle's computer based on inputs from the ABS wheel speed sensors. If a wheel starts to spin, the computer can pulse the clutch on and off as necessary to control the amount of wheel slippage.

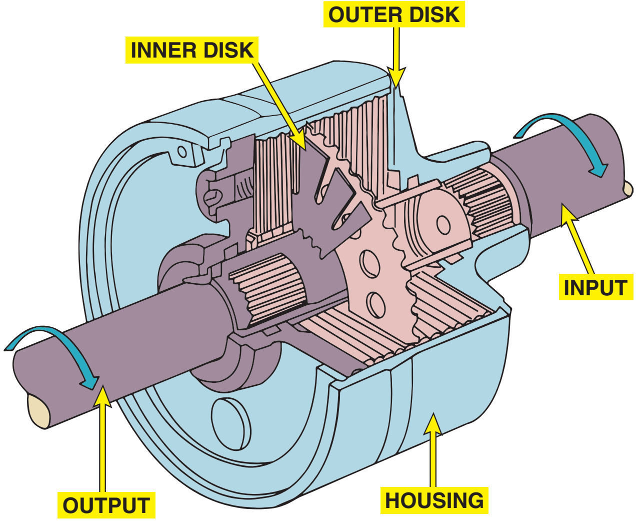


FIGURE 126–6 A viscous coupling is a sealed unit containing many steel discs. One-half of them are splined to the input shaft, with every other disc splined to the output shaft. Surrounding these discs is a thick (viscous) silicone fluid that expands when hot and effectively locks the discs together.

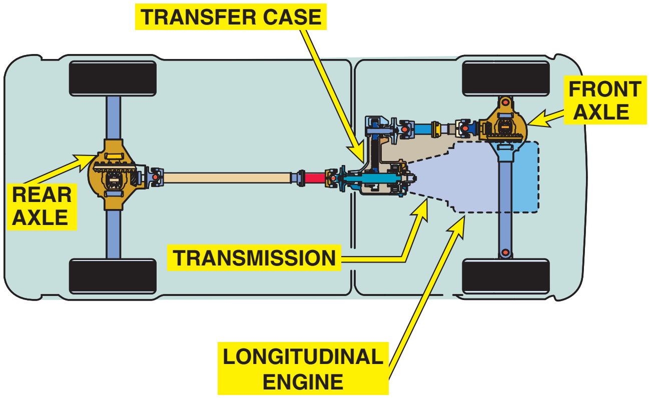


FIGURE 126–7 A typical four-wheel-drive vehicle that uses a longitudinal engine and a transfer case to send engine torque to both the front and rear wheel.

ALL-WHEEL DRIVE

Some cars and light trucks are equipped with an all-wheel-drive system that uses a transfer case with a center differential and only one speed (high). Low-range gear reduction is not used. A viscous coupling is usually incorporated into the center differential to provide superior all-weather traction. Combined with a limited-slip differential in the rear, and sometimes also in the front, an all-wheel-drive system can provide ideal road traction under all driving conditions without any action by the driver. ● **SEE FIGURE 126–8.**

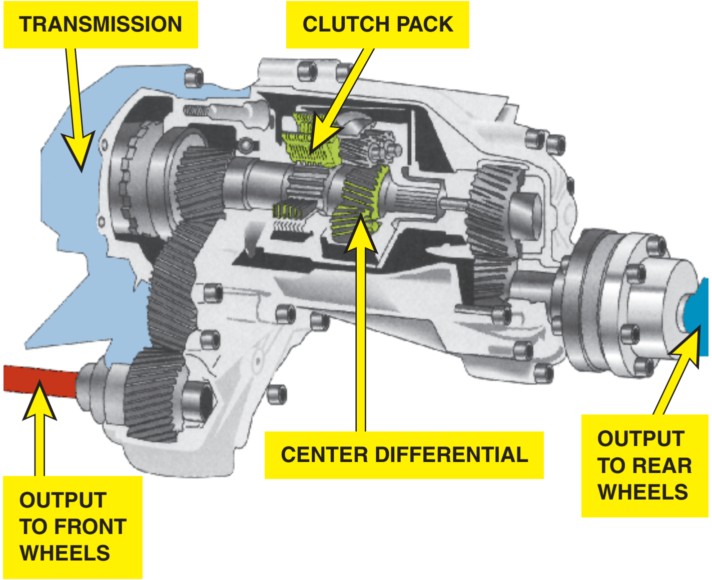


FIGURE 126–8 The center differential is the heart of a typical all-wheel-drive system. All-wheel-drive systems do not use a low range, and therefore the vehicle may not be able to go off-road like a vehicle equipped with a four-wheel drive with a low range.

FREQUENTLY ASKED QUESTION

What Is Brake-Actuated Traction Control?

The engine torque of a full-time four-wheel-drive vehicle (with the center differential unlocked) is split into four nearly equal parts. One quarter of the torque is applied to each wheel. If a brake is applied to a spinning wheel, the torque to that wheel is increased, which will increase the torque to all of the other wheels. The increased torque applied to the wheels that have contact with a surface that has some traction will enable the vehicle to proceed. This is the principle involved in brake-controlled traction control such as is used on the Mercedes M4 sport utility vehicle (SUV).

FRONT AND REAR DIFFERENTIAL AXLE RATIOS

In most four-wheel-drive vehicles, the overall gear ratio of the front differential is slightly higher than the overall ratio of the rear differential. The overall ratio is determined by multiplying the gear ratio by the differential ratio. See the following chart comparing the ratios for the front and rear differentials of a typical four-wheel-drive vehicle equipped with a manual five-speed transmission.

Manual Transmission and Final-Drive Gear Ratios

Speed	Gear Ratio	Final-Drive Ratio	Overall Ratio
1st	3.083:1	4.933 front 4.927 rear	15.208 front 15.190 rear
2nd	1.684:1	4.933 front 4.927 rear	8.307 front 8.297 rear
3rd	1.115:1	4.933 front 4.927 rear	5.500 front 5.494 rear
4th	0.833:1	4.933 front 4.927 rear	4.109 front 4.104 rear
5th	0.666:1	4.933 front 4.927 rear	3.285 front 3.281 rear

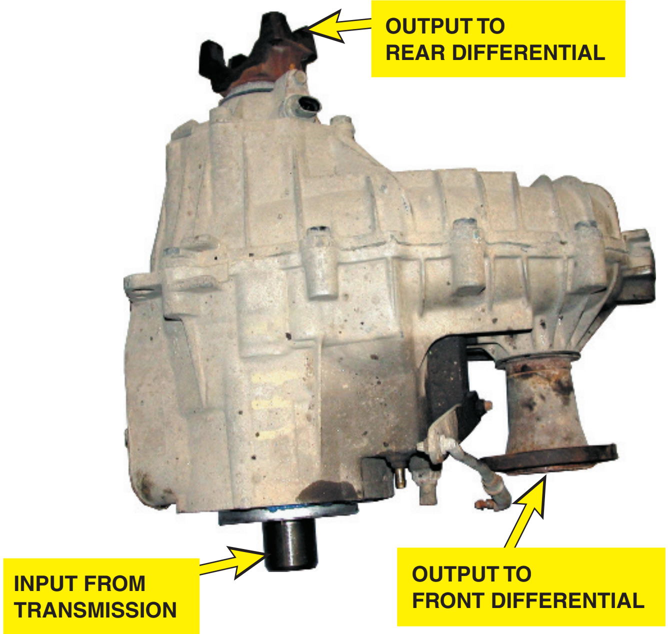


FIGURE 126–9 A typical transfer case is attached to the output of the transmission and directs engine torque to the rear or to the front and rear differentials.

Although the difference between the ratios is small, the purpose is to prevent the drive train from binding. With the front differential ratio being just slightly higher, the tendency is for the front of the vehicle to pull the vehicle, thereby eliminating the problem of having the rear pushing at the exact same ratio as the front is pulling. The different ratios also help reduce resonant vibration and noise created in the driveline.

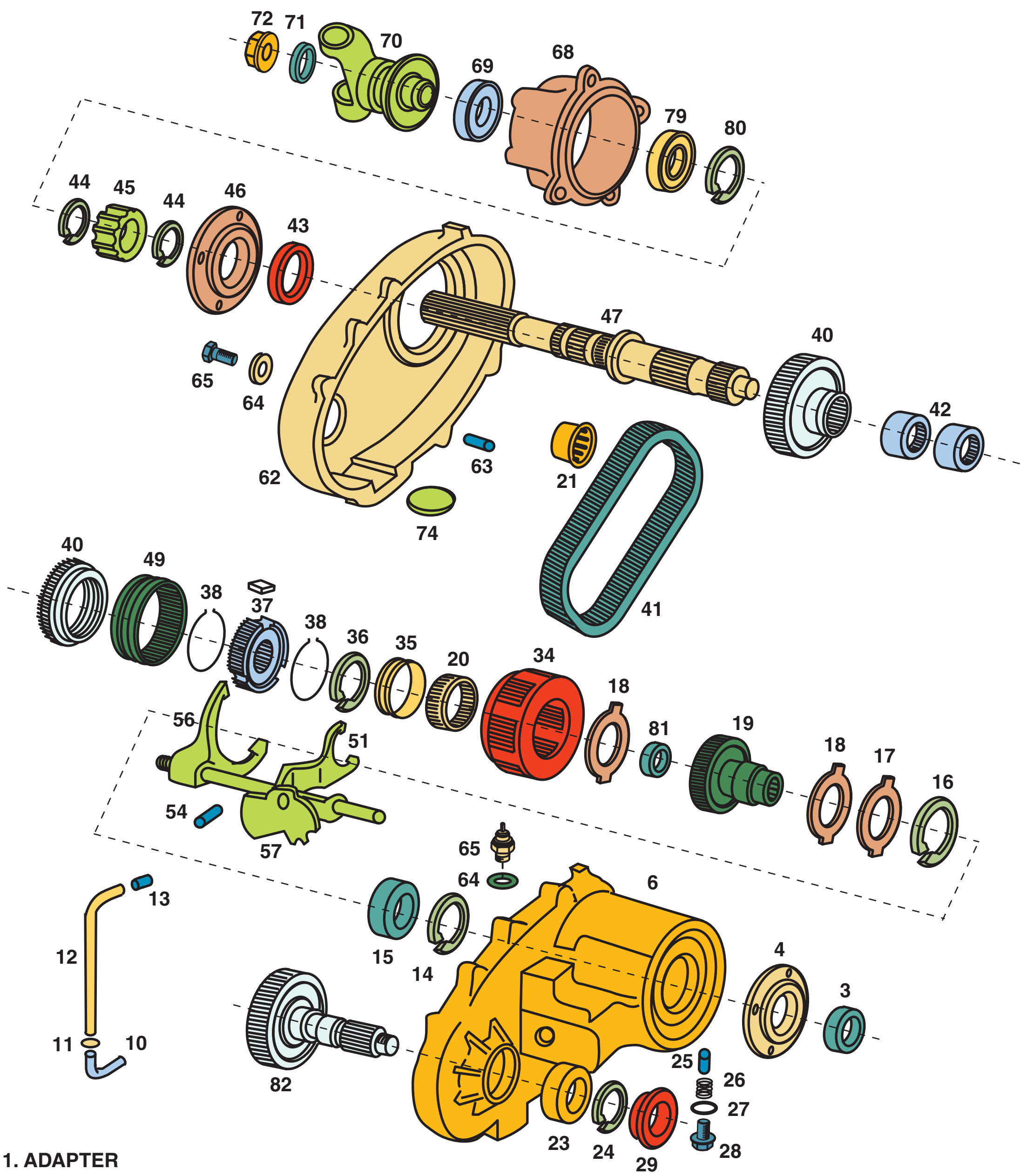
TRANSFER CASE

The purpose and function of the transfer case is to direct engine torque to the front and rear axle assemblies. ● **SEE FIGURE 126–9.** A four-wheel-drive transfer case is basically an auxiliary 2-speed transmission. It uses the transmission output as an input to a secondary gear train or planetary gear set, which provides a low and high range. The transfer of torque to the front axle output shaft can be accomplished either by a gear-to-gear transfer or a gear and chain transfer. The gear ranges can be engaged a number of ways, such as a manual lever, electrical, or vacuum actuators. A transfer case has one input shaft (connected to the output of the transmission) and two output shafts (● **SEE FIGURE 126–10).** The two output shafts are connected to the driveshafts and transfer torque to the front and rear differentials. Most transfer cases also provide for two types of shifts:

- **Mode shift.** Either two-wheel drive or four-wheel drive may be selected. Many transfer cases also have a neutral position. The mode shift is achieved by the use of a floor-mounted lever to engage and disengage a clutch inside the transfer case. This shift is usually performed when the vehicle is stopped. However, new designs allow the mode shift to be performed under most driving conditions.

NOTE: The mode shift is not available on all-wheel-drive vehicles.

- **Range shift.** A **low range** may be selected to deliver high torque at low speeds to the drive wheels. Low range usually provides a 2:1 to 3:1 gear reduction. High range (usually 1:1) simply transfers engine torque at the same speed as the output shaft of the transmission.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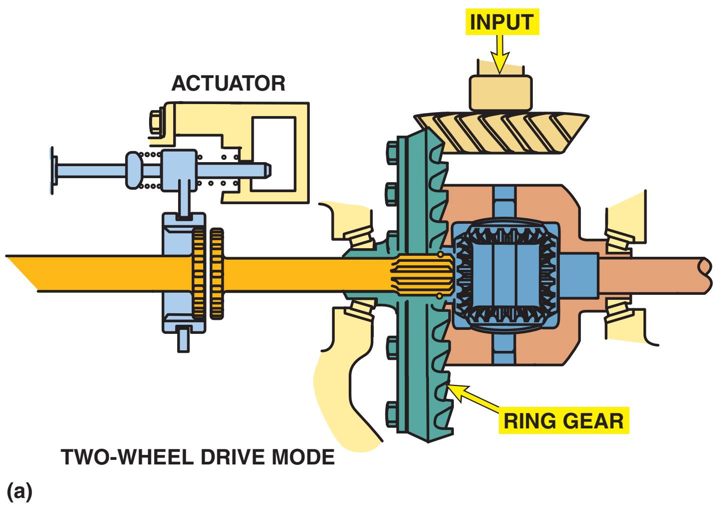
1. ADAPTER
2. LOCKNUT
3. FRONT RETAINER SEAL
4. FRONT BEARING RETAINER
5. RETAINER SCREW
6. FRONT CASE
7. CASE STUD
8. VACUUM SWITCH
9. O-RING
10. VENT
11. CLAMP
12. HOSE
13. HOSE END CAP
14. SNAP RING
15. BEARING
16. SNAP RING
17. RETAINER
18. THRUST WASHER
19. INPUT GEAR
20. PILOT BEARING
21. BEARING
22. OUTPUT SHAFT
23. BEARING
24. SNAP RING
25. DETENT PLUNGER
26. SPRING
27. O-RING
28. PLUG
29. SEAL
30. OIL SLINGER
31. YOKE
32. WASHER
33. NUT
34. LOW RANGE GEAR
35. SHIFT HUB
36. SNAP RING
37. SYNCHRONIZER
38. SPRINGS
39. STOP RING
40. SPROCKET
41. DRIVE CHAIN
42. BEARING
43. SEAL
44. SNAP RING
45. SPEEDOMETER GEAR
46. OIL PUMP
47. MAINSHAFT
48. SHIFT FORK PADS
49. RANGE FORK PADS
50. MODE FORK PADS
51. MODE FORK
52. SPRING
53. SHIFT RAIL
54. PIN
55. BUSHING
56. RANGE FORK
57. SHIFT SECTOR
58. O-RING
59. RETAINER
60. RANGE LEVER
61. NUT
62. REAR CASE
63. ALIGNMENT DOWEL
64. WASHER
65. BOLT
66. CASE BOLT
67. RETAINER SCREW
68. RETAINER
69. SEAL
70. YOKE
71. SEAL
72. YOKE NUT
73. WASHER
74. MAGNET
75. O-RING
76. OIL TUBE
77. TUBE CONNECTOR
78. SCREEN
79. BEARING
80. SNAP RING
81. PLUG
82. FRONT SHAFT
83. SNAP RING
84. GASKET

FIGURE 126–10 An exploded view of a New Venture 241 transfer case.



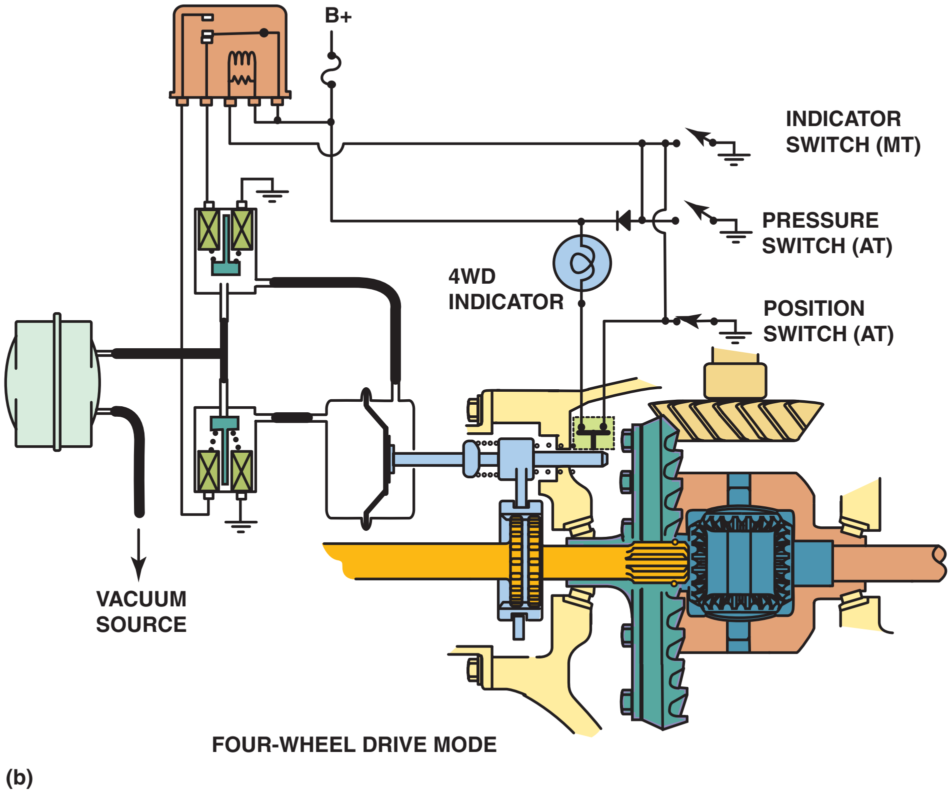


FIGURE 126–11 (a) When one axle shaft is disconnected, both front wheels can rotate independently, reducing excessive tire wear. (b) In four-wheel-drive mode, vacuum is applied to the front part and the opposite side is vented to atmospheric pressure retracting the shift motor stem. The shift fork and collar move into engagement with both axle shaft gears. Engine torque from the front differential can now be applied to both front axles. When the transfer case is placed in two-wheel drive, the vacuum is applied to the other side of the diaphragm and the shift collar moves, unlocking the front axles.

NOTE: Part-time four-wheel drive means that the transfer case does not include a differential.

GEAR-TO-GEAR TRANSFER CASES Gear-to-gear transfer cases are simple in design. Three gear shafts are in mesh within the transfer case. One gear shaft is attached to the transmission output shaft. The second shaft acts as an idler, and the third shaft is the output to the front axle. Gear-to-gear transfer cases, in most cases, have two speeds. The first, 4-wheel-drive low, is a gear reduction that is usually around two to one (2:1). The second gear in the transfer case is a direct drive. The gears are engaged by sliding collars or synchronizers to lock the gears to the shaft. Neutral is accomplished when neither gear collar is locking a gear in place.

TWO-WHEEL-DRIVE OPERATION When the transfer case controls are in two-wheel drive, the front differential assembly is disconnected from the transfer case. This disconnection is usually accomplished by disconnecting one of the drive axles, as shown in ● **FIGURES 126–11 AND 126–12.** The disconnect mechanism in the front axle and a synchronizer assembly in the transfer case combine to remove torque for the front wheels.

FOUR-WHEEL-DRIVE OPERATION To achieve four-wheel drive, two things must occur:

- A synchronizer assembly connects the torque from the engine to the front driveshaft in the transfer case.
- The drive axles must be connected to allow the torque from the front differential to be applied to the drive wheels.

PLANETARY GEAR SET TRANSFER CASES Many transfer cases use a planetary gear set for gear reduction in low range. A planetary gear set includes the following three elements:

1. **Sun gear.** This gear is in the center like the position of the sun is in our solar system.
2. **Planet pinions.** The planet pinion gears rotate around the sun gear, like the planets around the sun, and are attached by a **planet carrier**.

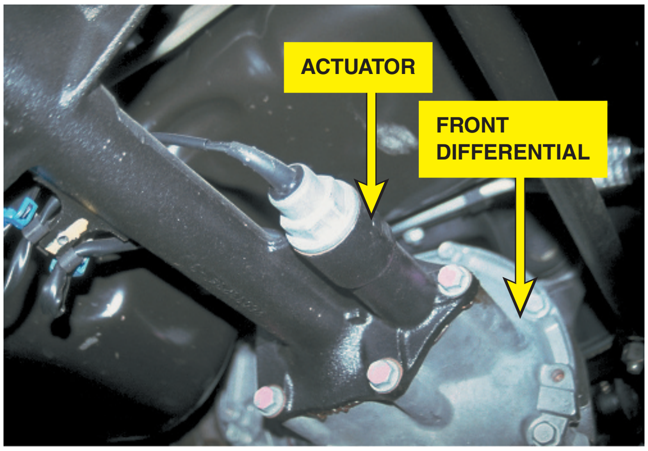

ACTUATOR
FRONT DIFFERENTIAL

FIGURE 126–12 A General Motors sport utility vehicle front axle showing the electric axle disconnect actuator.

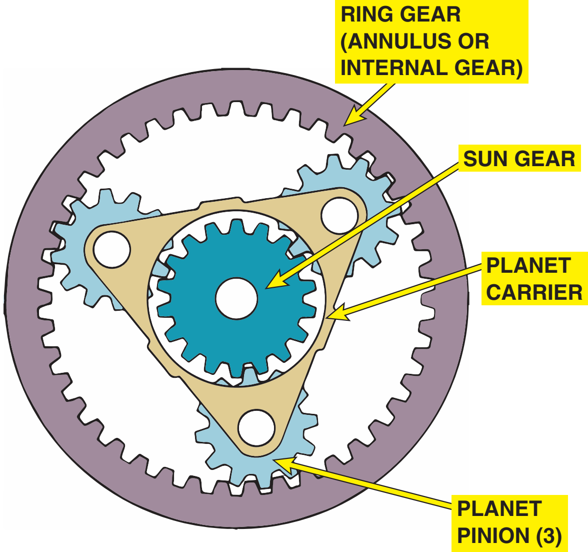

RING GEAR (ANNULUS OR INTERNAL GEAR)
SUN GEAR
PLANET CARRIER
PLANET PINION (3)

FIGURE 126–13 A typical planetary gear set used in a transfer case.

3. **Ring gear.** The outer ring gear has teeth on the inside that mesh with the teeth of the planet pinion gears. The ring gear is also called the **annulus gear** or **internal gear** because the gear teeth are on the inside (rather than the outside) portion of the gear.

The gear teeth of a planetary gear set remain in constant mesh. When gear reduction is needed, the sun gear is often the drive gear and the planet carrier is often the driven gear. The gear ratio reduction depends on the number of teeth on the various gears used in a planetary gear set. ● **SEE FIGURES 126–13 AND 126–14.** To achieve direct 1:1 output from the transfer case, any two of the three elements can be locked together and the entire assembly will rotate as a unit.

Power flows through a planetary gear set in several steps to get from the drive action of the first member to the driven action of the last member. The terms "drive" and "driven" simply describe how any two gears work together. When three or more gears are involved, the second gear is a *driven* gear in relation to the first, but a *drive* gear in relation to the third. For this reason, the drive member of a planetary gear set is called the **input member**, the held member, the **reaction member**, and the driven member, the **output member**. ● **SEE FIGURES 126–15 THROUGH 126–17.**

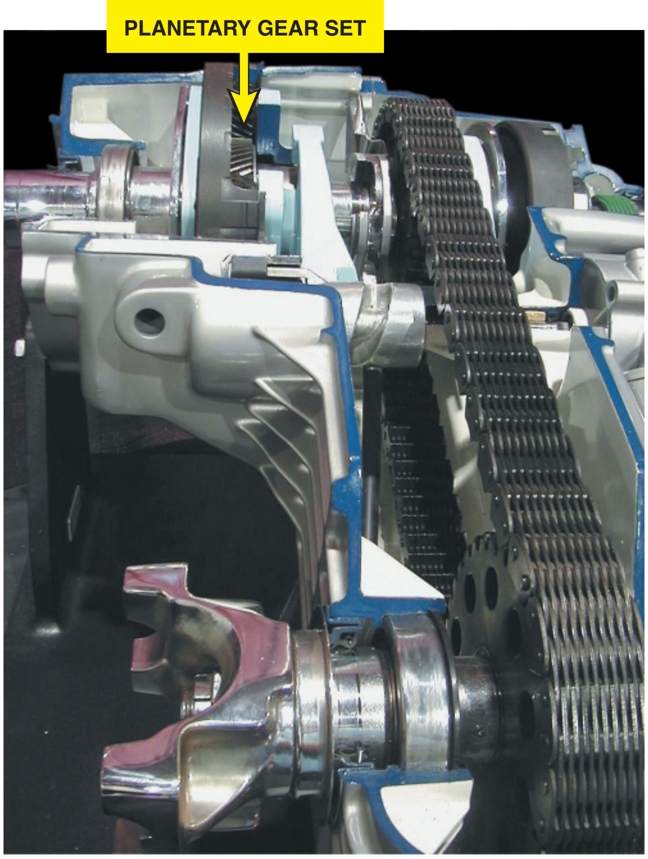

PLANETARY GEAR SET

FIGURE 126–14 Cutaway of a planetary gear set transfer case.

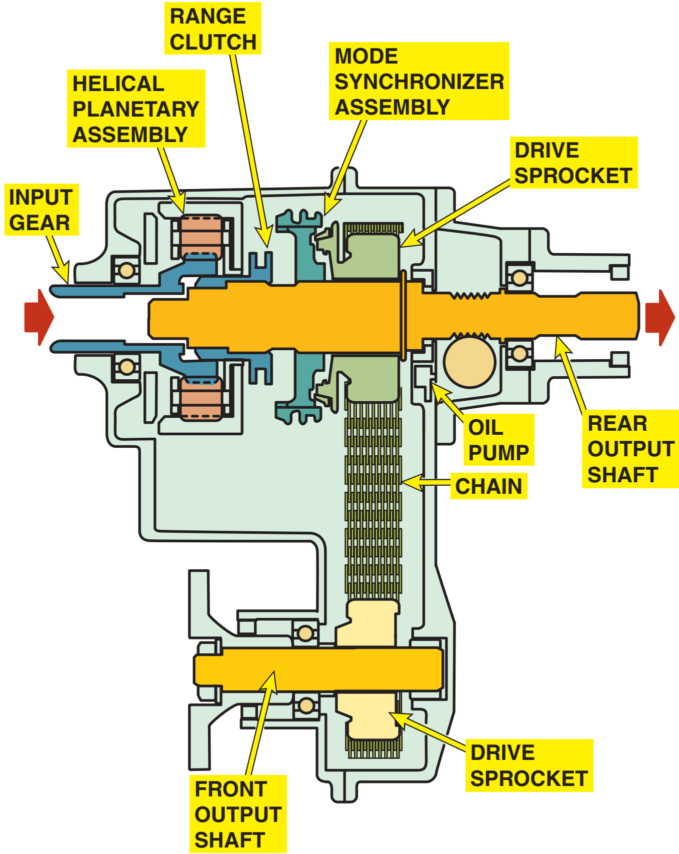

RANGE CLUTCH
HELICAL PLANETARY ASSEMBLY
MODE SYNCHRONIZER ASSEMBLY
DRIVE SPROCKET
INPUT GEAR
OIL PUMP
REAR OUTPUT SHAFT
CHAIN
DRIVE SPROCKET
FRONT OUTPUT SHAFT

FIGURE 126–15 Two-wheel-drive/high-range torque flow in a NV231 transfer case. The sliding range clutch is shifted to the forward position by the range lever and fork, which connects the input gear to the output shaft and rear axle. The mode synchronizer sleeve is moved out of engagement from the drive sprocket to remove torque from the front axle.

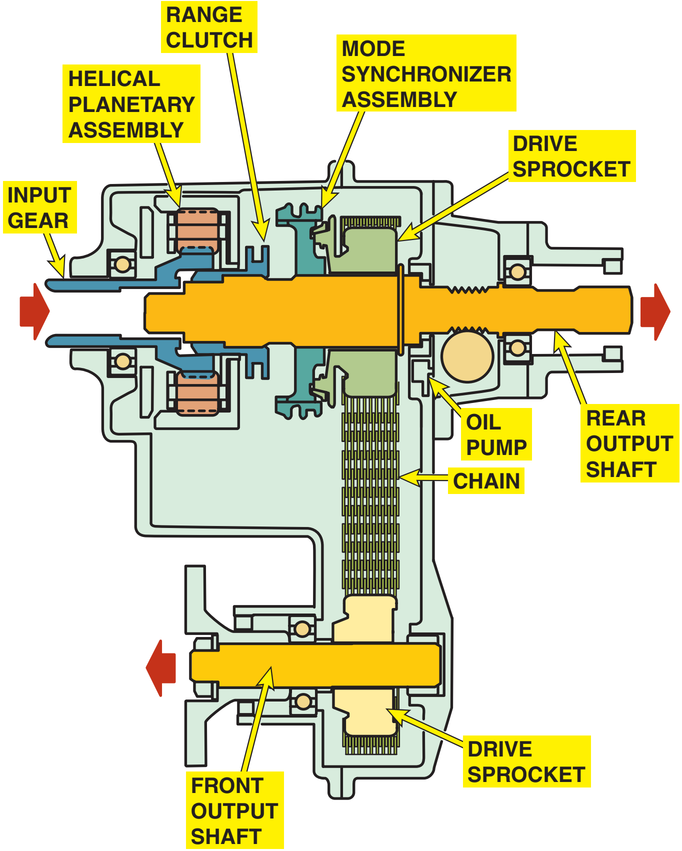

RANGE CLUTCH
HELICAL PLANETARY ASSEMBLY
MODE SYNCHRONIZER ASSEMBLY
DRIVE SPROCKET
INPUT GEAR
OIL PUMP
REAR OUTPUT SHAFT
CHAIN
DRIVE SPROCKET
FRONT OUTPUT SHAFT

FIGURE 126–16 Four-wheel-drive/high-range torque flow in a NV231 transfer case. The range clutch position remains the same as in two-wheel drive/high-range, but the synchronizer sleeve is moved rearward and engages the drive sprocket clutch teeth. This action connects the drive sprocket to the rear output shaft, thereby applying equal torque to both front and rear output shafts.

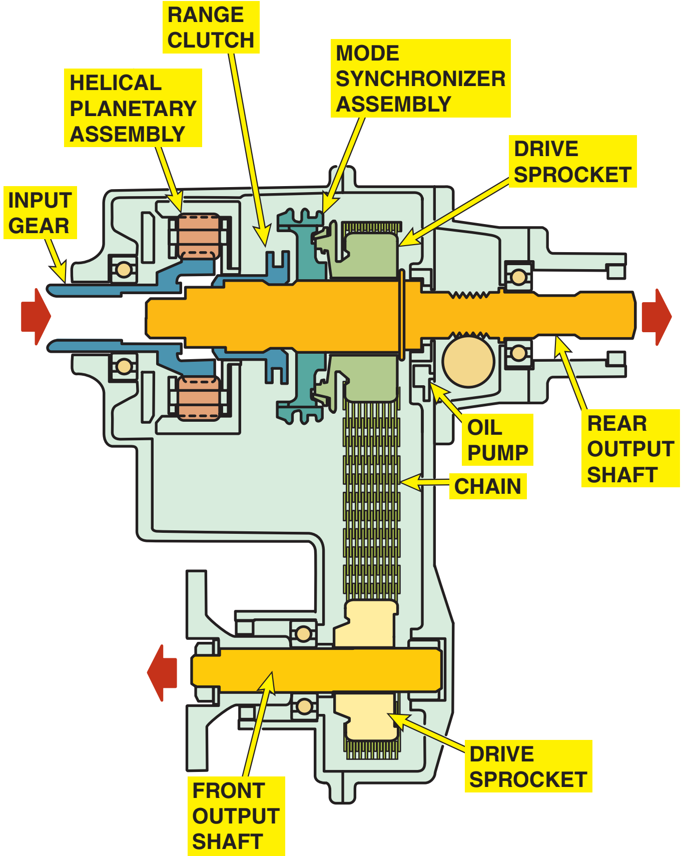

RANGE CLUTCH
HELICAL PLANETARY ASSEMBLY
MODE SYNCHRONIZER ASSEMBLY
DRIVE SPROCKET
INPUT GEAR
OIL PUMP
REAR OUTPUT SHAFT
CHAIN
DRIVE SPROCKET
FRONT OUTPUT SHAFT

FIGURE 126–17 Four-wheel-drive/low-range torque flow in a NV231 transfer case. The mode synchronizer assembly remains engaged and the range clutch is moved to the rearward position. The annulus (ring) gear is fixed to the case and the input (sun) gear drives the pinion gears, which walk around the stationary annulus gear and drive the planetary carrier and output shaft at a speed lower than the input gear.

INTERAXLE DIFFERENTIAL

All-the-time four-wheel-drive, all-wheel-drive, and full-time four-wheel-drive systems use an **interaxle differential (center differential)** to prevent driveline harshness and vibration, commonly referred to as driveline windup. An interaxle differential can be found in various configurations including

- Standard bevel gear differential
- Planetary gear differential
- Viscous coupling

Although they are different in appearance, interaxle differentials serve the same purpose, to maintain smooth operation while making turns in a four-wheel-drive/all-wheel-drive vehicle. The **bevel gear differential** uses two bevel gears or spider gears attached to the output shaft of the transmission. Two to four differential pinion gears are attached to a carrier, which is attached to the transfer gears. In other words, it operates in the same fashion as the differential in a rear axle; power is transferred to the tire with the least traction. When there is unequal traction between the front and rear axles, the axle with the most traction is allowed to slip enough to prevent damage to driveline components. ● **SEE FIGURE 126–18.**

With this setup, the loss of traction at one wheel could effectively disable the vehicle. For example, if one wheel had zero traction, the majority of engine torque would be applied to that wheel. In a standard bevel gear setup, torque is split between the front and rear axles. If there is a loss of traction in the front, the transfer of torque to the rear axle will be significantly lowered. To remedy this condition, auto manufacturers incorporate an internal clutch mechanism, much like a limited-slip unit, to increase torque transfer and still lessen driveline vibration and harshness.

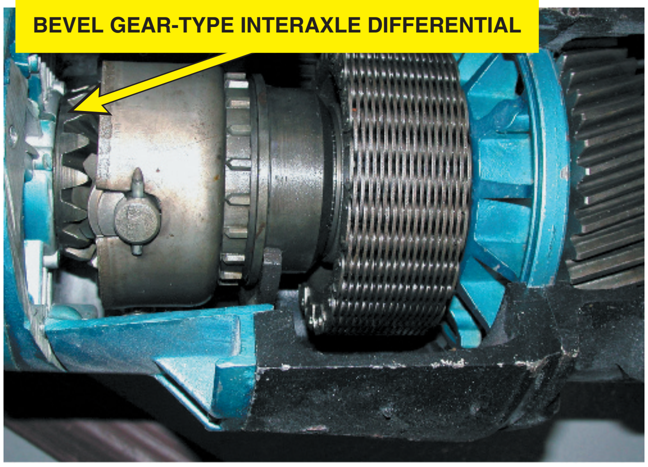

BEVEL GEAR-TYPE INTERAXLE DIFFERENTIAL

FIGURE 126–18 A bevel gear-type interaxle differential.

A planetary gear set is often incorporated in transfer cases to act as a differential.

A viscous coupling is nothing more than a selection of steel plates housed in a sealed steel drum. ● **SEE FIGURE 126–19.** The viscous coupling is not active during equal traction conditions.

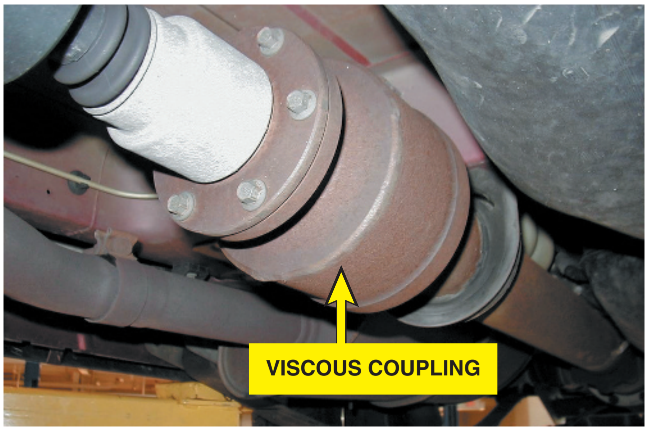


FIGURE 126–19 A viscous coupling. Note that the unit is attached to the output shaft between the transfer case (or transaxle) and the rear differential. A typical viscous coupling in a sealed unit is serviced as a complete assembly.

The viscous coupling does actively transfer torque during light to moderate cornering, but there is a certain amount of slippage under these conditions to prevent driveline windup. If there is a significant loss of traction, the speed differences between the front and rear axles increase, and this increase in plate speed heats the silicon fluid in the viscous coupling, causing it to thicken to the point that it transfers more torque to the axle that is losing traction. During a severe loss of traction, the viscous fluid thickens enough to lock the plates together, dividing engine torque equally 50/50 between the front and rear axles.

FOUR-WHEEL-DRIVE AXLES

Four-wheel-drive vehicles use a variety of driveshafts and U-joint designs:

- **Standard Cardan-type U-joints.** ● **SEE FIGURE 126–20.** If this type of U-joint is used on the front wheels of a four-wheel-drive vehicle, the different speeds it creates can cause the front wheels to skip, hop, and shake if engine torque is applied while on dry pavement and turning a corner at the same time. This is normal for this type of U-joint used on the front wheels of a four-wheel-drive vehicle.

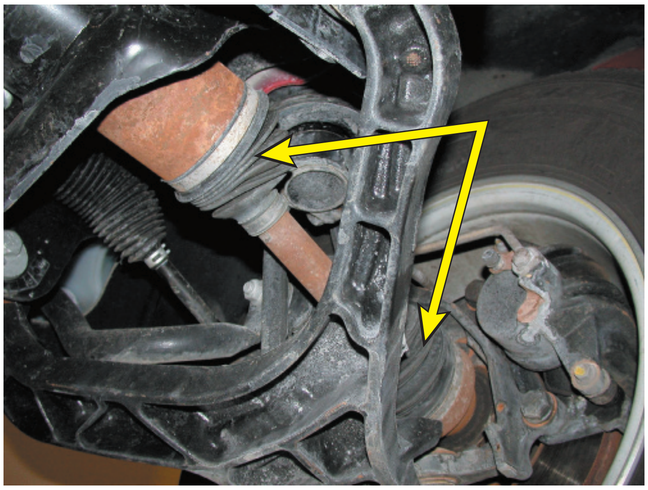


FIGURE 126–21 Constant velocity (CV) joints are used on the front axles of many four-wheel-drive vehicles like this Chevrolet Blazer.

- **Constant velocity (CV) joints.** The use of CV joints at the front wheels allows engine torque to be applied without changes in wheel speed, as can often occur if standard U-joints are used. ● **SEE FIGURE 126–21.**

NOTE: Constant velocity (CV) joints are commonly used on vehicles that have the differential assembly attached to the frame of the vehicle. This design reduces the amount of weight that has to move up and down during suspension movement and helps provide a smooth ride.

TRANSFER CASE SERVICE AND PROBLEM DIAGNOSIS

Four-wheel-drive transfer cases and related components are usually built strong enough for heavy-duty use. However, there is some preventative maintenance that may need to be done:

- **Draining and refilling the transfer case.** Most transfer cases require automatic transmission fluid (ATF), yet some (especially older) units require SAE 80W-90 GL-4 gear lube. Obviously, any fluid leaks should be corrected as soon as

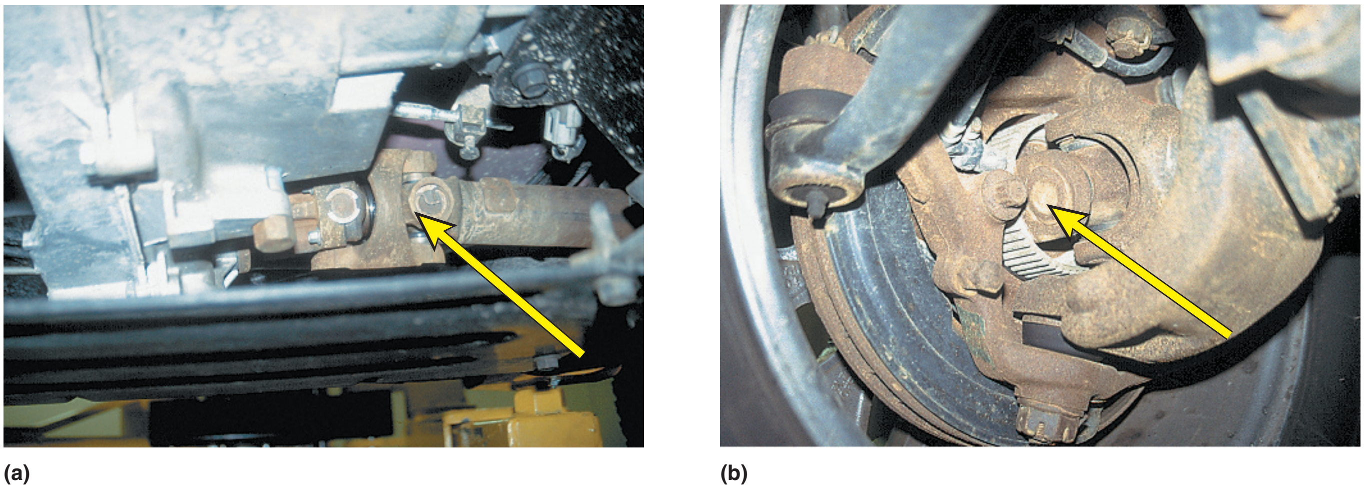


FIGURE 126–20 (a) A standard Cardan U-joint used on the output driveshaft from the transfer case to the front differential assembly. (b) A Cardan-type U-joint at the front drive wheels on a Jeep Wrangler.

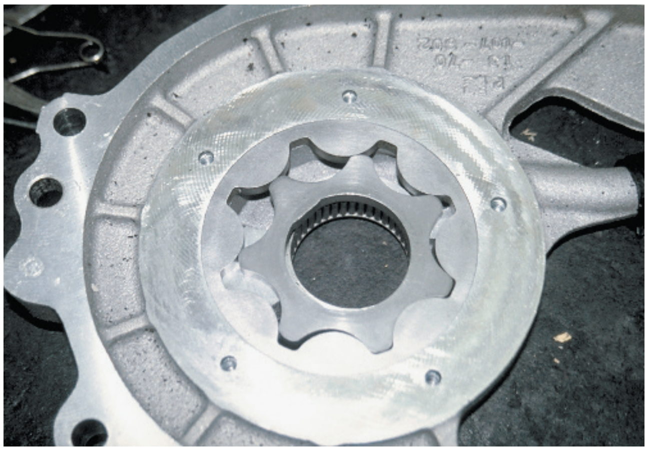


FIGURE 126–22 Most transfer cases use an internal oil pump to force the lubricant throughout the unit. Using the correct lubricant is critical to the proper operation of the transfer case.

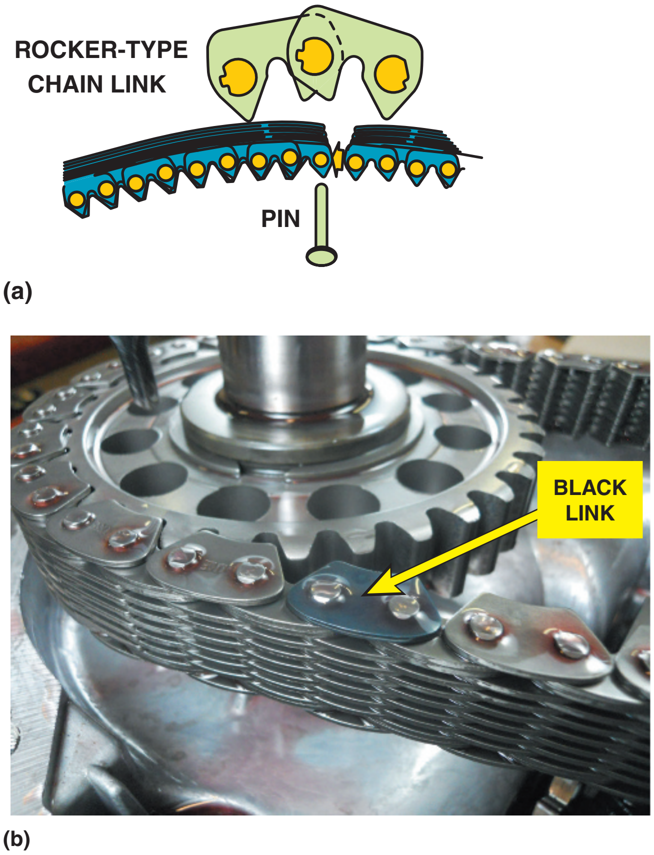


FIGURE 126–23 (a) A pin and rocker-type chain, which is also called a rocker joint-type chain, is used in transfer cases because of low noise and high efficiency, which improves fuel economy. (b) A rocker pin-type chain used in a transfer case.The black link faces upward and is used as an indicator to the service technician to help insure that the chain is replaced in the same side up when it is reassembled.

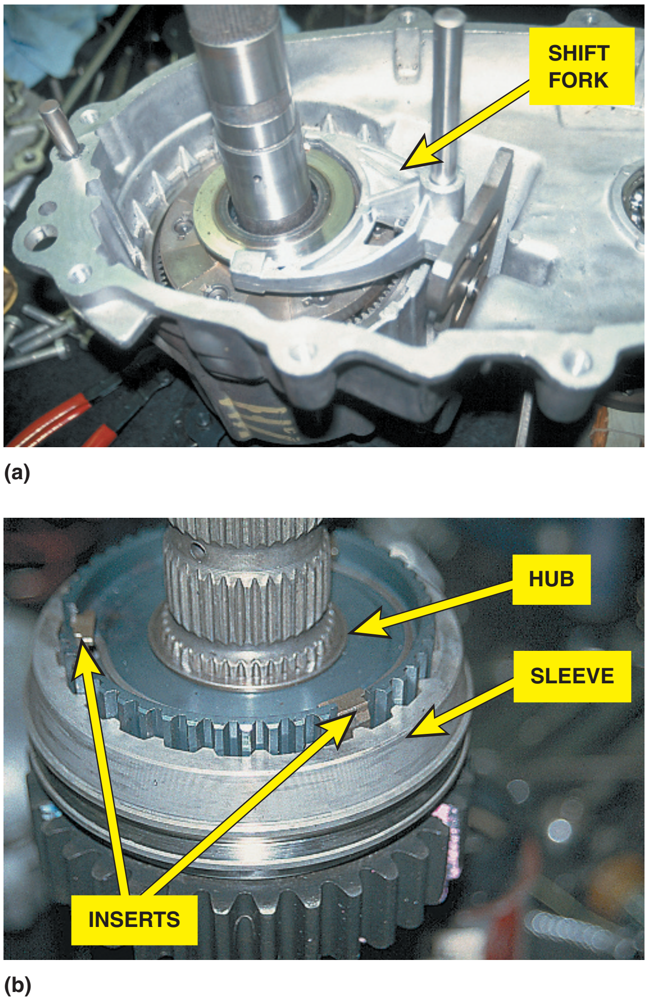


FIGURE 126–24 The transfer case shift forks attach to the synchronizer sleeve. (b) The sleeve, hub, and inserts are similar in design except larger than those used in a manual transmission/transaxle.

possible to avoid damage from low lubricant level. ● **SEE FIGURE 126–22.**

- **Drive chain.** The chain in chain-drive transfer cases can stretch and start hitting the inside of the transfer case. ● **SEE FIGURE 126–23.** This occurs most frequently in vehicles that use four-wheel drive under heavy loads for extended periods of time. The noise the chain makes is very loud, and the chain should be replaced as soon as possible to avoid excessive damage to the case.
- **Bearings.** Transfer case bearings may cause noise whenever the input shaft is rotating even if the transfer case is in neutral. Consult the factory service information for details on transfer case bearing noise diagnosis procedures.
- **Shifting.** Shifting problems can be caused by several items: shift linkage bent or binding, worn shift fork or synchronizer assembly (● **SEE FIGURE 126–24),** incorrect transfer case lubricant.

TECH TIP

Please Install Snap Rings Correctly

Many snap rings are tapered at their opening, as shown in ● **FIGURE 126–25.** This allows the snap ring pliers to grasp the points of the snap ring so that it can be expanded and easily removed. If the points are facing down, it is very difficult for snap-ring pliers to grasp the end of the snap ring. Therefore, to make it easier to disassemble a transfer case later, always install snap rings as they were designed to be installed.

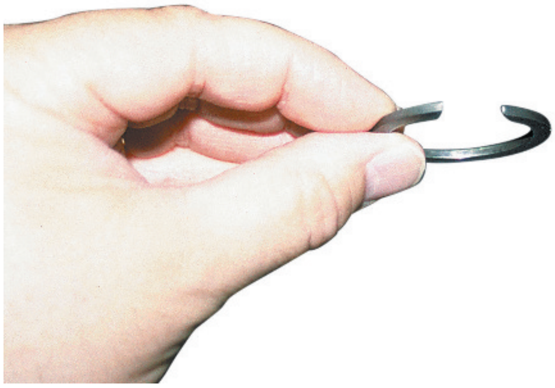


FIGURE 126–25 When reassembling a transfer case (or another automotive component) that includes a snap ring, always be sure that the upper opening is tapered from the top to allow snap-ring pliers room to get a grip on the open end.

NOTE: The transfer case may be difficult to shift if the recommended procedure is not followed. For example, many manufacturers recommend that the vehicle be completely stopped before attempting to make a mode and/or a range shift. Verify proper shifting procedures before further testing or disassembly.

DIAGNOSING AND SERVICING LOCKING HUBS

Locking front hubs should be cleaned periodically, especially if the vehicle has been driven under water or in dusty conditions. Most vehicle manufacturers recommend that the hubs be cleaned and lightly coated with grease at the same time the front wheel bearings are serviced. Check the service information for the exact procedure for the vehicle being serviced. ● **SEE FIGURE 126–26.**

Start the inspection of the front hubs by removing the cover plate. Many problems associated with locking hubs can be corrected by cleaning and lubricating the components. If noise is heard from the hubs, carefully inspect the inner components on both sides of the vehicle. A damaged part can cause noise in the hub on the other side. Service kits are often available for the hubs. These kits contain the gaskets, seals, and retaining rings necessary for installing the hubs correctly after wheel bearing or front brake work has been completed.

TECH TIP

Keep the Differential Vents Clear

All differentials are vented to allow for expansion and contraction of differential lubricant in all temperature ranges. Typically, these vents are shielded openings near the top of the differential. Most trucks, especially four-wheel-drive vehicles, use an extended vent hose to prevent water from getting into the differential if the vehicle is driven in deep water.

If mud gets into the vent, pressure can build up inside the differential and cause lubricant leakage past the rear axle seals. Therefore, whenever replacing rear axle seals, always check to make sure that the differential vent is clear. Remember that four-wheel-drive vehicles use two differentials and that both the front and rear vents plus the vent on the transfer case should be checked.

NOTE: Check the amount of axle end play. Excessive end play caused by defective bearings can cause the drive axle to move enough to damage the hubs.

TRANSFER CASE SERVICE Transfer cases usually require occasional lubricant change during normal service life. However, driver abuse often causes parts to break, requiring the overhaul or replacement of the entire assembly. Always follow the vehicle manufacturer's recommended servicing procedure.

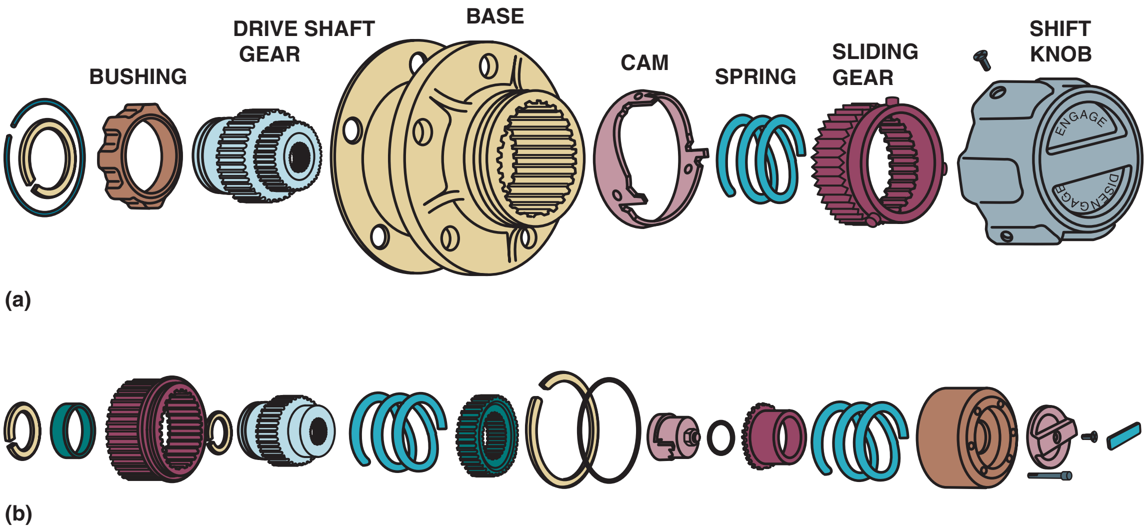


FIGURE 126–26 (a) An exploded view of a Dualmatic® manual locking hub. (b) A Warn® manual locking hub.

CASE STUDY

The Differential Lubricant Story

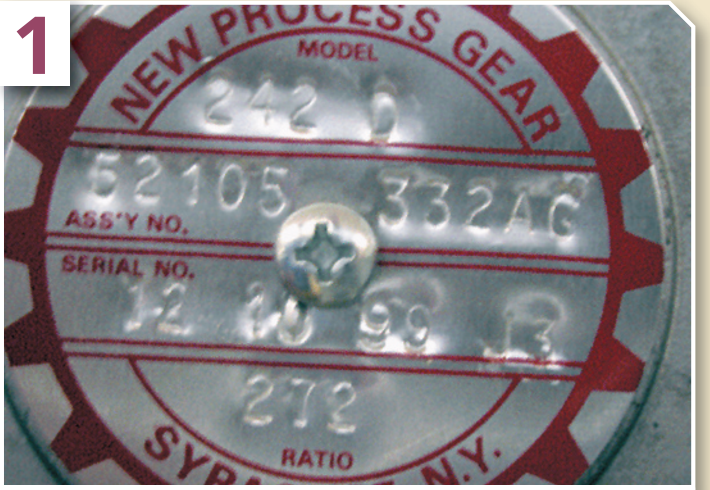
A four-wheel-drive vehicle was serviced and both differentials were drained and refilled as recommended by the vehicle manufacturer. The owner returned shortly after picking up the vehicle and complained that the vehicle drove as if the parking brake was still applied. The vehicle lacked power and would decelerate rapidly whenever the accelerator pedal was released. Careful inspection of the parking brake revealed that everything was functioning correctly. Because all that was done was the differential fluid service, the fluid level was checked and again, the level was correct and not overfull. Then the technician checked the container of gear lubricant that was used and discovered that the parts store had accidentally sent SAE 80W-140 instead of the requested, and more commonly used, SAE 80W-90. Both lubricants were listed GL-5, meaning that they were acceptable for differentials. The container of lubricant had been installed in the portable lubricating dispenser when it was delivered, and therefore the label on the container was not visible to the technician. The correct lower viscosity lubricant was installed in the differential and normal vehicle performance was restored. The technician and the parts store learned to double-check the product before shipping or using it.

Summary:

Complaint—The customer complained of poor performance after the differential fluid was replaced.
Cause—The incorrect fluid was used.
Correction—the correct viscosity fluid was used, which restored proper vehicle performance.

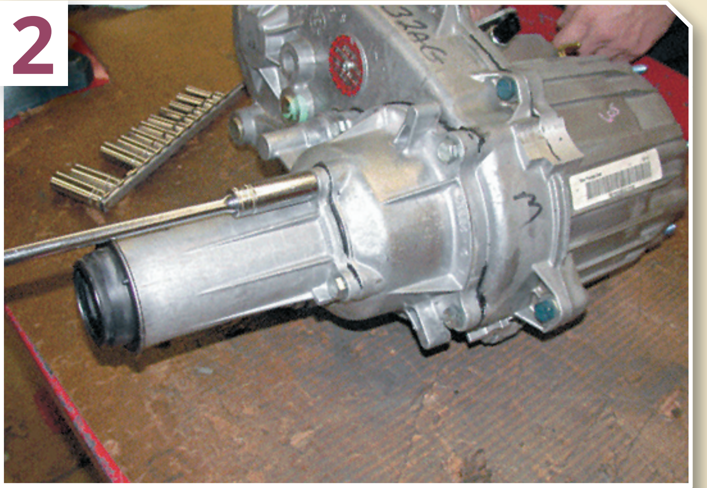
NV-242 TRANSFER CASE SERVICE

1


NEW PROCESS GEAR
MODEL
242 D
52105
332AG
ASS'Y NO.
SERIAL NO.
272
RATIO
N.Y.

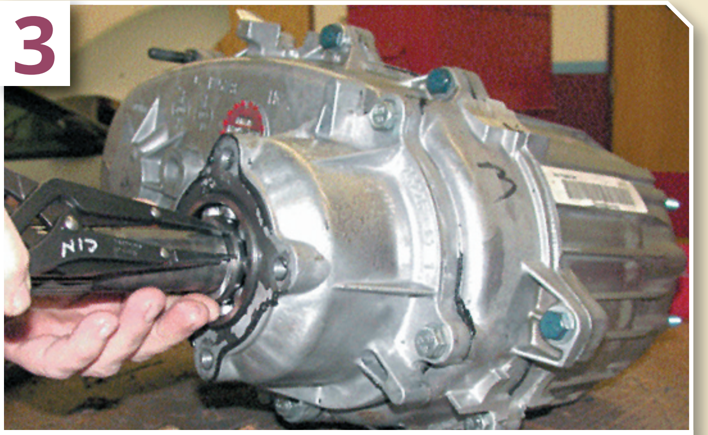
The identification plate on the housing indicates the transfer case is a New Venture (New Process) model #242 and has a low-range gear ratio of 2.72.1.

2



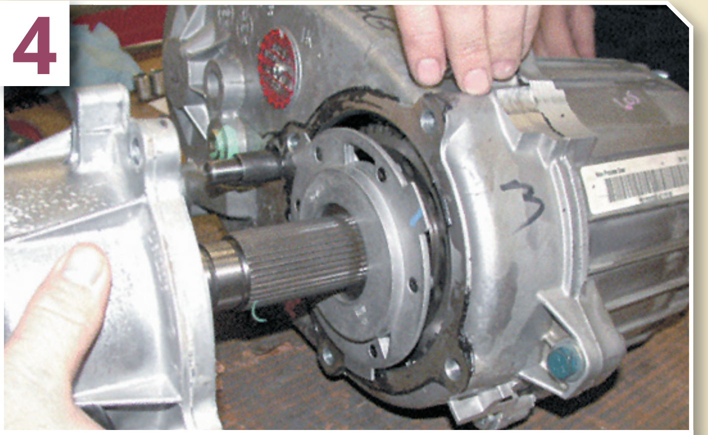
Rear output shaft housing being removed.

3



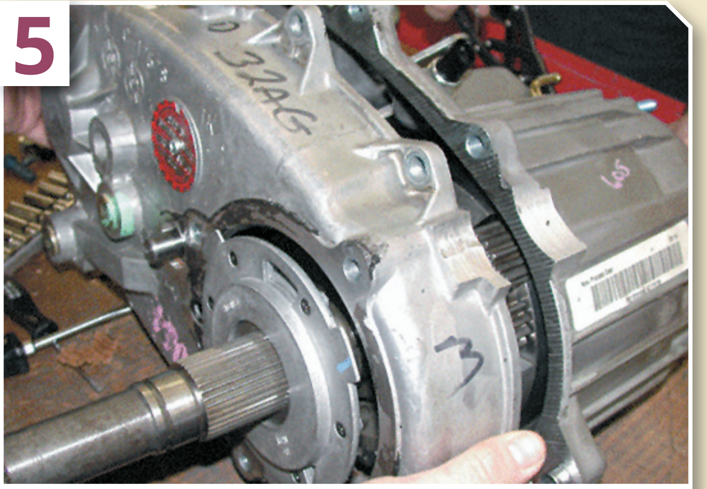
Before the case can be separated, the bearing retaining snap ring must be removed using snap-ring pliers.

4



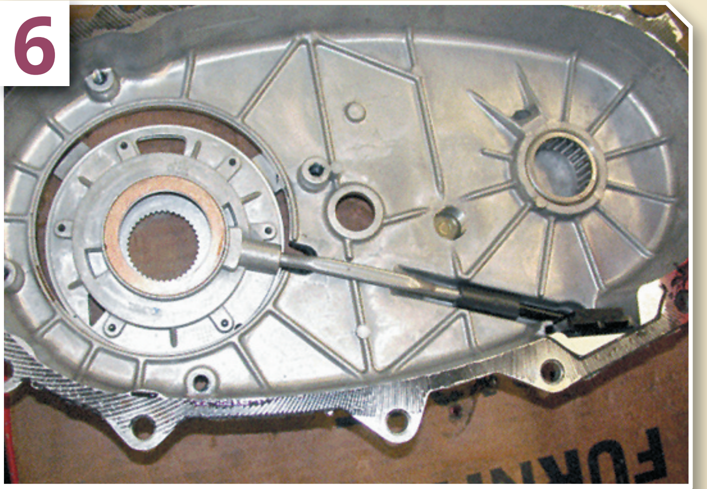
The lubricating oil pump is visible after the cover and bearing assembly have been removed.

5



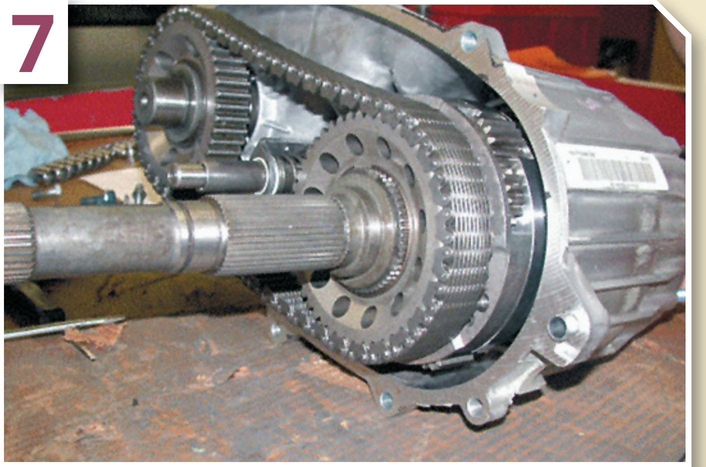
The two case halves are being separated.

6



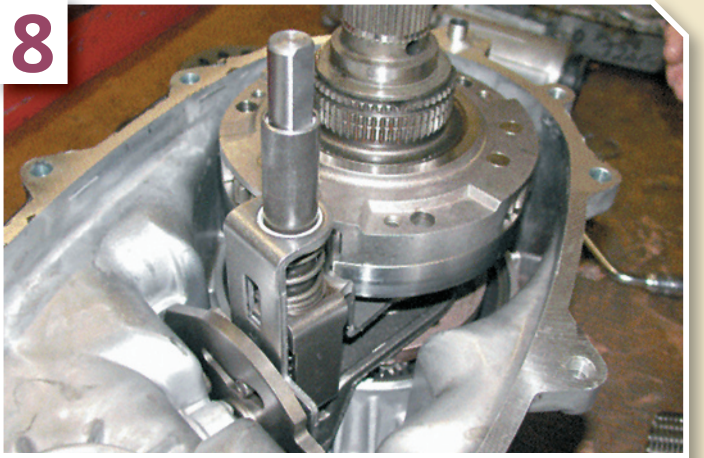
The oil pump assembly, pickup screen, and tube are visible on the backside of the case cover.

7



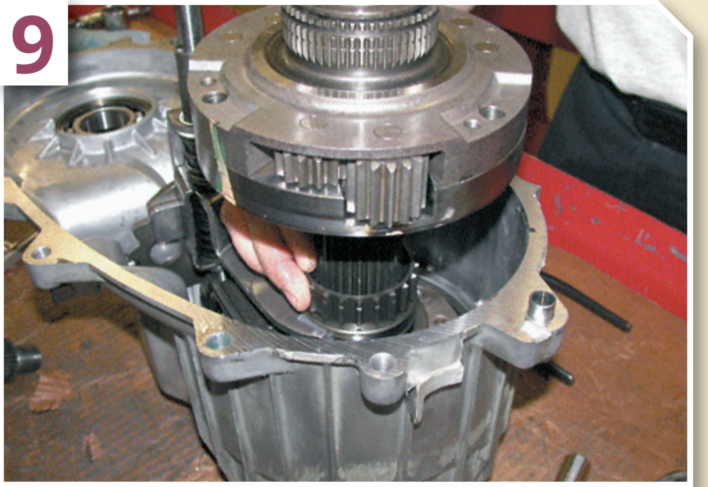
The rear output shaft and sprocket are visible on the right. The front output shaft and sprocket are visible on the left connected by the drive chain.

8



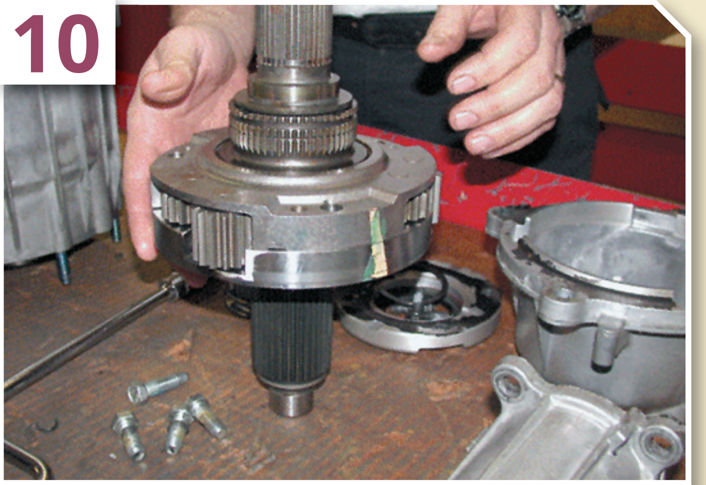
View of the shift levers and the center differential after the chain has been removed.

9



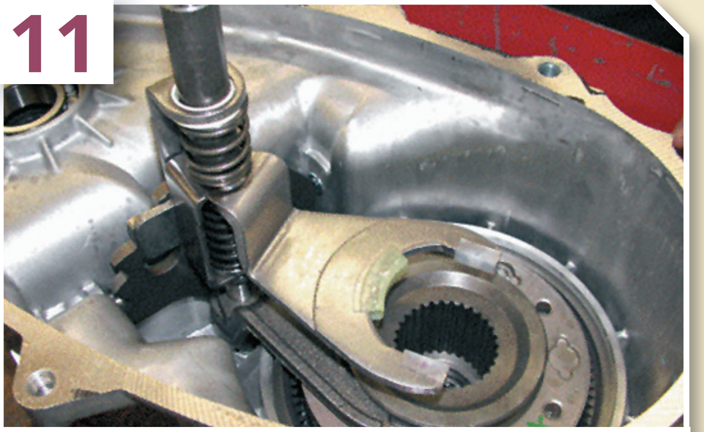
Differential being removed.

10



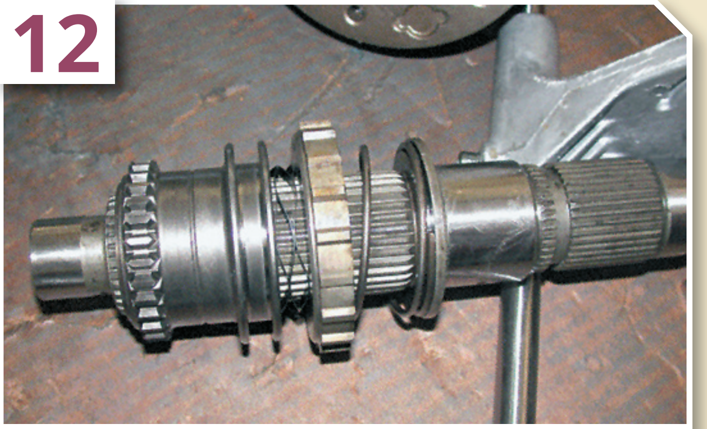
Center differential assembly after removal from the transfer case.

11



Mode shift fork (upper fork) is used to change two-wheel drive and four-wheel drive. The fork is attached to the range hub, which changes four-wheel drive high to four-wheel drive low.

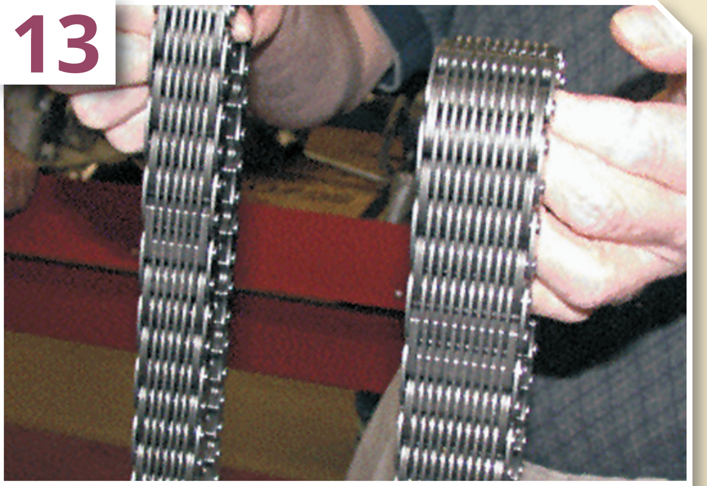
12



Main shaft showing the range hub (left), which changes the transfer case between four-wheel high and four-wheel low.

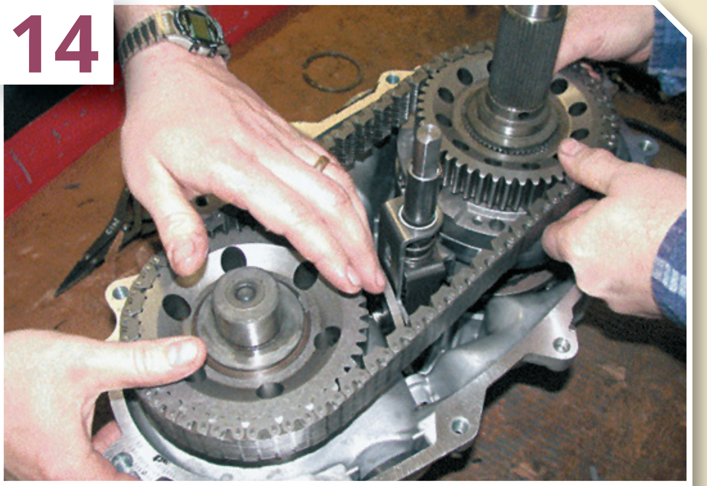
NV-242 TRANSFER CASE SERVICE

13



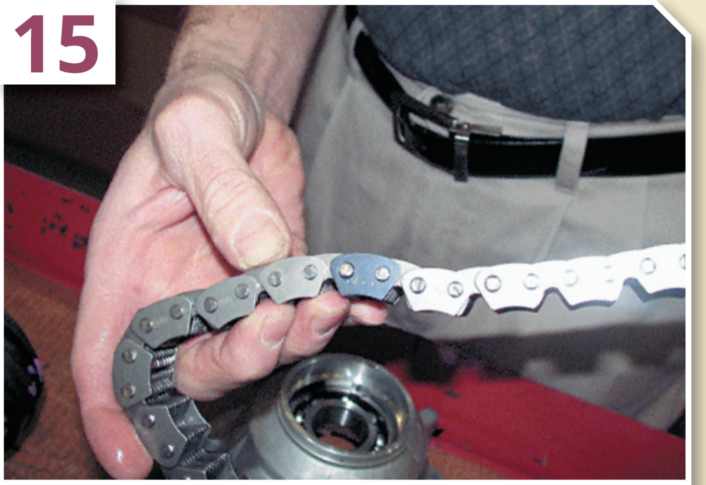
The chain used on the NV-242 (right) is larger than the chain used in the smaller version NV-231 (left).

14



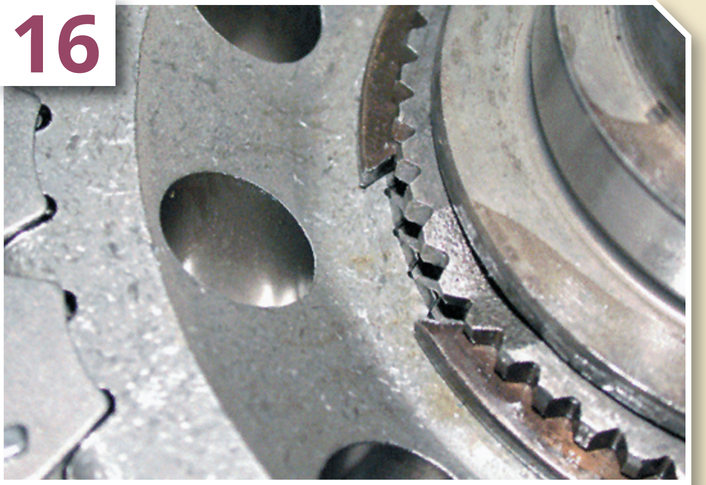
Reinstalling the components and the drive chain.

15



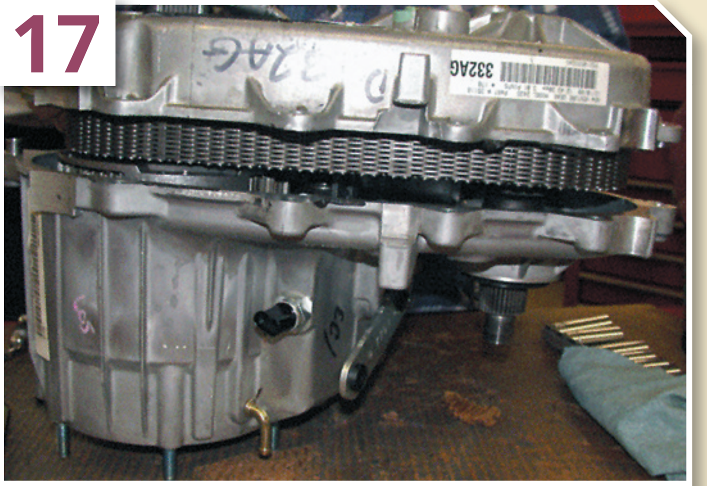
The drive chain should be installed with the black (dark) link(s) up.

16



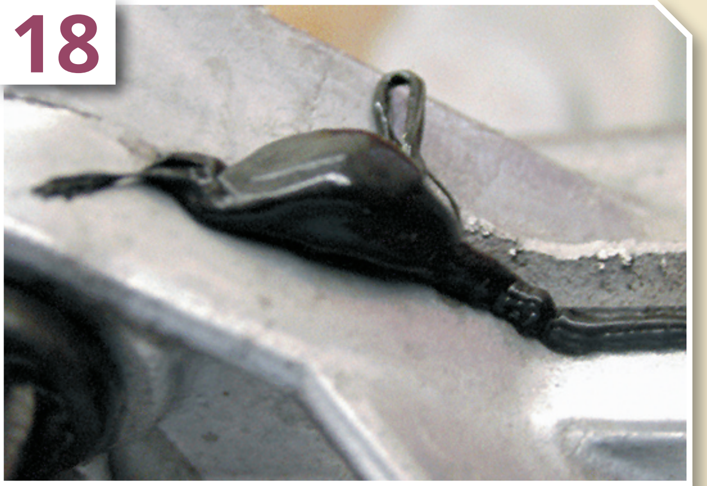
Install all snap rings so that the sharpest tips face up so snap-ring pliers can grab onto the tips for easier removal.

17



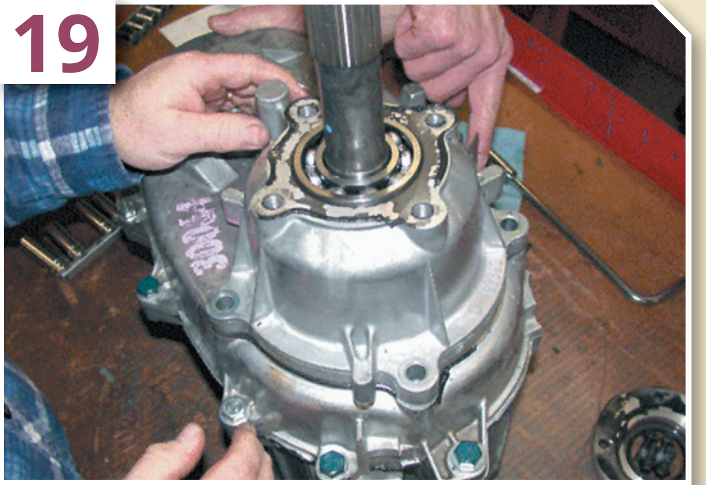
Assembling the case halves.

18



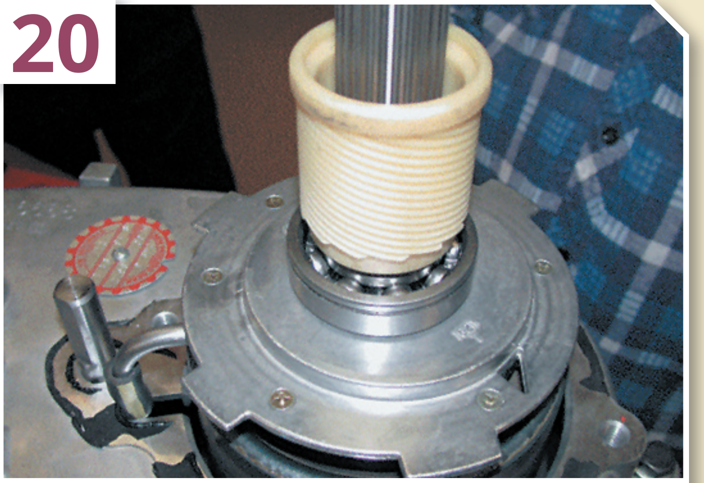
The parting surface should be sealed with RTV silicone. Do not use too much or the oil pump screen can become clogged.

19



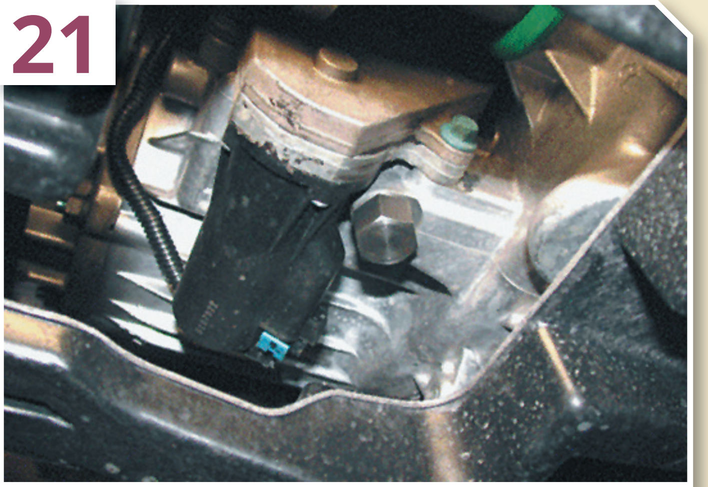
After attaching the oil pump and tube, the output shaft housing is installed.

20



The output shaft speed sensor drive gear is correctly installed in this photo. The slip yoke of the drive shaft slips onto the splines and inside the nylon gear.

21



The electronically-shifted version of the case is identical except that the shifting is performed using an electric motor, shown here installed in a vehicle.

REVIEW QUESTIONS

1. Explain the difference between four-wheel drive and all-wheel drive.
2. Explain why part-time four-wheel-drive vehicles use locking front hubs.
3. Describe the difference between a mode shift and a range shift in a transfer case.
4. Describe how a viscous coupling works.
5. List the elements of the planetary gear set used in many transfer cases.

CHAPTER QUIZ

1. Technician A says that the gear ratios of both differentials are the same in a four-wheel-drive vehicle. Technician B says that the rear differential has a slightly higher ratio (lower number) than the front differential. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. Technician A says that a vehicle equipped with part-time four-wheel drive should be driven in four-wheel drive only on slippery surfaces. Technician B says that full-time four-wheel-drive vehicles use a center differential in the transfer case. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Two technicians are discussing the towing of a four-wheel-drive vehicle. Technician A says that the vehicle should be transported on a flatbed truck to avoid the possibility of doing damage to the drive train. Technician B says that the wheels not lifted off the ground by the tow truck should be placed on a dolly to prevent doing damage to the drive train. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Two technicians are discussing the front axle disconnect mechanism. Technician A says that the front axles are only disconnected if the vehicle is being towed. Technician B says that this unit is only used on all-wheel-drive vehicles. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Which type of system uses a one-speed transfer case and a center differential with a viscous coupling?
   - **a.** Part-time four-wheel drive
   - **b.** Full-time four-wheel drive
   - **c.** Full-time four-wheel drive with automatic locking front hubs
   - **d.** All-wheel-drive
6. A customer complained that the front wheel would skip, hop, and shake while cornering and accelerating at the same time. Technician A says that a fault in the transfer case is the most likely cause. Technician B says that the vibration may be normal if the vehicle is equipped with Cardan U-joints at the front wheels. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Technician A says that most transfer cases have a built–in oil pump. Technician B says that most transfer cases use a heavy grease as a lubricant. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Technician A says that a transfer case may use GL-4 gear lube such as SAE 80W-90. Technician B says that a transfer case may use automatic transmission fluid (ATF). Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
9. A transfer case is extremely noisy in all selections whenever the vehicle is moving. Technician A says the drive chain may be stretched, causing the noise as it hits the inside of the case. Technician B says that one or more of the transfer case bearings could be defective. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. Technician A says that a range shift is used to select high or low gear ratios within transfer case. Technician B says that a mode shift is used to select two wheel drive or four wheel drive. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter 127

VIBRATION AND NOISE DIAGNOSIS AND CORRECTION

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss vibration and noise concerns in vehicles.
- List the procedures for a test-drive when diagnosing vibration/noise problems.
- Explain the vibration speed ranges.
- Explain how to determine the frequency of a vibration.
- Explain ways to diagnose drive-line vibrations and noise.
- Discuss how to find and correct noises.

KEY TERMS:

Companion flange 1616 • Driveline angles 1616 • Driveshaft runout 1616 • EVA 1614 • Frequency 1612 • Hertz (Hz) 1612 • Neutral run-up test 1612 • NVH 1609 • Rolling circumference 1613 • Vibration order 1612 • Witness mark 1610

VIBRATION AND NOISE

NOISE IS A VIBRATION Vibration and noise are two of the most frequent complaints from vehicle owners and drivers. If something is vibrating, it can move air; changes in air pressure (air movement) are what we call noise. Though anything that moves vibrates, wheels and tires account for the majority of vehicle vibration problems. Dampening weights are fastened to engines or transmissions in an effort to minimize noise, vibration, and harshness (called **NVH**).

If a new vehicle has a vibration or noise problem, then the most likely cause is an assembly or parts problem. This is difficult to diagnose because the problem could be almost anything, and a careful analysis procedure should be followed as outlined later in this chapter.

If an older vehicle has a vibration or noise problem, the first step is to question the vehicle owner as to when the problem first appeared. Some problems and possible causes include the following:

Problem	Possible Causes
Vibration at idle	Engine mount could be defective or not reinstalled correctly after an engine or transmission repair.
Noise/vibration	Exhaust system replacement or repair. ● **SEE FIGURE 127–1**.

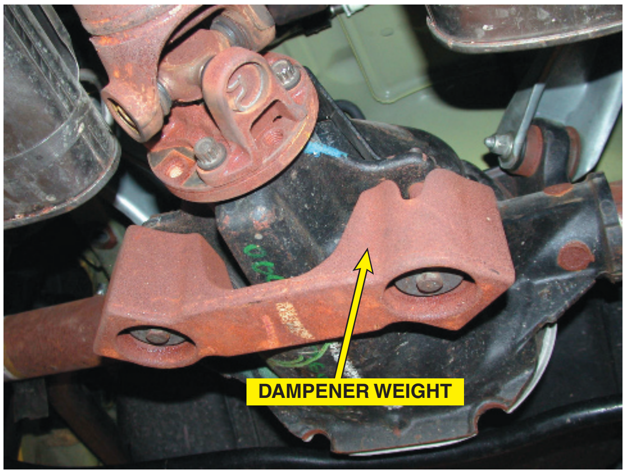


FIGURE 127–1 Many vehicles, especially those equipped with four-cylinder engines, use a dampener weight attached to the exhaust system or differential, as shown, to dampen out certain frequency vibrations.

NOTE: A typical exhaust system can "grow" or lengthen up to 2 inches (1 cm) when warm compared with room temperature. Always inspect an exhaust system when warm, if possible, being careful to avoid being burned by the hot exhaust components.

CASE STUDY

The Vibrating Ford Transmit Connect

The owner of a Ford Transit Connect complained of a severe vibration at idle. The technician checked for any stored diagnostic trouble codes (DTCs) and any related technical service bulletins (TSBs) and found a TSB that the lower engine mount could be the cause. The transmission (powertrain) mount was found to be cracked so this was also replaced. The vibration was still present. Thinking that the engine mounts could be an issue the technician found them to be clean without any leaks or cracks. Checking with other technicians on www.iatn.net resulted in several responses that suggested that the upper mount, being fluid (gel) filled, has been found to be the cause of a vibration even if it is not leaking. Taking the advice of other technicians who have solved a vibration by replacing the upper mount, the technician did replace it and this corrected the vibration concern.

Apparently the failed engine mounts caused the engine to vibrate because they were not in the original position where they were designed to dampen engine noise and vibrations.

Summary:

Complaint—The owner complained of a vibration in the engine when at idle speed only.
Cause—Defective engine mounts including the upper liquid filled mount were found to be the root cause.
Correction—All three engine (powertrain) mounts were replaced based on a TSB and a visual inspection, plus advice from other service technicians.

Vibration at higher vehicle speeds	Incorrect driveshaft angles could be the result of a change in the U-joints, springs, transmission mounts, or anything else that can cause a change in driveshaft angles.
Noise over rough roads	Exhaust system or parking brake cables are often causes of noise while driving over rough road surfaces. ● **SEE FIGURE 127–2.** Defective shock absorbers or shock absorber mountings are also a common cause of noise.

TEST-DRIVE

The first thing a technician should do when given a vibration or noise problem to solve is to duplicate the condition. This means the technician should drive the vehicle and observe when and where the vibration is felt or heard. See the chart in ● **FIGURE 127–3**.

Though there are many possible sources of a vibration, some simple observations may help to locate the problem quickly:

1. If the vibration is felt or seen in the steering wheel, dash, or hood of the vehicle, the problem is most likely to be caused by defective or out-of-balance *front* wheels or tires. ● **SEE FIGURE 127–4.**

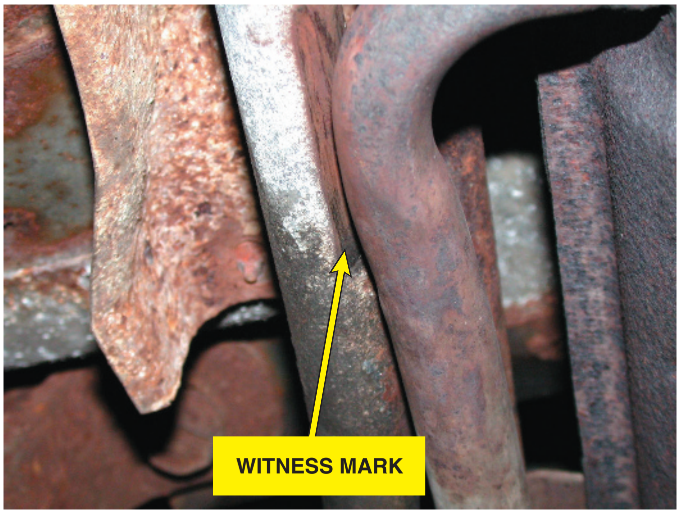


FIGURE 127–2 The exhaust was found to be rubbing on the frame rail during a visual inspection. Rubber exhaust system hangers are used to isolate noise and vibration from the exhaust system from entering the interior. These rubber supports can fail, causing the exhaust system to be out of proper location. It was found by looking for evidence of **witness marks**.

2. If the vibration is felt in the seat of the pants or seems to be all over the vehicle, the problem is most likely to be caused by defective or out-of-balance *rear* wheels or tires. In a rear-wheel-drive vehicle, the driveshaft (propeller shaft) and related components might also be the cause.

While on the test-drive, try to gather as much information about the vibration or noise complaint as possible.

STEP 1 Determine the vehicle speed (MPH or km/h) or engine speed (RPM) where the vibration occurs. Drive on a smooth, level road and accelerate up to highway speed, noting the vehicle speed or speeds at which the vibration or noise occurs.

STEP 2 To help pin down the exact cause of the vibration, accelerate to a speed slightly above the point of maximum vibration. Shift the vehicle into neutral and allow it to coast down through the speed of maximum vibration.

TECH TIP

The Duct Tape Trick

A clicking noise heard at low speeds from the wheels is a common noise complaint. This noise is usually most noticeable while driving with the windows lowered. This type of noise is caused by loose disc brake pads or noisy wheel covers. To confirm exactly what is causing the noise, simply remove the wheel covers and drive the vehicle. If the clicking noise is still present, check the brakes and wheels for faults. If the noise is gone with the wheel covers removed, use duct tape over the inner edge of the wheel covers before installing them onto the wheels. The duct tape will cushion and dampen the wheel cover and help reduce the noise. The sharp prongs of the wheel cover used to grip the wheel will pierce through the duct tape and still help retain the wheel covers.

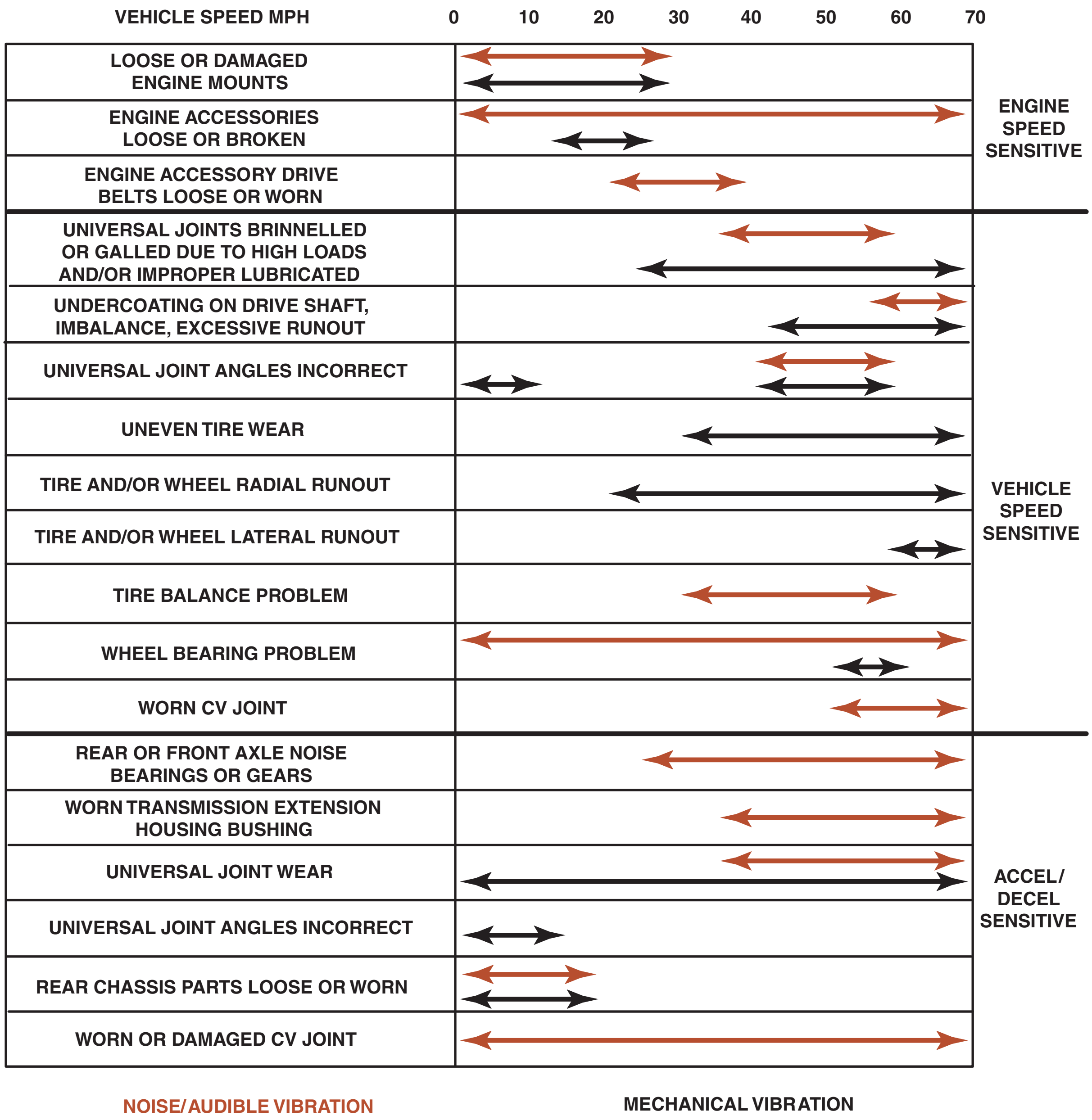


FIGURE 127–3 A chart showing the typical vehicle and engine speeds at which various components will create a noise or vibration and under what conditions.

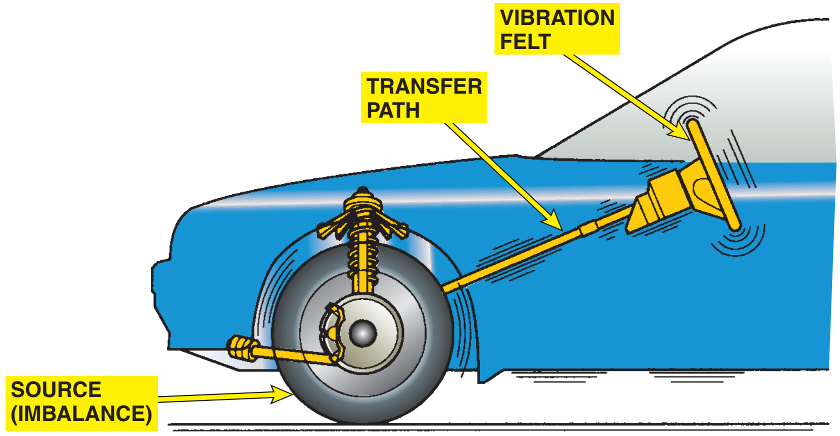

VIBRATION FELT
TRANSFER PATH
SOURCE (IMBALANCE)

FIGURE 127–4 Vibration created at one point is easily transferred to the passenger compartment. MacPherson strut suspensions are more sensitive to tire imbalance than SLA-type suspensions.

If the vibration still exists, then the cause of the problem could be wheels, tires, or other rotating components, *except* the engine.

If the vibration is eliminated when shifted out of gear, the problem is related to the engine or transmission.

NOTE: If the engine or transmission has been removed from the vehicle, such as during a clutch replacement, carefully observe the location and condition of the mounts. If an engine or transmission mount is defective or out of location, engine and driveline vibrations are often induced and transmitted throughout the vehicle.

NEUTRAL RUN-UP TEST The **neutral run-up test** is used to determine if the source of the vibration is engine-related. With the transmission in Neutral or Park, slowly increase the engine RPM and with a tachometer, observe the RPM at which the vibration occurs. *Do Not Exceed the Manufacturer's Recommended Maximum Engine RPM.*

If the fault is found in the engine itself, further engine testing is needed to find the root cause.

VIBRATION DURING BRAKING A vibration during braking usually indicates out-of-round brake drums, warped disc brake rotors, or other braking system problems. The *front* rotors are the cause of the vibration if the steering wheel is also vibrating (moving) during braking. The *rear* drums or rotors are the cause of the vibration if the vibration is felt throughout the vehicle and brake pedal, but *not* the steering wheel. Another way to check if the vibration is due to rear brakes is to use the parking brake to stop the vehicle. If a vibration occurs while using the parking brake, the rear brakes are the cause.

NOTE: Wheels should *never* be installed using an air impact wrench. Even installation torque is almost impossible to control, and overtightening almost always occurs. The use of impact wrenches causes the wheel, hub, and rotor to distort, resulting in vibrations and brake pedal pulsations. Always tighten wheel lugs in the proper sequence and with proper torque value, using a torque wrench or torque-limiting adapter bars.

VIBRATION SPEED RANGES

FREQUENCY *Vibration* describes an oscillating motion around a reference position. The number of times a complete motion cycle takes place during a period of one second is called **frequency** and is measured in **hertz (Hz)** (named for Heinrich R. Hertz, a nineteenth-century German physicist). ● **SEE FIGURES 127–5 AND 127–6**.

The unit of measure for frequency was originally cycles per second (CPS). This was changed to hertz in the 1960s.

To help understand frequency, think of the buzzing sound made by some fluorescent light fixtures. That 60 Hz hum is the same frequency as the alternating current. A 400 Hz sound is high pitched. In fact, most people can only hear sounds between 20 and 15,000 Hz. Generally, low-frequency oscillations between 1 and 80 Hz are the most disturbing to vehicle occupants.

VIBRATION ORDER **Vibration order** is the number of vibrations created in one revolution of a component. A single high spot on a tire, for example, will cause one bump per revolution, which is a first-order vibration. If the tire rotates 10 times per

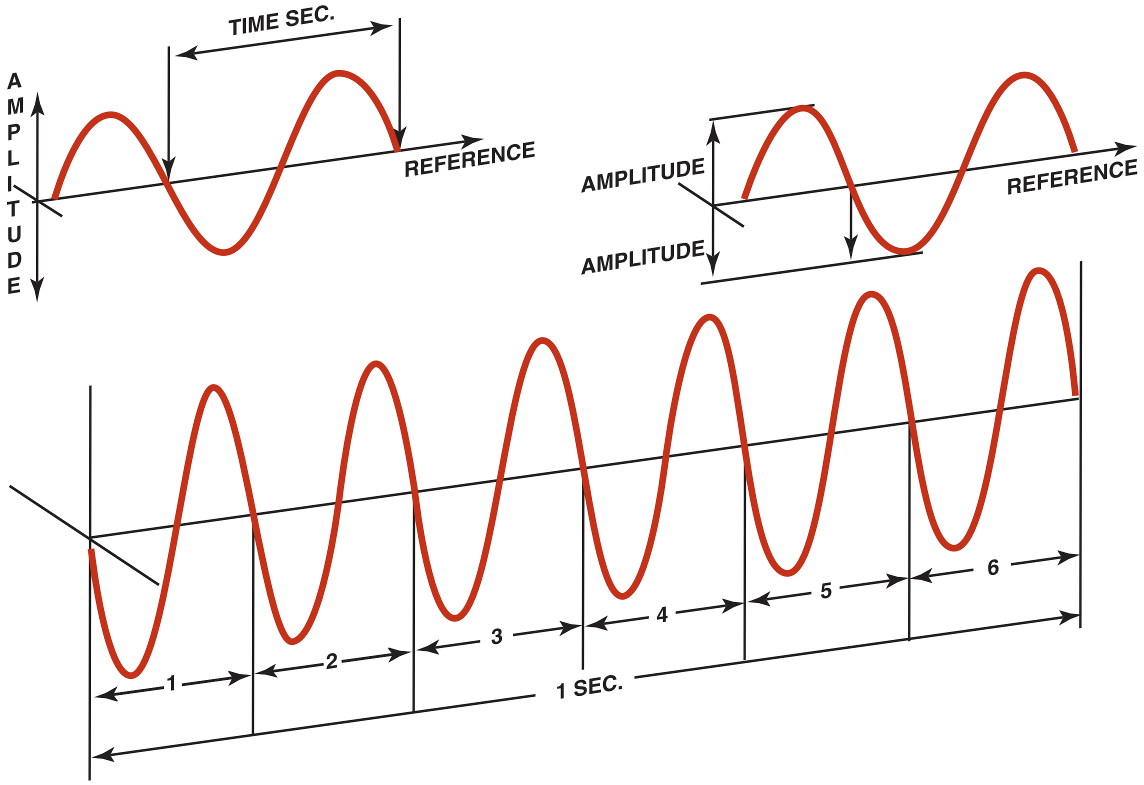


FIGURE 127–5 Hertz means *cycles* per *second*. If six cycles occur in one second, then the frequency is 6 Hz. The amplitude refers to the total movement of the vibrating component.

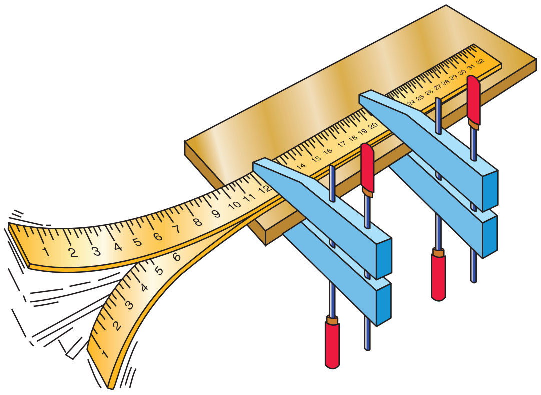


FIGURE 127–6 Every time the end of a clamped yardstick moves up and down, it is one cycle. The number of cycles divided by the time equals the frequency. If the yardstick moves up and down 10 times (10 cycles) in two seconds, the frequency is 5 Hz (10 ÷ 2 = 5).

CASE STUDY

S-10 Pickup Truck Frame Noise

The owner of a Chevrolet S-10 pickup truck complained of a loud squeaking noise, especially when turning left. Several technicians attempted to solve the problem and replaced shock absorbers, ball joints, and control arm bushings without solving the problem. The problem was finally discovered to be the starter motor hitting the frame. A measurement of new vehicles indicated that the clearance between the starter motor and the frame was about 1/8 inch (0.125 in.) (0.3 cm)! The sagging of the engine mount and the weight transfer of the engine during cornering caused the starter motor to rub up against the frame. The noise was transmitted through the frame throughout the vehicle and made the source of the noise difficult to find.

Summary:

Complaint—Owner complained of a loud squeaking noise.
Cause—The starter was found to be hitting the frame due to a collapsed engine mount.
Correction—Both engine mounts were replaced, which proved to be the root cause.

second, there are 10 disturbances per second, which is also called a first-order vibration of 10 Hz. If there are two bumps on a tire, a second-order vibration is created that would generate a vibration of 20 Hz if the tire were rotating 10 times per second.

TIRE AND WHEEL VIBRATIONS Typical vehicle components that can cause vibration in specific frequency ranges at 50 MPH (80 km/h) include the following:

LOW FREQUENCY (5–20 HZ) This frequency range of vibration is very disturbing to many drivers because this type of vibration can be seen and felt in the steering wheel, seats, mirrors, and other components. Terms used to describe this type of vibration include *nibble*, *shake*, *oscillation*, *shimmy*, and *shudder*.

Tires and wheels are the most common source of vibration in the low-frequency range. To determine the *exact* frequency for the vehicle being checked, the following formula and procedure can be used.

CASE STUDY

The Vibrating Van

After the engine was replaced in a rear-wheel-drive van, a vibration that felt like an engine miss was noticed by the driver. Because the vibration was not noticed before the engine was replaced, the problem was thought to be engine-related. Many tests failed to find anything wrong with the engine. Even the ignition distributor was replaced, along with the electronic ignition module, on the suspicion that an ignition misfire was the cause.

After hours of troubleshooting, a collapsed transmission mount was discovered. After replacing the transmission mount, the "engine miss" and the vibration were eliminated. The collapsed mount caused the driveshaft U-joint angles to be unequal, which caused the vibration.

Summary:

Complaint—Owner complained of a vibration during acceleration only that was believed to be an ignition misfire.
Cause—The transmission mount was found to have collapsed, which affected the driveshaft angles.
Correction—The transmission mount was replaced, which restored the proper driveshaft angles.

Tire rolling frequency is calculated as follows:

$$\text{Hz} = \frac{\text{MPH} \times 1.47}{\text{tire circumference in ft}}$$

This formula works for all vehicles regardless of tire size. The circumference (distance around the tread) can be measured by using a tape measure around the tire. The **rolling circumference** of the tire is usually shorter due to the contact patch. To determine the rolling circumference, follow these easy steps:

STEP 1 Inflate the tire(s) to the recommended pressure. Park the vehicle with the valve stem pointing straight down and mark the location on the floor directly below the valve stem.

STEP 2 Slowly roll the vehicle forward (or rearward) until the valve stem is again straight down. Mark the floor below the valve stem.

STEP 3 Measure the distance between the marks in feet. ● **SEE FIGURE 127–7**. To change inches to feet, divide by 12 (e.g., 77 in. divided by 12 in. = 6.4 ft). To determine the rolling frequency of this tire at 60 MPH, use 6.4 ft as the tire circumference in the formula.

$$\text{Frequency} = \frac{60\ \text{MPH} \times 1.47}{6.4\ \text{ft}} = 13.8\ \text{Hz}$$

NOTE: Tire circumference is critical on four-wheel-drive vehicles. The transfer case can be damaged and severe vibration can occur if the rolling circumference is different by more than 0.6 inch (15 mm) on the same axle, or more than 1.2 inch (30 mm) front to rear.

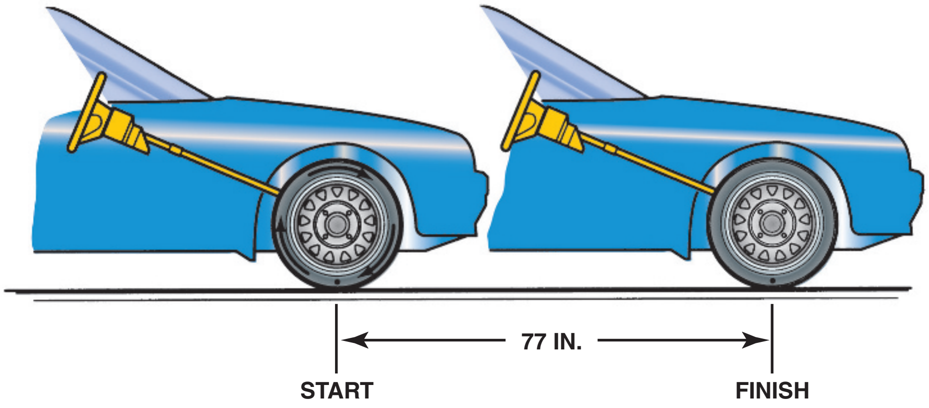


FIGURE 127–7 Determining the rolling circumference of a tire.

DRIVELINE VIBRATIONS

MEDIUM FREQUENCY (20–50 HZ) This frequency range of vibrations may also be described as a shake, oscillation, or shimmy. These higher frequencies may also be called *roughness* or *buzz. Components become blurred and impossible to focus on above a vibration of 30 Hz.*

ENGINE-RELATED VIBRATIONS

HIGH FREQUENCY (50–100 HZ) Vibrations in this range may also be *heard* as a moan or hum. The vibration is high enough that it may be felt as a numbing sensation that can put the driver's hands or feet to sleep. Engine-related vibrations vary with engine speed, regardless of road speed. Frequency of the vibration from an engine is determined from the engine speed in revolutions per minute (RPM).

$$\text{Frequency in Hz} = \frac{\text{engine RPM}}{60}$$

For example, if a vibration occurs at 3,000 engine RPM, then the frequency is 50 Hz.

$$\text{Hz} = \frac{3{,}000 \text{ RPM}}{60} = 50 \text{ Hz}$$

VIBRATION FREQUENCY

MEASURING FREQUENCY Knowing the frequency of the vibration greatly improves the speed of tracking down the source of the vibration. Vibration can be measured using a reed tachometer or an **electronic vibration analyzer (EVA).** ● **SEE FIGURE 127–8.**

A reed tachometer is placed on the dash, console, or other suitable location inside the vehicle. The vehicle is then driven on a smooth, level road at the speed where the vibration is felt the most. The reeds of the reed tachometer vibrate at the frequency of the vibration.

NOTE: Other types of vibration diagnostic equipment may be available from vehicle or aftermarket manufacturers.

CORRECTING LOW-FREQUENCY VIBRATIONS A low-frequency vibration (5–20 Hz) is usually due to tire/wheel problems, including the following:

1. Tire and/or wheel imbalance. ● **SEE FIGURES 127–9 THROUGH 127–11.**
2. Tire and/or wheel radial or lateral runout.

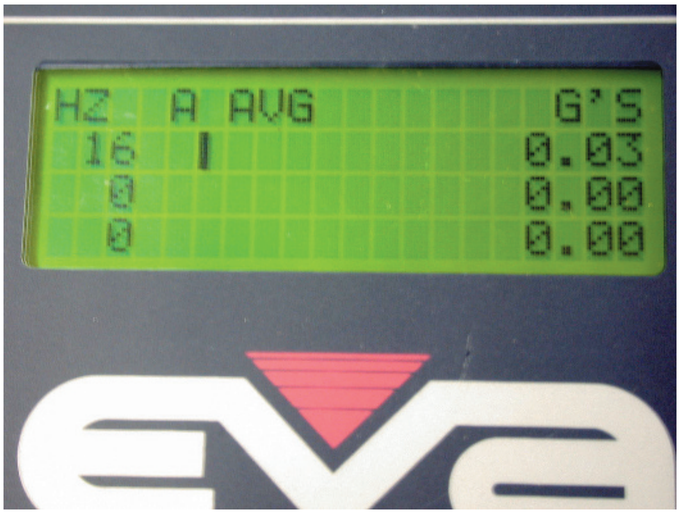


FIGURE 127–8 An electronic vibration analyzer.

3. Radial force variation within the tire itself.
4. If front-wheel drive, a bent or damaged drive axle joint or shaft.
5. Warped rotors.

Tires that are out of round or defective will be most noticeable at low speeds, will get better as speed increases, and then will vibrate again at highway speeds.

Tires that are out of balance will tend not to be noticeable at low speeds and will be most noticeable at highway speeds.

NOTE: High-performance tires are manufactured with different carcass and belt package angles as well as a stiffer, harder tread rubber compound than standard tires. While these construction features produce a tire that allows sporty handling, the tire itself causes a stiff ride, often with increased tire noise. High-performance tires also generate and transmit different frequencies than regular tires. Using replacement high-performance tires on a vehicle not designed for this type of tire may create noise and vibration concerns for the driver/owner that the technician cannot correct.

CORRECTING MEDIUM-FREQUENCY VIBRATIONS Medium-frequency vibrations (20–50 Hz) can be caused by imbalances of the driveline as well as such things as the following:

1. Defective U-joints. Sometimes an old or a newly installed U-joint can be binding. This binding of the U-joint can cause

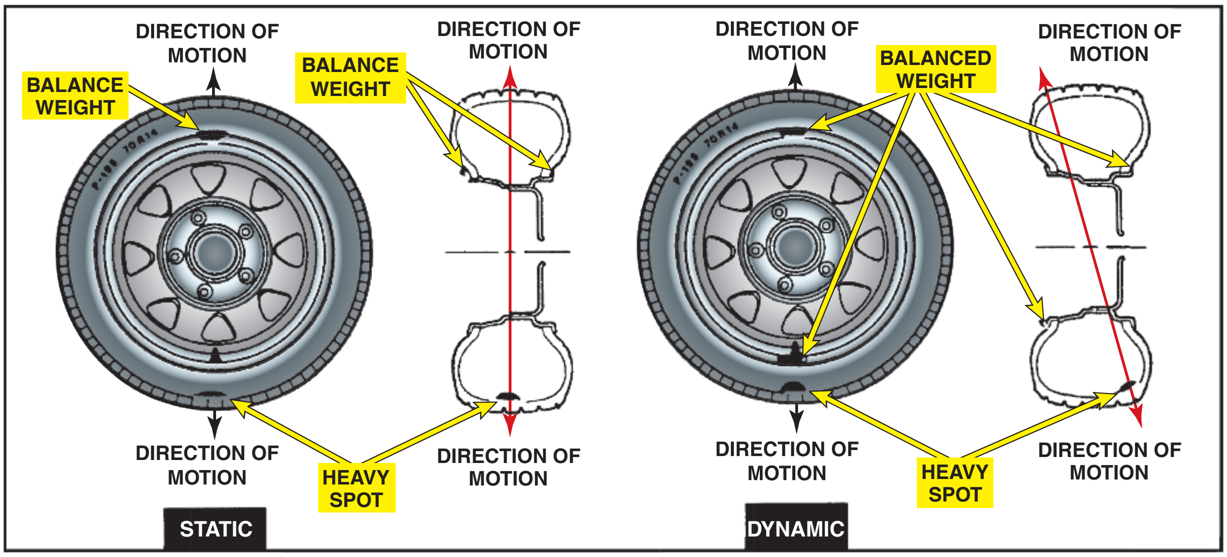

BALANCE WEIGHT
DIRECTION OF MOTION
BALANCE WEIGHT
DIRECTION OF MOTION
DIRECTION OF MOTION
BALANCED WEIGHT
DIRECTION OF MOTION
DIRECTION OF MOTION
HEAVY SPOT
DIRECTION OF MOTION
DIRECTION OF MOTION
HEAVY SPOT
DIRECTION OF MOTION
STATIC
DYNAMIC

FIGURE 127–9 Properly balancing all wheels and tires solves most low-frequency vibrations.

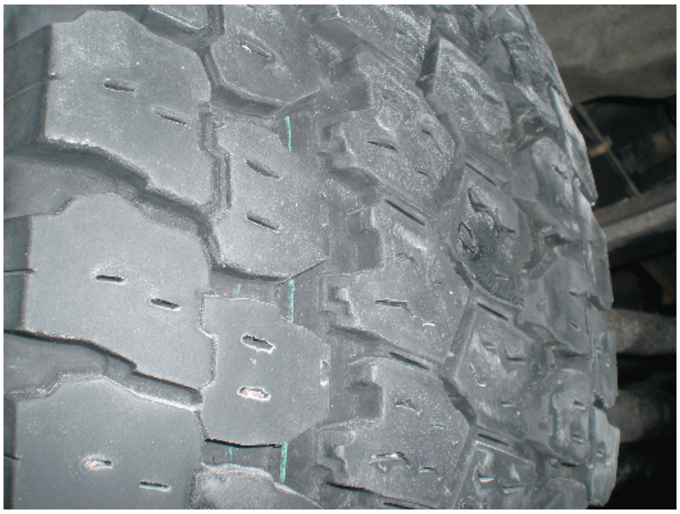


FIGURE 127–10 An out-of-balance tire showing scallops or bald spots around the tire. Even if correctly balanced, this cupped tire would create a vibration.

TECH TIP

Squeaks and Rattles

Many squeaks and rattles commonly heard on any vehicle can be corrected by tightening all bolts and nuts you can see. Raise the hood and tighten all fender bolts. Tighten all radiator support and bumper brackets. Open the doors and tighten all hinge and body bolts.

An even more thorough job can be done by hoisting the vehicle and tightening all under-vehicle fasteners, including inner fender bolts, exhaust hangers, shock mounts, and heat shields. It is amazing how much this quiets the vehicle, especially on older models. It also makes the vehicle feel more solid with far less flex in the body, especially when traveling over railroad crossings or rough roads.

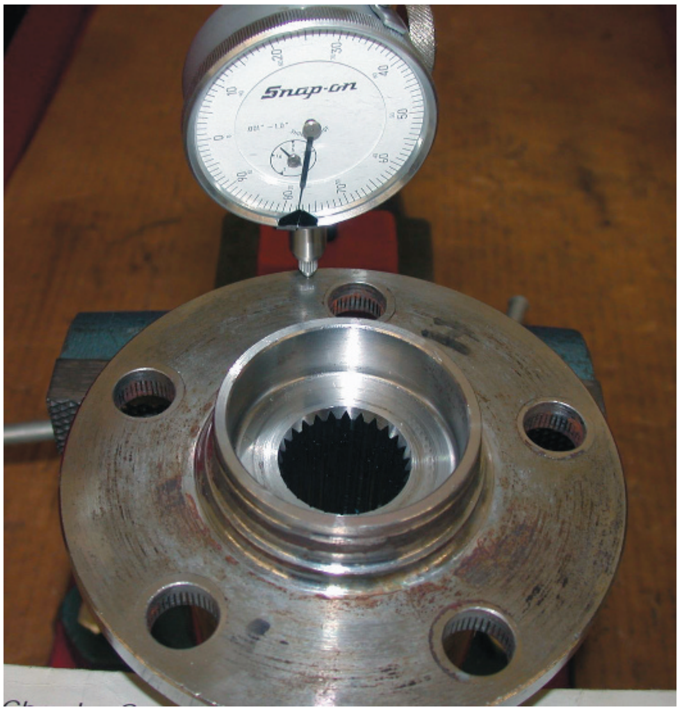


FIGURE 127–11 Another cause of a vibration that is often blamed on wheels or tires is a bent bearing hub. Use a dial indicator to check the flange for runout.

a vibration. Often a blow to the joint with a brass hammer can free a binding U-joint. This is often called *relieving the joint*. Tapping the joint using a brass punch and a hammer also works well.

2. Driveshaft imbalance (such as undercoating on the driveshaft) or excessive runout.
3. Incorrect or unequal driveshaft angles.

Driveline vibrations are usually the result of an imbalance in the rotating driveshaft (propeller shaft) assembly.

The driveshaft of a typical rear-wheel-drive (RWD) vehicle rotates at about three times the speed of the drive wheels. The differential gears in the rear end change the direction of the power flow from the engine and driveshaft, as well as provide for a gear reduction.

Front-wheel-drive (FWD) vehicles do not have medium-frequency vibration caused by the driveshaft because the differential is inside the transaxle and the drive axle shafts rotate at the same speed as the wheels and tires.

All driveshafts are balanced at the factory, and weights are attached to the driveshaft, if necessary, to achieve proper balance. A driveshaft should be considered one of the items checked if the medium-frequency vibration is felt throughout the vehicle or in the seat of the pants.

NOTE: If a vibration is felt during heavy acceleration at low speeds, a common cause is incorrect universal joint angles. This often happens when the rear of the vehicle is heavily loaded or sagging due to weak springs. If the angles of the U-joints are not correct (excessive or unequal from one end of the driveshaft to the other), a vibration will also be present at higher speeds and is usually torque-sensitive.

CORRECTING HIGH-FREQUENCY VIBRATIONS High-frequency vibrations (50–100 Hz) are commonly caused by a fault of the clutch, torque converter, or transmission main shaft that rotates at engine speed; in the engine itself, they can be caused by items such as the following:

1. A defective spark plug wire
2. A burned valve
3. Any other mechanical fault that will prevent any one or more cylinders from firing correctly
4. A defective harmonic balancer

If the engine is the cause, run in Neutral at the same engine speed. If the vibration is present, perform a complete engine condition diagnosis. Some engines only misfire under load and will not vibrate while in Neutral without a load being placed on the engine, even though the engine is being operated at the same speed (RPM).

Exhaust system pulses occur at the following conditions:

4-cylinder engine	2 × engine RPM
6-cylinder engine	3 × engine RPM
8-cylinder engine	4 × engine RPM

If the exhaust system is touching the body, it will transfer these pulses as a vibration. Exhaust system vibrations vary with engine speed and usually increase as the load on the engine increases.

DRIVELINE DIAGNOSIS

CORRECTING DRIVELINE ANGLES Incorrect **driveline angles** are usually caused by one or more of the following:

1. Worn, damaged, or improperly installed U-joints.
2. Worn, collapsed, or defective engine or transmission mount(s).
3. Incorrect vehicle ride height. (As weight is added to the rear of a rear-wheel-drive vehicle, the front of the differential rises and changes the working angle of the rear U-joint.)
4. Bent or distorted driveshaft.

CHECKING DRIVESHAFT RUNOUT Check to see that the driveshaft is not bent by performing a **driveshaft runout** test using a dial indicator. Runout should be measured at three places along the length of the driveshaft.

The maximum allowable runout is 0.030 inch (0.8 mm). If runout exceeds 0.030 inch, remove the driveshaft from the rear end and reindex the driveshaft onto the **companion flange** at 180 degrees from its original location. Remeasure the driveshaft runout. If the runout is still greater than 0.030 inch, the driveshaft is bent and needs replacement *or* the companion flange needs replacement. ● **SEE FIGURE 127–12**.

MEASURING DRIVESHAFT U-JOINT PHASING Measuring driveshaft U-joint phasing involves checking to see if the front and rear U-joints are directly in line or parallel with each other. With the vehicle on a drive-on lift, or if using a frame-contact hoist, support the weight of the vehicle on stands placed under the rear axle. Place an inclinometer on the front U-joint bearing cup and rotate the driveshaft until horizontal; note the inclinometer reading. Move the inclinometer to the rear U-joint. The angles should match. If the angles are not equal, the driveshaft is out of phase and should be replaced. Incorrect phasing is usually due to a twisted driveshaft or an incorrectly welded end yoke.

CHECKING COMPANION FLANGE RUNOUT The companion flange is splined to the rear axle pinion shaft and provides the mounting for the rear U-joint of the driveshaft. Two items should be checked on the companion flange while diagnosing a vibration:

1. The companion flange should have a maximum runout of 0.006 inch (0.15 mm) while being rotated. If the flange was pounded off with a hammer during a previous repair, the deformed flange could cause a vibration.

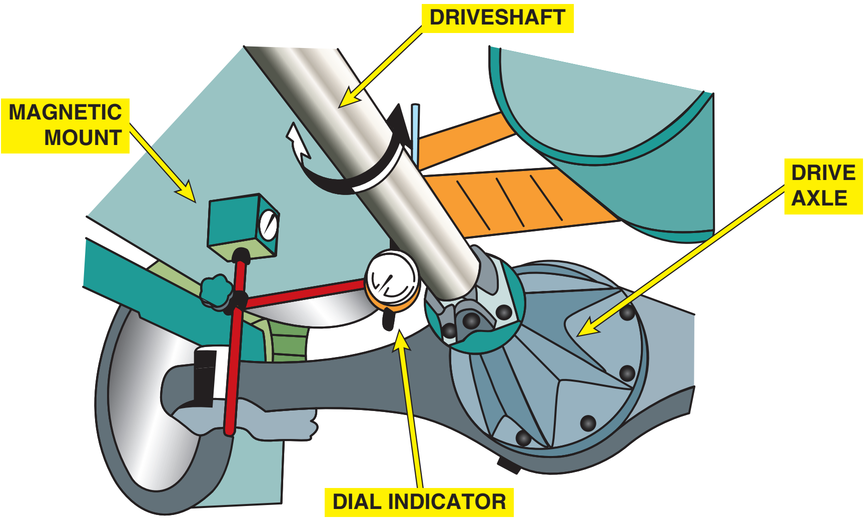


FIGURE 127–12 Checking a driveshaft for runout using a magnetic mounted dial indicator.

2. Check the companion flange for a missing balance weight. Many flanges have a balance weight that is spot-welded onto the flange. If the weight is missing, a driveline vibration can result.

BALANCING THE DRIVESHAFT If the driveshaft (propeller shaft) is within runout specification and a vibration still exists, the balance of the shaft should be checked and corrected as necessary.

The procedure for testing driveshaft balance using a strobe balancer includes the following:

NOTE: Driveshaft balance is more important than front drive axle shaft balance because a driveshaft rotates much faster. A typical driveshaft rotates about three times faster than the drive wheels due to the gear reduction in the differential. Drive axle shafts rotate at the same speed as the drive wheels.

STEP 1 Raise the vehicle and mark the driveshaft with four equally spaced marks around its circumference. Label each mark with a 1, 2, 3, and 4. ● **SEE FIGURE 127–13**.

STEP 2 Attach the strobe balancer sensor to the bottom of the differential housing as close to the companion flange as possible. ● **SEE FIGURE 127–14**.

NOTE: The sensor does not rotate with the driveshaft but picks up the vibration of the driveshaft through the differential housing.

STEP 3 With the vehicle securely hoisted and the drive wheels off the ground, start the engine and put the transmission into gear to allow the drive wheels to rotate.

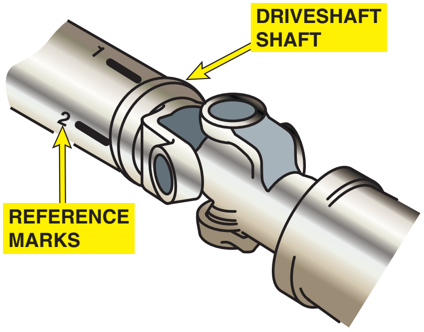
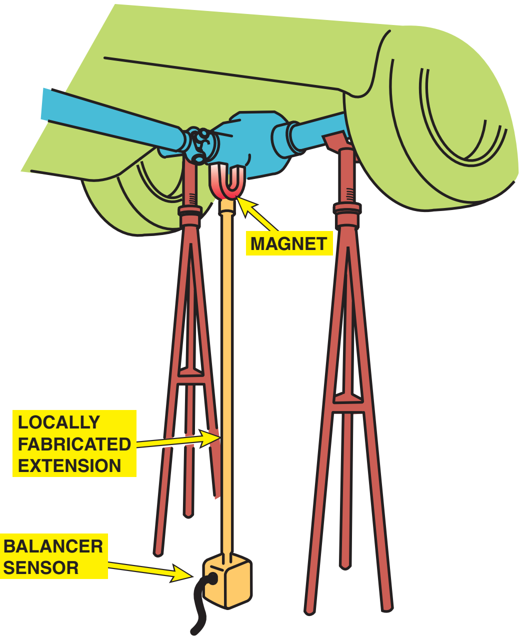


FIGURE 127–13 When checking the balance of a driveshaft, make reference marks around the shaft so that the location of the unbalance may be viewed when using a strobe light.



NOTE: LOCALLY FABRICATED EXTENSION FOR BALANCER PICKUP CONSISTS OF 3/8 IN. TUBE AND COMPRESSION FITTINGS

FIGURE 127–14 Using a strobe balancer to check for driveline vibration requires that an extension be used on the magnetic sensor. Tall safety stands are used to support the rear axle to keep the driveshaft angles the same as when the vehicle is on the road.

STEP 4 Hold the strobe light close to the marks on the driveshaft.

a. If the light does *not* flash, the driveshaft is balanced and no corrective action is necessary.

b. If the light *does* flash, observe what number mark is shown by the flashing light.

STEP 5 Apply hose clamps so that the screw portion of the clamp(s) is *opposite* the number seen with the strobe light. The screw portion of the hose clamp is the corrective weight. Remember, the strobe light sensor was mounted to the *bottom* of the differential housing. The strobe light flashes when the heavy part of the driveshaft is facing *downward.* If the heavy part of the driveshaft is down, then corrective weight must be added to the opposite side of the driveshaft. ● **SEE FIGURES 37–15 AND 37–16**.

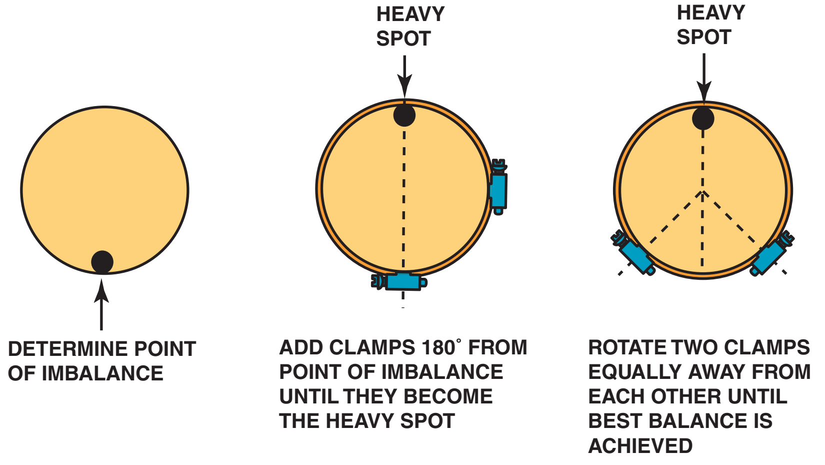

HEAVY SPOT
HEAVY SPOT
DETERMINE POINT OF IMBALANCE
ADD CLAMPS 180° FROM POINT OF IMBALANCE UNTIL THEY BECOME THE HEAVY SPOT
ROTATE TWO CLAMPS EQUALLY AWAY FROM EACH OTHER UNTIL BEST BALANCE IS ACHIEVED

FIGURE 127–15 Typical procedure to balance a driveshaft using hose clamps.

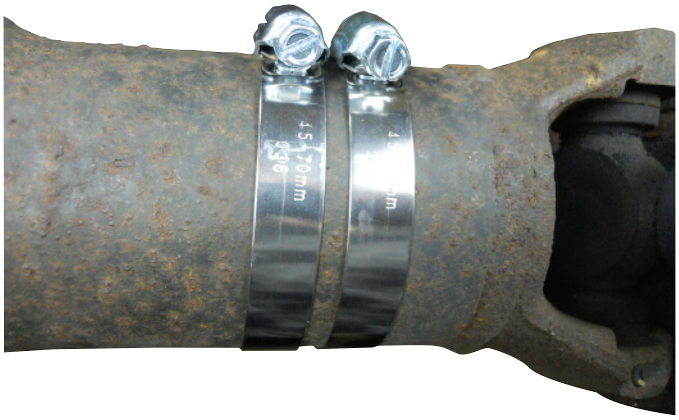


FIGURE 127–16 Two clamps were required to balance this front driveshaft of a four-wheel-drive vehicle. Be careful when using hose clamps so that the ends of the clamps do not interfere with the body or other parts of the vehicle.

NOISE

NOISE DIAGNOSIS Noise diagnosis is difficult because a noise is easily transmitted from its source to other places in the vehicle. For example, if a rear shock absorber mount is loose, the noise may be heard as coming from the middle or even the front of the vehicle. As the axle moves up and down, the noise is created where metal touches metal between the shock absorber bolt and the axle shock mount. The noise is then transmitted throughout the frame of the vehicle, and therefore causes the sound to appear to come from "everywhere." To help pin down the exact location of the sound, perform a thorough test-drive, including driving beside parked vehicles or walls with the vehicle windows open. (See the following chart for driveline and bearing-type noise diagnosis.)

Some noises may be normal; a similar vehicle should be driven and compared before replacing parts that may not be defective. Noises usually become louder and easier to find as time and mileage increase. An occasional noise usually becomes a constant noise.

CASE STUDY

Everything Is OK until I Hit a Bump

The owner of an eight-year-old vehicle asked that the vibration in the steering wheel be repaired. It seemed that the vehicle drove fine until the front wheels hit a bump in the road—then the steering wheel shimmied for a few seconds.

This problem is typical of a vehicle with excessive steering linkage freeplay. When driving straight, centrifugal (rolling) force on the tires tends to force the front wheels outward (toe-out). When one or both wheels hit a bump, the play in the linkage becomes apparent, causing the steering wheel to shimmy until the rolling force again equalizes the steering.

The service technician performed a test-drive and a careful steering system inspection and discovered freeplay in both inner tie rod end sockets of the rack-and-pinion unit. The steering unit also had some power steering leakage at the tie rod bellows. A replacement remanufactured power-rack-and-pinion steering unit was recommended to the customer. The customer approved the replacement rack and authorized the required realignment. A careful test-drive confirmed that the problem was corrected.

Summary:

Complaint—Owner complained of vibration but only after hitting a bump in the road.
Cause—The rack-and-pinion steering had excessive looseness in both the inner and outer tie rods.
Correction—The steering gear assembly was replaced and the problem was corrected.

NOISE CORRECTION The proper way to repair a noise is to repair the cause. Other methods that have been used by technicians include the following:

1. Insulating the passenger compartment to keep the noise from the passengers.
2. Turning up the radio!

While these methods are usually inexpensive, the noise is still being generated, and if a noisy bearing or other vehicle component is not corrected, more expensive damage is likely to occur. Always remember: *Almost all vehicle faults cause noise first—do not ignore the noise because it is the early warning signal of more serious and possibly dangerous problems*.

Some of the things that can be done to correct certain vibrations and noise include the following:

1. Check all power steering high-pressure lines, being certain that they do not touch any part of the body, frame, or engine except where they are mounted.
2. Carefully check, tighten, and lubricate the flexible couplings in the exhaust system. Use a drive-on lift to ensure normal suspension positioning to check the exhaust system clearances. Loosen, then tighten, all exhaust clamps and hangers to relieve any built-up stress.
3. Lubricate all rubber bushings with rubber lube and replace any engine or transmission mounts that are collapsed.
4. Replace and/or tighten all engine drive belts and check that all accessory mounting brackets are tight.

FREQUENTLY ASKED QUESTION

What Is "Chassis Ears"?

Chassis ears is a brand name for a tool that uses microphones that can be attached to parts under the vehicle and transmit noise to a receiver. The receiver can be tuned so that a technician can listen to one microphone at a time while someone else is driving. This tool makes finding the source of a noise easier.
● **SEE FIGURE 127–19**.

Noise	Diagnostic Procedure
Tire noise	Change tire pressure; if no change, then the problem is not tires but bearings, or other components. Drive on various road surfaces—smooth asphalt reduces tire noise. Rotate the tires front to rear, if possible. Various tread designs can cause added noise (● **SEE FIGURE 127–17**).
Engine/exhaust noise	Operate the engine at various speeds and loads. Drive faster than the speed where the noise occurs, place the transmission in Neutral, and "coast" down through the speed of maximum noise. Determine if the engine speed or vehicle speed is the cause of the noise.
Wheel bearing noise (● **SEE FIGURE 127–18**)	Drive the vehicle slowly on a smooth road. Make left and right turns with the vehicle. Wheel bearing noise changes as weight is transferred side to side. If noise occurs when turning to the right, then the left bearing is the cause. if noise occurs when turning to the left, then the right bearing is the cause. Hoist the vehicle and rotate the wheel by hand to verify the roughness.
Differential side bearing noise	Drive the vehicle slowly on a smooth road. Differential bearing noise is a low-pitch noise that does not change when turning. The noise varies with vehicle speed.
Differential pinion bearing noise	A whine noise increases with the vehicle speed. Drive on a smooth road and accelerate, coast, and hold a steady speed (float). A defective front pinion bearing may be louder on acceleration. A defective rear pinion bearing may be louder on deceleration. Pinion bearing noise usually peaks in a narrow speed range.
U-joint noise	Drive slowly on a smooth road surface. Drive in reverse and forward. U-joints usually make a "chirp, chirp, chirp" noise in reverse because of lack of lubrication and brinelling from driving forward. Driving in reverse changes the force on the needle bearings in the U-joint, and noise is created.
Clutch noise	**Transmission input bearing:** Start the engine with the transmission in Neutral and the parking brake set. The clutch should be engaged (foot off the clutch pedal). If the bearing noise is heard, the transmission input bearing is the source. **Release (throw-out) bearing:** Start the engine with the transmission in Neutral and the parking brake set. Lightly depress the clutch pedal just enough to take up freeplay (usually 1 in. or less). If the noise is now heard, the source is the release (throw-out) bearing as the clutch fingers make contact with the bearing. **Pilot bearing:** Start the engine with the transmission in Neutral and the parking brake set. Push the clutch pedal fully to the floor (disengage the clutch). If the bearing noise is heard with the clutch disengaged, it is caused by the pilot bearing.

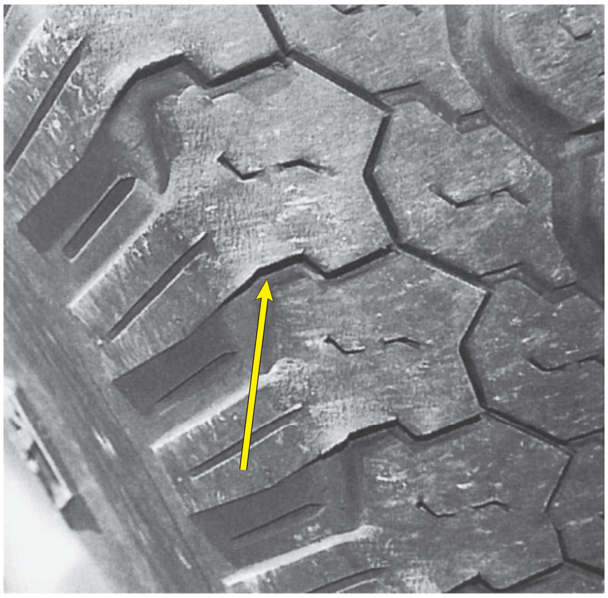


FIGURE 127–17 Tire wear caused by improper alignment or driving habits, such as high-speed cornering, can create tire noise. Notice the feather-edged outer tread blocks.

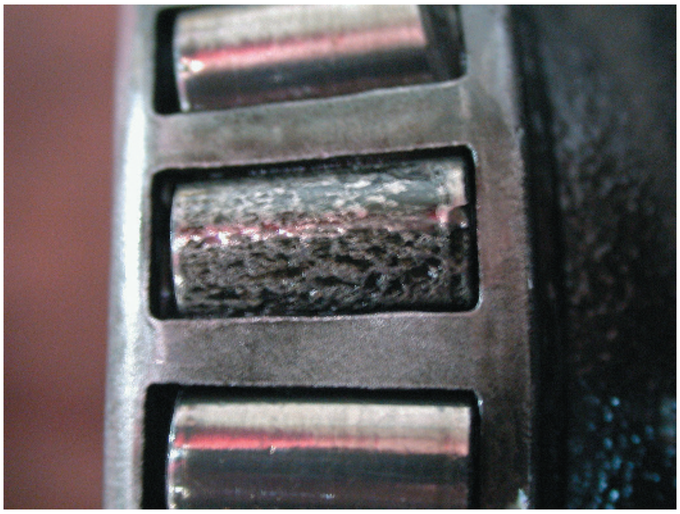


FIGURE 127–18 This bearing was found on a vehicle that had been stored over the winter. This corroded bearing produced a lot of noise and had to be replaced.

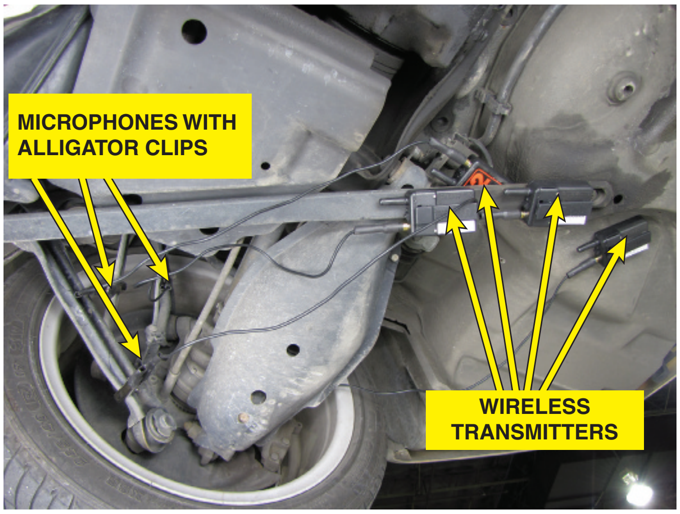


FIGURE 127–19 Chassis ear microphones attached to various suspension components using the integral clamps. The sound is transmitted wirelessly to the receiver inside the vehicle where an assistant technician can listen for noises while the vehicle is being driven.

TECH TIP

RAP It

Many technicians who service transmissions and drive axles frequently replace *all* bearings in the differential when there is a noise complaint. While this at first may seem to be overkill, these technicians have learned that one defective bearing may put particles in the lubricant, often causing the destruction of all the other bearings. This practice has been called *RAP* (replace all parts), and in the case of differentials, RAP may not be such a bad idea.

CASE STUDY

Engine Noise

An experienced technician was assigned to diagnose a loud engine noise. The noise sounded like a defective connecting rod bearing or other major engine problem. The alternator belt was found to be loose. Knowing that a loose belt can "whip" and cause noise, the belt was inspected and the belt tensioner was replaced but the noise was still heard. After stopping the engine, the technician found that the alternator belt was still loose. The problem was discovered to be a missing bolt that attached the alternator mounting bracket to the engine. The forces on the alternator caused the bracket to hit the engine. This noise was transmitted throughout the entire engine. Replacing the missing bracket bolt solved the loud engine noise and pleased a very relieved owner.

Summary:

Complaint—Owner complained of a loud engine noise.
Cause—The alternator bracket was loose, causing the noise due to a broken bracket bolt.
Correction—The alternator bracket bolt was replaced and the proper alternator belt tension was restored, and the noise was eliminated.

REVIEW QUESTIONS

1. Describe how you can tell if the source of a vibration is at the front or the rear of a vehicle during a test-drive.
2. What are the steps to perform a neutral run-up test?
3. List two types of frequency-measuring instruments.
4. Discuss why the balance of a driveshaft on a rear-wheel-drive vehicle is more important than the balance of a front-wheel-drive axle shaft.
5. Explain how to check and balance a driveshaft on a rear-wheel-drive vehicle.

CHAPTER QUIZ

1. A vibration or noise can be caused by all of the following *except* ___________.
   a. exhaust system
   b. wheels and tires
   c. incorrect driveshaft angles
   d. exhaust smoke
2. An engine-related vibration can be best detected by performing a ___________.
   a. neutral run-up test
   b. test drive on a rough road
   c. hard acceleration from a stop
   d. Any of the above
3. Driveline vibrations due to a bent or out-of-balance driveshaft on a rear-wheel-drive vehicle usually produce a vibration that is___________.
   a. felt in the steering wheel
   b. seen as a vibrating dash or hood
   c. felt in the seat or all over the vehicle
   d. felt by the rear passengers only
4. A vibration is felt in the steering wheel during braking only. A common cause of the vibration is___________.
   a. worn idler arm
   b. out-of-balance front tires
   c. loose or defective wheel bearing(s)
   d. warped or nonparallel front disc brake rotors

5. The rolling circumference of both tires on the same axle of a four-wheel-drive vehicle should be within ___________.

a. 0.1 inch (2.5 mm)
b. 0.3 inch (7.6 mm)
c. 0.6 inch (15 mm)
d. 1.2 inch (30 mm)

6. Wheel/tire imbalance is the most common source of vibrations that occur in what frequency range?

a. 5–20 Hz
b. 20–50 Hz
c. 50–100 Hz
d. 100–150 Hz

7. The maximum allowable driveshaft runout is___________.

a. 0.030 inch (0.8 mm)
b. 0.10 inch (2.5 mm)
c. 0.50 inch (13 mm)
d. 0.015 inch (0.4 mm)

8. Measuring driveshaft U-joint phasing involves checking to see if the front and rear U-joints are ___________ with each other.

a. parallel
b. crossed
c. at an angle
d. opposite phased

9. A driveshaft can be checked for proper balance by marking the circumference of the shaft in four places and running the vehicle drive wheels to spot the point of imbalance using a(n) ___________.

a. reed tachometer
b. strobe light
c. electronic vibration analyzer
d. scan tool

10. A defective clutch release (throw-out) bearing is usually heard when the clutch is ___________.

a. engaged in neutral
b. disengaged in a gear
c. depressed to take up any freeplay
d. engaged in first gear or reverse

SECTION XIV

AUTOMATIC TRANSMISSIONS (A2)

CHAPTERS

128 Automatic Transmission/Transaxle Principles
129 Continuously Variable and Dual-Clutch Automatic Transmissions
130 Hydraulic Components and Control Systems
131 EV And HEV Transmissions
132 Automatic Transmission/Transaxle Diagnosis and In-Vehicle Service
133 Automatic Transmission/Transaxle Unit Repair

Chapter 128

AUTOMATIC TRANSMISSION/ TRANSAXLE PRINCIPLES

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the purpose, function, and operation of torque converters.
- Explain the purpose, function, and operation of lockup torque converters.
- Describe the various shift modes.
- Discuss planetary gear sets.
- Discuss compound planetary gear sets.
- Discuss automatic transaxles.
- Discuss nonplanetary gear automatic transaxles.

KEY TERMS:

Coupling phase 1625 • Creep 1625 • Impeller 1622 • Input member 1629 • Lapelletier gear set 1630 • Output member 1629 • Planet carrier 1628 • Ravigneaux gear set 1630 • Reaction member 1629 • Ring (annulus) gear 1628 • Rotary flow 1624 • Simpson gear set 1630 • Stall speed 1625 • Stator 1622 • Sun gear 1628 • Torque converter clutch (TCC) 1626 • Turbine 1622 • Vortex flow 1624

TORQUE CONVERTERS

PURPOSE AND FUNCTION The torque converter is located between the engine and the transmission/transaxle and performs the following functions:

1. Transmits and multiplies engine torque
2. Acts as a clutch between the engine and the transmission/transaxle
3. Allows slippage, which makes it possible for the transmission to be engaged in gear even when the vehicle and wheels are stopped.

PARTS The three major parts of the torque converter include

1. **Impeller.** The **impeller** is the driving member and rotates with the engine, and is located on the transmission side of the converter. The impeller inside the torque converter is also called the *pump* (not to be confused with the pressure pump).
2. **Turbine.** The **turbine** is located on the engine side of the converter. The impeller vanes pick up fluid in the converter housing and direct it toward the turbine. Fluid flow drives the turbine, and when the flow between the impeller and the turbine is adequate, the turbine rotates and turns the transmission input shaft.
3. **Stator.** A torque converter also contains the **stator**, or reactor, which is a reaction member mounted on a one-way clutch. ● **SEE FIGURE 128–1**.

The vanes used in each of the three elements of a torque converter are curved to increase the angle of the fluid flow. This also increases the force exerted by the fluid and improves the hydraulic advantage. The outlet side of the impeller vanes accelerates the fluid as it leaves the impeller to increase torque transfer to the turbine. The impeller and the turbine contain a curved shelf known as *split rings* to more efficiently move the fluid. ● **SEE FIGURE 128–2**.

OPERATION A torque converter acts like two fans pointing toward each other. Air pushed by the powered fan causes the

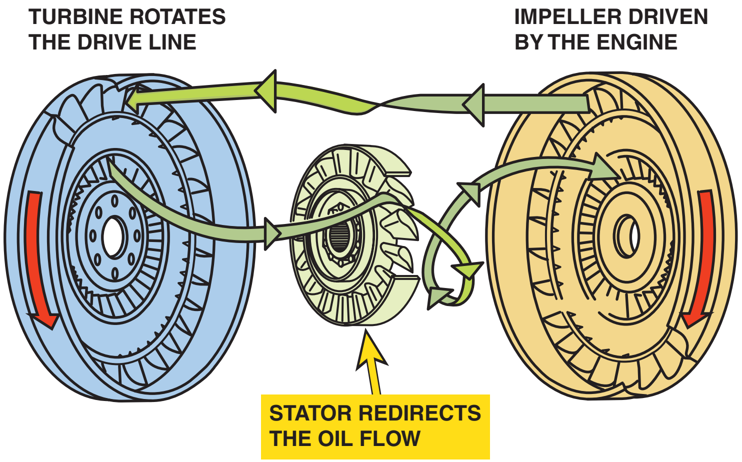

TURBINE ROTATES THE DRIVE LINE
IMPELLER DRIVEN BY THE ENGINE
STATOR REDIRECTS THE OIL FLOW

FIGURE 128–1 A torque converter is made from three parts: The impeller is located at the transmission end, attached to the housing, and is driven by the engine. The turbine is located at the engine side and is driven by the fluid flow from the impeller and drives the input shaft of the transmission. The stator redirects the flow to improve efficiency and multiply torque.

blades of the nonpowered fan to rotate. In the case of a torque converter, the two fans are the turbine and the impeller. The transmission fluid is the air that is being forced to turn the nonpowered fan. ● **SEE FIGURE 128–3**.

The fluid-only connection between the impeller and the turbine allows for absorption of sudden and harsh shocks in speed and/or torque. The curve of the stator vanes is opposite to the curve of the impeller and turbine vanes.

Since the stator is located between the impeller and turbine, it changes the direction of the fluid as it leaves the turbine, and thereby multiplies the torque from the impeller.

Torque converters are single-piece, welded and balanced assemblies that cannot be disassembled or easily repaired. Although they can be rebuilt using specialized equipment, most shops simply replace converters as a unit if they fail.

TORQUE CONVERTER FLEXPLATE The torque converter is typically bolted to a thin metal disc called a flexplate. The center of the flexplate often has a pilot indention for the nose of the converter, and the flexplate itself is bolted to the rear flange of the engine. ● **SEE FIGURE 128–4**.

The flexplate replaces the heavy flywheel used with a manual transmission. An important function of a flywheel is to smooth out engine pulsations and dampen vibrations. An automatic transmission does not require a conventional flywheel because the weight of the torque converter provides enough mass to dampen engine vibrations.

An external ring gear generally attaches to the outer rim of the flexplate, while on some applications the ring gear may be welded to the outside of the torque converter cover. This ring gear engages the starter motor pinion gear to turn the engine during starting. Some manufacturers also place the crankshaft position sensor tone ring in the outer lip of the flexplate.

NOTE: Hybrid vehicles may use a torque dampener plate in place of the torque converter. The dampener plate contains springs to absorb driveline shock, similar to a manual transmission clutch disc. It also drives the mechanical fluid pump and input shaft; however, it does not have transmission fluid, turbine, impeller, or stator elements inside it.

TORQUE CONVERTER DRIVES THE PUMP Oil pump drive shafts generally pass through the converter inside a hollow input or transfer shaft and internally connect to the converter housing by splines or a hexagon-shape shaft. The torque converter is also responsible for driving the transmission oil pump, sometimes called the *front pump,* because some early 1950s transmissions used a *rear pump* attached to the output shaft to allow "push starting" of automatic transmission-equipped vehicles. The inner portion of the front pump couples to the torque converter hub by using either "flats" or "tangs." The converter drive hub at the rear of the torque converter housing passes over the stator support and through the front oil seal to engage with and drive the oil pump. Because the shell of the torque converter is bolted to and rotates with the engine, this ensures that the fluid pump will only spin when the engine spins. ● **SEE FIGURE 128–5**.

One method is to attach the inner pump gear/rotor to the converter hub (most RWD transmissions); and the other is to use a separate oil pump drive shaft that connects the torque converter to the front oil pump (most FWD transaxles).

NOTE: Hybrid vehicles supplement the converter-driven pump with an electric-driven pump to ensure fluid flow and pressure even when the engine is stopped.

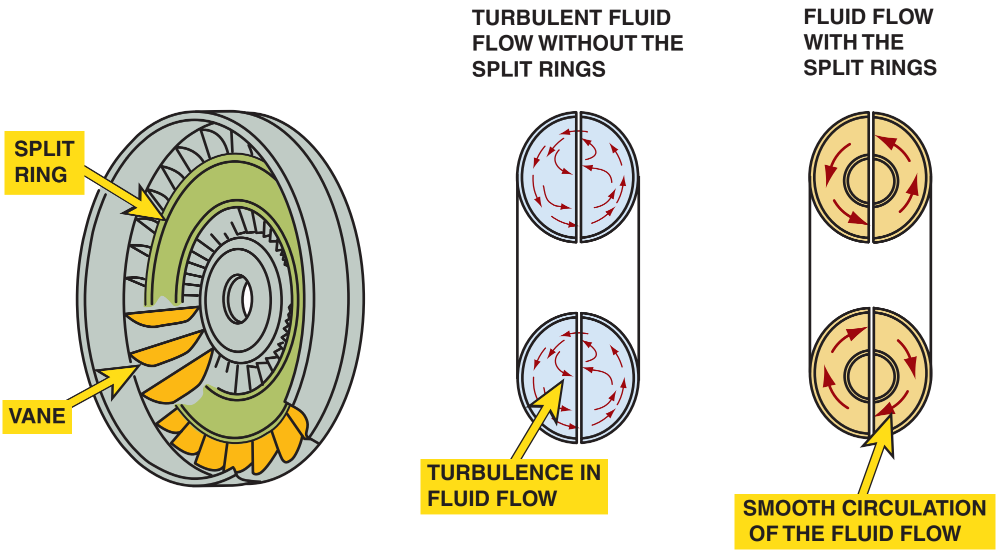

TURBULENT FLUID FLOW WITHOUT THE SPLIT RINGS
FLUID FLOW WITH THE SPLIT RINGS
SPLIT RING
VANE
TURBULENCE IN FLUID FLOW
SMOOTH CIRCULATION OF THE FLUID FLOW

FIGURE 128–2 The split rings help direct the flow of fluid and improve the efficiency of the torque converter by reducing turbulence.

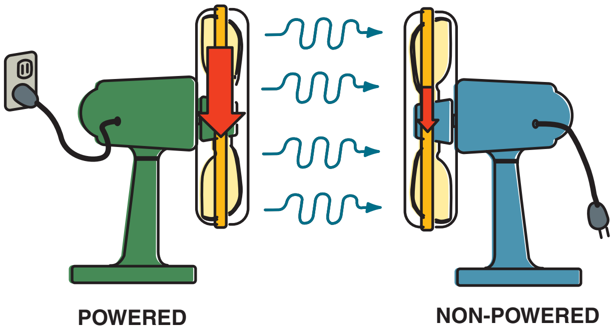


FIGURE 128–3 Two fans can be used to show how fluid, or air in the case of fans instead of automatic transmission fluid, can be used to transfer energy. If one fan is operating, the blades of a second fan will be rotated by the flow of air past the fan that is unplugged, causing the blades to rotate.

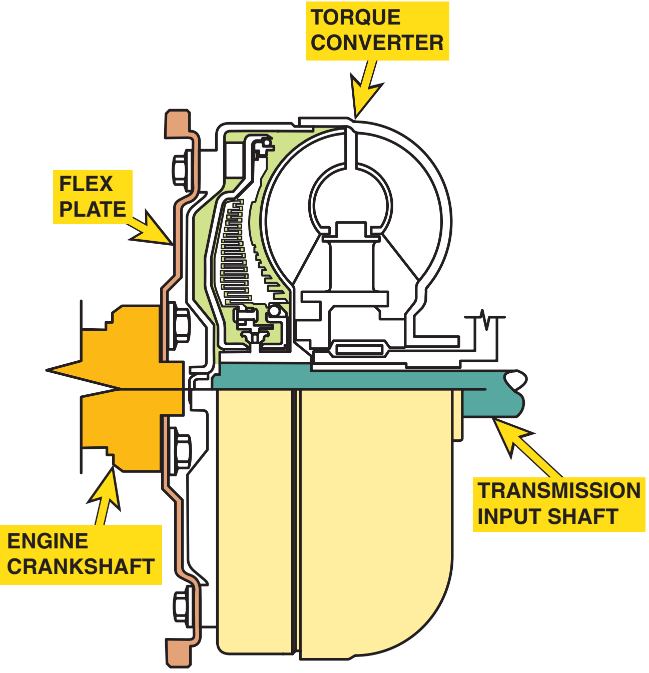


FIGURE 128–4 The torque converter bolts to the flexplate that is attached to the engine crankshaft and rotates at engine speed.

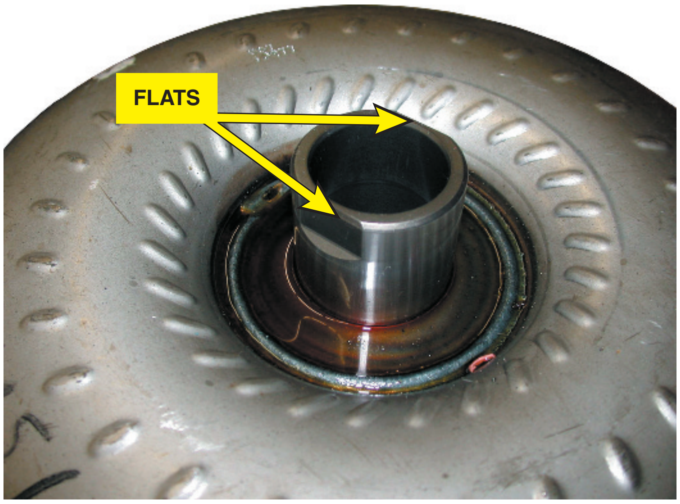


FIGURE 128–5 The flat sections that are cut into the hub of the torque converter are used to drive the fluid pump.

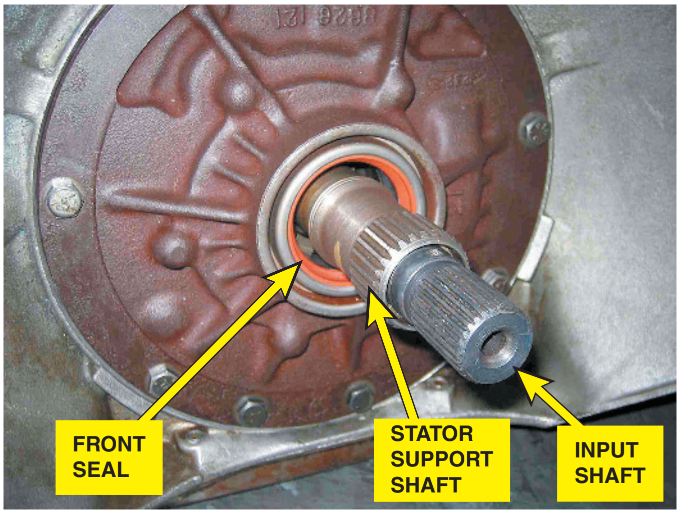


FIGURE 128–6 The internal splines inside the torque converter are connected to the splines on the stator support shaft and the turbine splines to the input shaft.

TRANSMISSION INPUT SHAFT Most rear-wheel-drive transmissions use an inline method to drive the converter and provide a direct mechanical connection between the turbine and the transmission input shaft. In a typical design, splines on the turbine connect it to the transmission input shaft and the stator hub mounts on a one-way overrunning clutch. The one-way clutch mounts on splines to a stationary extension of the oil pump called the *stator support,* or *reaction shaft.* ● **SEE FIGURE 128–6**.

TORQUE CONVERTER OPERATION Fluid sent to the torque converter from the transmission oil pump is picked up by the rotating vanes of the impeller and transferred to the turbine vanes. The two types of fluid flow inside a torque converter are rotary flow and vortex flow.

1. **Rotary flow** is created by the rotation of the torque converter and causes the oil (ATF) to flow around the circumference of the torque converter.
2. **Vortex flow** is the flow of the fluid from the impeller to the turbine and back to the impeller.

TORQUE MULTIPLICATION PHASE Torque multiplication in a torque converter occurs due to the following series of events inside the torque converter.

1. Fluid leaving the turbine vanes strikes the concave, or front side, of the stator vanes.
2. The stator vanes change the direction of the fluid so that it pushes the back side of the impeller vanes.
3. The stator redirects fluid flow because it remains stationary during the torque multiplication phase.
4. The stator hub mounts on a one-way clutch, freewheeling in a clockwise direction, but locking when driven in a counterclockwise direction.
5. The stator redirects fluid flow because it remains stationary during the torque multiplication phase.
6. When fluid from the turbine strikes the concave face of the stator vanes, it tries to drive the stator counterclockwise. By locking the stator, it can redirect the fluid back to the impeller.

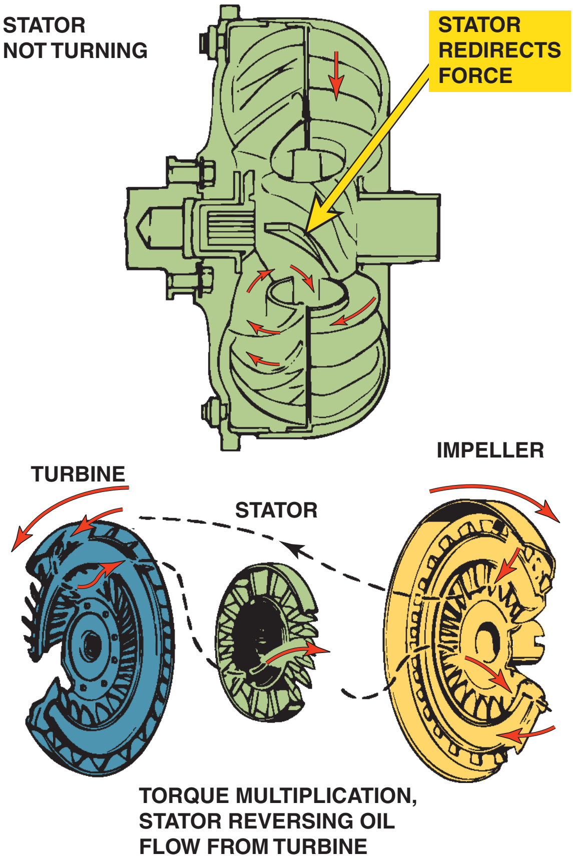

STATOR NOT TURNING
STATOR REDIRECTS FORCE
TURBINE
STATOR
IMPELLER
TORQUE MULTIPLICATION, STATOR REVERSING OIL FLOW FROM TURBINE

FIGURE 128–7 Torque multiplication occurs when fluid leaving the turbine strikes the front of the stator vanes and is redirected back to the impeller.

7. The force of the fluid redirected from the stator adds to the force of the fluid flowing to the impeller, to increase the overall torque being transferred from the impeller to the turbine. This is called the *torque multiplication phase.* ● **SEE FIGURE 128–7**.

Torque multiplication occurs whenever the vortex flow makes a full cycle from impeller to turbine, through the stator and back to the impeller. A torque converter multiplies torque in relation to the speed ratio.

- At low speed ratios, the impeller (engine speed) is turning much faster than the turbine (transmission input shaft speed), so vortex flow is high and torque multiplication occurs.
- As turbine speed increases and approaches impeller speed, rotary flow increases, which reduces both vortex flow and torque multiplication.
- As the speed ratio approaches 90%, torque multiplication becomes minimal and a torque converter functions like a fluid coupling.

The stator hub mounts on a one-way clutch, freewheeling in a clockwise direction, but locking when driven in a counterclockwise direction. When fluid from the turbine strikes the concave face of the stator vanes, it tries to drive the stator counterclockwise. By locking the stator, it can redirect the fluid back to the impeller. ● **SEE FIGURE 128–8**.

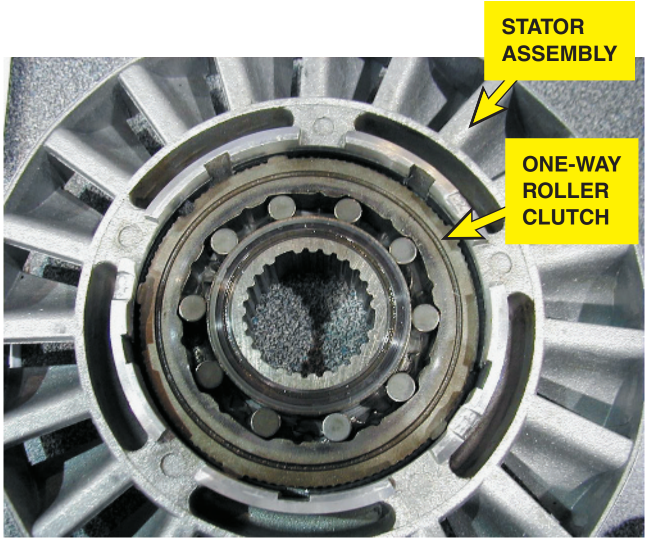


FIGURE 128–8 A stator contains a one-way roller clutch that locks it from rotating in one direction and allows it to rotate freely in the opposite direction.

COUPLING PHASE When the speed ratio is 90° or more, fluid flow in the torque converter is mostly rotary flow and the angle of flow from turbine to stator increases. This is called the **coupling phase**. When the torque converter reaches this phase, the turbine is traveling at nearly the same speed as the impeller, rotary flow is much greater than vortex flow, and the torque multiplication drops. During this phase, fluid from the turbine strikes the convex side, or backside, of the stator vanes rather than the concave side. As the force of fluid striking the backside becomes great enough to drive the stator clockwise, the stator one-way clutch overruns. With the clutch overrunning the turbine, impeller, and stator, all rotate in the same direction and at approximately the same speed. The stator unlocks and freewheels once the angle of fluid flow changes enough to strike the opposite side of the stator vanes and rotate the stator clockwise.

Torque multiplication drops as the torque converter approaches the coupling phase because the stator no longer redirects fluid to increase the flow from impeller to turbine. When the torque converter reaches coupling speed, the turbine is traveling at nearly the same speed as the impeller, rotary flow is much greater than vortex flow, and the torque converter simply transmits torque like a fluid coupling. During the coupling phase, most converters lose about 10% coupling efficiency, which means that there is a 10% speed difference between the impeller and turbine.

STALL SPEED **Stall speed** is the engine speed when the engine drives the impeller at the maximum speed possible without moving the turbine. The engine speed at which this occurs is called the torque converter stall speed. When the impeller rotates but the turbine does not, the speed ratio is zero. This is the lowest possible speed ratio and the greatest possible torque multiplication. Most modern torque converters multiply torque in the range of 2:1 to 2.5:1 at the stall speed. Typical stall speeds are designed to match the needs of individual vehicles and engines and range from a low of about 1450 RPM to as high in some stock vehicles as 2500 RPM or even higher for high-performance torque converters.

NORMAL OPERATION When the transmission selector is moved from park (P) or neutral (N) into a drive gear, some engine torque is transferred to the input shaft of the transmission or transaxle. The vehicle will move slightly if the brakes are released. This slight movement of the vehicle when the engine is at idle speed and the brakes are released is called **creep**. Therefore, a slight movement is normal for a vehicle equipped with an automatic transmission.

NOTE: Vehicle creep is more noticeable when the engine is cold due to the higher idle speed.

TORQUE CONVERTER DIAMETER The outside diameter of a torque converter and the angle of its stator blades determine the stall speed of the converter. When both a small and large diameter converter share the same stator blade angle and turn at the same speed, the smaller converter creates less centrifugal force to move the fluid inside. As a result, the small diameter converter has a higher stall speed, multiplies torque at higher engine speeds, and will not couple until the engine reaches high speeds. In comparison, the large diameter converter has a lower stall speed, multiplies torque at lower engine speeds, and also couples at a lower engine speed.

Vehicle manufacturers select torque converters to match the powertrain requirements and operating demands of each vehicle application.

- A vehicle with a large engine that produces a lot of torque at low RPM will often use a torque converter that couples at low speeds for greater fuel economy and lowest possible exhaust emissions.
- Vehicles with smaller engines that produce less torque at low RPM will use a torque converter that allows the engine to operate higher in its torque curve, where more power is available. High-performance vehicles with automatic transmissions use small diameter converters for the same reason.
- Therefore, the vehicle manufacturer selects the best stall speed based on the power band of the engine and the weight of the vehicle.

LOCKUP TORQUE CONVERTER

PURPOSE AND FUNCTION Even the most efficient torque converters slip 8% to 12% during operation because the fluid that transmits torque exhibits a type of slippage known as fluid shear. Fluid shear creates friction heat, but performs no work when the different layers of fluid slide past each other.

Eliminating torque converter slippage can improve fuel economy by approximately 4% to 5% during freeway cruising. With the increased emphasis on fuel economy and low exhaust emissions for late model vehicles, this became an important goal for automotive engineers. An additional benefit to reducing slippage is a reduction of transmission operating temperature, which increases transmission life expectancy. Lockup torque converters reduce slippage by using a **torque converter clutch (TCC)** to lock the impeller to the cover (shell). Similar to a clutch for a manual transmission, a TCC uses a friction disc operated by a hydraulic piston to mechanically couple the turbine to the converter (cover/shell). Engaging the clutch creates mechanical connection between the engine and transmission, resulting in a direct 1:1 drive ratio without slippage. ● **SEE FIGURE 128–9**.

CONVERTER CLUTCH CONTROL The first hydraulic lockup converters were controlled entirely by hydraulic pressure and spool valves in the transmission valve body. Some older designs added simple electric switches and solenoids to control pressure to the converter clutch. Since the early 1990s, the powertrain control module (PCM) or the transmission control module (TCM) regulates the timing and application of the clutch. The torque converter clutch operates under the following conditions:

- Lockup may also be limited to specific vehicle speeds or operating conditions. For most vehicles, lockup can occur at speeds over 25 to 30 MPH (40 to 48 km/h) but can occur sooner in many newer transmissions/transaxles.
- Once lockup occurs, the clutch may disengage automatically during certain operating conditions such as part- or full-throttle downshift. At these times, the increased acceleration requirements generally override the need for better fuel economy.
- Most computer systems can lock and unlock or modulate a converter clutch hundreds of times per minute to meet the vehicle demands of the moment and some recent systems also allow partial lockup of the torque converter. Traditional lockup torque converters operate either locked or unlocked. Partial lockup converters allow a regulated amount of slippage at the clutch. Each type of torque converter requires a certain type of friction material. ● **SEE FIGURE 128–10**.
- This allows the converter to lock up smoothly, improving fuel economy and performance, without the drawback of shock to the driveline. Using the wrong type of automatic transmission fluid (ATF) can alter the frictional properties

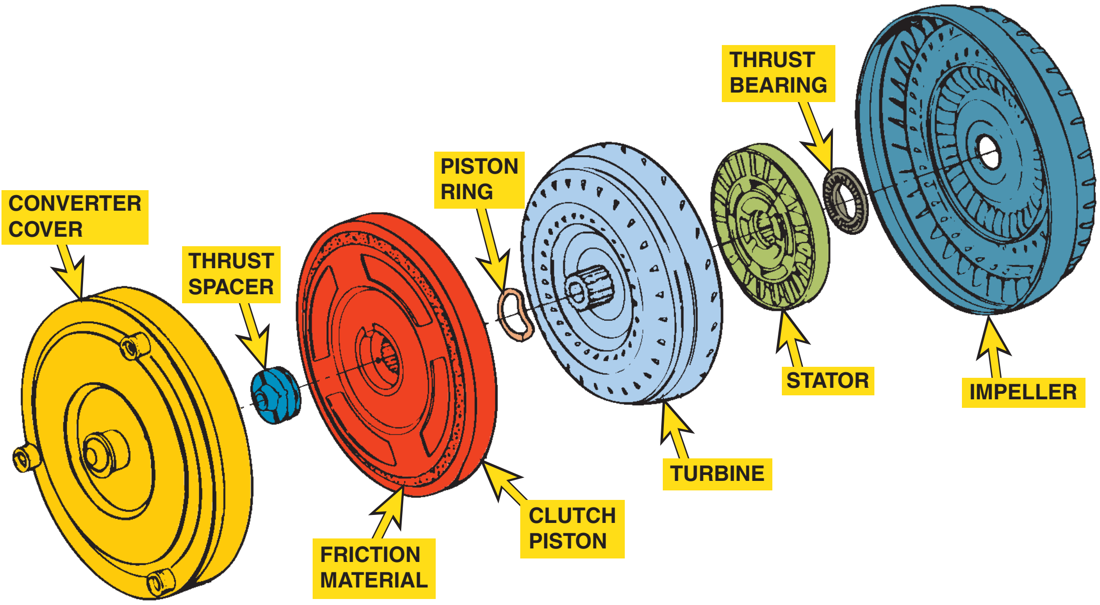


FIGURE 128–9 An expanded view of a typical torque converter assembly showing the torque converter clutch (TCC).

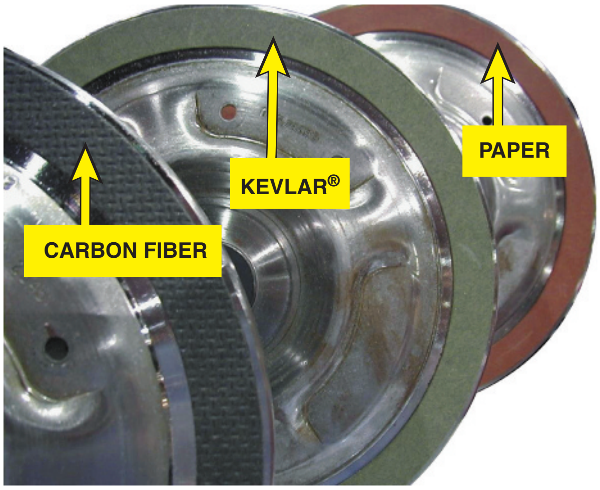


FIGURE 128–10 Torque converter clutch friction material is determined by the vehicle manufacturer to provide the needed coefficient of friction needed. For example, many older units use a paper-type friction material because they are fully applied or released, whereas most newer units use a synthetic material such as Kevlar® or carbon fiber because the torque converter clutch is pulsed on and off, therefore requiring a more robust material for long service life.

of the lockup clutch, leading to shudder or other similar customer complaints.

- Most lockup converters automatically disengage the torque converter clutch each time the brake pedal is depressed by the driver or if the accelerator pedal is released for more than a couple of seconds, which is necessary for vehicle deceleration without stalling the engine. ● **SEE FIGURE 128–11**.

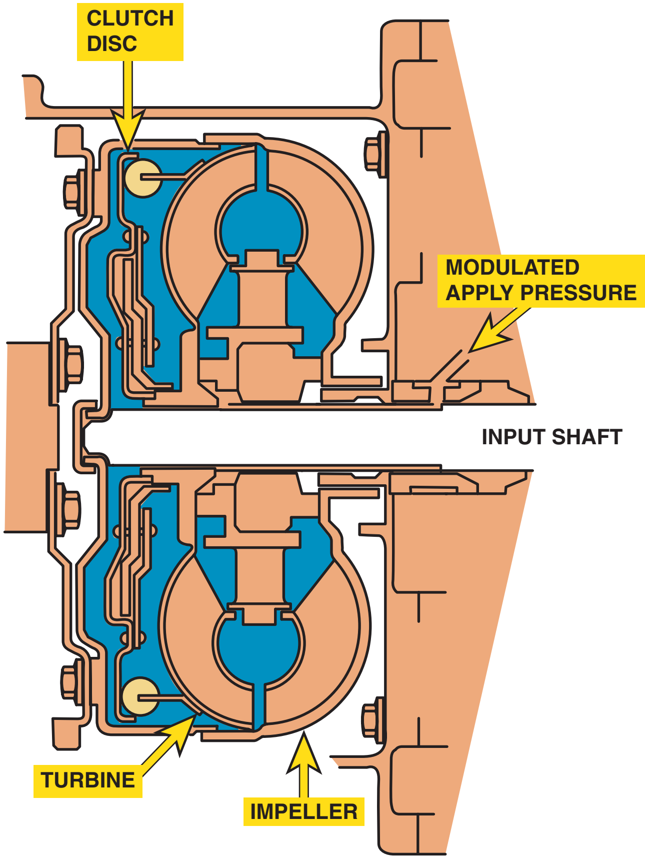


FIGURE 128–11 A cross-sectional view of a pulse-width-modulated (PWM) torque converter clutch. The powertrain control module (PCM) pulses the control solenoid, which then controls the fluid flow to apply the torque converter clutch.

TECH TIP

Use a Smaller Diameter Torque Converter for Improved Performance

A smaller-than-stock-diameter torque converter will not be capable of absorbing as much torque as a larger (stock) torque converter. As a result, the stall speed is increased. Because an engine develops more torque with increased speed (up to a point), the smaller torque converter will allow the engine to increase to a higher speed and create more torque to the transmission than would be capable with the stock torque converter.

This is especially helpful for modified engines because an engine having a camshaft with increased lift and duration usually lacks low RPM torque. By using a smaller torque converter, the stall speed is increased to better match the engine torque.

CAUTION: Using a torque converter with a different stall speed rating is likely to increase exhaust emissions and decrease fuel economy as well as void the warranty on the vehicle.

SHIFT MODES

Most automatic transmissions and transaxles include the following shift modes. ● **SEE FIGURE 128–12**.

- **Park.** In the park position, the output shaft is locked to the case of the transmission/transaxle, which keeps the vehicle from moving. No power is transmitted through the unit so the engine can remain running while the vehicle is held stationary. In the park position:
  1. The engine can be started by the driver.
  2. To move the shifter out of the park position on a late model vehicle, the brake pedal must be depressed to release the brake transmission shift interlock.
- **Reverse.** The reverse gear selector position is used to move the vehicle in reverse. Reverse usually uses a lower gear ratio than any of the forward gears.

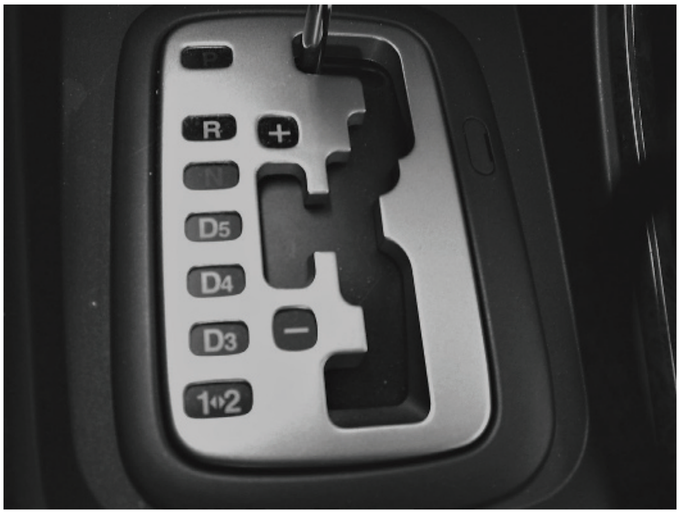


FIGURE 128–12 The gear selector is often called the "PRNDL," pronounced "prindle," regardless of the actual letters or numbers used.

- **Neutral.** In the neutral position, no torque is being transmitted through the automatic transmission/transaxle. In this position, the engine can be started by the driver.
- **Overdrive (OD).** The OD is the normal position for the shift selector for most driving conditions. This position allows the transmission or transaxle to shift through all forward gears as needed for the best fuel economy and lowest exhaust emissions.
- **Drive (D).** The D position includes the overdrive ratios in most vehicles. If there is an overdrive shift mode, however, then D is used to provide all forward gears except overdrive. Use this position when driving in hilly areas or when towing in the vehicle equipped with an overdrive selection.
- **Third (3).** In third position, the transmission/transaxle will upshift normally to third gear but will not upshift to a higher gear. When the third (3) position is selected while driving in a higher gear, the transmission will downshift into third if the vehicle speed is low enough to prevent the engine from being overrevved. This gear selection is used for the gentle grades at a moderate vehicle speed.
- **Second (2).** The second position is used for slowing the vehicle while descending long grades. In this gear selection, the vehicle speed is controlled and the engine speed is increased to provide engine compression braking. This gear selection is used for the gentle grades at a moderate vehicle speed.
- **First (1 or Low).** The first (or low) position is used for slowing the vehicle while descending long grades. In this gear selection, the vehicle speed is controlled and the engine speed is increased to provide engine compression breaking. This gear selection is used for the steepest grades at the lowest possible speed.

PLANETARY GEAR SETS

PURPOSE AND FUNCTION In a manual transmission, different gear ratios are obtained by sliding the gears into mesh. However, torque flow must be momentarily interrupted (accomplished by using a clutch) before the gears are shifted. With an automatic transmission there is no driver-operated clutch, so gear shifts are not made by sliding gears into mesh. Most automatic transmissions use a planetary gear set system that does not require manual gear shifting or an interruption of torque flow to change gear ratios.

PARTS AND OPERATION A simple planetary gear set consists of three primary components:

- Sun gear
- Planet carrier (including planet pinion gears)
- Ring (annulus) gear

As discussed in the last chapter on transfer cases, the **sun gear** gets its name from its position at the center of the gear set. The **planet carrier** holds the pinion gears, also known as planet gears, which revolve around the sun gear. The planet carrier assembly is commonly referred to simply as "the carrier."

The outermost member of the gear set is the **ring gear**, the internal type with teeth inside. The ring gear is sometimes called an annulus or internal gear. The pinion gears are in simultaneous mesh with both the sun gear and the ring gear. ● **SEE FIGURE 128–13**.

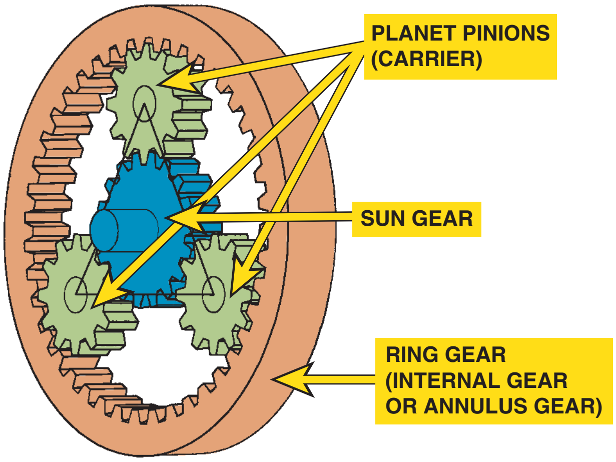


FIGURE 128–13 A typical planetary gear set showing the terms that are used to describe each member.

The pinion gears are free to rotate on pins that are part of the carrier, and the entire assembly rotates to direct torque flow. Most transmission gear sets use three, four, or even five planet pinions.

The pinions are fully meshed with both the sun gear and internal ring gear at all times. The planetary gears never disengage to change gear ratios; torque is simply redirected. The torque flow through a planetary gear set, both input and output, occurs along a single axis.

PLANETARY GEAR SET TORQUE FLOW In a planetary gear set, the following is done to achieve the various gear ratios and reverse.

- One of the members is being driven (input).
- One of the members is being held (reaction member).
- One of the members is the output.

Therefore, driving one gear will cause all of the other gears to rotate as well. This allows the gear set to provide different gear ratios, depending upon how torque is distributed through the assembly. To transmit torque through a planetary gear set, a drive member rotates while a second member is held, which causes a third member to be driven. ● **SEE FIGURE 128–14**.

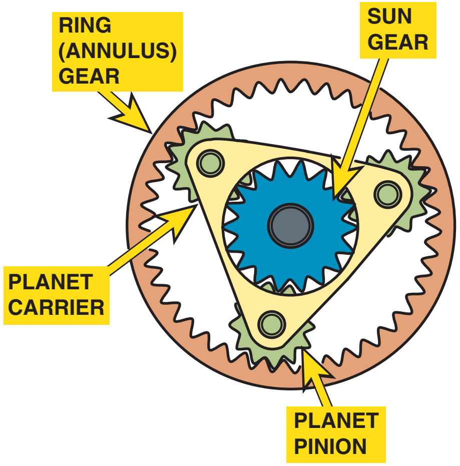


FIGURE 128–14 A typical planetary gear set showing the planet carrier, which supports all of the pinion gears (also called planet pinion gears).

Each member of a planetary gear set can play any one of these three roles to transmit torque. The various combinations of drive, held, and driven members result in the number of gear ratios available and change the direction of rotation as well for reverse.

NOTE: The held member can also be allowed to move one direction or another as it is being held and does not necessarily need to be held to zero RPM to create a variable gear ratio. This is done in hybrid electric vehicle transmissions.

Torque flows through a planetary gear set in several steps to get from the drive action of the first member to the driven action of the last member.

- The terms "drive" and "driven" simply describe how any two gears work together.
- When three or more gears are involved, the second gear is a *driven* gear in relation to the first, but it becomes a *drive* gear in relation to the third gear.
- For this reason, the drive member of a planetary gear set is known as the **input member**, the held member is the **reaction member**, and the driven member is the **output member**.

SIMPLE PLANETARY GEAR SET SYSTEMS A simple planetary gear set system consists of one sun gear, the carrier, and a ring gear. A single planetary gear set can provide all of the necessary gear ratios for a basic automatic transmission. ● **SEE FIGURES 128–15 THROUGH 128–17.**

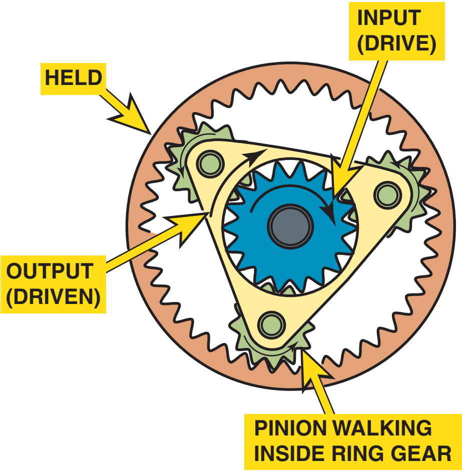


FIGURE 128–15 Maximum reduction can be achieved by using the sun gear as the input, holding the ring gear and using the planet carrier as the output.

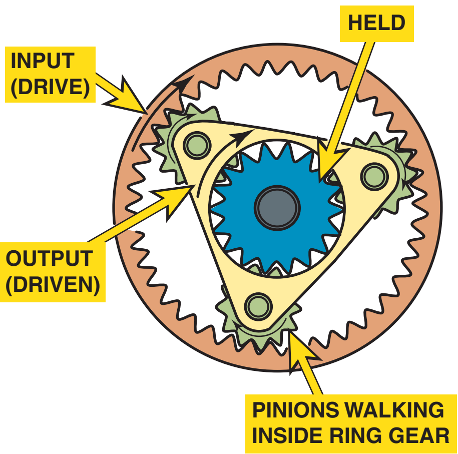


FIGURE 128–16 Minimum reduction can be achieved by using the ring gear as the input, holding the sun gear and using the planet carrier as the output.

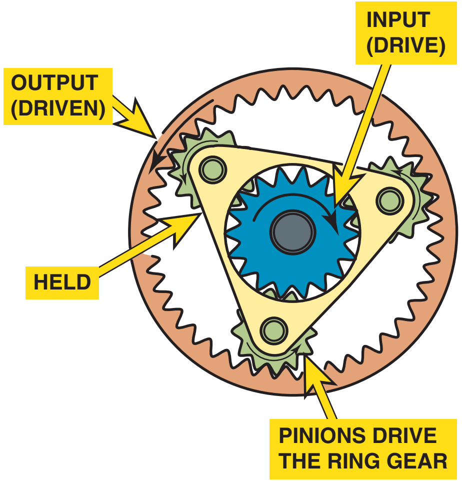


FIGURE 128–17 Reverse can be achieved by using the sun gear as the input, holding the planet carrier and using the ring gear as the output.

A simple planetary gear set is often used together with a compound planetary gear set to provide additional gear ratios. ● **SEE CHART 128–1** for the six possible gear ratios and how they are achieved.

SUN GEAR	PLANET CARRIER	RING GEAR	SPEED	TORQUE	DIRECTION
Input (Drive)	Output (Driven)	Held	Maximum reduction	Increase	Same as Input
Output (Driven)	Input (Drive)	Held	Maximum increase	Reduction	Same as Input
Held	Output (Driven)	Input (Drive)	Minimum reduction	Increase	Same as Input
Held	Input (Drive)	Output (Driven)	Minimum increase	Reduction	Same as Input
Input (Drive)	Held	Output (Driven)	Reduction	Increase	Reverse of Input
Output (Driven)	Held	Input (Drive)	Increase	Reduction	Reverse of Input

CHART 128–1

If any two members are locked together, then the resulting output is 1:1 ratio in the same direction as the input (direct drive). If no member is held (locked), then there is no output (neutral).

COMPOUND PLANETARY GEAR SET

A *compound planetary gear set* system is a configuration that contains more than just the three basic members of a simple planetary system. A compound planetary gear set is one or more simple planetary gears sets with one or more common gears. Compound planetary gear sets are capable of providing various combinations of gear reduction, direct drive, neutral, reverse, and overdrive.

SIMPSON GEAR SET One of the most popular compound planetary designs is the **Simpson gear set**. Named for its inventor, Howard Woodworth Simpson (1892–1963), an American automotive engineer, the Simpson gear set consists of two simple planetary gear sets that share a common sun gear. ● **SEE FIGURE 128–18**.

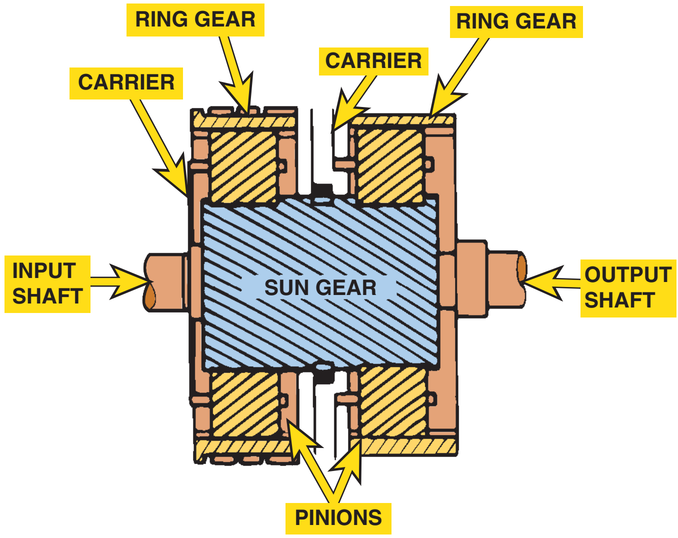


FIGURE 128–18 A Simpson planet gear set is composed of two ring gears and two planet carrier assemblies that share one sun gear.

FREQUENTLY ASKED QUESTION

What Companies Build Automatic Transmissions?

Many larger automobile manufacturers make their own automatic transmissions, including General Motors, Ford, Chrysler, and Honda. However, several companies manufacture automatic transmissions and transaxles that are used in a variety of vehicles. These include

- **ZF Friedrichshafen AG.** This German company manufactures manual and automatic transmissions and transaxles for many vehicle manufacturers, including Mercedes, BMW, Volvo, VW, Audi, Jaguar, Chrysler, Bentley, and Maserati.
- **Aisin AW.** This Japanese company makes automatic transmissions for many vehicle manufacturers, including Ford, Toyota, Nissan, Mazda, Mitsubishi, Subaru, Kia, and VW.
- **JATCO (Japan Automatic Transmission Company).** This is a Japanese manufacturer of automatic transmissions and transaxles for many vehicle manufacturers, including Nissan, Mazda, Infinity, VW, Mitsubishi, and Suzuki.

FREQUENTLY ASKED QUESTION

What Do All the Letters and Numbers Mean in Transmission Designations?

The numbers and letters usually mean the following:

- **Number of forward speeds.** The number of forward speeds may include four, five, or six (such as GM 4T60-E four speed unit).
- **Front-wheel drive or rear-wheel drive.** The letter **T** usually means *transverse* (front-wheel-drive transaxle) such as the Chrysler 41-TE; the **L** means *longitudinal* (rear-wheel-drive transmission) such as the General Motors 6L80; and the **R** means *rear-wheel drive* such as the Ford 5R55E.
- **Electronically controlled.** The letter **E** is often used to indicate that the unit is electronically controlled, and **M** or **H** is used to designate older mechanically (hydraulically) controlled units. All automatic transmissions built since the early 1990s are electronically controlled; therefore, **E** is often included in the designation of newer designs of transmission or transaxles.
- **Torque rating.** The torque rating is usually designated by a number where the higher the number, the higher the amount of torque that the unit is designed to handle. In a GM 6L80-E. the torque rating is 80.

Always check service information for the exact transmission designation for the vehicle being studied or serviced.

This combination is capable of providing three forward gears, as well as neutral and reverse. Basic operation, construction, and methods of obtaining various gear ratios with a simple planetary gear set also apply to the Simpson gear set. The main difference is the number of gear ratios that are available using more than one planetary gear set.

RAVIGNEAUX GEAR SET Another popular compound planetary design is the **Ravigneaux gear set**. The Ravigneaux system has the following:

- Two sun gears
- Two planet pinion sets, one longer than the other, supported in one carrier
- A single ring gear

● **SEE FIGURE 128–19**.

This design provides four forward gears (two in reduction, one direct, and one overdrive) as well as neutral and reverse. Basic planetary gear set operation, construction, and control methods also apply to the Ravigneaux gear set. An overdrive ratio means the following:

- The output shaft is rotating faster (higher RPM) than the engine crankshaft.
- The ratio is always expressed to the relative ratio of the input shaft speed so that all overdrive ratios are less than 1. For example, 0.75:1 is an overdrive ratio meaning the output is rotating 25 percent faster than the input shaft speed.

LAPELLETIER GEAR SET The **Lapelletier** (pronounced “la-plet-e-ay”) **gear set** was invented by Pierre Lapelletier, a

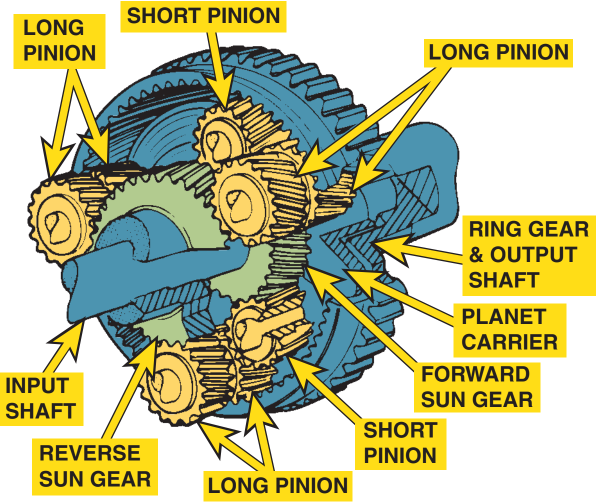

LONG PINION
SHORT PINION
LONG PINION
RING GEAR & OUTPUT SHAFT
PLANET CARRIER
FORWARD SUN GEAR
SHORT PINION
INPUT SHAFT
REVERSE SUN GEAR
LONG PINION

FIGURE 128–19 A Ravigneaux gear set is composed of two sun gears, one planet carrier that supports two sets of pinion gears, and a single ring gear.

retired engineer who devised a unique way to create a simple and efficient six-speed automatic transmission gear set. It was first produced by ZF in 2002. The Lapelletier gear set is constructed by connecting a planetary gear set in front of a Ravigneaux gear set. Besides ZF, General Motors uses the Lapelletier gear set in the 6L45, 6L50, and 6L90 rear-wheel-drive transmissions, and Ford uses it in the 6R60, 6R75, and 6R80 transmissions.

AUTOMATIC TRANSAXLES

TERMINOLOGY Automatic transaxles include a differential assembly as well as the planetary gear sets of an automatic transmission. The engine torque also needs to be transferred by the use of a chain or gears to provide a shorter overall length so it can be used with an engine mounted transversely in the engine compartment. Some use gears and others use a chain to transfer engine torque to either the planetary gear sets or to the differential (final drive) assembly. ● **SEE FIGURES 128–20 AND 128–21**.

A transaxle can be used in the following applications:

- Front engine, front-wheel drive
- Rear engine, rear-wheel drive
- Front engine, all-wheel drive
- Mid engine, rear-wheel drive

FINAL DRIVE UNITS A transaxle includes a differential assembly, often called a *final drive* assembly as part of the transaxle. This final drive assembly connects the output from the gear sets to the drive axle shafts. The final drive assembly includes the side gears and pinions gears as well as the housing. ● **SEE FIGURE 128–22**.

NONPLANETARY GEAR AUTOMATIC TRANSAXLES

Honda and Saturn vehicles use an automatic transmission with no planetary gear sets. This type is similar to and uses many of the same parts as their manual transaxles. This design uses hydraulic clutches instead of synchronizers to make the shift between gears. By using the same parts as manual transaxles, this automatic transaxle has the following advantages:

1. It allows both manual and automatic transmissions to be manufactured in the same plant, therefore reducing cost.
2. By using many of the same parts for both manual and automatic transaxles, manufacturers see a cost reduction.
3. Honda automatic transaxles are diagnosed, and if an internal fault is detected, the entire assembly is replaced with a remanufactured unit. Honda dealership technicians do not repair automatic transaxles. ● **SEE FIGURE 128–23**.

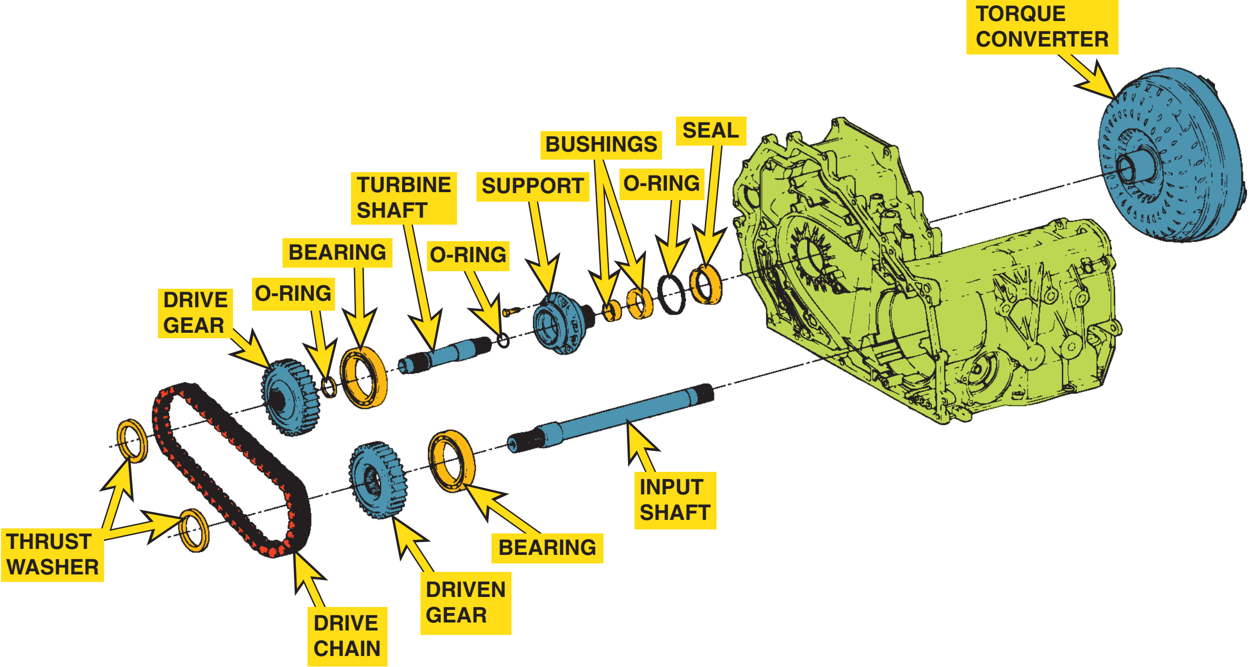

TORQUE CONVERTER
BUSHINGS
SEAL
TURBINE SHAFT
SUPPORT
O-RING
BEARING
O-RING
DRIVE GEAR
O-RING
INPUT SHAFT
THRUST WASHER
BEARING
DRIVEN GEAR
DRIVE CHAIN

FIGURE 128–20 On one style of transaxle, the turbine shaft drives the input shaft through a drive chain assembly.

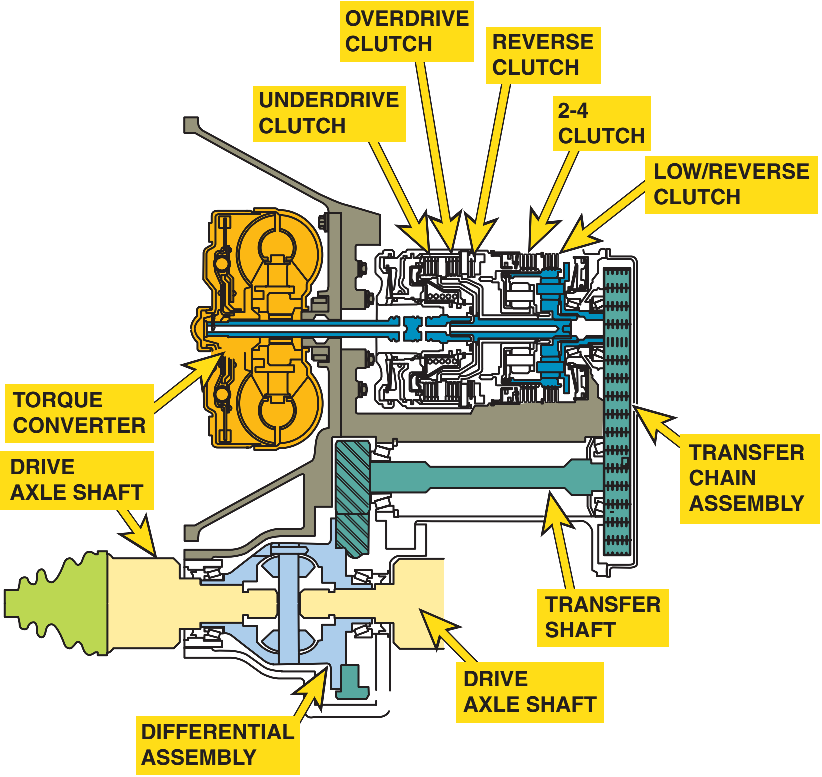

OVERDRIVE CLUTCH
REVERSE CLUTCH
UNDERDRIVE CLUTCH
2-4 CLUTCH
LOW/REVERSE CLUTCH
TORQUE CONVERTER
DRIVE AXLE SHAFT
TRANSFER CHAIN ASSEMBLY
TRANSFER SHAFT
DRIVE AXLE SHAFT
DIFFERENTIAL ASSEMBLY

FIGURE 128–21 Another type of transaxle uses a chain to transfer engine torque from the output of the gear sets to the differential assembly (final drive).

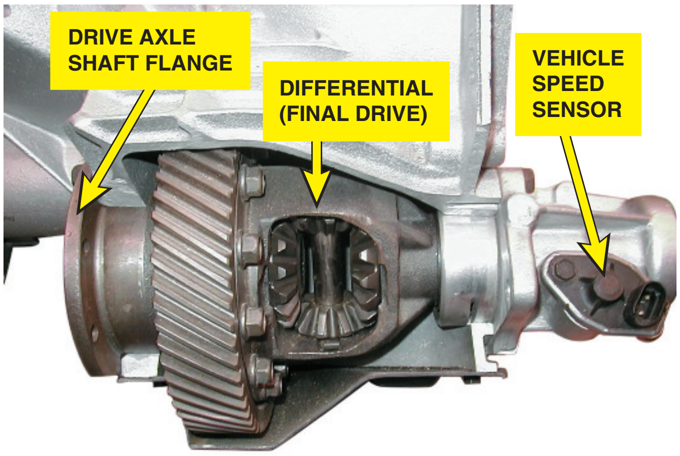

DRIVE AXLE SHAFT FLANGE
DIFFERENTIAL (FINAL DRIVE)
VEHICLE SPEED SENSOR

FIGURE 128–22 A cutaway showing the final drive assembly of a transaxle.

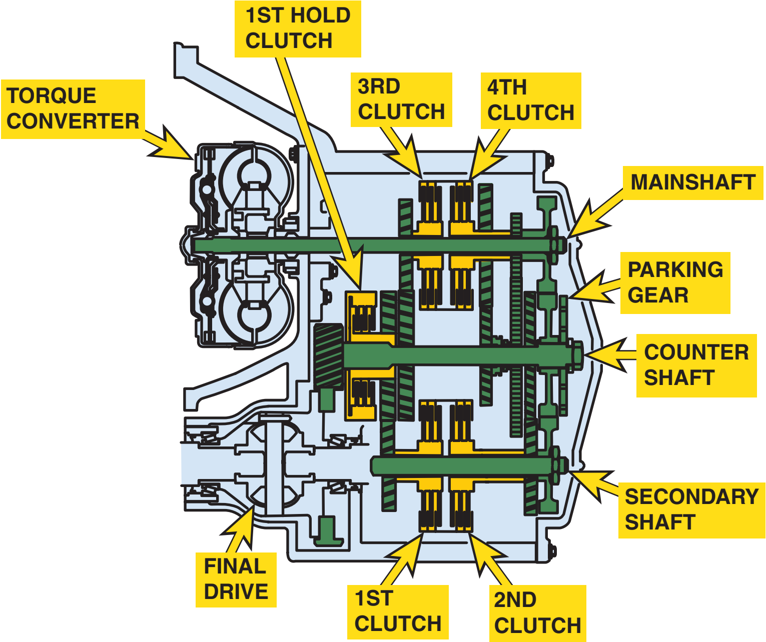

1ST HOLD CLUTCH
TORQUE CONVERTER
3RD CLUTCH
4TH CLUTCH
MAINSHAFT
PARKING GEAR
COUNTER SHAFT
SECONDARY SHAFT
FINAL DRIVE
1ST CLUTCH
2ND CLUTCH

FIGURE 128–23 A Honda nonplanetary gear set-type automatic transmission that uses helical cut gears instead of planetary gears. Hydraulically applied clutches as commanded by the PCM with fluid flow controlled by shift solenoids to make the shifts.

REVIEW QUESTIONS

1. How can torque converters double engine torque?
2. What are the three members of a planetary gear set?
3. How can various gear ratios and reverse be obtained by using a compound planetary gear set?
4. What are the typical automatic transmission shift modes?
5. What is meant by a "nonplanetary" automatic transmission?

CHAPTER QUIZ

1. Two technicians are discussing automatic transmissions/transaxles. Technician A says that it is normal for a vehicle to move slightly when the gear selector is in the drive position with the brakes released. Technician B says that the stator may be defective if the vehicle moves while in gear when the engine is at idle speed. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

2. Which component in the torque converter multiplies engine torque?
- **a.** Stator
- **b.** Impeller
- **c.** Turbine
- **d.** Converter clutch

3. What is the purpose and function of a lock-up part of the torque converter?
- **a.** Improves fuel economy by eliminating slippage
- **b.** Increases vehicle performance by allowing more torque multiplication
- **c.** Allows the transmission/transaxle to shift faster
- **d.** Increases fluid pressure in the transmission /transaxle

4. Technician A says that the torque converter impeller drives the transmission input shaft. Technician B says that the torque converter turbine drives the transmission input shaft. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

5. Technician A says that a held member is also called the reaction member. Technician B says that if any two elements are locked together then the output will be 1:1. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

6. Technician A says that when an automatic transmission/transaxle shifts into overdrive, the output shaft is rotating faster (higher RPM) than the engine crankshaft. Technician B says that an overdrive ratio is a ratio where the first number is less than 1. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

7. Technician A says that one planetary gear set can provide gear reduction, overdrive, and reverse. Technician B says that most transmissions today use compound (multiple) planetary gear sets. Which technician is correct?
- **a.** Technician A only
- **b.** Technician B only
- **c.** Both Technicians A and B
- **d.** Neither Technician A nor B

8. Automatic transaxles include a _____________ in addition to the planetary gear sets.
- **a.** transversal
- **b.** dry clutch
- **c.** differential assembly
- **d.** spur gear

9. The torque converter clutch eliminates _____________ in the torque converter.
- **a.** leakage
- **b.** slippage
- **c.** vibrations
- **d.** oil foaming

10. A nonplanetary gear set type automatic transmission uses _____________ instead of planetary gears.
- **a.** helical cut gears
- **b.** chains
- **c.** bevel cut gears
- **d.** All of the above

Chapter 129

CONTINUOUSLY VARIABLE AND DUAL-CLUTCH AUTOMATIC TRANSMISSIONS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the function, advantages, and disadvantages of a continuously variable transmission.
- Describe the construction of a continuously variable transmission.
- Discuss the electronic controls of a CVT.
- Discuss the operation of a CVT.
- Explain CVT pressure testing.
- Discuss CVT fluid.
- Discuss CVT-related DTCs.
- Discuss the parts and operation of a dual-clutch automatic transmission.
- Discuss the dual-clutch transaxle.
- Describe the diagnostic and service procedures for a dual clutch transmission/transaxle system.

KEY TERMS:

Automated manual transmission (AMT) 1641 • Clutch cooling flow solenoid (CCFS) 1644 • Clutch pressure cut (CPCUT) 1644 • Clutch shift pressure solenoid 1644 • Concentric clutch 1642 • Continuously variable transmission (CVT) 1634 • Direct shift gearbox (DSG) 1641 • Input speed sensor (ISS) 1637 • Line pressure solenoid (LPS) 1637 • Output speed sensor (OSS) 1637 • Parallel clutch 1642 • Porsche Doppelkupplung (PDK) 1641 • Primary oil pressure (POP) 1637 • Primary pressure sensor (PPS) 1637 • Pull chain 1636 • Push belt 1636 • Ratio control motor 1638 • Rubber band effect 1636 • Secondary oil pressure (SOP) 1637 • Secondary pressure sensor (SPS) 1637 • Shift cooling multiplex solenoid (SHCMS) 1644 • Transmission range sensor (TRS) 1637 • Transmission temperature sensor (TTS) 1637 • Twin clutch transmission 1641 • Variators 1635

CONTINUOUSLY VARIABLE TRANSMISSION (CVT)

PURPOSE AND FUNCTION A **continuously variable transmission (CVT)** is usually found on some front-wheel-drive vehicles that use a transaxle. A CVT varies the gear ratio in a continuous manner instead of in a series of steps or fixed gear ratios. The power flow is through a steel belt between two pulleys that change their width and effective diameter. When the vehicle accelerates from a standing start, the driving pulley is small and the driven pulley is large. This gives a gear reduction identical to a small gear driving a large gear, which provides an increase in torque and a decrease in speed. CVTs are more efficient than either manual or automatic transmissions while still providing the driving ease of an automatic transmission. ● **SEE FIGURE 129–1**.

ADVANTAGES A CVT offers the following advantages over a planetary-gear automatic transmission:

- Compact, very short
- Lighter weight
- Constant, stepless acceleration with engine staying at the RPM for maximum power
- Efficient fuel use and emissions, cruise with engine staying at the RPM for maximum efficiency
- Lower internal power loss

One method used to compare transmissions is the engine revolutions for a specific driving cycle. A test vehicle using a 3.0-L engine and a CVT showed 3% fewer revolutions than the same vehicle with a five-speed transmission and 11% less than with a four-speed transmission. This should equal a gain of about 12% in fuel economy. These transmissions are used by Audi, Dodge, Ford, Honda, Subaru, Toyota, and Nissan.

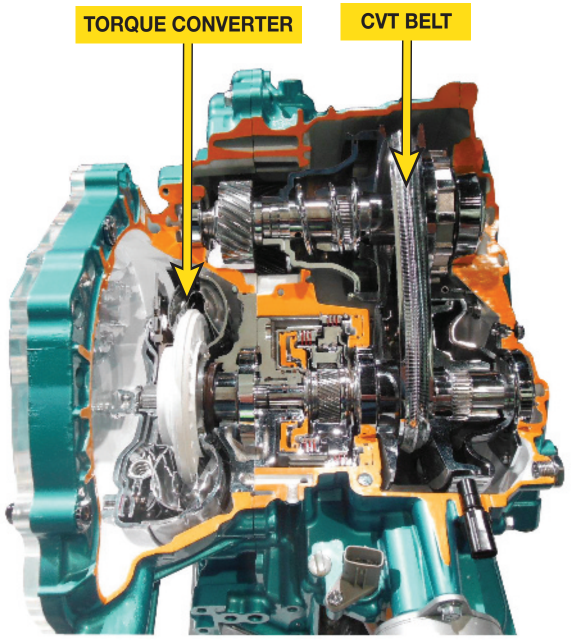


FIGURE 129–1 A typical CVT transaxle cutaway showing the torque converter and CVT belt.

DISADVANTAGES The disadvantages of a CVT compared to conventional automatic transmission include

- High and constant engine speed when accelerating rapidly.
- Requires special fluid that may not be readily available.
- Often not repaired but instead replaced as an assembly if the unit fails.

CONTINUOUSLY VARIABLE GEAR RATIOS As the speed increases, the diameter of the driving pulley increases as the sides of the pulley move together. While this happens, the driven pulley is made wider, and therefore, smaller in diameter. At cruising speeds, the driving pulley is larger than the driven pulley, which produces an overdrive ratio.

The pulleys change size smoothly and evenly, which produces a somewhat odd sensation when the vehicle accelerates from a stop. When the throttle is depressed, the engine speed increases to the point of good torque output and the gear ratio selected by the CVT causes the engine to stay at this RPM while the vehicle accelerates. The pulleys move to higher ratios as vehicle speed increases. This is a different sensation than the familiar engine speed increase in each gear and the engine speed decrease after an upshift. ● **SEE FIGURES 129–2 AND 129–3**.

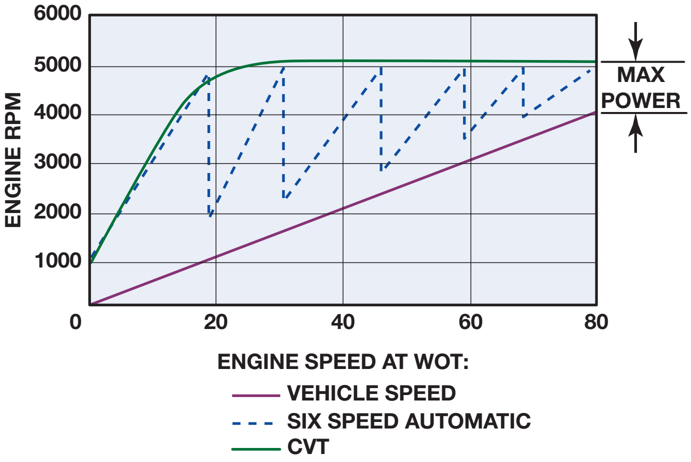


FIGURE 129–3 Engine speed and vehicle speed of a CVT transaxle compared to a typical six-speed conventional automatic transaxle.

CONSTRUCTION

TERMINOLOGY Instead of using three or more gears, a continuously variable transmission uses two variable-width pulleys, sometimes called **variators**, to change the gear ratio.

OPERATION The pulleys used in CVT design can vary their width by varying the hydraulic pressure applied to them. Each pulley has a movable face and a fixed face.

- The movable face for each pulley is attached to a piston that has hydraulic control pressure applied to it.
- Higher application pressure on the movable face causes the pulley to become narrow and this makes the steel belt ride closer to the outside diameter of the pulley. A lower application pressure will allow the pulley to become wider and the belt will ride closer to the pulley axis.

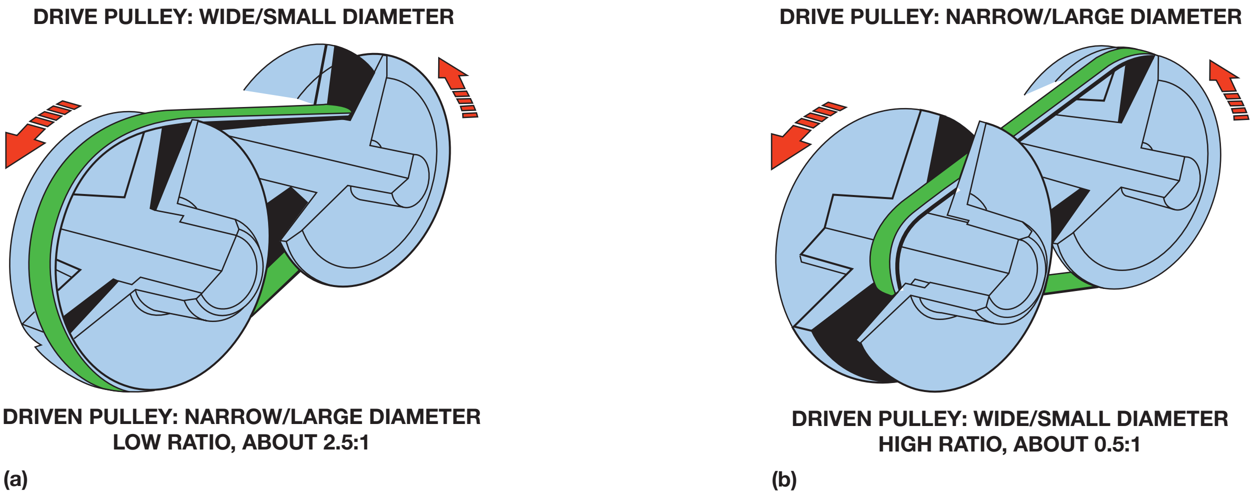

DRIVE PULLEY: WIDE/SMALL DIAMETER
DRIVEN PULLEY: NARROW/LARGE DIAMETER
LOW RATIO, ABOUT 2.5:1
(a)
DRIVE PULLEY: NARROW/LARGE DIAMETER
DRIVEN PULLEY: WIDE/SMALL DIAMETER
HIGH RATIO, ABOUT 0.5:1
(b)

FIGURE 129–2 A belt and pulley CVT uses variable-width pulleys to provide an infinite number of speed ratios.

FREQUENTLY ASKED QUESTION

What Is It Like to Drive a Vehicle Equipped with CVT?

For most people, driving a vehicle equipped with a continuously variable transmission (CVT) is the same as driving the vehicle equipped with a conventional automatic transmission/transaxle. The vehicle creeps slightly when the brake is released and accelerates normally when the throttle is opened. Because no shifts occur, the first thing the driver and passenger notice is that it is very smooth. If the vehicle is equipped with a tachometer, the driver may notice that the engine speed increases when first accelerating and often remains higher until the vehicle speed increases. During periods of rapid acceleration, the engine speed may be close to its maximum and thereby creates noise and vibration often not experienced in a similar vehicle. Because the vehicle speed slowly catches up to the engine speed, this effect is often referred to as the "**rubber band effect**" and is most noticeable only during periods of rapid acceleration. However, the fuel economy improvement of a CVT compared to a conventional automatic transmission makes the slight difference a reasonable trade-off.

If a low hydraulic pressure is applied to the drive pulley and a high hydraulic pressure is applied to the driven pulley, a low speed ratio is achieved.

A CVT has an infinite number of gear ratios between its lowest ratio (about 3.7:1) and highest ratio, which is a 0.27:1 overdrive.

A CVT improves efficiency by changing ratios from underdrive/reduction to overdrive in a gradual, continuous manner. The primary/drive pulley is attached to the input shaft. The secondary/driven pulley is on the output shaft and drives the final drive gears. Each pulley, also called a *sheave*, has two sides:

1. One is fixed so it cannot move.
2. The other can float sideways to change pulley width.

When the vehicle is at rest, the primary pulley is wide so the belt sits low on the pulley, and the secondary pulley is narrow so the belt sits high. This produces the lowest underdrive ratio. ● **SEE FIGURE 129–4**.

The secondary pulley is spring loaded to force it to a narrow position. The primary pulley is adjusted to control the gear ratio, and the secondary pulley is adjusted to maintain tension on the belt. The belt must never be loose between the pulleys.

- At start, the pulley halves/discs on the input (primary) shaft are spread apart, and the pair of pulley halves on the output (secondary) shaft are pushed together. This produces a small pulley driving a large pulley, which produces the lowest drive ratio.
- As the vehicle moves, the floating side of the primary pulley moves inward, making the pulley narrower and forcing the belt to move out to a wider diameter. This produces a higher gear ratio.
- Both pulleys must maintain enough pressure on the drive belt to transfer the required torque. Fluid pressure is used to force the drive piston/pulley to a narrower position and the driven pulley to a wider position. The secondary pulley is spring loaded to force it to a narrow position. The primary pulley is adjusted to control the gear ratio, and the secondary pulley is adjusted to maintain tension on the belt. The belt must never be loose between the pulleys.

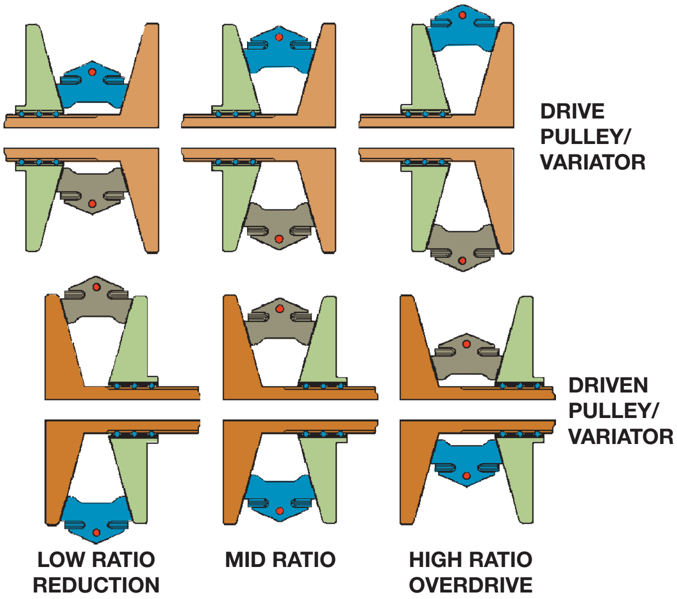


FIGURE 129–4 The drive pulley is wide while the driven pulley is narrow for a low ratio vehicle start (left). The ratio changes by making the drive pulley narrow and the driven pulley wider.

A reverse gear set, controlled by a multi-plate clutch pack, is used to produce reverse.

DRIVE BELT Two different styles of fixed-length steel belts are used.

1. **Push belt** It is made up of about 400 wedge-shaped segments that are held together by two steel bands. Each band is made of multiple layers to allow flexibility. The segment sides contact the pulley sides. A push belt is often called the *Van Doorne design*. This style of belt is directional, and is usually marked with an arrow to show belt direction. ● **SEE FIGURE 129–5**.
2. **Pull chain** It is made up of links and link pins, much like a silent chain. The ends of the link pins contact the pulley sides. This style is also called a *Luk chain drive*. ● **SEE FIGURE 129–6**.

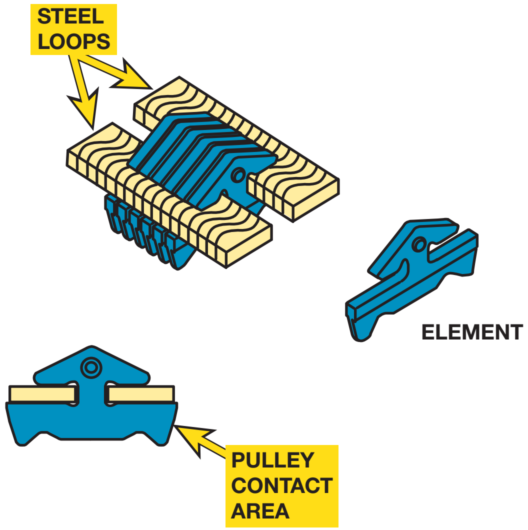


FIGURE 129–5 A Typical push-type CVT belt construction.

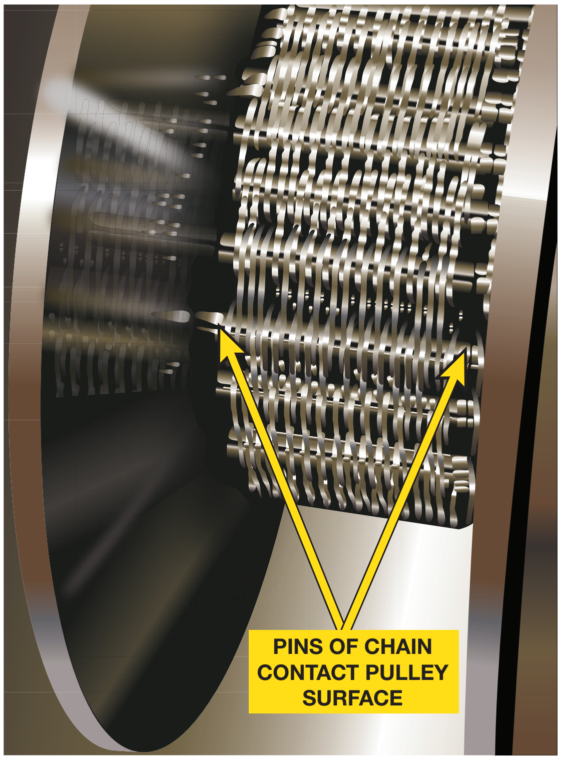


FIGURE 129–6 The pull chain looks similar to a silent chain.

VEHICLES THAT USE A BELT OR A CHAIN

● **SEE CHART 129–1** for a list of vehicles that use each type of continuously variable automatic transaxles.

VEHICLES THAT USE A PUSH-TYPE CVT (BELT-TYPE)	VEHICLES THAT USE A PULL-TYPE CVT (CHAIN-TYPE)
Honda (Accord, Civic, Civic hybrid, Insight hybrid)	Audi (A4, S4, RS4)
Dodge Caliber	Ford (500, Freestar, Freestyle)
Jeep (Compass, Patriot)	Mercury (Montego, Monterey)
Mini Cooper	Subaru Lineartronic (Legacy, Forester, Impreza, Outback)
Mitsubishi (Lancer, Outlander)	
Nissan (Altima, Cube, Maxima, Murano, Rogue, Sentra, Versa)	
Saturn (Aura, Ion, Vue)	
Subaru Justy	
Suzuki SX4	
Toyota Corolla	

CHART 129–1

Vehicles that use a CVT transaxle, separated by type: either push-type (belt) or pull-type (chain). Check service information for the exact years and types of transmissions used for each model.

CVT ELECTRONIC CONTROLS

The transmission control module (TCM) of a CVT uses direct and indirect inputs to monitor transmission and engine operation. ● **SEE FIGURE 129–7**.

INPUTS Direct inputs are as follows:

- **Transmission range sensor (TRS)**. A multi-contact switch operated by the manual shift lever.
- **Input speed sensor (ISS)**. Can be a magnetic or a Hall-effect sensor.
- **Output speed sensor (OSS)**. Can be a magnetic or a Hall-effect sensor.
- **Primary pressure sensor (PPS)**. A pressure transducer to monitor primary pulley pressure. The pressure measured is called the **primary oil pressure (POP)**.
- **Secondary pressure sensor (SPS)**. A pressure transducer to monitor secondary pulley pressure. The pressure measured is called the **secondary oil pressure (SOP)**.
- **Transmission temperature sensor (TTS)**. A negative temperature coefficient (NTC) thermistor used to measure the temperature of the transaxle.

INPUTS FROM CAN BUS Indirect inputs from CAN bus include

- PCM requests
- Engine output torque
- Brake switch
- ABS status signals
- Charging system voltage
- Engine RPM
- Engine coolant temperature
- Accelerator pedal position
- Vehicle speed
- A/C system requests

OUTPUTS The TCM controls the drive ratio to match vehicle needs. It can adjust the ratio during vehicle cruise to produce the maximum fuel economy, best emissions, or maximum pulling power. It continuously monitors ISS and OSS signals to ensure that the speeds match the desired ratio.

- The stepper motor, also called a **ratio control motor**, is a linear position motor that changes the position of the upper end of the pulley ratio link. The stepper motor controls the hydraulic ratio valve through the link, which in turn controls fluid flow to the piston. The lower end of this link moves with the floating side of the primary/drive pulley and the *ratio control valve* is connected to the center of this link. Movement of the stepper motor or the floating sheave will move the ratio control valve to produce a ratio change. ● **SEE FIGURE 129–8.**
  TCM outputs include
- Stepper motor that operates the ratio control valve, which controls the ratio changes commanded by the TCM.
- **Line pressure solenoid (LPS)**, which controls the line pressure to the transmission hydraulic system.

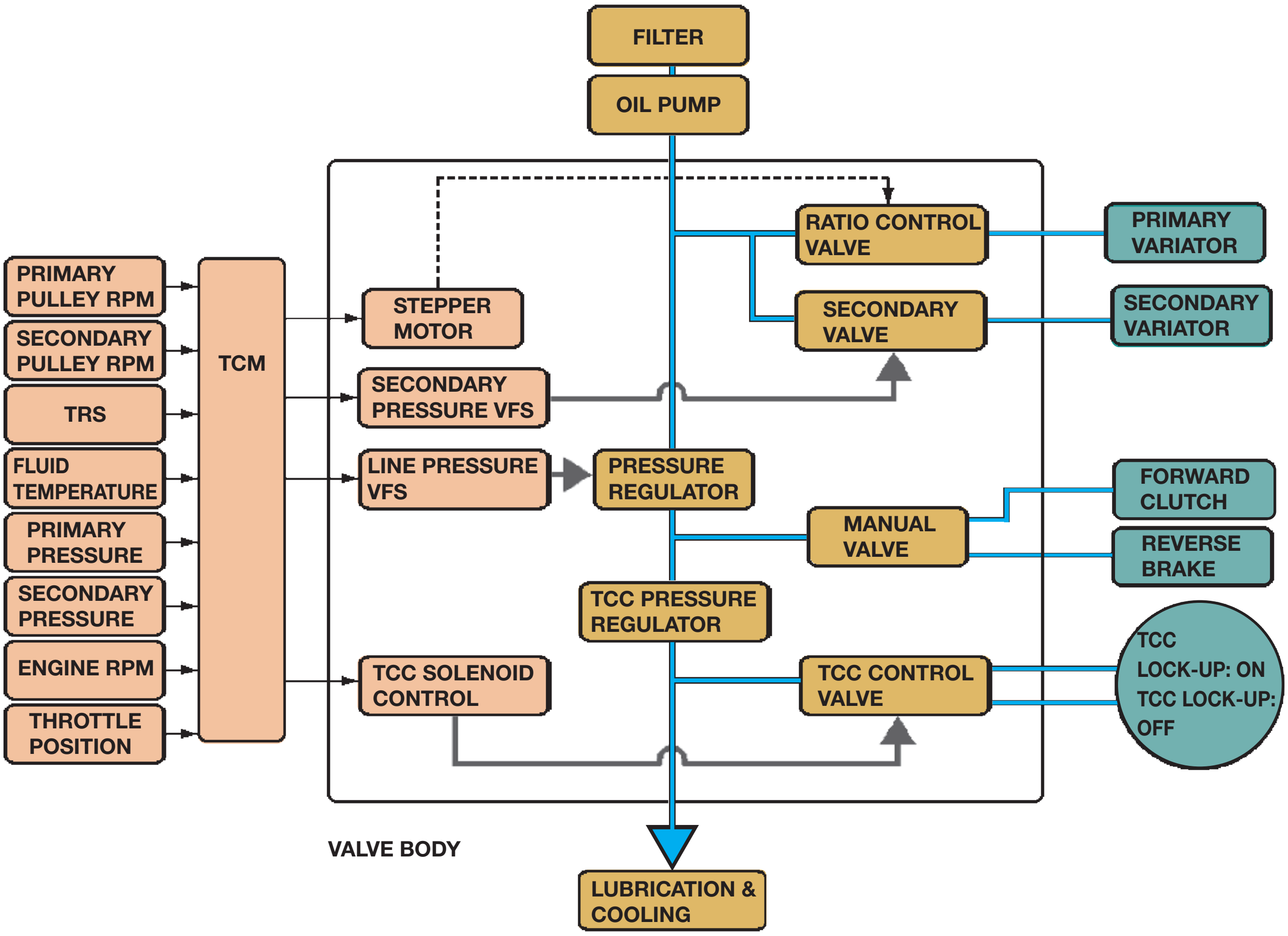

FILTER
OIL PUMP
RATIO CONTROL VALVE
PRIMARY VARIATOR
PRIMARY PULLEY RPM
SECONDARY PULLEY RPM
TRS
FLUID TEMPERATURE
PRIMARY PRESSURE
SECONDARY PRESSURE
ENGINE RPM
THROTTLE POSITION
TCM
STEPPER MOTOR
SECONDARY VALVE
SECONDARY VARIATOR
SECONDARY PRESSURE VFS
LINE PRESSURE VFS
PRESSURE REGULATOR
FORWARD CLUTCH
MANUAL VALVE
REVERSE BRAKE
TCC PRESSURE REGULATOR
TCC SOLENOID CONTROL
TCC CONTROL VALVE
TCC LOCK-UP: ON
TCC LOCK-UP: OFF
VALVE BODY
LUBRICATION & COOLING

FIGURE 129–7 Block diagram showing the relationship between the TCM, electrical actuators, valve body, and hydraulic actuators for a CVT transmission.

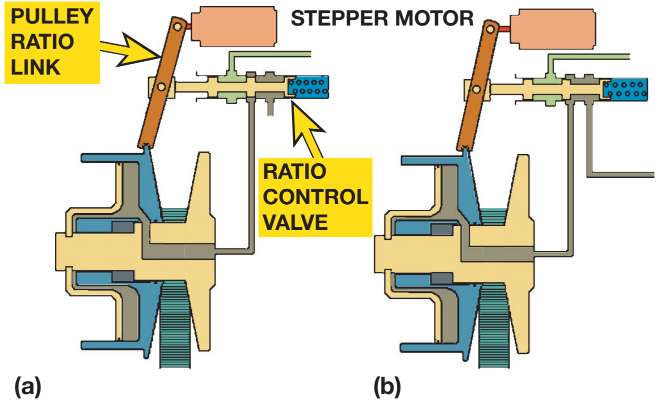

PULLEY RATIO LINK
STEPPER MOTOR
RATIO CONTROL VALVE
(a)
(b)

FIGURE 129–8 (a) The stepper motor and pulley ratio link with the CVT in low ratio. (b) The stepper motor has extended, moving the ratio link and ratio control valve; this should cause the primary pulley to become narrower to produce a higher ratio.

- *Secondary pressure solenoid (SPS)*, which controls the pressure to the secondary pulley system.
- TCC lockup solenoid, which controls the torque converter clutch operation.

The TCM controls the drive ratio to match vehicle needs. It can adjust the ratio during vehicle cruise to produce the maximum fuel economy, lowest emissions, or maximum pulling power. ● **SEE FIGURE 129–9**.

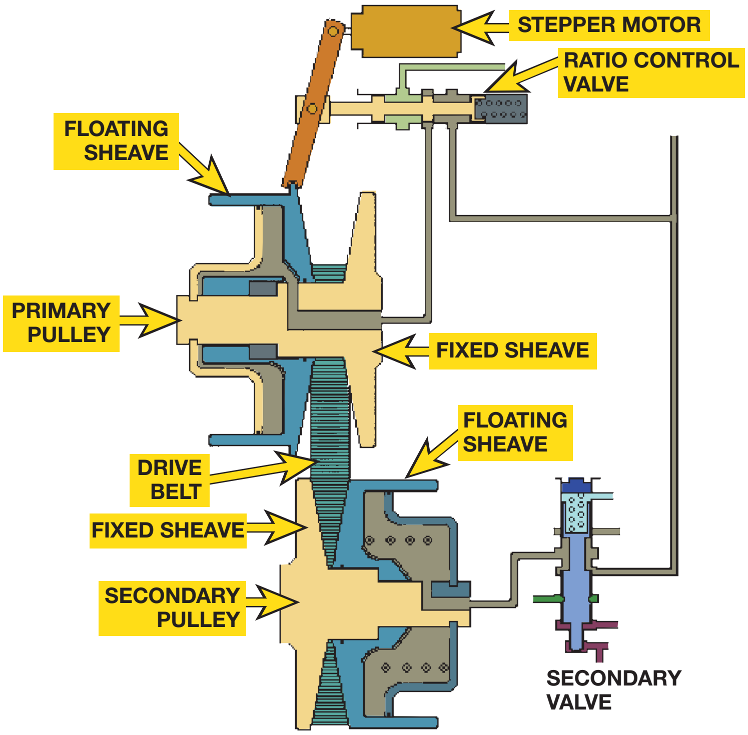

STEPPER MOTOR
RATIO CONTROL VALVE
FLOATING SHEAVE
PRIMARY PULLEY
FIXED SHEAVE
FLOATING SHEAVE
DRIVE BELT
FIXED SHEAVE
SECONDARY PULLEY
SECONDARY VALVE

FIGURE 129–9 Movement of either the stepper motor or primary floating sheave will move the ratio control valve to add or remove fluid from the primary pulley. The secondary valve maintains the necessary pulley pressure on the drive belt.

The TCM also controls fluid pressure to the secondary/driven pulley and torque converter as well as TCC lockup. Some vehicles use predetermined stepper motor position to mimic upshifts and downshifts.

CVT OPERATION

STARTING With no fluid pressure, the secondary pulley spring forces the floating side to a narrow, high-belt position, which in turn moves the primary pulley to a wide, low-belt position. This produces an underdrive that is always used as the vehicle starts moving. Continued fluid flow to the primary piston will change the ratio from an underdrive/reduction through 1:1 to an overdrive.

REVERSE A planetary gear set is needed for reverse-direction operation, and this is a simple planetary with a carrier that can be held by the reverse clutch. The input shaft drives the ring/internal gear, and the sun gear drives the shaft to the primary pulley.

FORWARD OPERATION A forward clutch is mounted on the input shaft from the torque converter; it is mounted inside a clutch drum that also contains the planetary ring gear. When it applies, the forward clutch drives the planetary sun gear so both the sun and ring gears are driven. This locks the gear set to produce a 1:1 ratio.

CVT TORQUE CONVERTER Most CVT transmissions use a low-profile elliptical torque converter with a lockup clutch. Since CVTs are infinitely variable, the torque converter is not needed once the vehicle is moving. Therefore, the converter is used to multiply the torque to get the vehicle moving from a stop, and then becomes a mechanical connection between the engine and the CVT. The torque converter clutch apply will occur at about 12 MPH (20 km/h) and stay locked until the vehicle comes to a stop. Some small vehicles with CVTs do not use a torque converter. The forward and reverse clutches are released for stops and one will be applied to start the vehicle moving.

PRESSURE TESTING A CVT

TYPICAL PRESSURES Measuring the CVT oil pressures is similar to performing pressure testing on conventional automatic transmissions/transaxles. Always check service information for the exact procedures to follow and the location of the pressure tap. ● **SEE FIGURE 129–10**.

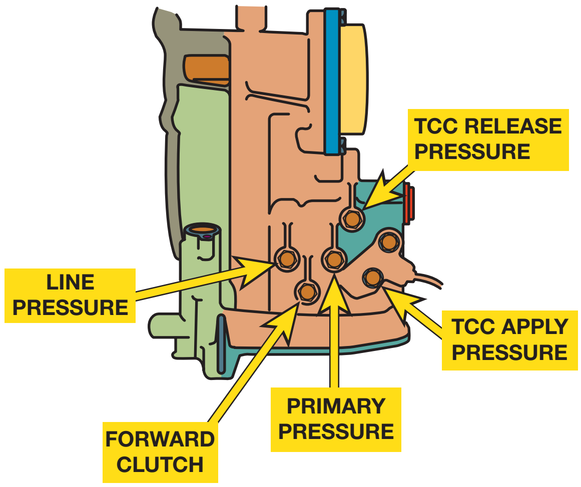


FIGURE 129–10 The pressure tap locations as found on a Dodge Caliber CVT transaxle.

WARNING

The pressure can exceed 1,000 PSI (6,900 kPa) and a leak from the tester could cause personal injury. Always uses a high-pressure gauge and follow the vehicle manufacturer's recommended procedures.

Typical pressures include

- Mainline pressure 70 to 900 PSI (485 to 6,200 kPa)
- Primary pressure 15 to 900 PSI (100 to 6,200 kPa)
- Secondary pressure 15 to 900 PSI (100 to 6,200 kPa)

CVT FLUID

CHECKING CVT FLUID LEVEL A dipstick is used to check the level in some units, and fluid may be poured into the dipstick pipe to bring the level up if it is low. CVT fluid is usually green to help distinguish it from conventional ATF.

CAUTION: Wipe off the dipstick before removing it to prevent any dirt from falling into the fill tube when checking the level of the fluid. Any dirt in the fluid can cause severe damage to the CVT transaxles.

REPLACING CVT FLUID When replacing the CVT fluid, make sure that the specified CVT fluid is used. There is often a drain plug on the transmission pan, and a filler hole located on the transmission case. When refilling the CVT, be sure to check the level regularly to make sure it is not being overfilled. Both the drain and filler plugs should have their gaskets replaced before installing them in their respective holes. Be certain to observe torque specifications when tightening these plugs to prevent damage to the threads in the transmission case and oil pan.

CVT FLUID OPTIONS The shop has two options when filling or replacing CVT automatic transmission fluid:

Option 1. The use of the exact specified fluid as recommended by the vehicle manufacturer is preferred in all cases. A minor disadvantage is that some fluids may be hard to find from local parts suppliers and may have to be purchased from a dealer. ● **SEE FIGURE 129–11**.

Honda Genuine HG
CONTINUOUSLY VARIABLE TRANSMISSION FLUID
ADVANCED PROTECTION
Formulated specifically for Honda vehicles.
CVT
HONDA

FIGURE 129–11 Using the exact fluid recommended by the vehicle manufacturer is the preferred choice when servicing a CVT transaxles.

CASE STUDY

The Case of the Delayed Shift Subaru

The owner of a Subaru Legacy complained that the CVT (TR580) transmission was slow to engage from park to reverse and from drive to reverse. The technician assigned to the vehicle was able to verify that it required as long as four seconds to shift from drive to reverse or from neutral to reverse. After performing a through visual inspection, including a fluid level check, and not finding any issues, a scan tool was used to see if there were any transmission related diagnostic trouble codes. There were none so the technician checked for any technical service bulletins (TSBs) and found one (#16-97-15) that did address the customer complaint. In the TSB, there was a procedure to follow to relearn the TCM, which stated that this should be performed if there is a lag time greater than 1.5 seconds. The technician performed the relearn control procedure that included the following steps:

- Shift into "N" for 5 second, then shift into "R" for 3 seconds, and then shift back into "N". Repeat 10 times.
- Stay in "N" for 5 seconds, then shift into "D" for 3 seconds, and then shift back into "N". Repeat 10 times.

After 10 times, perform the "time lag test" again to confirm if this procedure corrected the customer complain.

The technician was pleased that the relearn procedure did result in a delay time of less than a second. The customer was very pleased too because it did not require an expensive repair.

Summary:

Complaint—Customer complained of excessive time into a drive gear.
Cause—The transmission needed to be relearned.
Correction—The relearn procedure as found in a TSB was used to relearn the shifting of the CVT. ● **SEE FIGURE 129–12**.

FIGURE 129–12 The "fix" to the customer concern was to perform a relearn procedure using the gear selector following the instructions found in a TSB.

Option 2. Use a multi-vehicle fluid, also called *universal CVT fluid,* that is designed to meet the specifications of several different makes and both belts and chains used in CVTs. This is commonly used by many shops and can be successfully used if the fluid is within the specified viscosity and the fluid manufacturer states that it meets the O.E. requirement for friction coefficient.

CVT-RELATED DIAGNOSTIC TROUBLE CODES

For some of the diagnostic trouble codes (DTCs) associated with a CVT transmission and the description, ● **SEE CHART 129–2**.

DUAL-CLUTCH AUTOMATIC TRANSMISSIONS

PURPOSE AND FUNCTION A dual-clutch automatic transmission or transaxle uses a manual-type transmission and two clutches that engage either the inner or outer transmission shaft. This type of transmission is designed to achieve the following goals, compared to a conventional automatic transmission or transaxle equipped with a torque converter and planetary gear sets.

1. Improve fuel economy.
2. Reduce the cost of assembly by using manual transmission components.
3. Improve the speed of gear changes.
4. Provide smoother operation.

TERMINOLOGY A dual-clutch automatic transmission/transaxle can also be referred to as

DIAGNOSTIC TROUBLE CODE (DTC)	DESCRIPTION
P0219	Engine speed excessive—check for speed sensor or transmission slip codes
P0571	Brake switch fault detected
P0707; P0708	TCM detects improper signal from transmission range switch (P0707—signal low; P0708—signal high)
P0711; P0712; P0713	Transmission temperature sensor (TSS) fault detected (P0711—circuit performance; P0711—signal low; P0713— signal high)
P0716; P0717	Transmission input speed sensor (ISS) fault detected (P0716—circuit performance; P0717—no signal)
P0721; P0722	Transmission output speed sensor (OSS) fault detected (P0721—circuit performance; P0722—no signal)
P0730	Incorrect gear ratio detected (transmission slip)
P0746	Line pressure sensor performance issue detected
P0776; P0777	Secondary pressure sensor (SPS) fault detected (P0776—performance fault; P0777—stuck on)
P0842; P0843	Primary oil pressure (POP) sensor fault detected (P0842—sensor circuit low; P0843—sensor circuit high)
P0847; P0848	Secondary oil pressure (SOP) sensor fault detected (P0847—sensor circuit low; P0848—sensor circuit high)

CHART 129–2

Typical continuously variable transmission (CVT) diagnostic trouble codes (DTCs) and code description. Transmission-related DTCs are usually P07XX or P08XX, where XX represents the specific fault code.

- **Direct shift gearbox (DSG)**. Most commonly used by the VW/Audi Group (VAG) of vehicles.
- **Porsche Doppelkupplung (PDK)**. The Porsche term used to describe their dual-clutch automatic.
- **Automated manual transmission (AMT)**. Original term no longer commonly used.
- **Twin clutch transmission**. Another variation of the term used for a dual-clutch automatic transmission.

PARTS AND OPERATION A dual-clutch automatic transmission/transaxle uses two clutches that are mounted together. One clutch drives the odd number gears (first, third, fifth, and seventh). The other clutch drives the even number gears (second, fourth, and sixth). ● **SEE FIGURE 129–13**.

The shifts occur without interrupting the torque from the engine by applying torque to the clutch while at the same time disconnecting the other clutch. These actions result in a rapid shift without the slight delay usually associated with an automatic transmission.

There are two types of clutches used depending on application:

1. Dual dry clutches are used in low powered vehicles, such as small front-wheel-drive vehicles. ● **SEE FIGURE 129–14**.
2. Dual wet clutches are often used in higher powered vehicles.

Vehicles that use a dual-clutch automatic-type transmission /transaxle include certain models of Audi, Nissan, Mercedes, BMW, Porsche, Ford, Ferrari, VW, and Mitsubishi.

ADVANTAGES The advantages of a dual-clutch automatic transmission/transaxle compared to a conventional automatic transmission include

1. Quicker throttle response
2. No drop in engine speed when the driver releases the throttle
3. Instant gear changes
4. Improved fuel economy

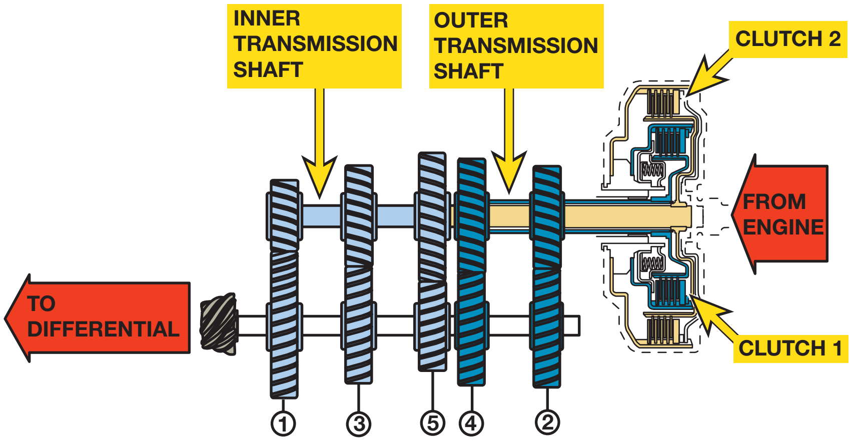


FIGURE 129–13 A dual clutch automatic uses the best features of an automatic transmission without the power loss of a torque converter.

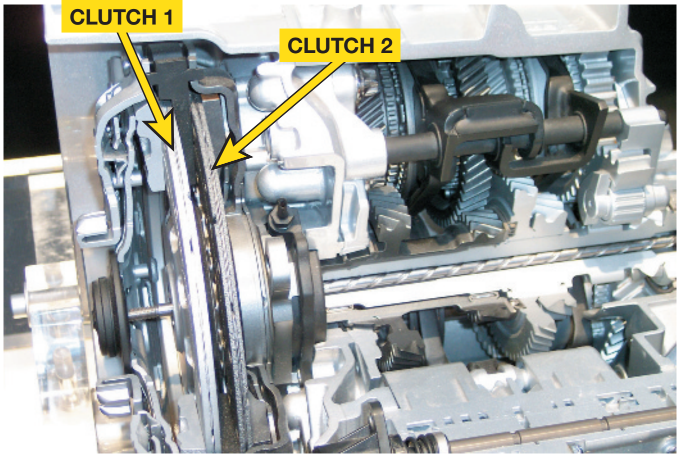


FIGURE 129–14 Dual-clutch automatic transaxles that use two dry clutches. The larger clutch drives the odd number gear ratios (first, third, and fifth) and the smaller clutch drives the even numbered gear ratios (second, fourth, and sixth).

DISADVANTAGES The disadvantages of a dual-clutch automatic transmission/transaxle compared to conventional or continuously variable automatic transmissions include

1. No torque multiplication advantage of a torque converter
2. Not as fuel efficient as a continuously variable transmission (CVT) or transaxle

DUAL-CLUTCH TRANSAXLE

TERMINOLOGY A dual-clutch transaxle is essentially two transmissions built into one case. Each portion is driven by one of the clutches, and these clutches are applied, one at a time, to transfer power. A dual-clutch transmission is essentially an automatic transmission that uses manual transmission-style gear layout and synchronizers with two countershafts. The shifts can occur vary rapidly, being controlled by how fast each clutch can be applied and with partially engaging one clutch while slipping the other during shifts.

CONCENTRIC AND PARALLEL CLUTCH DESIGNS There are two basic wet clutch designs used in dual-clutch automatic transmissions:

1. A **concentric clutch** (also called a *nested-type clutch*) is a design where both plates share the same vertical plane and provide a shorter assembly.
2. A **parallel clutch** design is used in a side-by-side arrangement. ● **SEE FIGURE 129–15**.

GEAR ARRANGEMENTS The 1–3 and 5 synchronizer assemblies are driven by clutch 1 and the 2–4 and 6-reverse synchronizers are driven by clutch 2. Vehicle movement begins with the 1–3 synchronizer shifted to first gear and clutch 1 applied. The 2–4 synchronizer is then shifted into second gear by a hydraulic servo, and the 1–2 upshift will occur when clutch 1 is released and clutch 2 is applied. The remaining upshifts occur in the same manner, with the synchronizer preshifted or shifted early, and the actual shift occurring when the clutches are cycled. ● **SEE FIGURE 129–16**.

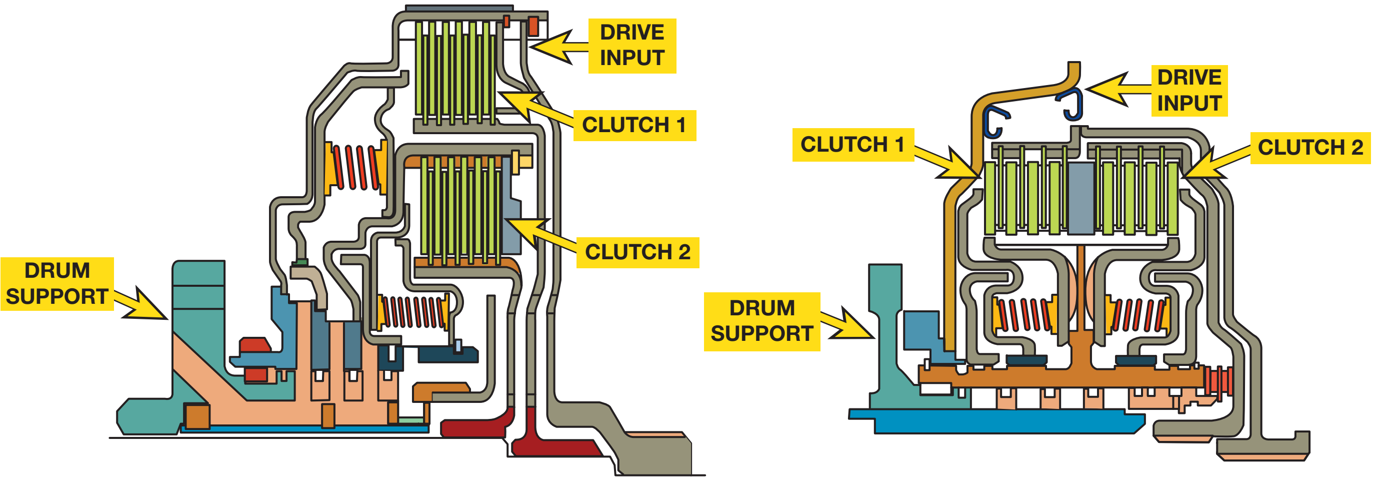
The driver can control the transmission/transaxle using a floor-mounted shift lever or one of a pair of paddles mounted on the steering wheel.

- Clutches 1 and 2 are applied by hydraulic pressure, similar to automatic transmission clutches.

FREQUENTLY ASKED QUESTION

How Does a Dual-Clutch-Type Transmission Achieve Better Fuel Economy?

One of the advantages of a dual-clutch automatic is that it is able to provide improved fuel economy over a conventional torque converter-type automatic. One strategy is to have the unit go into neutral when the vehicle is stopped by disengaging the clutches. This allows the engine to remain running but reduces the load on the engine, which improves fuel economy and reduces vibrations. The clutch is engaged when the driver releases the brake.



(a) (b)

FIGURE 129–15 (a) A concentric (nested) clutch design, the assembly is shorter in length but taller in height. (b) A parallel clutch design is longer but has a smaller diameter drum assembly.

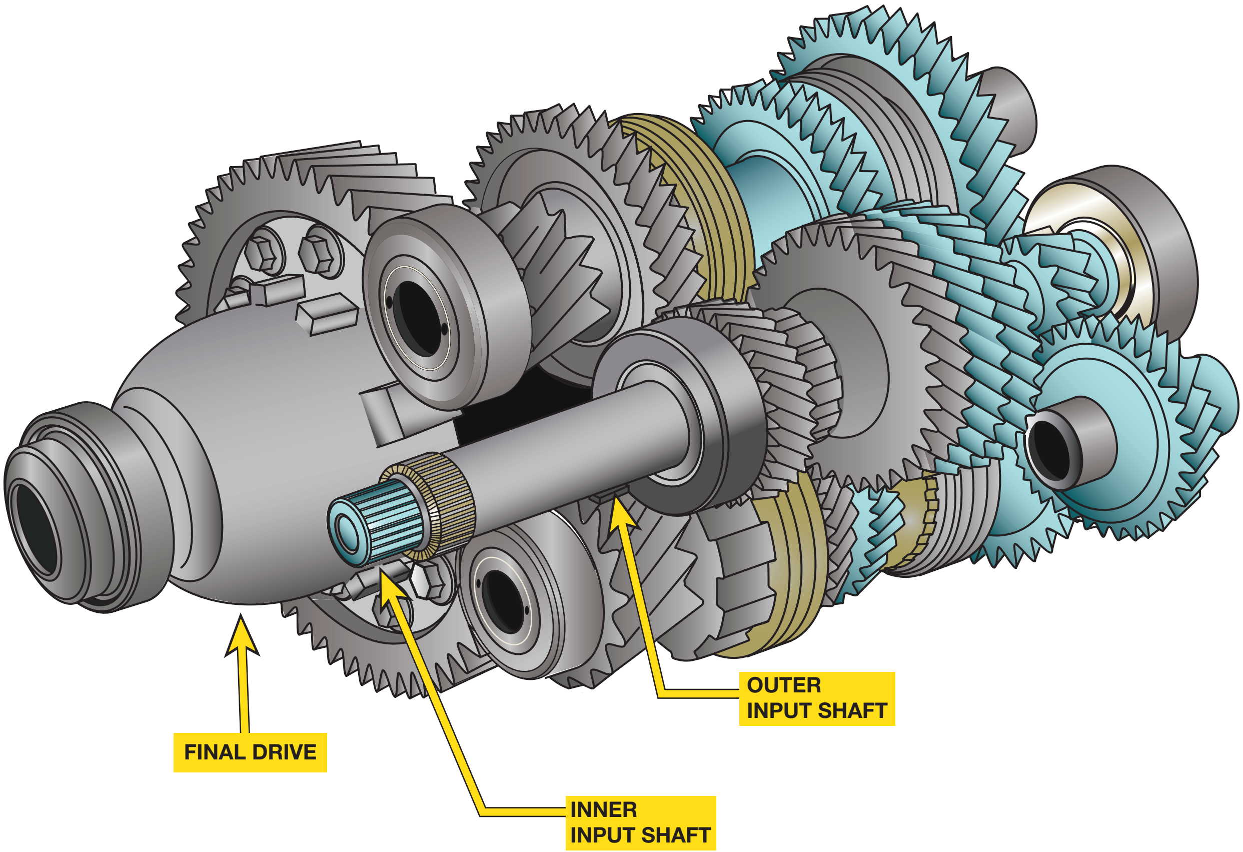


FIGURE 129–16 Notice the two concentric input shafts. Each shaft is splined to a clutch.

- The hydraulic flow to the clutches and servos is controlled electronically by a control module.

SPEED SENSORS Speed sensors include

- **Engine RPM sensor.** Inputs the engine RPM to the TCM from the sensor located on the clutch drum housing.
- **Speed sensor input shaft odd gears.** Gives the TCM information on input shaft RPM (after the C1 clutch) for odd gears, 1, 3, 5, and R.
- **Speed sensor input shaft even gears.** Gives the TCM information on input shaft RPM (after the C2 clutch) for even gears, 2, 4, and 6.

TEMPERATURE SENSORS Temperature sensors include

- **Clutch fluid temperature.** Used to measure the temperature of the fluid leaving the clutches.
- **Transmission fluid temperature.** Used to measure the temperature of the fluid in the transmission.
- **Oil temperature sensor.** Located on the TCM, which provides information on transmission oil temperature.

The TCM uses temperature information to determine correct system pressure, for controlling the clutch, for cold starts, and for overheating protection.

PRESSURE SENSORS Pressure sensors give the TCM information on hydraulic pressure of the clutches. The TCM supplies the sensors with 5 volts. The sensors register the oil pressure to control the clutch pressure so that the TCM can control the solenoids to provide correct clutch pressure for each clutch.

POSITION SENSORS Position sensors include

- *Fork position sensors*—These sensors give the TCM information on the position of the four gear shift forks that handle shifting in the transmission. Includes 1-R; 3-5; 2-4; and 6-N.
- *Transmissions Range Sensor (TRS)*—This sensor provides the actual P R N D gear selection.

The transmission electronic control module uses information from the sensors to determine the proper clutch and shift servo operation. Once the TCM determines the required gear range and driving conditions, actuators are turned on or off to control hydraulic pressure, gear selection, clutch control, and shift lock.

FREQUENTLY ASKED QUESTION

Why Is the TCM Using the Position of the Steering Wheel?

The steering wheel position (SWP) sensor information is sent to the transmission control module (TCM) over the network to prevent the transmission from upshifting when cornering. This helps the driver by allowing the vehicle to be accelerated when exiting a corner. If the steering wheel position was not part of the shift program, the transmission might likely upshift to a higher gear as the vehicle slows, then the transmission may have to downshift again when the vehicle exits the corner.

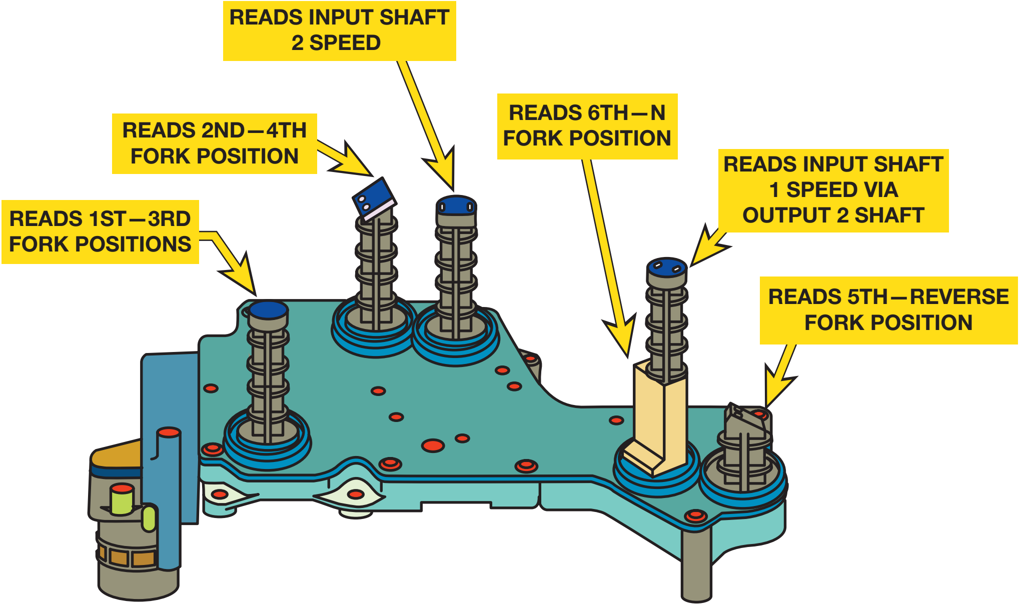

READS INPUT SHAFT 2 SPEED
READS 2ND—4TH FORK POSITION
READS 6TH—N FORK POSITION
READS INPUT SHAFT 1 SPEED VIA OUTPUT 2 SHAFT
READS 1ST—3RD FORK POSITIONS
READS 5TH—REVERSE FORK POSITION

FIGURE 129–17 Fork position and shaft speed sensors are used as inputs to the TCM.

SOLENOIDS A typical dual-clutch automatic transmission/transaxle includes the following solenoids:

- **Line pressure solenoid (LPS)**—Controls system pressure in the transmission by directing the hydraulic oil to clutch, shifting, cooling flow, and then returning the oil to the oil sump.
- **Clutch cooling flow solenoid (CCFS)**—Controls hydraulic oil for cooling of clutches.
- **Shift cooling multiplex solenoid (SHCMS)**—Controls position of gearshift forks as well as cooling of clutch.
- **Clutch shift multiplex solenoid (CSMS1)**—Leads the pressure between odd clutch and shifting, activates odd gears, as well as controls cooling flow for clutches.
- **Clutch shift multiplex solenoid (CSMS2)**—Leads the pressure between even clutch and shifting, controls cooling flow for clutches, and can turn off the valve for dumping clutch pressure.
- **Clutch shift pressure solenoid (CSPS1)**—Controls hydraulic pressure for odd clutch or shifting.
- **Clutch shift pressure solenoid (CSPS2)**—Controls hydraulic pressure for even clutch or shifting.
- **Clutch pressure cut (CPCUT)**—Safety valve that controls pressure dumping in the hydraulic system.
- **Shift select solenoid (SHSS1)**—Controls shifting for gearshift fork 1 and 3.
- **Shift select solenoid (SHSS2)**—Controls shifting for gearshift fork 2 and 4.

SHIFT FORK POSITION The transmission control module (TCM) operates shift solenoids. These pistons apply force to the shift forks through lever points to help increase the force applied. Both an even and an odd gear can be commanded at the same time in parallel. Position sensors are located inside the case, and this information is used by the TCM to determine the actual position of each shift fork. ● **SEE FIGURE 129–17**.

DIAGNOSIS AND SERVICE

DIAGNOSTIC PROCEDURES To diagnose faults with dual clutch automatic transmission/transaxle systems, follow the recommended procedures found in service information. The usual procedure involves the following steps:

STEP 1 Verify the customer concern (complaint). This step includes trying to duplicate what the customer or driver is concerned about.

STEP 2 Perform a thorough visual inspection, including

- Checking the level and condition of the fluid
- Checking the drivetrain mounts for damage or faults

STEP 3 Check service information for the specified procedure to follow. Most vehicles require the use of a factory-brand scan tool. ● **SEE FIGURE 129–18**.

FIGURE 129–18 The use of a factory or a factory-level aftermarket scan tool is often needed to diagnose the dual clutch transmission system.

STEP 4 Follow the troubleshooting procedure as specified to fix the root cause of the problem. This means following the instructions displayed on the scan tool or service information.

STEP 5 Repair the fault.

STEP 6 Road test the vehicle under the same conditions that were performed to verify the fault to ensure that the repair is completed.

TYPICAL DIAGNOSTIC TROUBLE CODES As part of any diagnostics, checking for diagnostic trouble codes is one of the first steps. ● **SEE CHART 129–3** for some examples of dual-clutch automatic transmission-related DTCs.

FLUID AND FILTER SERVICE The transmission fluid is usually high-quality synthetic oil, which is unique for this type of transmission. Dual-clutch transmission fluid is usually green to help identify it as a unique fluid and prevent someone from using conventional automatic transmission fluid. Always use the specified fluid.

For example, the Ford Dry Dual Clutch Fluid is specifically formulated for use in the DPS6 power shift twin dry clutch transmission. This fluid is used only in transmissions requiring a fluid meeting WSS-M2C200-D2.

Most dual-clutch automatic transmissions/transaxles use an external filter that is serviceable and an internal filter that is a nonserviceable part unless the unit is totally disassembled. Always follow the vehicle manufacturer's recommended fluid and filter service intervals.

P0715	Input shaft 1 (odd number gear axle) speed sensor system (output high range out)
P0716	Input shaft 1 (odd number gear axle) speed sensor system (poor performance)
P0717	Input shaft 1 (odd number gear axle) speed sensor system (output low range out)
P0746	Line pressure solenoid system (drive current range out)
P0753	Shift select solenoid 1 system (open circuit)
P0758	Shift select solenoid 2 system (open circuit)
P0776	Clutch cooling flow solenoid system (drive current range out)
P0842	Clutch 1 pressure sensor system (output low range out)
P0960	Line pressure solenoid system (open circuit)

CHART 129–3

Selected dual-clutch transmission-related diagnostic trouble codes.

REVIEW QUESTIONS

1. What is the advantage of a CVT compared to a regular six-speed transmission?
2. What are the types of belts used in a CVT?
3. What controls the movement of the variator?
4. What are the disadvantages of a dual-clutch automatic transmission?
5. What sensors are used in a typical dual-clutch automatic transaxle?

CHAPTER QUIZ

1. How is a variable ratio achieved in a CVT?
   a. By using multiple gears
   b. By using a steel belt with two variable-width pulleys
   c. By using a start clutch assembly
   d. By using a variable-torque converter
2. Measuring the oil pressure on a CVT is similar to performing pressure testing on ___________.
   a. an engine
   b. a conventional automatic transmission
   c. a manual transmission
   d. an air-conditioning system
3. CVT transmission-related DTCs are usually ___________, where XX represents the specific fault code.
   a. P03XX
   b. P04XX
   c. P05XX
   d. P07XX or P08XX
4. Which of these is NOT part of the CVT electronic control system?
   a. Input speed sensor
   b. Ratio control motor
   c. Line pressure solenoid
   d. Shift solenoids
5. The recommended fluid to use in a CVT is usually ___________.
   a. Dexron VI ATF
   b. specific CVT fluid
   c. Mercon V or Dexron VI
   d. Any of the above depending on the specific unit
6. All of the following are advantages of a dual clutch automatic transmission/transaxle *except* ___________.
   a. instant gear changes
   b. no torque multiplication advantage of a torque converter
   c. quicker throttle response
   d. improved fuel economy

7. A dual dry clutch system is used in what type of vehicle?
- **a.** Small front-wheel drive
- **b.** Heavy rear-wheel drive
- **c.** All-wheel-drive trucks and SUVs
- **d.** High-power front-wheel drive

8. A concentric clutch is ____________.
- **a.** a type of wet clutch
- **b.** a type of dry clutch
- **c.** also called a nested-type clutch
- **d.** Both a and c

9. DTC position sensors include____________.
- **a.** fork position
- **b.** transmission range
- **c.** Both a and b
- **d.** Neither a nor b

10. Service and diagnostic procedures for a dual clutch transmission/transaxle include____________.
- **a.** checking service information for the specified procedure to follow
- **b.** using only the specified fluid
- **c.** using a scan tool to retrieve any diagnostic trouble codes
- **d.** All of the above

Chapter

130

HYDRAULIC COMPONENTS AND CONTROL SYSTEMS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the different types of automatic transmission fluid.
- Explain the function of automatic transmission fluid coolers.
- Explain the function of transmission oil pumps.
- Explain the function of apply/holding devices.
- Discuss bands.
- Discuss multi-plate clutches.
- Discuss accumulators.
- Discuss one-way clutches.
- Explain the construction of a valve body.
- Explain electronically controlled transmissions.
- Discuss the typical torque flow in these transmissions.

KEY TERMS:

Apply devices 1650 • Automatic transmission fluid (ATF) 1647 • Balance valve 1649 • Check balls 1656 • Clutch drum 1652 • Clutch pack 1652 • Default gear 1659 • Electronic pressure control 1649 • Force motors 1649 • Holding devices 1650 • Integral accumulator 1654 • Limp-in gear 1659 • Lube oil 1648 • Manual valve 1656 • Multiple-plate clutch 1652 • One-way clutch 1654 • One-way valve 1656 • Pressure control 1649 • Pressure control solenoids 1649 • Pressure plate 1652 • Pressure regulator valve 1649 • Reaction member 1651 • Separator plate 1655 • Servo 1651 • Sprags 1654 • Transmission band 1651 • Valve body 1654 • Variable force solenoids (VFS) 1649 • Worm holes 1655 • Worm tracks 1655

AUTOMATIC TRANSMISSION FLUID

PURPOSE AND FUNCTION **Automatic transmission fluid (ATF)** is a highly refined oil with a viscosity similar to SAE 20W-20 oil and is specially designed for use in an automatic transmission. Newer ATFs are lower in viscosity and are similar to SAE 0W-10 oil. The purposes and functions of ATF are as follows:

- Transfers power in torque converter
- Provides hydraulic pressure in clutches and servos
- Lubricates bearings, bushings, and gears
- Transfers heat to cool transmission parts
- Provides the correct friction for clutch and band application
- Acts as the medium to control transmission shifting by traveling through passageways, acting on valves, and being directed by solenoids

TYPES The three basic types of ATF include

1. **Non-friction modified.** The first ATF did not have friction reducing additives. This type of fluid was used in early band-type automatics (all first generation). Type F ATF is an example of a non-friction-modified ATF.
2. **Friction modified.** Friction-modified ATF types include Dexron.
3. **Highly friction modified.** All current original equipment manufacturers use automatic transmission fluids that are highly friction modified. These include Dexron VI, Mercon V, ATF + 4, and ATF WS. Friction modifiers added to the ATF, along with hydraulic devices (orifices and accumulators) and electronic controls, help produce "proper shift quality."

TYPICAL ATF APPLICATIONS Automatic transmission fluid is formulated to work in specific transmissions. Using the specified fluid is the key to proper operation. Check service information for the exact automatic transmission fluid to use.

AUTOMATIC TRANSMISSION FLUID COOLER

PURPOSE AND FUNCTION The torque converter generates a great amount of heat because of fluid shear as its internal elements spin at different speeds in relation to each other. The greatest amount of heat is generated when the vehicle is operating under a heavy load and the torque converter clutch is disengaged. The ATF can reach high temperatures (over 250°F [120°C])

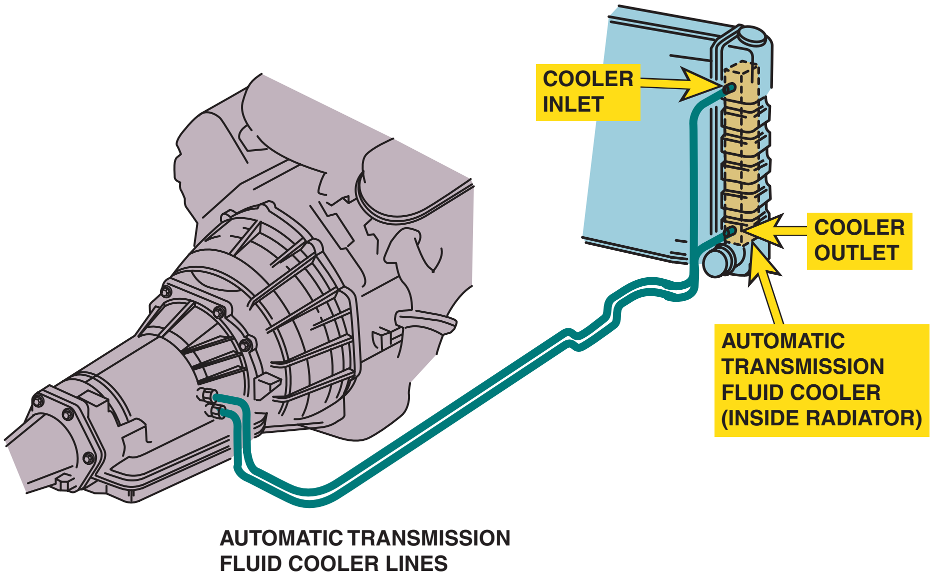

COOLER INLET
COOLER OUTLET
AUTOMATIC TRANSMISSION FLUID COOLER (INSIDE RADIATOR)
AUTOMATIC TRANSMISSION FLUID COOLER LINES

FIGURE 130–1 Automatic transmission fluid is routed from the torque converter, where most of the heat is generated, to the radiator where it is cooled. The fluid then returns to the transmission/transaxle to lubricate the bearings and bushings.

very quickly, which is why an automatic transmission fluid cooler is used. Most vehicles use a small section of the engine cooling system radiator to transfer heat from the ATF to the coolant, which cools the ATF.

PARTS AND OPERATION Automatic transmissions/transaxles use a pump to circulate ATF and provide the necessary hydraulic flow to operate the hydraulic components of the unit. The ATF is pumped (directed) from the torque converter (greatest source of heat) to the cooler when the torque converter clutch is not applied. The ATF flows through the cooler, which has the following characteristics:

- It is a separate section of the radiator tank.
- The hotter transmission fluid gives up heat to the cooler engine coolant.
- Some manufacturers use a *cooler bypass valve* that will allow fluid to bypass the cooler if restricted. Some vehicles also use a temperature controlled valve to block the flow of fluid during low-temperature operation such as is used in Dodge (Ram) trucks.
- Many vehicles with towing packages use a larger cooler or a combination of a liquid-to-liquid and a liquid-to-air cooler in series with each other to handle the extra heat load of towing.

The ATF returns to the transmission/transaxle to passages that lubricate the internal moving parts. This returned fluid is called **lube oil**. ● **SEE FIGURES 130–1 AND 130–2**.

CAUTION: Because the lube oil uses the ATF flowing from the cooler, if there is a blockage in the cooler, the transmission/transaxle may not have enough fluid flow to properly cool or lubricate the bearings and bushings inside the unit, leading to wear and eventually premature failure.

TRANSMISSION FLUID HEATER The cooler is located in the radiator in most vehicles and, as a result, the coolant will also warm the ATF when the temperatures are cold. Some vehicles are equipped with a transmission fluid heater that uses the coolant to warm the fluid when it is cold. Warm fluid works better than cold fluid to lubricate moving parts inside the unit. ● **SEE FIGURE 130–3**.

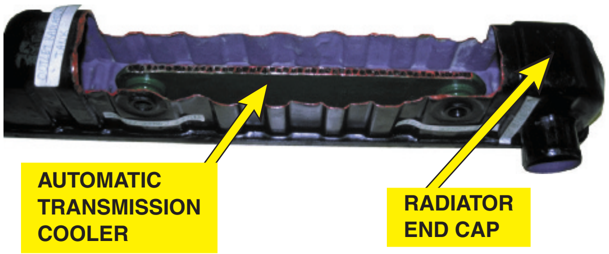


FIGURE 130–2 A cutaway of a typical radiator showing the automatic transmission cooler. The heat from the automatic transmission fluid is released to the engine coolant. The engine coolant also warms the fluid as soon as the coolant flows through the radiator.

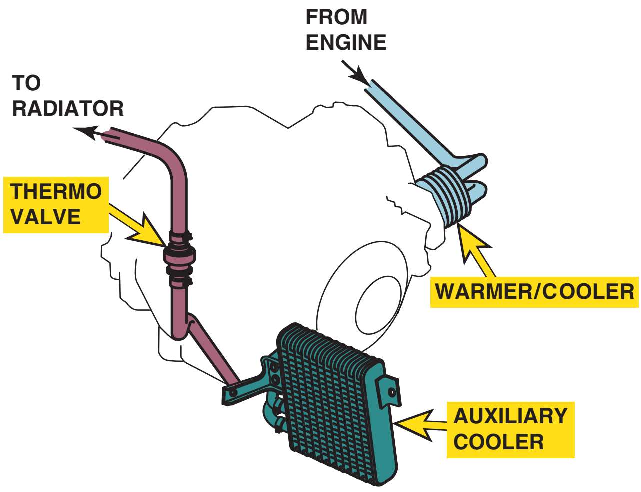


FIGURE 130–3 Engine coolant from the engine block flows through the passages in the cooler/warmer, and then out through the thermo valve to the upper radiator tank. The thermo valve uses a wax element–type valve to control the flow of engine coolant through the case-mounted cooler/warmer. The thermo valve improves the ATF warm-up times and maintains ATF temperature within the optimum operating range between 170° and 190°F (77°and 88°C)

TRANSMISSION OIL PUMP

PURPOSE AND FUNCTION Every hydraulic system requires a *pump* to supply fluid flow and pressurize the system. However, the pump itself does not develop pressure but instead pressure occurs when there is a resistance to flow. Initially, fluid flows freely when a hydraulic circuit is empty or partially filled. Once the circuit is completely full, there is a resistance to further flow. At this point, pressure begins to build up in the circuit as the pump continues to create flow.

PARTS AND OPERATION Most oil pumps mount directly behind the torque converter and are usually driven by the converter drive hub. This connects the pump to the engine and allows it to respond quickly to engine demand. This type of oil pump operates whenever the engine is running. ● **SEE FIGURE 130–4**.

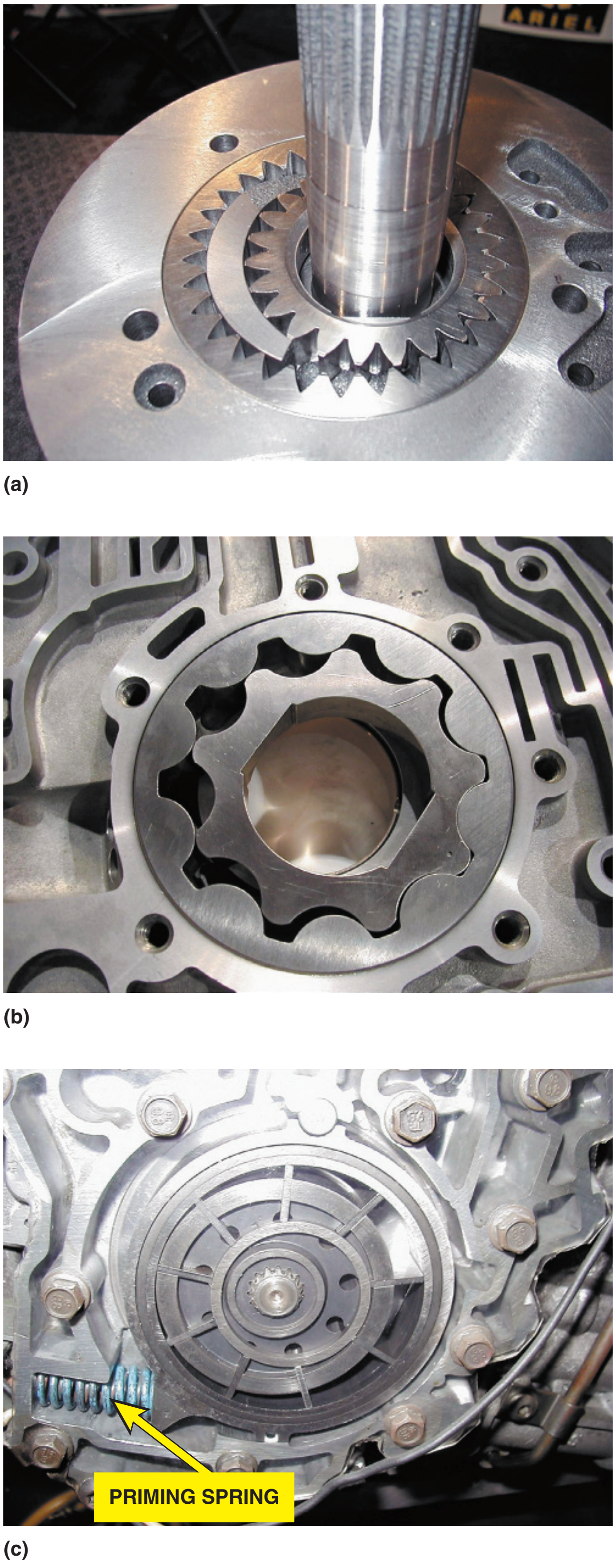


FIGURE 130–4 (a) Gear-type pump. (b) Gerotor-type pump. (c) Vane-type pump.

PRESSURE REGULATION Transmission oil pumps are capable of creating an excessive amount of pressure quickly; therefore, every transmission uses a **pressure regulator valve**, or *pressure control valve,* to control hydraulic pressure. This is usually a spool valve and spring combination. This regulated pressure, commonly known as *mainline pressure,* is the working pressure for the entire hydraulic system. Most pressure regulator valves balance pump pressure on one side of the valve against a preset spring force acting on the other side of the valve.

When hydraulic pressure is greater than the spring force, the valve moves in its bore far enough to uncover an exhaust port. ● **SEE FIGURE 130–5**.

The exhaust port provides a low-pressure path to the transmission oil pan (sump) where excess ATF is stored. Excess pressurized fluid flowing through this port reduces system pressure. When hydraulic pressure drops below spring pressure, the regulator valve closes the port and pressure begins to build up again.

In operation, the opening and closing of the exhaust port occurs many times per second. This sequence of events achieves a steady pressure as the valve balances both the spring pressure and the hydraulic pressure. Because of this action, this type of valve is sometimes called a **balance valve**.

VARIABLE DISPLACEMENT PUMP Many newer automatic transmissions and transaxles use a variable displacement pump to reduce the power needed to achieve fluid pressure to the amount required instead of being based on pressure alone. The use of a variable displacement pump helps improve fuel economy and reduce exhaust emissions. ● **SEE FIGURE 130–6**.

ELECTRONIC PRESSURE REGULATION Electronic automatic transmissions/transaxles often regulate hydraulic system pressure using computer-controlled solenoids called any of the following:

- **Pressure control solenoids (PCS)**
- **Electronic pressure control (EPC)**
- **Pressure control (PC)**
- **Variable force solenoids (VFS)**
- **Force motors**

An onboard computer switches the solenoids on and off very quickly using pulse-width modulation (PWM). The solenoid pushes against an internal valve, which opens and closes the hydraulic circuit it regulates. **Electronic pressure control** allows precise hydraulic system pressure regulation and can also be used to modify the timing and feel of transmission shifting. ● **SEE FIGURE 130–7**.

TYPICAL PRESSURES Line pressure is controlled by the powertrain control module (PCM) or the transmission control module

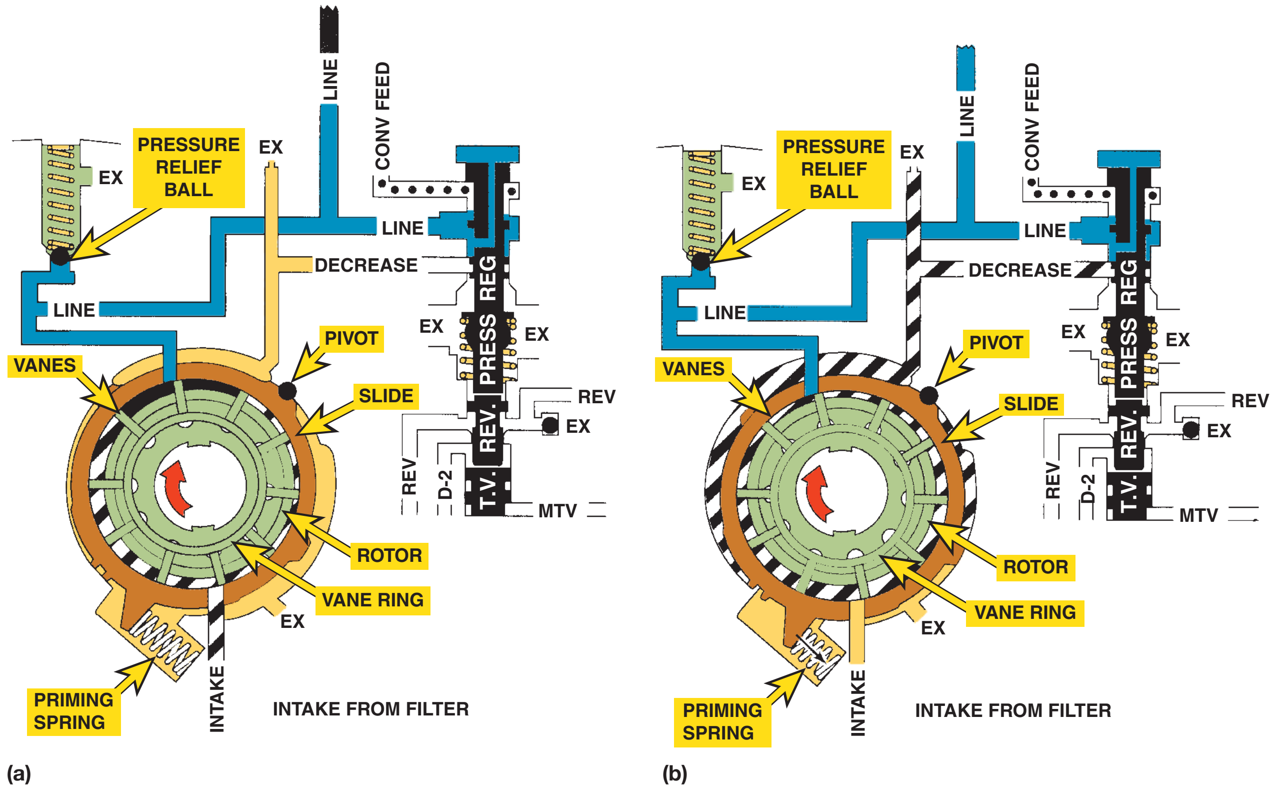

PRESSURE RELIEF BALL
EX
EX
LINE
CONV FEED
LINE
DECREASE
LINE
VANES
PIVOT
SLIDE
EX
EX
PRESS. REG
REV.
T.V.
REV
EX
REV
D-2
MTV
ROTOR
VANE RING
EX
PRIMING SPRING
INTAKE
INTAKE FROM FILTER
(a)
(b)

FIGURE 130–6 The variable pump is at the maximum output position (a) until the regulator valve moves enough to decrease volume by rotating the slide against the force of the priming spring (b). The position of the pump constantly varies depending on the needs of the transmission/transaxle and the driving conditions.

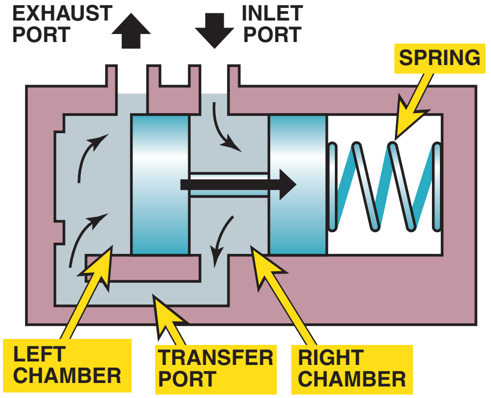

EXHAUST PORT
INLET PORT
SPRING
LEFT CHAMBER
TRANSFER PORT
RIGHT CHAMBER

FIGURE 130–5 When pressure on the face of the pressure regulator valve overcomes spring force, the valve moves to open the exhaust port.

(TCM) to provide the specific pressure needed by the system based on input from the sensors such as vehicle speed and engine load. Line pressure is reduced to improve fuel economy because lowering pressure reduces draw on the engine, which is driving the pump.

Typical line pressures include

- Normal line pressure = 60 to 120 PSI (414 to 830 kPa)
- The accelerator pedal pressed to wide open throttle (WOT) = 90 to 150 PSI (620 to 1,304 kPa)
- The gear selector in reverse or manual low (1) = 150 to 300 PSI (1,034 to 2,068 kPa)

Higher pressures are necessary in reverse because these apply devices are usually smaller and or have fewer clutch plates to ensure that the clutches are firmly applied, in order to avoid slippage when the engine is producing maximum torque.

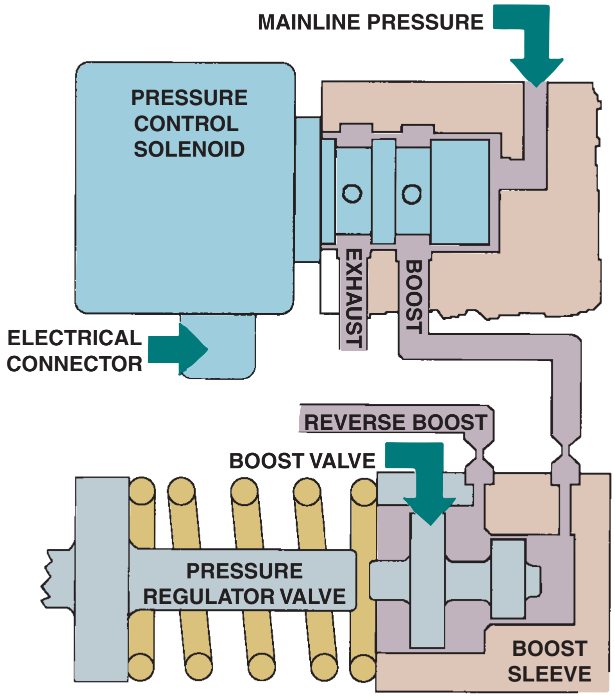

MAINLINE PRESSURE
PRESSURE CONTROL SOLENOID
EXHAUST
BOOST
ELECTRICAL CONNECTOR
REVERSE BOOST
BOOST VALVE
PRESSURE REGULATOR VALVE
BOOST SLEEVE

FIGURE 130–7 The pressure control solenoid controls the mainline pressure, which is in turn controlled by the powertrain control module (PCM) or the transmission control module (TCM), by applying pressure to the spring side of the pressure regulator valve.

APPLY OR HOLDING DEVICES

PURPOSE AND FUNCTION **Apply devices** or **holding devices** are the mechanical or hydraulic assemblies that provide the force to hold or drive members of a planetary gear set.

Automatic transmissions typically use the following as apply devices:

- Transmission bands
- Multiple-plate clutches
- One-way clutches

BANDS

TERMINOLOGY Transmission bands are holding (braking) devices. The planetary gear set member held is known as a **reaction member**. A **transmission band** stops and holds one planetary gear set member so that another member can react against the held member and develop output motion. The reaction member has a control surface for the band to ride on, known as a drum. The band directly affects the drum, and the drum directly affects the planetary gear set member. ● **SEE FIGURE 130–8**.

The band provides a holding force around the outside of the drum, closing tightly to keep it from turning. To repeat, a transmission band is a holding device and is not capable of driving any member of the planetary gear set.

Transmission bands are made of cast iron or steel with friction material lining on the inside surface. Transmission design and component size dictate the type and size of band used. Bands fall into one of two categories:

- Single wrap
- Double wrap

The single-wrap band is a simple one-piece design, while the double-wrap band is a split band with overlapping ends. Bands may also be classified as either flexible or fixed, depending on how well they hold their shape when they are off the drum. ● **SEE FIGURE 130–9**.

HYDRAULIC SERVOS A band is applied by using a hydraulically operated piston that travels inside a machined cylinder bore.

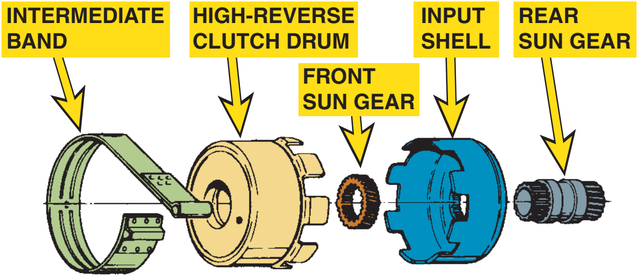


FIGURE 130–8 Gear set members are attached to a drum and are held stationary when the band applies.

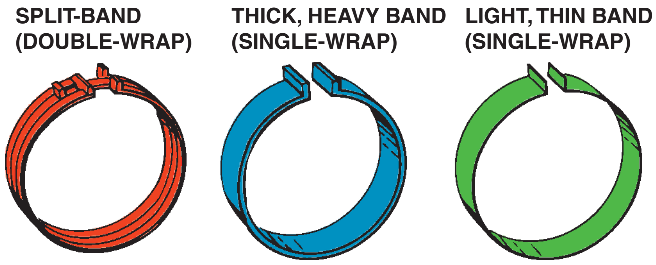

SPLIT-BAND (DOUBLE-WRAP)
THICK, HEAVY BAND (SINGLE-WRAP)
LIGHT, THIN BAND (SINGLE-WRAP)

FIGURE 130–9 Transmission bands come in several designs and thicknesses.

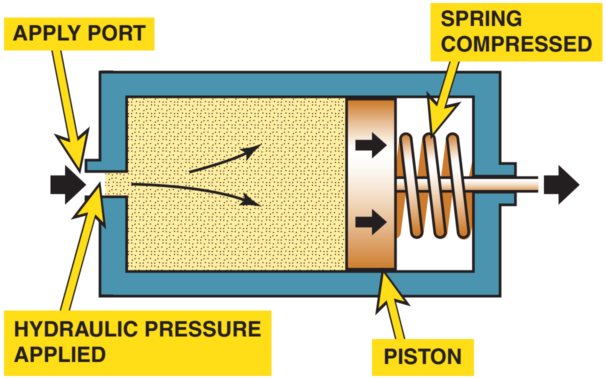


FIGURE 130–10 A servo uses hydraulic pressure to move a piston, which applies a band.

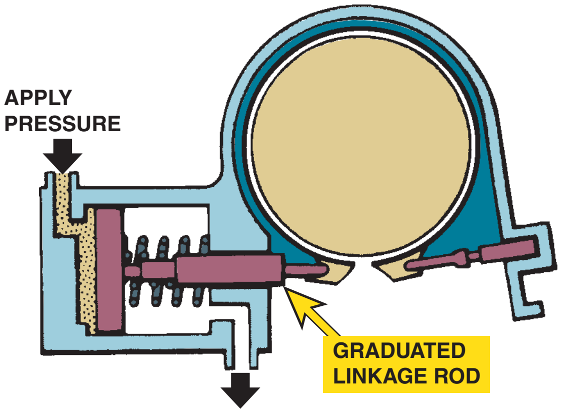


FIGURE 130–11 One end of a band is held stationary and the other end is attached to the servo.

This piston and cylinder assembly is known as a **servo**. ● **SEE FIGURE 130–10**.

A piston return spring normally holds the servo piston in its unapplied position. To apply the band, hydraulic fluid, under pressure, enters the servo cylinder and acts on the piston. The piston begins moving once hydraulic pressure overcomes spring force.

SERVO LINKAGES A mechanical rod, called a *strut,* and linkage attaches to the piston and connects it to the band. As the piston moves, the linkage applies the band by tightening it around the drum. Servo *rods* and *struts* transfer the servo apply force to the transmission band. Rods are round metal bars and struts are flat metal plates. These may be used at either or both ends of the band. Linkages connect the band to the servo or an anchor. One end of a band is often anchored to the transmission case and whenever the band is applied, the drum that the band wraps around is held from rotating. ● **SEE FIGURE 130–11**.

NOTE: Some bands have a provision for adjustment and may be adjusted in vehicle while others are adjusted or set during transmission assembly.

MULTIPLE-PLATE CLUTCHES

TERMINOLOGY Like a transmission band, a multiple-plate hydraulic clutch is a type of apply device. Clutches have more friction area so they can develop more force and handle more torque than a band, and they are self-adjusting.

PARTS The **multiple-plate clutch** consists of plates, a piston, drum (retainer), and snap ring. Hydraulic pressure acts upon the clutch piston, which moves in the drum. The piston movement compresses the plates together to provide either a holding or driving function. When the pressure is released, the piston returns to an unapplied position via a return spring assembly. The entire assembly is commonly known as a **clutch pack**. ● **SEE FIGURE 130–12**.

The plates of a multiple-plate clutch assembly consist of a friction plate alternated with steel plates.

- A friction plate, also called simply a *friction,* has a rough surface friction material applied to both faces. The friction (clutch lining) material is made from a mixture of natural and synthetic fiber. Natural fibers include cotton or wood (paper), and synthetic fibers are aramid (Kevlar®) or carbon. The exact mixture is determined by the transmission engineer to provide the desired heat resistance and durability standards.
- A steel plate, also called simply a *separator plate* or *steel,* has a smooth, flat surface finish with no friction material.
- Some transmissions may not have separate frictions and steels but rather combine them. One side of the plate will be coated with the frictional surface while the other side is flat metal like the steels.
- Collectively, the friction and steel plates are called clutch plates.

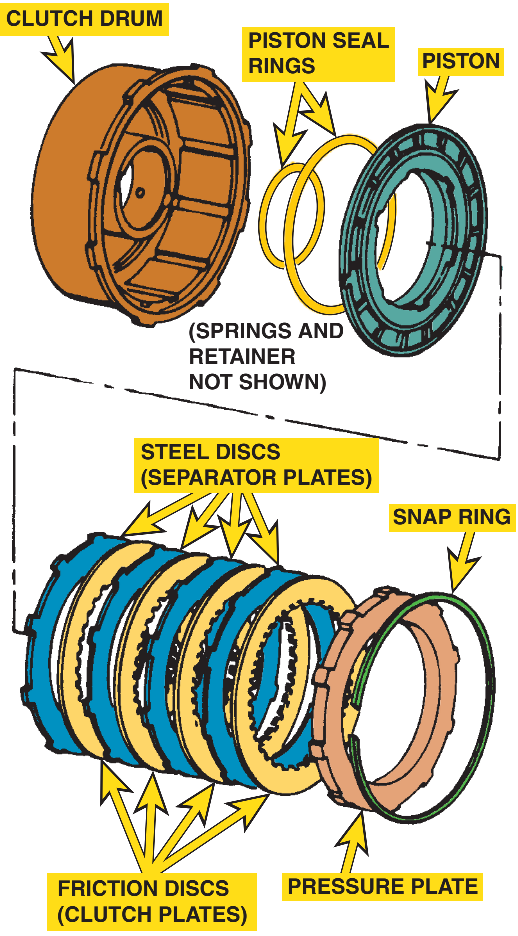

CLUTCH DRUM
PISTON SEAL RINGS
PISTON
(SPRINGS AND RETAINER NOT SHOWN)
STEEL DISCS (SEPARATOR PLATES)
SNAP RING
FRICTION DISCS (CLUTCH PLATES)
PRESSURE PLATE

FIGURE 130–12 An exploded view of a multiple-plate clutch pack assembly.

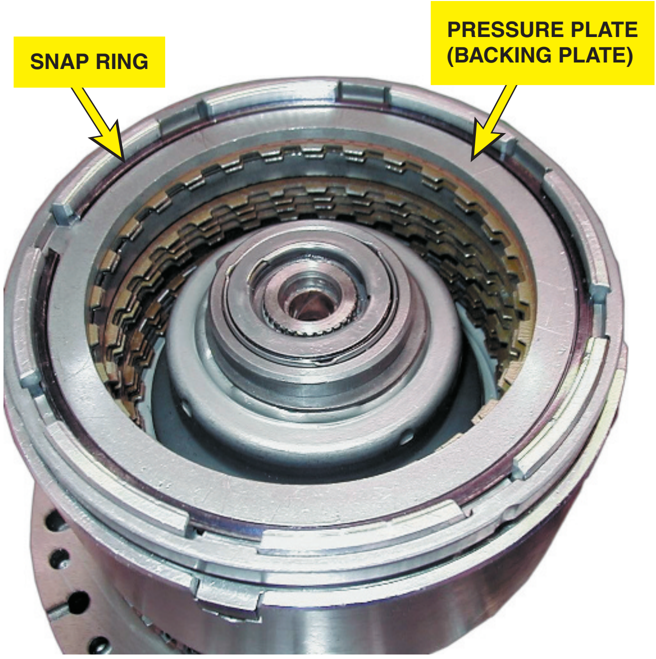


FIGURE 130–13 A typical clutch pack assembly.

Generally, the steel plates have splines on their outer edge, while the friction plates have splines on their inner edge. Each set of splines engages matching splines on a

- Shaft
- Drum
- Planetary gear set member or
- Transmission case

The piston compresses the clutch plates against a thicker reaction plate known as the **pressure plate**. Pressure plates may be used at one or both ends of the clutch pack and are available in selective (specific) sizes for adjusting clutch pack clearance. The pressure plate and clutch assembly components fit into either a **clutch drum** (retainer) or a machined bore in the transmission case. Snap rings retain all the clutch assembly components and are available in selective (specific) sizes for adjusting clearance. ● **SEE FIGURE 130–13**.

Some transmissions use a special wave-type spring to return the piston and cushion clutch applications. The piston returns to an unapplied position via a return spring assembly. These springs are designed to return the piston to the released position when apply fluid pressure is removed from the clutch pack. The two types of springs commonly used are the coil spring and the Belleville spring.

CLUTCH OPERATION To apply the clutch, pressurized fluid enters the drum through an internal passage in the input shaft. When the clutch applies, hydraulic pressure acting on the piston squeezes the two sets of plates together to mechanically connect the two components that engage the splines of the plates.

The fluid acts on the piston and moves it against return spring force to clamp the clutch plates together and hold them against the pressure plate. ● **SEE FIGURE 130–14**.

The friction between the plates then locks the clutch drum to the hub, causing them to turn as one unit.

To release the clutch, hydraulic fluid to the apply side of the piston is cut off and exhausted through an exhaust port. The piston return springs, which were compressed when the clutch was applied, are now free to expand and move the piston back, allowing the clutch plates to disengage.

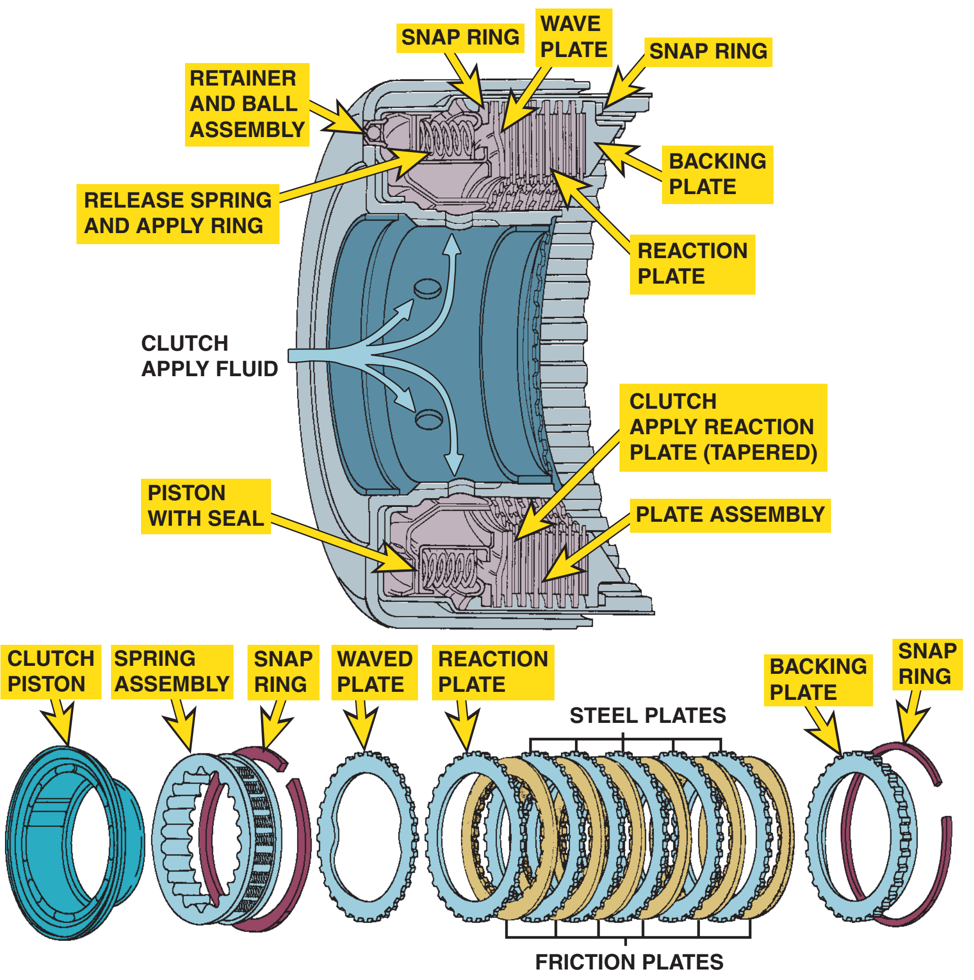

SNAP RING
WAVE PLATE
SNAP RING
RETAINER AND BALL ASSEMBLY
RELEASE SPRING AND APPLY RING
BACKING PLATE
REACTION PLATE
CLUTCH APPLY FLUID
CLUTCH APPLY REACTION PLATE (TAPERED)
PISTON WITH SEAL
PLATE ASSEMBLY
CLUTCH PISTON
SPRING ASSEMBLY
SNAP RING
WAVED PLATE
REACTION PLATE
STEEL PLATES
BACKING PLATE
SNAP RING
FRICTION PLATES

FIGURE 130–14 Hydraulic fluid under pressure enters the clutch housing and exerts a force on the clutch piston. The clutch piston forces the steel plates and the friction plates together, creating a shift.

TWO TYPES OF CLUTCHES Although a multiple-plate clutch is an apply device similar to a transmission band, it differs from a band because it can also be used to drive members of planetary gear sets as well as hold them. There are two types of multiple-plate clutches.

1. **Holding (braking) clutches.** A clutch contains frictions discs which are splined to one member and the steel disc are splined to another member of a planetary gearset. When the clutch is applied, the friction surfaces are clamped or held together keeping whatever the clutch plates are splined to from rotating. ● **SEE FIGURE 130–15**.
2. **Driving clutches.** There are two types of multiple-plate driving clutches, and both types are commonly used in automatic transmissions. In one configuration, splines connect a set of friction plates to the transmission input shaft so that these plates function as the driving member. The alternating set of steel plates is splined to the inside of the clutch drum and serves as the driven member. When the clutch is released, the drive plate rotates with the input shaft, but they do not drive the driven plate that splines to the drum.

   When the clutch applies, the piston takes up clearance and forces both sets of plates firmly together. Now, the input shaft and drum rotate together at the same speed and torque transfers from one gear set member to another. A passageway carries fluid to the clutch apply piston.

   With the second driving clutch configuration, the drum connects directly to the input shaft so the drum always rotates with the shaft. Splines connect the steel plate to the

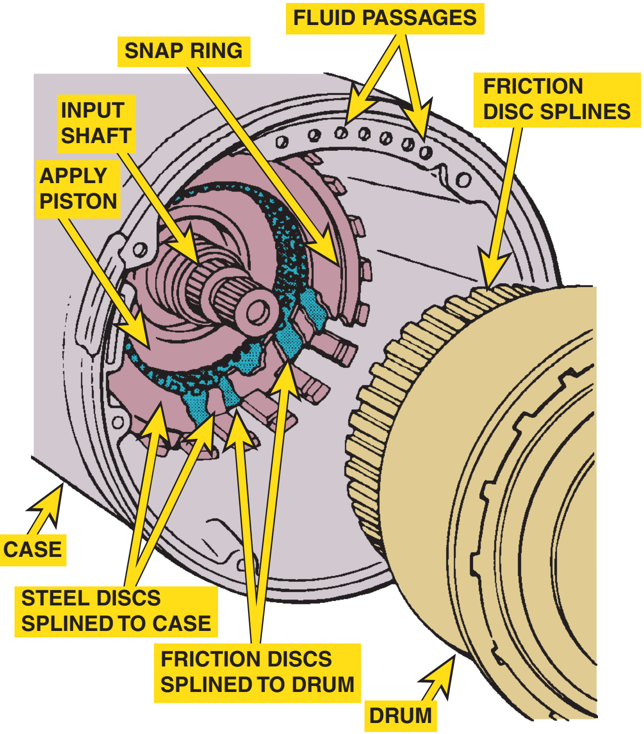

FLUID PASSAGES
SNAP RING
FRICTION DISC SPLINES
INPUT SHAFT
APPLY PISTON
CASE
STEEL DISCS SPLINED TO CASE
FRICTION DISCS SPLINED TO DRUM
DRUM

FIGURE 130–15 In a holding clutch, one set of discs engages splines on the transmission case and the other set engages splines on the drum. By applying the clutch, the drum is locked to the case.

inside of the drum and the friction plate to the outside of a clutch hub. When the clutch applies, hydraulic pressure compresses the clutch pack to lock the drum and clutch hub together. The input shaft then drives the output shaft and both turn at the same speed.

ACCUMULATORS

PURPOSE AND FUNCTION An accumulator cushions or dampens the apply force during a shift. An accumulator reduces hydraulic pressure surges by temporarily diverting part of the fluid flow in a hydraulic circuit into a parallel circuit or chamber. Accumulators can be described as "hydraulic shock absorbers" because they absorb or reduce the shock of engagement of the clutch or band. The diversion allows pressure in the main apply circuit to increase gradually and provides a smooth engagement of the band or clutch.

Piston-type accumulators look and function much like servo pistons. In fact, some piston-type accumulators share a bore with one of the transmission servos. This common bore design is known as an **integral accumulator**. ● **SEE FIGURE 130–16**.

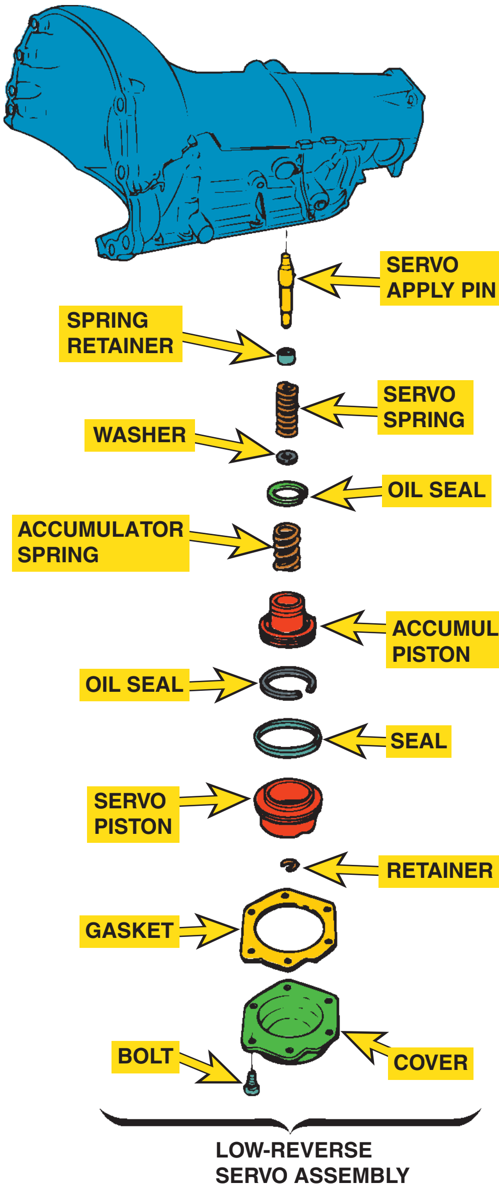


FIGURE 130–16 An integral accumulator is combined with a servo in a single bore in the transmission housing.

OPERATION As hydraulic pressure enters both circuits, the clutch piston or band servo piston starts to move first. Once the clearance is taken up and resistance increases, the circuit pressure increases. This is when the accumulator piston starts to dampen the clamping force and time of the apply device. The accumulator piston area and spring are designed to absorb fluid during the clutch circuit pressure rise when the clutch piston stops moving. The result of this dampening action results in a slight increase in the clutch application. When the time is increased between the initial clutch application and complete application of the clutch, the result is a smoother shift.

NOTE: Accumulators are disappearing in modern, electronic transmissions due to adaptive learning. The PCM or TCM measures the shift time, and if it is too long or too short, it will raise or lower line pressure so shift time matches the programming.

ONE-WAY CLUTCHES

TERMINOLOGY Another common type of automatic transmission device is the **one-way clutch (OWC)**, or overrunning clutch. Like a transmission band, a one-way clutch is always a holding device. One-way clutches are either roller or sprag clutches, although the roller clutch is more common.

ONE-WAY ROLLER CLUTCH A one-way roller clutch consists of a hub, rollers, and springs that fit inside a drum. The inner circumference of the drum has a series of machined ramps, or cam cuts, to accommodate the rollers and springs. Each ramp is narrower at one end than at the other.

If the drum is held while rotating the hub clockwise, the rollers will compress their springs and move toward the larger end of the ramps. This unlocks the clutch because there is enough clearance between the rollers and the drum for the hub to freewheel.

Rotate the hub counterclockwise while holding the drum. The rollers move toward the narrow end of the ramp, wedging themselves between the hub and drum to lock the clutch. With the rollers at the narrow end of the ramp there is no roller-to-drum clearance. Therefore, the hub cannot turn counterclockwise because the drum is being held. ● **SEE FIGURE 130–17**.

ONE-WAY SPRAG CLUTCH A **one-way sprag clutch** that consists of a hub and a drum separated by a number of figure-eight-shaped metal pieces called **sprags**. ● **SEE FIGURE 130–18**.

Sprags lock and unlock the clutch in a manner similar to the rollers in a one-way roller clutch. The shape of a sprag provides two effective working lengths. The direction the sprag tilts determines if working length is short or long.

NOTE: Some one-way clutches, either roller or sprag types, can be installed in a transmission or transaxle upside down by mistake. The transmission will not work correctly and will require that the unit be removed and disassembled again. Also check service information on how the one-way clutches should be installed.

VALVE BODY

PURPOSE AND FUNCTION A **valve body** is where most of the valves in a transmission are located and is attached to the case with bolts. Valve bodies can be either cast aluminum or cast iron. The valve body in most rear-wheel-drive transmissions is located

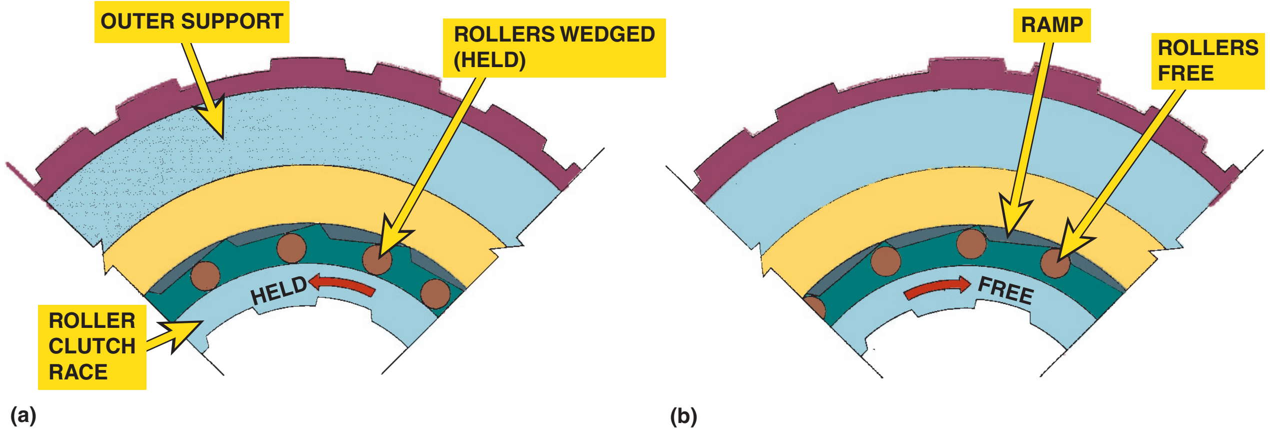

OUTER SUPPORT
ROLLERS WEDGED (HELD)
HELD
ROLLER CLUTCH RACE
(a)
RAMP
ROLLERS FREE
FREE
(b)

FIGURE 130–17 (a) Roller one-way clutch in the locked (held) position. Note how the rollers are wedged into the ramp that is machined into the outer support. (b) Roller one-way clutch in released (free) position. When the inner roller clutch race rotates faster than the outer support, the rollers move out of the wedge and are free to rotate, thereby unlocking the one-way clutch.

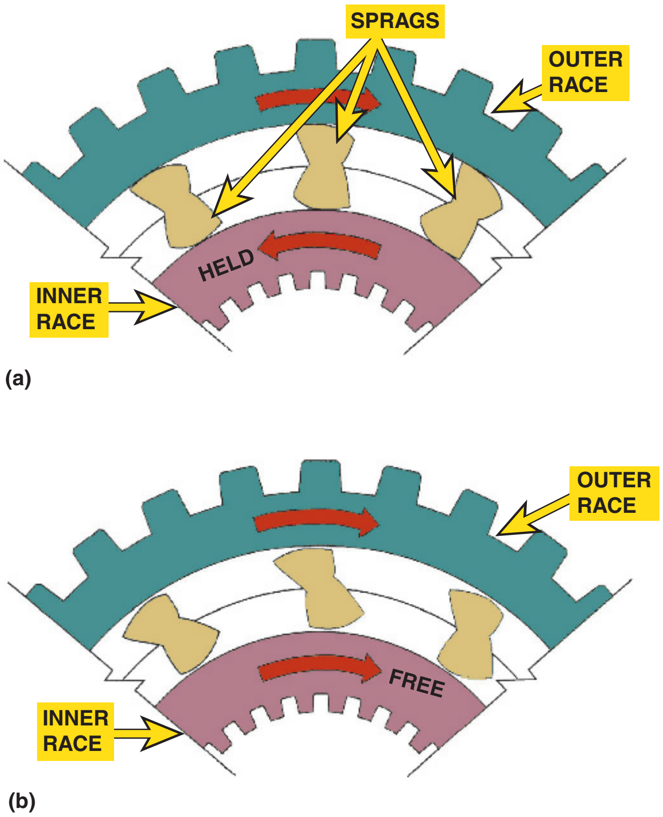

SPRAGS
OUTER RACE
HELD
INNER RACE
(a)
OUTER RACE
FREE
INNER RACE
(b)

FIGURE 130–18 (a) The sprag in the holding (locked) position. Note how the long portion of the sprag is wedged between the inner and outer race. (b) The sprag in the released position. The inner race is free to rotate faster than the outer race.

inside the oil pan at the bottom of the case. A transaxle valve body may be at the bottom of the case, on the backside of the torque converter housing, or on the top or side of the transaxle housing depending on the specific application. ● **SEE FIGURE 130–19.**

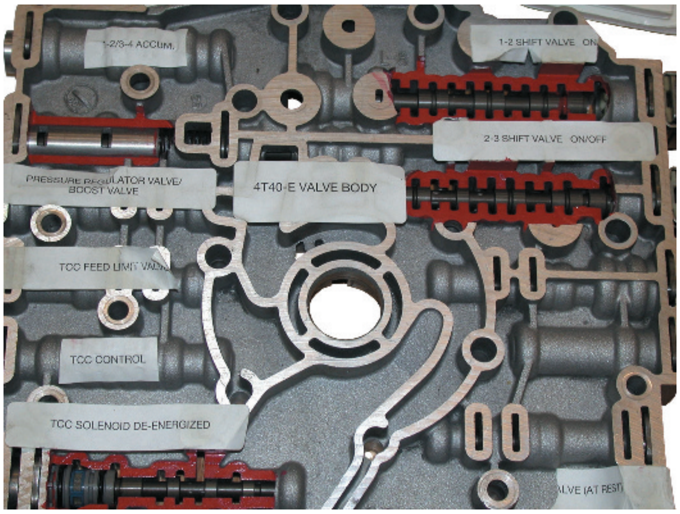

1-2/3-4 ACCUM.
1-2 SHIFT VALVE ON
2-3 SHIFT VALVE ON/OFF
PRESSURE REGULATOR VALVE/ BOOST VALVE
4T40-E VALVE BODY
TCC FEED LIMIT VALVE
TCC CONTROL
TCC SOLENOID DE-ENERGIZED
LVE (AT REST)

FIGURE 130–19 A partially cutaway valve body from a General Motors 4T40-E transaxle.

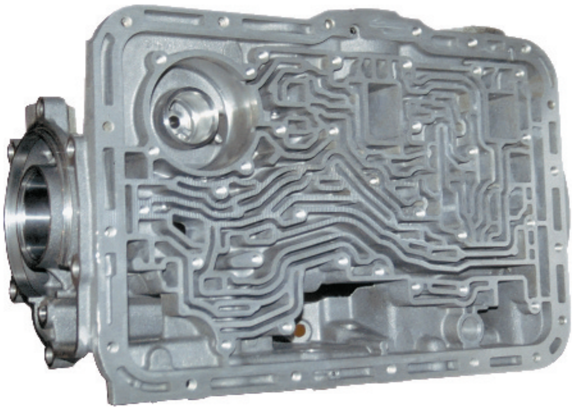


FIGURE 130–20 A typical upper valve body showing the fluid passages ("worm holes").

PARTS Valve bodies have many fluid passages for the various transmission hydraulic circuits cast into them. These are sometimes called **worm holes** or **worm tracks**. ● **SEE FIGURE 130–20.**

Some of these passages may be widened to form pockets that contain steel, nylon, or rubber check balls. Most valve bodies consist of two or more cast sections that bolt together with a flat metal separator plate between them. The upper section of the valve body is part of the transmission case casting. The **separator plate**, also called a *spacer plate,* provides rigidity and contains calibrated holes and openings that help manage fluid flow. Valve bodies contain specialized valves and circuits that are particular to a specific transmission. Electronic solenoids are used in place of some valves on electronically controlled transmissions/transaxles. Some transmissions/transaxles incorporate the TCM right on the valve body. This eliminates the wire harness between

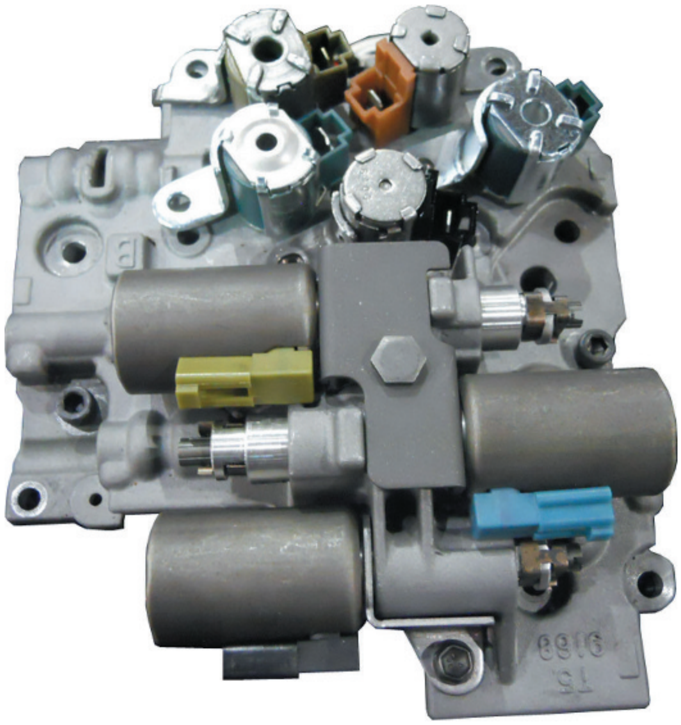


FIGURE 130–21 Electronically controlled automatic transmissions/transaxles use solenoids located in the valve body to control line pressure and to open and close passages in the valve body to control shifts.

the TCM and the solenoids, which in turn eliminates connector problems. ● **SEE FIGURE 130–21**.

FLOW-DIRECTING VALVES Flow-directing valves, or switching valves, control the direction and distribution of fluid flow in the hydraulic system. These valves may open or close passages, fill hydraulic circuits, apply or release clutches and bands, and control the direction of fluid flow from one passage or circuit to another.

ONE-WAY VALVES A **one-way valve** allows fluid to flow in one direction. The spring-loaded ball check valve is an example of a one-way valve. Valve operation is similar to that of a poppet valve. The spring holds the ball against its seat at the inlet port until fluid pressure overcomes spring force to push the ball from its seat. Fluid flows through the valve as long as hydraulic pressure exceeds the force of the spring.

Spring-loaded ball check valves are used as pressure-relief valves, and work well on bypass circuits because they provide a fast apply rate with a slow release. A second type of one-way valve is a simple gravity valve, as commonly used in transmission valve bodies.

CHECK BALLS The **check balls** in these valves are usually made of steel, but they can be nylon, rubber, or some composite material as well. The type of material used depends on the manufacturer and application. Steel balls generally hold up better, but cause greater seat wear because of their hardness. The softer composite balls are easier on seats and cannot be magnetized. ● **SEE FIGURE 130–22**.

ORIFICES Orifices are holes in the separator plate and are used for several reasons, including

- To control the rate of fluid movement and timing of clutch/accumulator application (shift feel)

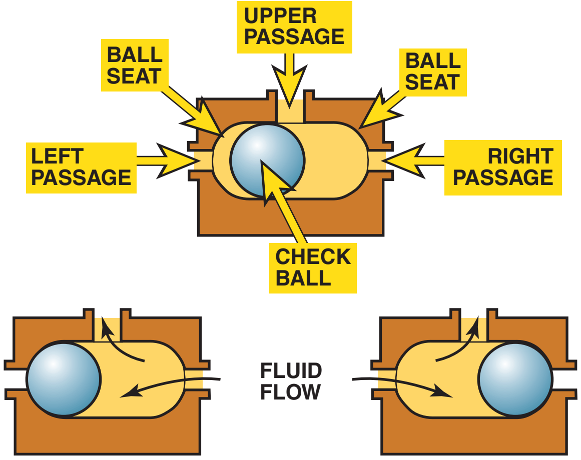


FIGURE 130–22 Check balls are used in the valve body to allow hydraulic circuits to share a common passage.

- To separate hydraulic circuits inside the transmission, so a big leak in one circuit will not cause pressures to drop in the rest of the transmission as well

MANUAL VALVE The **manual valve** is the primary flow-directing valve in an automatic transmission. This valve connects to a shift lever in the transmission, which in turn connects to the gear selector lever through a mechanical linkage. The driver controls manual valve position through the gear selector and shift linkage.

Mechanical linkage physically positions the manual valve in its bore for the particular gear range selected. The part used to position the manual valve is commonly called the “rooster comb” because of its shape. ● **SEE FIGURE 130–23**.

The manual valve receives mainline pressure from the regulated pump output and distributes it to the hydraulic circuits uncovered by the valve lands.

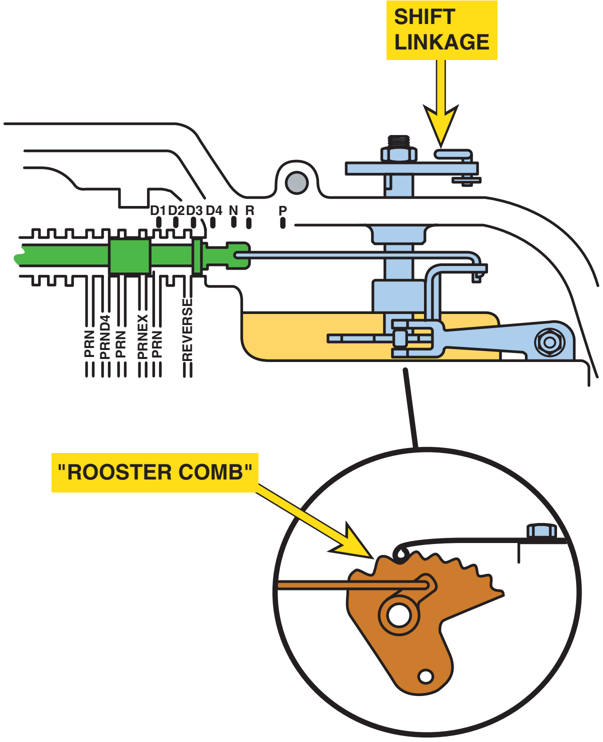


FIGURE 130–23 A rooster comb is the detent that helps retain the manual valve in the various positions in the valve body.

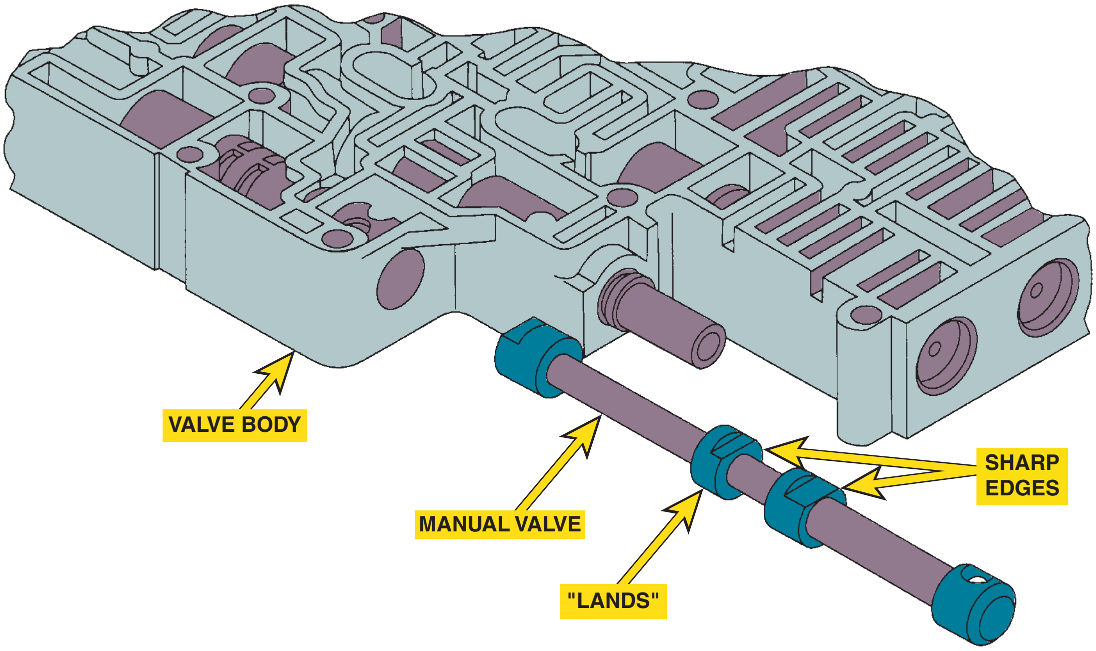


FIGURE 130–24 The manual valve is a spool valve that is moved by the shift linkage. All valves in the valve body have sharp edges on the lands. Any dirt in the valve body area can cause shifting problems due to the close tolerances between the valves and the bores in the valve body.

FREQUENTLY ASKED QUESTION

What Is a Spool Valve?

A spool valve is named after a spool of thread. A spool of thread is wooden and a spool valve used in an automatic transmission/transaxle is aluminum or steel. The ridges (larger diameter) of the spool valve fit closely into a smooth bore in the valve body and are used to direct the flow of automatic transmission fluid.

- The larger diameter sections of the spool valve are called *lands*.
- The smaller diameter sections of the valve are called *grooves or valleys*.
- The fluid is blocked by the lands and flows through the grooves or valleys. ● **SEE FIGURE 130–24**.

ELECTRONICALLY CONTROLLED TRANSMISSIONS

BACKGROUND Electronically controlled transmissions and transaxles have been used by most vehicle manufacturers since the early 1990s. Compared to hydraulically controlled units, using the powertrain control module (PCM) or the transmission control module (TCM) to operate and control shifting results in smoother operation. Also, the PCM or TCM can monitor the circuits and set a diagnostic trouble code if a fault is detected.

NOTE: All transmissions use hydraulic pressure and automatic transmission fluid to do the actual shifting. The difference between hydraulically controlled and electronically controlled automatic transmissions is the way that the shift points are controlled.

INPUTS The following are inputs to the powertrain control module (PCM) and their purposes:

- **Transmission range switch.** This sensor is used by the PCM to detect the gear being commanded by the driver. If reverse or a manual forward gear is selected, then higher line pressure will be needed and the shifts will be delayed to provide more power being delivered to the drive wheels. ● **SEE FIGURE 130–25**.
- **Engine speed.** The speed of the engine has a direct relation to the amount of power the engine is developing. The engine speed information is taken from the crankshaft position (CKP) sensor and is used by the PCM or TCM to control shift points and regulate line pressure.
- **Throttle position (TP) sensor.** This sensor is used by the PCM to detect the throttle opening being commanded by

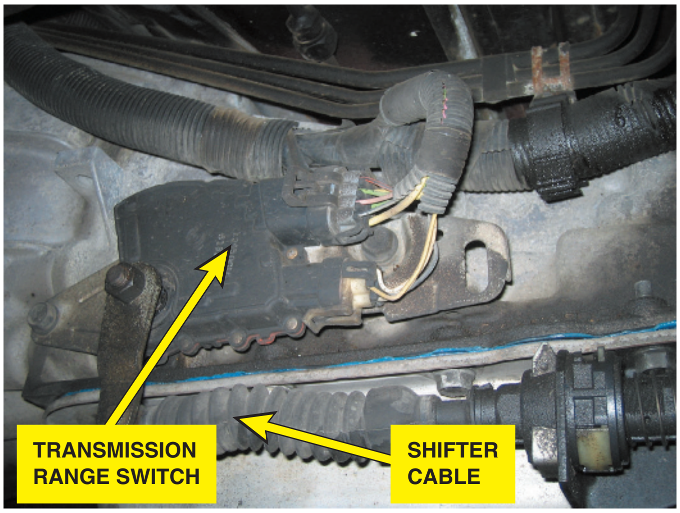


FIGURE 130–25 A transmission range switch on a rear-wheel-drive automatic transmission mounted directly to the side of the case of the unit and accessible from underneath the vehicle.

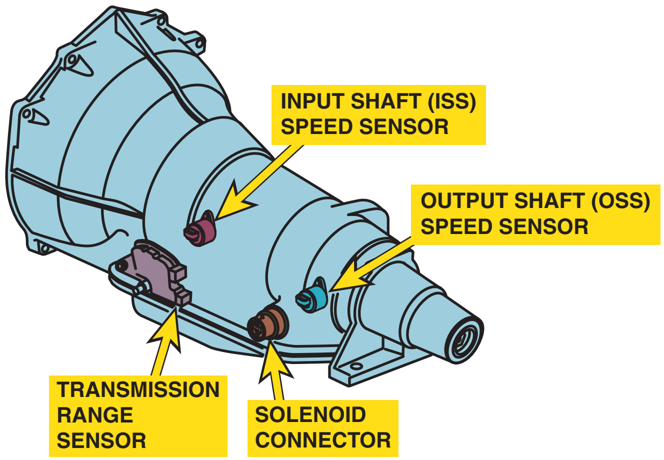

INPUT SHAFT (ISS) SPEED SENSOR
OUTPUT SHAFT (OSS) SPEED SENSOR
TRANSMISSION RANGE SENSOR
SOLENOID CONNECTOR

FIGURE 130–26 Speed sensors are used by the powertrain control module (PCM) or the transmission control module (TCM) to control shifts and detect faults such as slippage when the two speeds do not match the predetermined ratio for each gear commanded.

the driver. A higher throttle opening means that higher line pressure will be needed and the shifts will be delayed to provide more power being delivered to the drive wheels.

- **Manifold absolute pressure (MAP) sensor.** This sensor is used by the PCM to detect the amount of load on the engine. The greater the load, the more fuel that needs to be supplied, and the greater the amount of power the engine will create. This signal is used to determine the best shift points and regulate line pressure.
- **Mass airflow (MAF) sensor.** This sensor is used by the PCM to detect the amount of air entering the engine. The greater the amount of air, the more fuel that needs to be supplied and, therefore, the greater the amount of power the engine will create. This signal is used to determine the best shift points and regulate line pressure.
- **Speed sensors.** These sensors measure the speed of the input shaft and output shaft or sometimes other shaft speeds in the automatic transmission or transaxle. The output shaft speed sensor is often used to provide vehicle speed information to the PCM and for adaptive learning and self-diagnosis. ● **SEE FIGURE 130–26**.
- **Transmission fluid temperature (TFT) sensor.** This sensor is used by the PCM or TCM to detect the temperature of the automatic transmission fluid. This signal is used to determine the best shift points and regulate line pressure. It will cause the PCM or the TCM to engage the torque converter clutch (TCC) sooner and disable overdrive, to help reduce the fluid temperature if it reaches higher than normal.

OUTPUTS Outputs to the powertrain control module (PCM) or transmission control module (TCM) and their purposes include the following:

- **Pressure control.** The PCM or TCM controls the line pressure by changing the signal to the pressure control solenoid. Using the input signal to detect the conditions that the vehicle is being driven, the specified line pressure is commanded to provide smooth shifts without slippage.

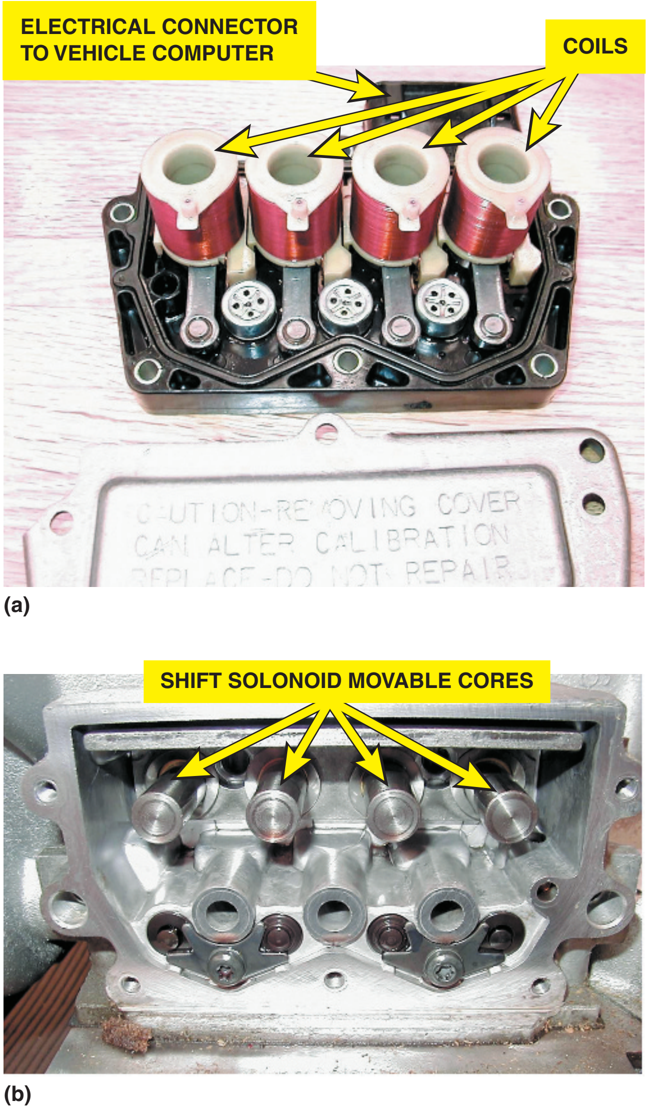


FIGURE 130-27 (a) An example the shift solenoids installed in a valve body assembly, showing the coils and (b) the solenoid cores.

- **Shift control solenoids.** The PCM or TCM controls the shifting by applying power or ground to the correct control solenoid(s) at the right time. ● **SEE FIGURE 130–27**.
- **Torque converter clutch (TCC).** The PCM or TCM controls the application of the torque converter clutch (TCC) by applying power or ground to the correct control solenoid at the right time.

ADAPTIVE LEARNING Most late model electronically controlled automatic transmissions/transaxles use the PCM or TCM to monitor the time it takes to complete a shift. The PCM can determine this from the comparison between the engine speed and the output speed sensor data. When a shift is commanded, there should be a change in the speed of the output shaft. If the change in speed is longer than normal, which could indicate normal wear in the clutch pack, the PCM can learn from this and start the shift sooner to allow time for the clutch to be fully engaged.

SHIFT SOLENOIDS Solenoids used in electronically controlled automatic transmissions/transaxles are

- **On-off solenoids.** These can be normally open to fluid flow or normally closed to block fluid flow.

They are commanded on or off by the PCM or TCM. The resistance of most on-off shift solenoids is 10 to 15 ohms.

- **Linear solenoids.** This type of solenoid can be varied by changing the amount of on time to precisely control the fluid flow through the solenoid valve. The variable power or ground applied to the linear solenoids is pulse-width modulated (PWM) and allows the PCM precise control over the shifting and the fluid pressure. The resistance of most linear (PWM) shift solenoids is about half of the on-off type and ranges from 4 to 6 ohms.

Shift solenoids control the pressure force, which in turn controls the position of the shift valve. Shift solenoids may be labeled 1 and 2 or A and B. Using a combination of the two shift solenoids prevents the actuation of four forward gears.

A **default** (or **limp-in**) **gear** is the forward speed that is used if there is a failure in the electronic or computer system. If neither solenoid is engaged, then either second or third gear is actuated, depending on the exact make and model of the transmission or transaxle. ● **SEE CHARTS 130–1 AND 130–2** for examples of two General Motors transmissions.

GENERAL MOTORS 4T60-E (FRONT-WHEEL-DRIVE TRANSAXLE)		
GEAR RANGE	**SOLENOID A**	**SOLENOID B**
First gear	On	On
Second gear	Off	On
Third gear	Off	Off
Fourth gear	On	Off

CHART 130–1

In this example, the vehicle would start out and remain in third gear if there was a fault with the computer or wiring.

GENERAL MOTORS 4L80-E (REAR-WHEEL-DRIVE TRANSMISSION)		
GEAR RANGE	**SOLENOID A**	**SOLENOID B**
First gear	On	Off
SecOnd gear	Off	Off
Third gear	Off	On
Fourth gear	On	On

CHART 130–2

In this example, the vehicle would start out and remain in second gear if there was a fault with the computer or wiring.

TECH TIP

Parking Brake before Parking Pawl

To prevent possible damage to the transmission/transaxle case or other internal components, most experts agree that the parking brake should be applied *before* placing the gear selector into the park position, especially when parking on a hill. This procedure keeps the weight of the vehicle from being exerted entirely on the parking pawl and makes it easier to move the gear selector out of the park position.

TYPICAL TORQUE FLOW

The General Motors 4L60-E can provide an example of how a typical electronically controlled rear-wheel-drive automatic transmission works. ● **SEE CHART 130–3**.

PARK AND NEUTRAL With the gear selector level in P or N, there is no torque flow through the gear set, even though the low-reverse clutch is applied in the 4L60-E. The clutch holds the

RANGE	GEAR	SHIFT SOLENOIDS		2-4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3-4 CLUTCH	LOW ROLLER CLUTCH	LOW REVERSE CLUTCH
		“A”	“B”								
Park		On	On								Applied
Reverse		On	On		Applied						Applied
Neutral		On	On								
Ⓓ	First	On	On				Applied	Holding		Holding	
	Second	Off	On	Applied			Applied	Holding			
	Third	Off	Off				Applied	Holding	Applied		
	Fourth	On	Off	Applied			Applied		Applied		
D	First	On	On				Applied	Holding		Holding	
	Second	Off	On	Applied			Applied	Holding			
	Third	Off	Off			Applied	Applied	Holding	Applied		
2	First	On	On			Applied	Applied	Holding		Holding	
	Second	Off	On	Applied		Applied	Applied	Holding			
1	First	On	On			Applied	Applied	Holding		Holding	Applied
	Second	Off	On	Applied		Applied	Applied	Holding			

CHART 130–3

The General Motors 4L60-E electronically controlled rear-wheel-drive transmission clutch, band, and solenoid application chart.

reaction carrier stationary, but torque input to the gear set stops at the input housing.

The torque converter housing and impeller rotate clockwise at engine speed to hydraulically drive the turbine and mechanically drive the oil pump. The transmission input drum assembly rotates clockwise at turbine speed to drive the gear set. Turbine speed is slightly less than engine crankshaft speed. However, there is nothing connecting the input drum assembly to drive the gear sets and transfer torque at this time.

In neutral, the output shaft is free to rotate in either direction, and the vehicle can be pushed or towed. However, use caution because if the engine is not running, the pump is not providing lube fluid to components. In park, a mechanical pawl or finger engages one of many large notches cut into a gear mounted on the output shaft, preventing the vehicle from moving in either direction.

OVERDRIVE FIRST With the gear selector lever in overdrive, the transmission starts off in first gear, and then upshifts into second, third, and fourth gears as the vehicle continues to accelerate. To engage first gear, the forward clutch applies, transferring engine torque from the input shaft to the input sun gear through the forward sprag clutch, driving the sun gear clockwise.

With the input sun gear turning clockwise, the input pinion gears spin counterclockwise in the stationary carrier and attempt to drive the input ring (internal) gear and reaction carrier counterclockwise. However, the forward sprag clutch is holding, so the pinions walk clockwise inside the ring (internal) gear, turning the input carrier clockwise. Then, the input carrier drives the output shaft clockwise in gear reduction. ● **SEE FIGURE 130–28**.

The reaction ring (internal) gear turns clockwise along with the output shaft and drives the reaction pinions clockwise on the stationary reaction carrier assembly. Pinion action drives the reaction sun gear counterclockwise. However, the reaction sun gear is not connected to a gear set member, so the reaction gear set simply freewheels. The low roller clutch prevents the reaction carrier from turning counterclockwise.

As long as the vehicle continues to accelerate in overdrive first, torque transfers through the gear set to the output shaft. During closed-throttle coasting, the clockwise torque load on the forward sprag clutch and the counterclockwise torque load on the low roller clutch are released. Both one-way clutches overrun so the gear sets freewheel on deceleration, and engine braking is not available.

OVERDRIVE SECOND As the vehicle continues to accelerate in the overdrive range, the transmission upshifts to second gear by applying the 2-4 band. The band holds the reverse drum, input shell, and reaction sun gear stationary. The forward clutch remains applied, while the input shaft drives the input sun gear clockwise through the forward sprag clutch. ● **SEE FIGURE 130–29**.

As in first gear, the input sun gear rotates clockwise and drives the input pinions counterclockwise. Since the 2-4 band is holding, the input pinions walk inside the internal gear, driving the input carrier and output shaft clockwise in gear reduction.

At the same time, the output shaft drives the reaction internal ring gear and pinion gears clockwise. With the reaction sun gear held, the pinion gears walk clockwise and drive the reaction carrier clockwise with them.

Clockwise rotation of the reaction carrier transfers to the input ring (internal) gear through the reaction carrier shaft. With the input ring (internal) gear turning clockwise, the input pinions spin counterclockwise and drive the input carrier clockwise. This removes the counterclockwise torque load from the low roller clutch so that it overruns at this time. There is no engine compression braking available in overdrive second because the forward sprag clutch overruns.

OVERDRIVE THIRD To automatically upshift into third gear as the vehicle continues to accelerate, the transmission releases the 2-4 band and applies the 3-4 clutch. Also, the forward clutch remains applied so the input shaft drives the input sun gear clockwise through the forward sprag clutch. ● **SEE FIGURE 130–30**.

Applying the 3-4 clutch connects the input shaft to the input ring (internal) gear, which drives the ring (internal) gear clockwise at turbine speed. Now that two members of the input gear set—the sun and ring (internal)—are being driven at turbine speed, the gear set provides direct drive as it locks up and turns as a unit.

As long as the vehicle is accelerating in overdrive third, torque transfers through the planetary gear set to the output

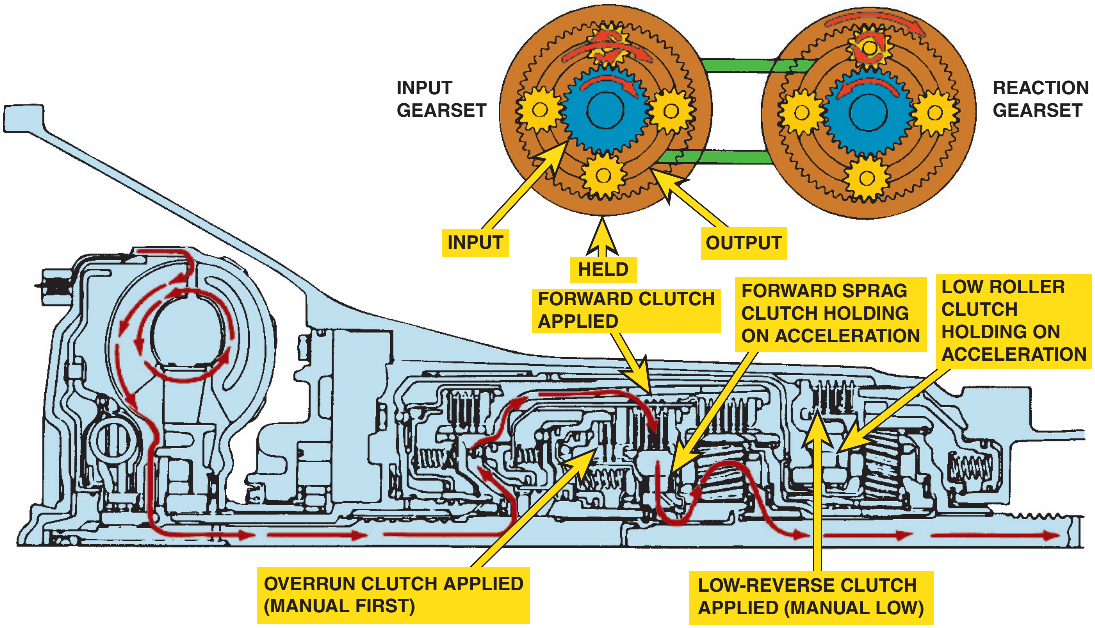

INPUT GEARSET
REACTION GEARSET
INPUT
HELD
OUTPUT
FORWARD CLUTCH APPLIED
FORWARD SPRAG CLUTCH HOLDING ON ACCELERATION
LOW ROLLER CLUTCH HOLDING ON ACCELERATION
OVERRUN CLUTCH APPLIED (MANUAL FIRST)
LOW-REVERSE CLUTCH APPLIED (MANUAL LOW)

FIGURE 130–28 A GM 4L60-E torque (power) flow in overdrive first gear.

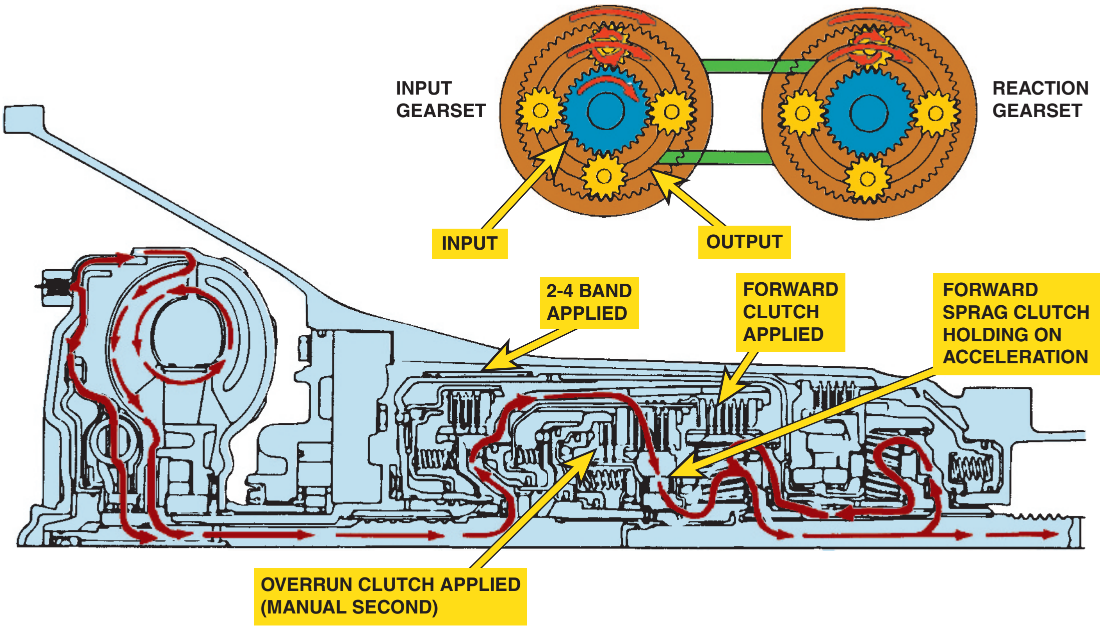

INPUT GEARSET
REACTION GEARSET
INPUT
OUTPUT
2-4 BAND APPLIED
FORWARD CLUTCH APPLIED
FORWARD SPRAG CLUTCH HOLDING ON ACCELERATION
OVERRUN CLUTCH APPLIED (MANUAL SECOND)

FIGURE 130–29 A GM 4L60-E torque (power) flow in overdrive second gear.

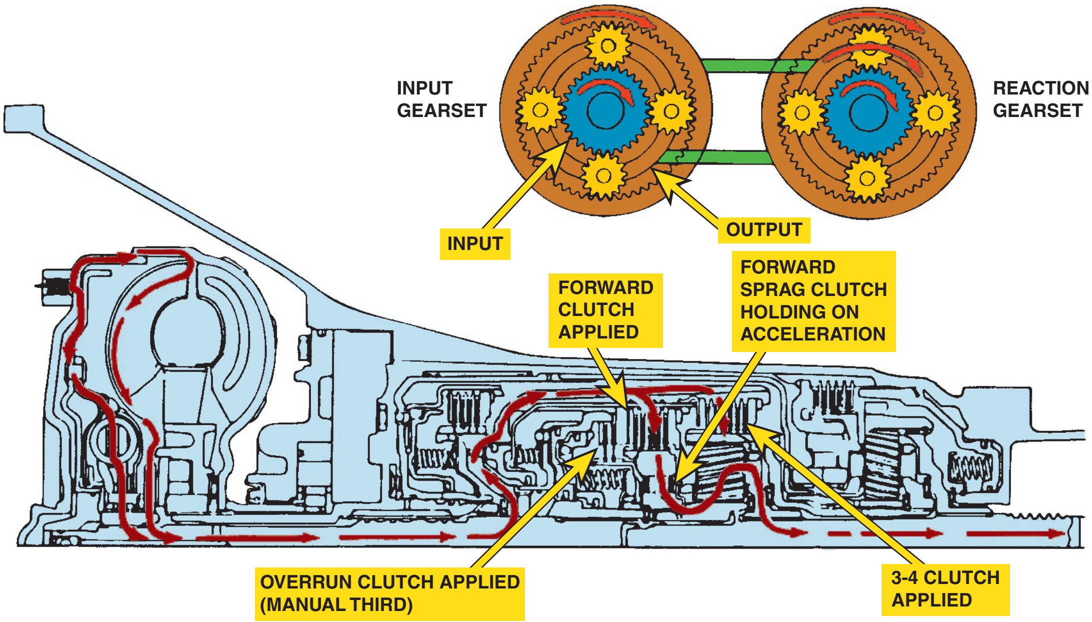

INPUT GEARSET
REACTION GEARSET
INPUT
OUTPUT
FORWARD CLUTCH APPLIED
FORWARD SPRAG CLUTCH HOLDING ON ACCELERATION
OVERRUN CLUTCH APPLIED (MANUAL THIRD)
3-4 CLUTCH APPLIED

FIGURE 130–30 A GM 4L60-E torque (power) flow in overdrive third gear.

shaft. There is no engine braking because the forward one-way clutch overruns and allows the input sun gear to freewheel.

OVERDRIVE FOURTH The transmission upshifts into fourth gear by applying the 2-4 band as the vehicle continues to accelerate in overdrive range. The 2-4 band holds the reverse drum and reaction sun gear stationary. Both the 3-4 and forward clutches remain applied, and the input drum continues to drive the input ring (internal) gear clockwise. ● **SEE FIGURE 130–31**.

This drives the reaction carrier clockwise as well, since it is in common with the input ring (internal) gear. As the carrier turns, the reaction pinions walk clockwise around the stationary reaction sun gear. This drives the reaction ring (internal) gear and output shaft clockwise at an overdrive ratio.

In fourth gear, the input ring (internal) gear turns at input shaft speed, while the input carrier turns at a faster output shaft speed; both gears turn clockwise. As a result, the input pinions turn counterclockwise and drive the sun gear clockwise faster than input speed. This causes the forward sprag clutch to overrun and renders the forward friction clutch, which remains applied, ineffective.

When the transmission is operating in fourth gear, the input member, the reaction carrier, is being driven by a multiple-plate clutch, while a band prevents the held member, the reaction sun gear, from turning in either direction. Therefore, engine compression braking is available. However, due to the overdrive gear ratio, the braking effect is not noticeable to the driver.

REVERSE With the gear selector lever in reverse, the low-reverse clutch applies to drive the reaction sun gear clockwise with the input shaft. The reaction carrier and input ring (internal) gear are held stationary by the applied reverse input clutch. This turns the reaction pinions counterclockwise and drives the carrier counterclockwise in gear reduction. ● **SEE FIGURE 130–32**.

In reverse gear, the input ring (internal) gear is held, while the input carrier is driven counterclockwise. This causes the input pinions to rotate clockwise and drive the input sun gear counterclockwise.

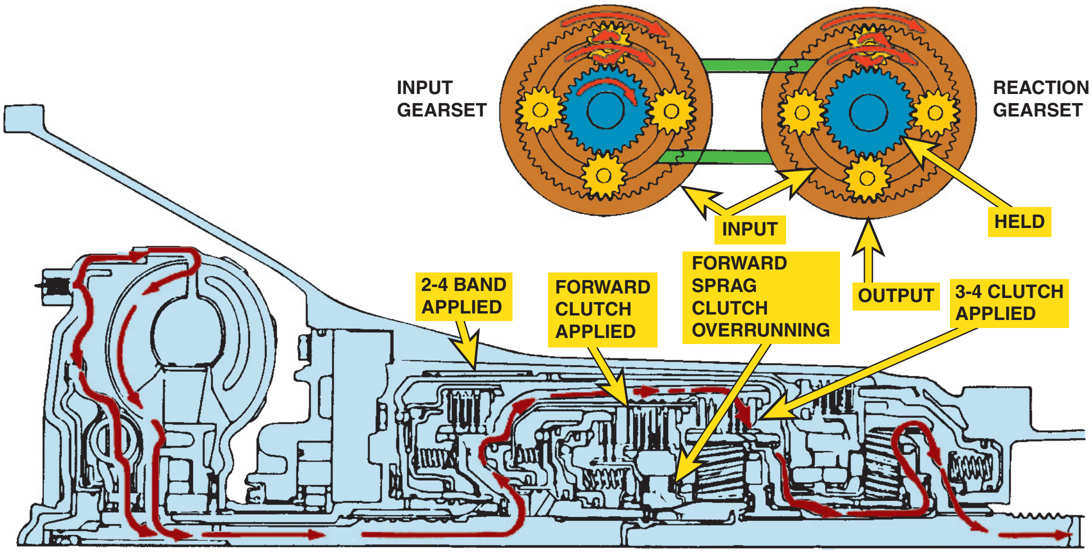

INPUT GEARSET
REACTION GEARSET
INPUT
HELD
FORWARD SPRAG CLUTCH OVERRUNNING
OUTPUT
3-4 CLUTCH APPLIED
2-4 BAND APPLIED
FORWARD CLUTCH APPLIED

FIGURE 130–31 A GM 4L60-E torque (power) flow in overdrive fourth gear.

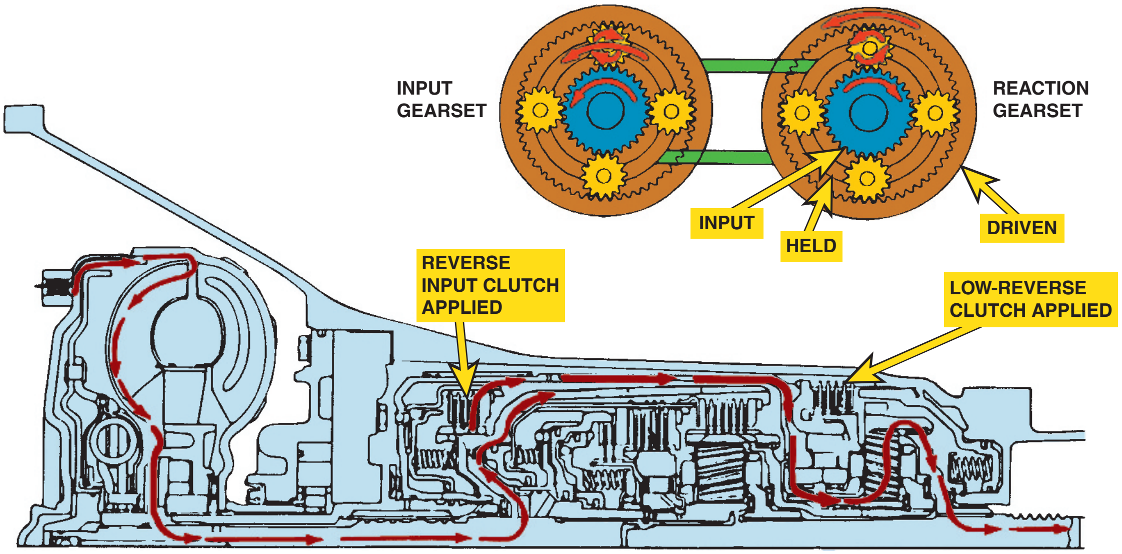

INPUT GEARSET
REACTION GEARSET
INPUT
HELD
DRIVEN
REVERSE INPUT CLUTCH APPLIED
LOW-REVERSE CLUTCH APPLIED

FIGURE 130–32 A GM 4L60-E torque (power) flow in reverse.

REVIEW QUESTIONS

1. What are three planetary gear set apply devices?
2. How are shift points achieved with a hydraulically controlled automatic transmission/transaxle?
3. How are solenoids used to control the shifting on electronically controlled automatic transmissions/transaxles?
4. What are the parts of a typical clutch pack assembly?
5. What are the solenoids used in a typical electronically controlled automatic transmission/transaxle?

CHAPTER QUIZ

1. All current-model automatic transmissions are designed to use ________________.
   - **a.** non-friction modified ATF
   - **b.** friction modified ATF
   - **c.** SAE 0W-20 engine oil dyed red
   - **d.** highly friction modified ATF
2. Two technicians are discussing automatic transmission/transaxle oil pumps. Technician A says that many automatic transmissions/transaxles use a variable displacement pump. Technician B says that the pump is driven by the torque converter. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Technician A says that the automatic transmission/transaxle fluid (ATF) cooler is designed to cool the automatic transmission fluid. Technician B says that the cooler also warms the ATF when the fluid is cold. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. If an automatic transmission is operating in one gear only and will not shift, this means ________________.
   - **a.** it is limp-in mode
   - **b.** it is operating normally
   - **c.** the transmission fluid level is low
   - **d.** the transmission fluid level is too high
5. Force motors are controlled by the computer by ___________.
   - **a.** increasing/decreasing current (amperes)
   - **b.** PWM
   - **c.** increasing/decreasing voltage
   - **d.** changing the resistance in the circuit
6. Two technicians are discussing one-way clutches. Technician A says that a sprag and a roller are two types of one-way clutches. Technician B says that a one-way clutch could be installed upside down and cause the automatic transmission/transaxle to not function correctly. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. What is the part of the planetary gear set called that is being held by a band?
   - **a.** Reaction member
   - **b.** Compound gear set
   - **c.** Simple gear set
   - **d.** Held member
8. What is the purpose and function of an accumulator?
   - **a.** To apply a clutch
   - **b.** To apply a band
   - **c.** To cushion or dampen pressure surges
   - **d.** Either a or b
9. Check balls used in the valve body are constructed of ________________.
   - **a.** steel
   - **b.** nylon
   - **c.** rubber
   - **d.** Any of the above
10. Technician A says the default or limp-in gear is usually second or third gear. Technician B says that a transmission clutch, band, and solenoid chart shows the technician what is being applied in each gear. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter 131

EV AND HEV TRANSMISSIONS

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Describe the powertrain configuration.
- Explain the principles involved with vehicle transmissions/transaxles.
- Describe the function of a hybrid electric vehicle (HEV) transmission.
- Discuss the transmission in GM parallel hybrid trucks (PHTs).
- Discuss the GM two-mode hybrid transmission.
- Discuss the Ford/Lincoln 10R80 MHT.
- Discuss the Toyota/Lexus power-split system.
- Discuss the diagnosis of an HEV transmission.
- Describe the transmissions used in electric vehicles (EVs).

KEY TERMS:

Electric auxiliary pump 1665 • Hydraulic impulse storage accumulator 1666 • Torque 1665

TRANSMISSIONS AND TRANSAXLES

POWERTRAIN CONFIGURATION In rear-wheel-drive (RWD) applications, it is most common to use a transmission along with a driveshaft and differential at the rear axle to transmit torque to the drive wheels. The Lexus GS450h and LS600h are both examples of rear-wheel-drive hybrid electric vehicles. The Ford Mustang Mach-E standard configuration is an example of a rear-wheel-drive electric vehicle. In a front-wheel-drive (FWD) vehicle, a transaxle assembly is used with half-shafts to transmit torque to the drive wheels. A transaxle is the combination of a transmission, differential, and final drive gears built together as one assembly. A Toyota Prius and Hyundai Sonata hybrid are examples of FWD hybrid vehicles. The Chevrolet Bolt is an example of an FWD electric vehicle. ● **SEE FIGURE 131–1**.

In a four-wheel-drive (4WD) or all-wheel-drive (AWD) vehicle, a transfer case or rear electric motor is used to distribute power to all four wheels. The Toyota Highlander/Lexus RX450h uses a transaxle on the front of the vehicle and an electric motor to drive the rear wheels in the 4WD model. The 4WD version of the Ford Escape hybrid uses a separate power takeoff (PTO) from the transaxle to mechanically drive the rear axle.

Example Vehicle Transmission Configurations

Vehicle	FWD/RWD/AWD	Configuration
Toyota Prius 2001–2009	FWD	ECVT 2 Motors/1 Planetary
Chevrolet Volt	FWD	ECVT 2 Motors/1 Planetary/Clutches
Toyota Prius 2010–2015	FWD	ECVT 2 motors/2 Planetary
Toyota Prius 2016–2021	FWD/ AWD	ECVT 2 Motors/2 Planetary/One-way clutch
General Motors 2 Mode	RWD/AWD	ECVT 2 Motors/3 Planetary/Clutches
Honda Accord Hybrid	FWD	ECVT 2 Motors/2 Clutches
Nissan Leaf	FWD	Electric Motor with gear reduction unit
Chevrolet Bolt	FWD	Electric Motor with gear reduction unit

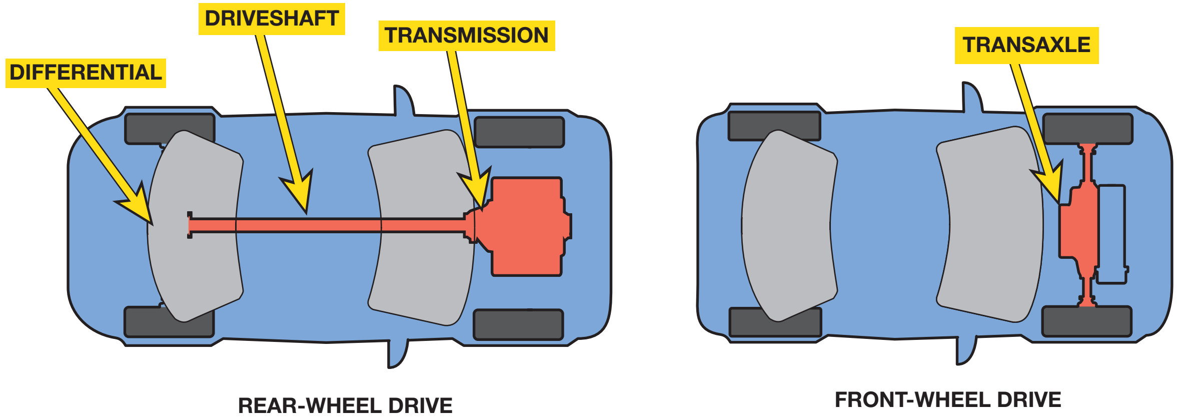


FIGURE 131–1 Rear-wheel-drive (RWD) vehicles use transmissions to send torque to the rear differential and final drive. Front-wheel-drive (FWD) vehicles use a transaxle, which incorporates the differential and final drive into the transaxle case.

PRINCIPLES INVOLVED

TORQUE DELIVERY To move a vehicle, torque must be applied to the drive wheels. **Torque** is *twisting force.*

Torque is applied to the drive wheels to make the vehicle accelerate. The vehicle transmission is responsible for increasing engine torque in the lower speed ranges when acceleration is required, and then reducing engine speed for the best fuel economy when the vehicle is cruising. Internal combustion engines (ICEs) are very different from electric motors in that they only produce torque in a relatively narrow RPM range. ● **SEE FIGURE 131–2**.

An ICE is most efficient when it is operating near its torque peak. This is the RPM when the engine is breathing most efficiently, and is typically where the engine can deliver the best fuel economy. However, it is difficult to keep the engine in this range during all phases of vehicle operation. Automotive engineers overcome this difficulty in two ways:

1. By increasing the RPM range where the engine produces torque ("flattening" the torque curve).
2. By increasing the number of gear ratios in the transmission.

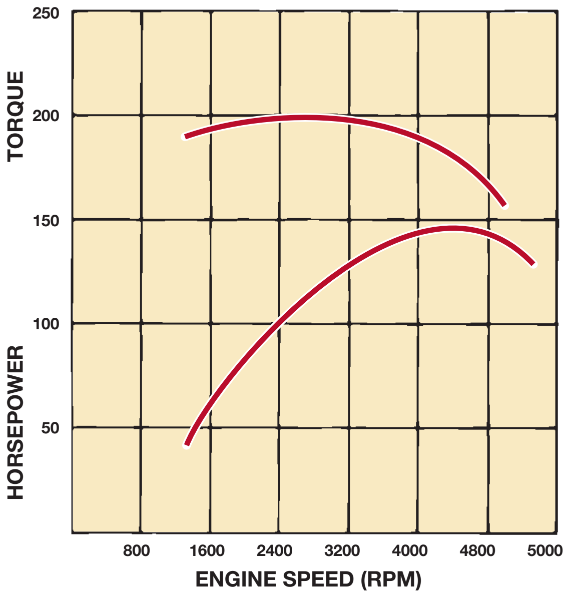


FIGURE 131–2 Graph showing engine torque vs. horsepower output for a typical internal combustion engine. ICEs produce maximum torque at a high RPM, whereas electric motors produce maximum torque at low RPM.

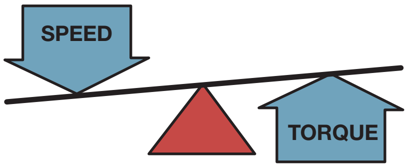


FIGURE 131–3 When output speed decreases in a transmission, output torque will increase.

With more transmission ratios, it is easier to match the vehicle road speed with the most efficient engine RPM. Therefore, any torque increase is generated at the expense of speed. In other words, when torque is increased in a transmission, output speed is decreased. ● **SEE FIGURE 131–3**.

MULTIPLE SPEED TRANSMISSIONS/TRANSAXLES Years ago, it was common for vehicles with automatic transmissions to have only 2, 3, or 4 gear ratios. Currently, 5-, 6-, 7-, 8-, and 10-speed automatic transmissions are becoming common. With more emphasis being placed on fuel economy and lower emissions, the continuously variable transmission (CVT) is becoming more popular as it provides infinite gear ratios and the best opportunity to maximize engine efficiency.

HEV TRANSMISSIONS

CLASSIFICATIONS HEV transmissions are different based on the level of the hybrid vehicle in which they are installed. A mild hybrid with stop-start system typically contains a transmission with a single electric motor. A full hybrid generally contains a transmission with two electric motors.

ELECTRIC AUXILIARY PUMP In order to adapt a conventional automatic transmission to a hybrid powertrain, an **electric auxiliary pump** is used to maintain fluid pressure in the transmission during ICE idle-stop. This pump is powered by a DC brushless (AC synchronous) motor, which requires a special controller to provide the correct operating frequency and pulse width. When the auxiliary pump is operating, it sends hydraulic pressure to the transmission regulator valve, and on to the manual valve where it is directed to the appropriate clutches. This prevents the transmission from shifting into "neutral" when the ICE is in idle-stop. Once the ICE restarts, the auxiliary pump is turned off and hydraulic pressure is again supplied by the mechanically driven transmission fluid pump. ● **SEE FIGURE 131–4**.

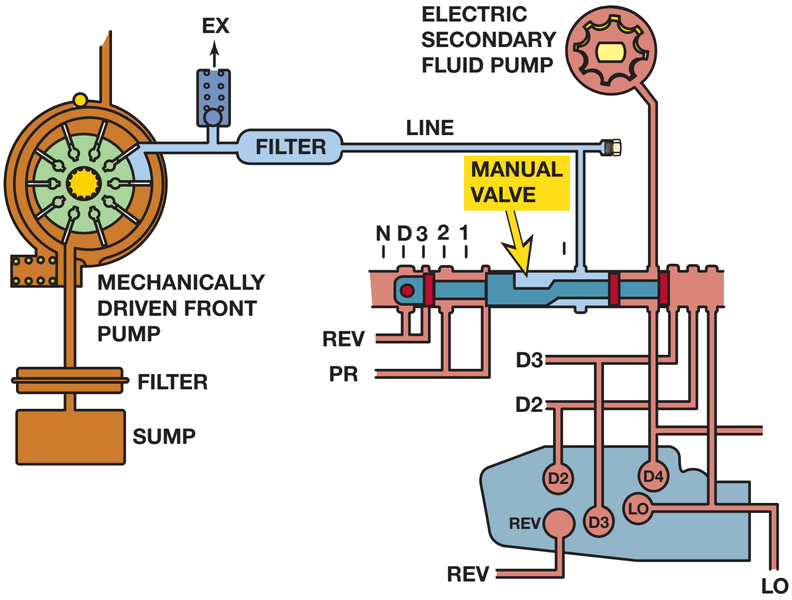


FIGURE 131–4 The hydraulic circuit diagram for this GM transmission includes a mechanical pump and an electric secondary fluid pump.

HYDRAULIC IMPULSE STORAGE ACCUMULATOR A **hydraulic impulse storage accumulator** is used to provide fluid pressure as the ICE restarts after the idle-stop mode. During normal engine operation, the mechanical transmission pump provides the hydraulic pressure and charges the accumulator. When the engine restarts, the accumulator provides the initial hydraulic pressure and the mechanical pump provides the continuation of the pressure. The pressure release from the accumulator ensures there is no delay in acceleration, and it eliminates the need for an electric auxiliary pump. ● **SEE FIGURE 131–5**.

GM PARALLEL HYBRID TRUCK (PHT)

DESCRIPTION The transmission in the 2004–2008 Chevrolet Silverado/GMC Sierra parallel hybrid truck (PHT) is based on the 4L60E electronically controlled automatic transmission design with minor modification to adjust for its new role in a hybrid powertrain. It has four forward speeds and one reverse, with the fourth speed being an overdrive. It is designed primarily for medium- and large-displacement engines and is used extensively in GM pickups and SUVs. The specific model used in the hybrid pickup is known as the M33.

OPERATION In idle-stop mode the engine stops, which will in turn stop the transmission oil pump and cause the transmission to go to "neutral." To prevent this, an electric secondary fluid pump is installed on the valve body inside the transmission oil pan. Whenever the engine goes into idle-stop, the electric fluid pump is turned on to maintain oil pressure on the transmission forward clutch and keep the drivetrain connected to the engine. This results in a smoother transition between idle-stop and engine restarting as the vehicle resumes operation. ● **SEE FIGURE 131–6**.

The conventional 4L60E transmission is made to allow the vehicle to coast or brake without any interference from the engine. To enable regenerative braking, the hybrid version of the 4L60E transmission is made to apply the overrun clutch during coast or braking in the D4 range and either third or second gear. This allows power to be transmitted back through the torque converter, which can then be used to generate electric current for recharging the 42-volt battery pack.

SERVICE Transmission service for the 4L60E model M33 is limited to fluid and filter changes. This transmission requires Dexron VI fluid. The filter on the electric secondary fluid pump is replaceable, but is not a regular maintenance item. Transmission pressure testing can be performed using the line pressure tap located on the transmission case. These tests are most often done by attaching a pressure gauge to the fitting on the side of the transmission and operating the transmission under various load conditions and road speeds. The test results are recorded and compared to charts to help determine what area(s) of the transmission might be malfunctioning.

A scan tool can be used to access DTCs (diagnostic trouble codes) and also to perform bidirectional testing of the transmission

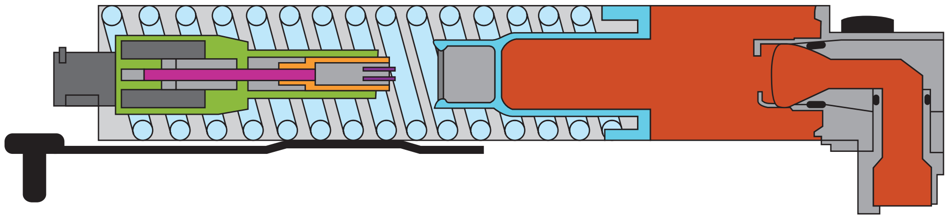


FIGURE 131–5 When the solenoid is energized, the accumulator releases the fluid creating the initial pressure needed at restart.

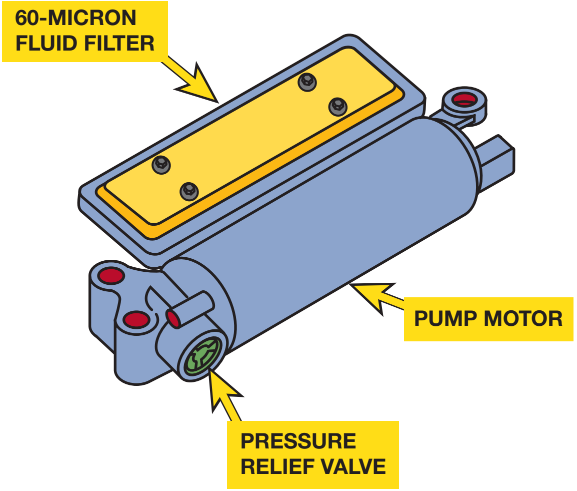


FIGURE 131–6 Electric secondary fluid pump from a transmission in a GM hybrid pickup.

solenoids. A scan tool can also be used for clearing the *transmission adaptive pressure* (*TAP*) values if any of the following has occurred:

1. If the transmission has been overhauled or replaced.
2. Repair or replacement of an apply or release component (band, clutch, servo, piston, etc.).
3. Repair or replacement of a component that directly affects line pressure.

GM TWO-MODE HYBRID TRANSMISSION

DESCRIPTION The two-mode hybrid transmission used in 2009–2013 General Motors hybrid trucks is labeled a 2ML70. This unit features two 60-kW motors in the hybrid drivetrain, a 300-volt battery pack, and a V8 engine. A two-mode hybrid electric vehicle can increase the fuel economy by about 25%, depending on the type of driving conditions. Like all hybrids, the two-mode combines the power of a gasoline engine with that of electric motors and includes the following:

- Regenerative braking that captures kinetic energy that would otherwise be lost
- Idle-stop

Some full-hybrid systems have a single mode of operation, using a single planetary gear set to split engine power to drive the wheels or charge the battery. These systems are effective at low speeds because they can move the vehicle without running the gasoline engine (ICE). But at higher speeds, when the engine is needed, using the electric motors has much less benefit. As a result, sending power through electric motors and a variable transmission is roughly 20% less efficient than driving the vehicle through a purely mechanical power path, using gears.

COMPONENTS The two-mode unit is effectively an electronically variable transmission (EVT). It includes three simple planetary gear sets with four multiplate clutches. It has four fixed gear ratios with two EV ratios for smooth, more efficient operation. The components of the two-mode transmission include the following:

- Two 60-kW electric motor/generators assemblies.
- Three planetary gear sets (one is located in front of motor/generator A, called M/G A; another is located between the two motor/generators; and the last planetary gear set is located behind motor/generator B, called M/G B).
- Four wet plate clutches (two friction [rotating] and two [reaction/stationary] clutch assemblies). ● **SEE FIGURE 131–7.**

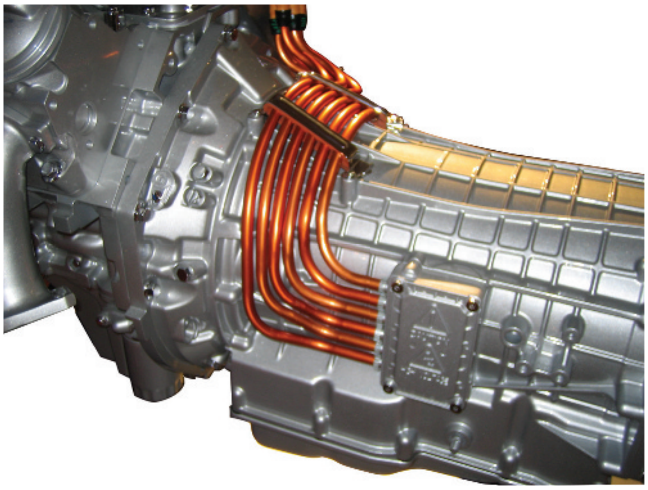


FIGURE 131–7 The two-mode transmission has orange high-voltage cables entering the unit to carry electric energy from the high-voltage battery pack to propel the vehicle and also charge the battery during deceleration.

The vehicle starts moving in EV 1 with a variable ratio from infinite low to 1.7:1. If the vehicle is launched with the engine off, M/G A will spin the engine crankshaft so it can start running. EV 2 has a ratio between 1.7:1 and 0.5:1.

FIRST MODE OF OPERATION The first mode is for accelerating from standstill to second gear. At low speed and light load, the vehicle can be propelled by

- Either electric motor alone
- The ICE alone
- Or a combination of the two (electric motor and/or ICE)

In this mode, the engine (if running) can be shut off under certain conditions and everything will continue to operate on electric power alone. The hybrid system can restart the ICE at any time as needed. One of the motor/generators operates as a generator to charge the high-voltage battery, and the other works as a motor to assist in propelling the vehicle.

SECOND MODE OF OPERATION The second mode takes the vehicle from second gear through to overdrive. At higher loads and speeds, the ICE always runs. In the second mode, the motor/generators and planetary gear sets are used to keep torque and horsepower at a maximum. As the vehicle speed increases, various combinations of the four fixed ratio planetary gears engage and/or disengage to multiply engine torque, and allowing one or the other of the motor/generators to perform as a generator to charge the high-voltage battery. ● **SEE FIGURE 131–8.**

TWO-MODE SERVICE Routine service is all that is needed or required of the two-mode transmission. Fluid-level check and visual inspection should be all that is required until the first scheduled fluid change. Always use Dexron VI. Faults in the system will often set a diagnostic trouble code. Unit repair of the unit requires an engine hoist or the lift arm of a vehicle lift to remove the motor assembly. ● **SEE FIGURE 131–9 A AND B.**

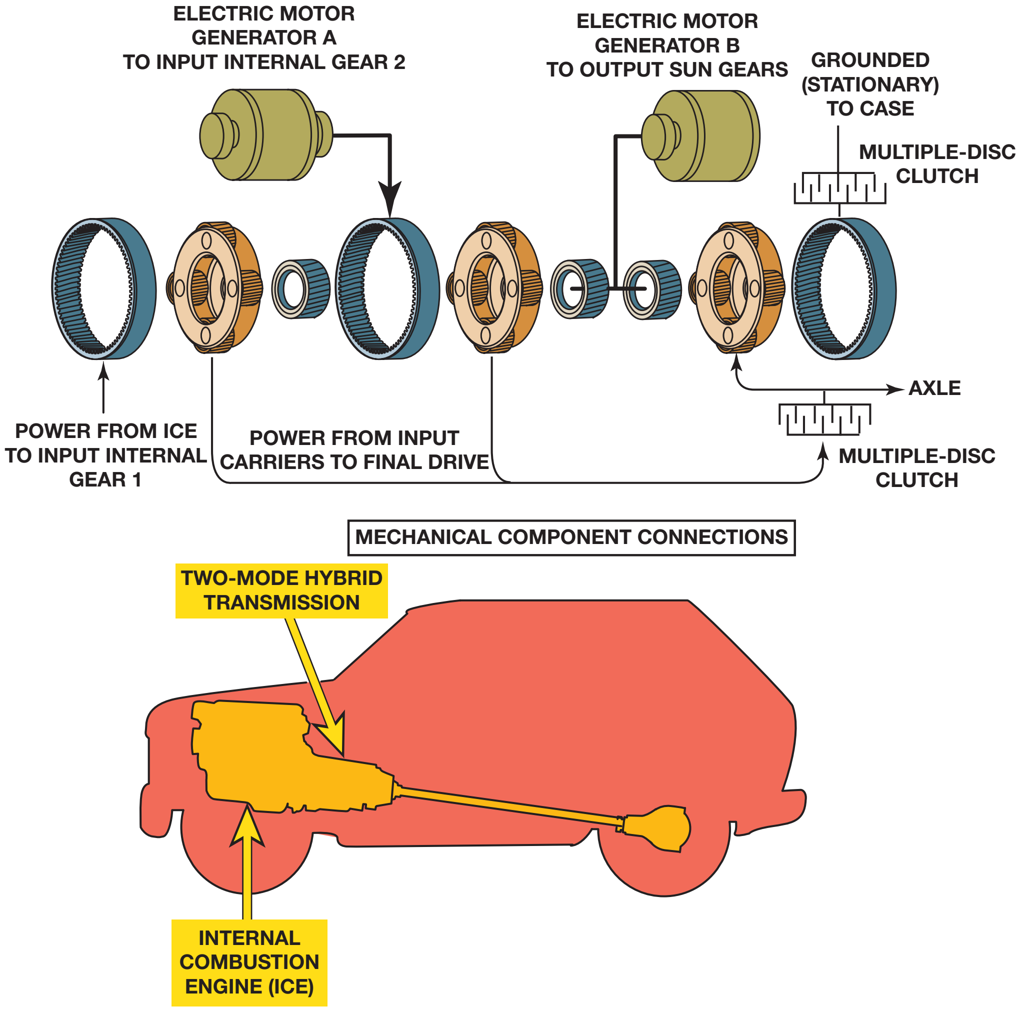

ELECTRIC MOTOR
GENERATOR A
TO INPUT INTERNAL GEAR 2
ELECTRIC MOTOR
GENERATOR B
TO OUTPUT SUN GEARS
GROUNDED
(STATIONARY)
TO CASE
MULTIPLE-DISC
CLUTCH
AXLE
POWER FROM ICE
TO INPUT INTERNAL
GEAR 1
POWER FROM INPUT
CARRIERS TO FINAL DRIVE
MULTIPLE-DISC
CLUTCH
MECHANICAL COMPONENT CONNECTIONS
TWO-MODE HYBRID
TRANSMISSION
INTERNAL
COMBUSTION
ENGINE (ICE)

FIGURE 131–8 Using two planetary gear sets, the ICE can be maintained in the most efficient speed of about 2000 RPM under most operating conditions.

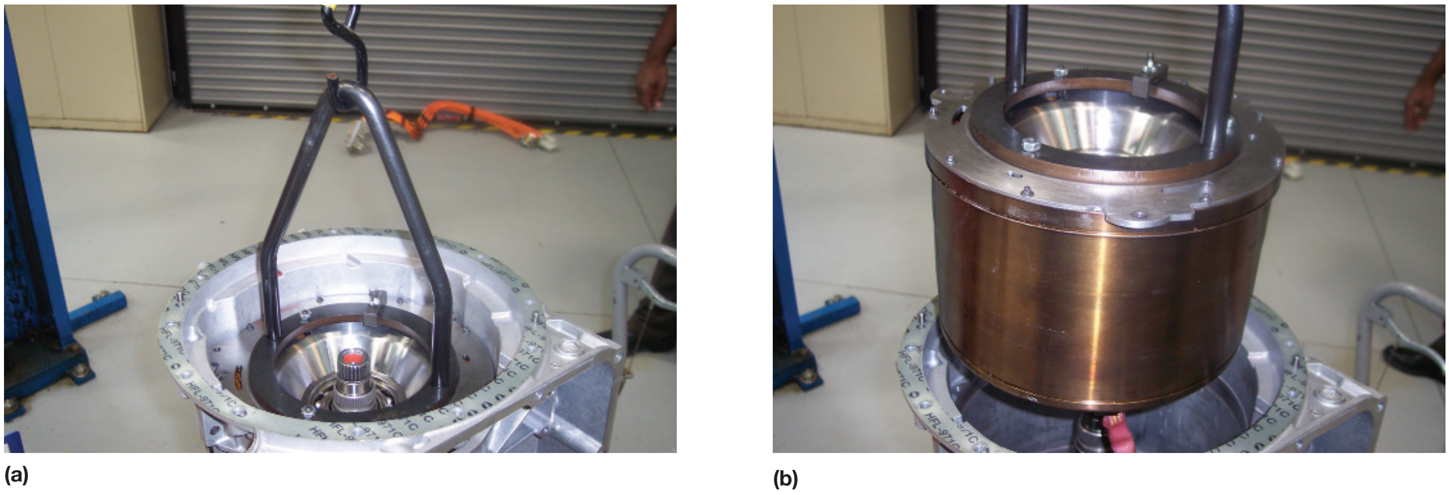


FIGURE 131–9 (a) Disassembly of the 2ML70 transmission requires the use of a special tool and a lift or engine hoist to remove the motor assembly. (b) The motor assembly after being removed from the transmission.

FORD/LINCOLN 10R80 MHT

DESCRIPTION The 10R80 MHT is a modular ten-speed hybrid transmission that was introduced in the 2020 Explorer and the 2020 Lincoln Aviator plug-in hybrid. The transmission is unique because unlike most hybrid transmissions it still uses a torque converter. The continued use of the torque converter improves towing and hauling capabilities. An electric motor and disconnect clutch are placed between the engine and the torque converter. In addition to providing stop-start capabilities, the electric motor provides low-speed torque and additional power. The MTH transmission is six inches longer than the non-hybrid model (10R80) and shares 90% of the same components. ● **SEE FIGURE 131–10 A AND B.**

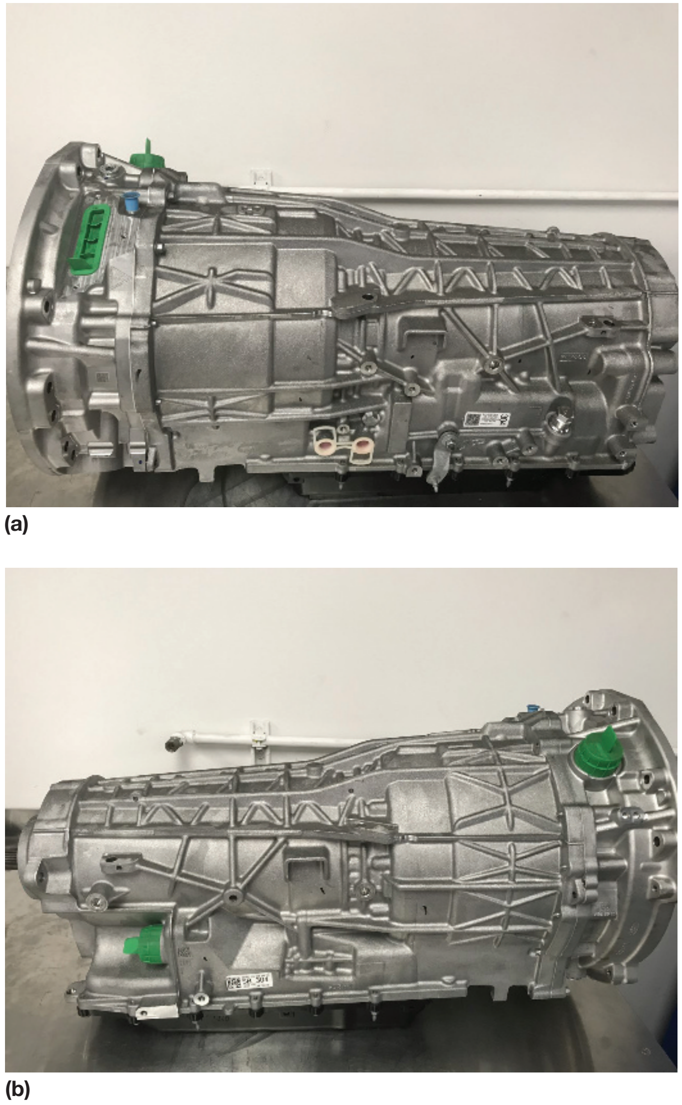


FIGURE 131–10 (a) The driver side of the transmission contains the high-voltage connections and the shift level assembly. The hybrid portion of the transmission is forward of the gasket. (b) The passenger side of the transmission contains the low-voltage connections.

COMPONENTS The components of the hybrid drive unit of the transmission are as follows:

- Electric motor
- Resolver (speed sensor)
- High-voltage connection
- Low-voltage connection

The hybrid drive unit is removed from the transmission as a unit. An engine hoist and special adapter are recommended when completing this task because of the weight of the unit. ● **SEE FIGURE 131–11 A AND B.**

The electric motor is a permanent magnet three-phase motor that generates 33 kW of power. ● **SEE FIGURE 131–12 A AND B.**

The resolver (speed sensor) provides the powertrain control module (PCM) with the speed, location, and direction of rotation of the electric motor. ● **SEE FIGURE 131–13.**

The high-voltage connector at the transmission allows the electric motor in the hybrid section of the transmission to be connected to the Inverter System Controller (ISC) via the orange-colored high-voltage insulated wiring. ● **SEE FIGURE 131–14.**

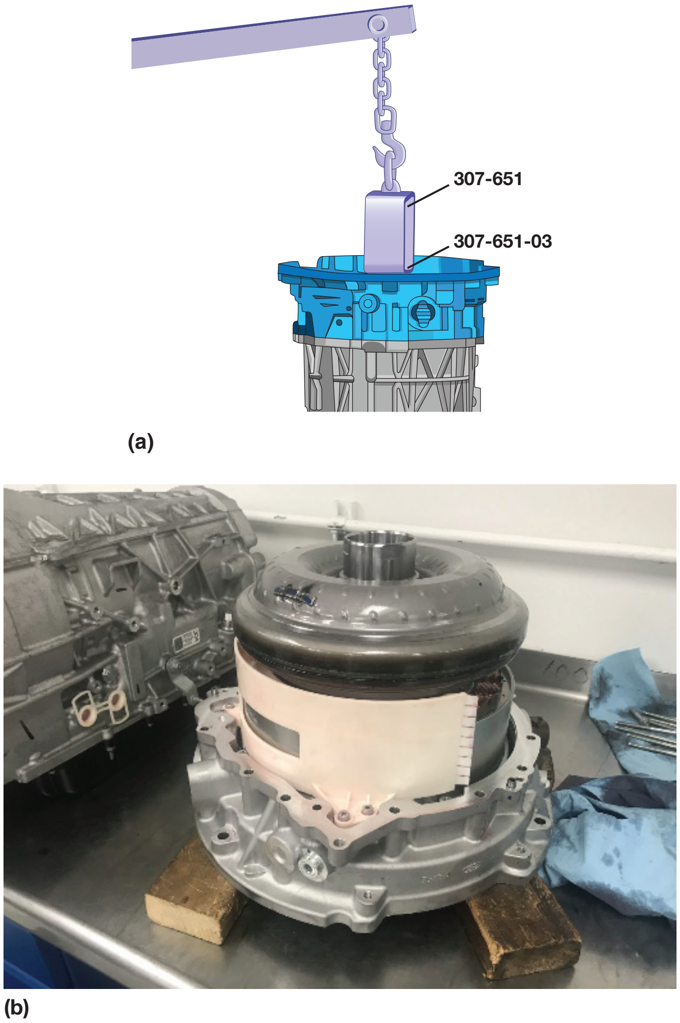


FIGURE 131–11 (a) An engine hoist and adapter are used to remove the hybrid portion of the transmission. (b) The hybrid portion of the transmission resting on two wooden blocks after being removed from the transmission.

The low-voltage connectors at the transmission provide for traditional transmission control and monitoring by the powertrain control module. ● **SEE FIGURE 131–15.**

SERVICE Service procedures performed at specific service intervals include the transmission fluid and filter. If the non-hybrid section of the transmission experiences a failure, a detailed overhaul procedure is provided. If the hybrid section of the transmission experiences a failure, it is replaced as a unit. Most electrical components, such as solenoids and sensors, are monitored by the powertrain control module (PCM) and supported with specific diagnostics related to a diagnostic trouble code (DTC). The external electrical components are serviceable.

TOYOTA/LEXUS POWER-SPLIT SYSTEM

APPLICATIONS The Toyota/Lexus power-split device drive system is used in the following models:

- Toyota Prius
- Toyota Corolla Hybrid
- Toyota Sienna

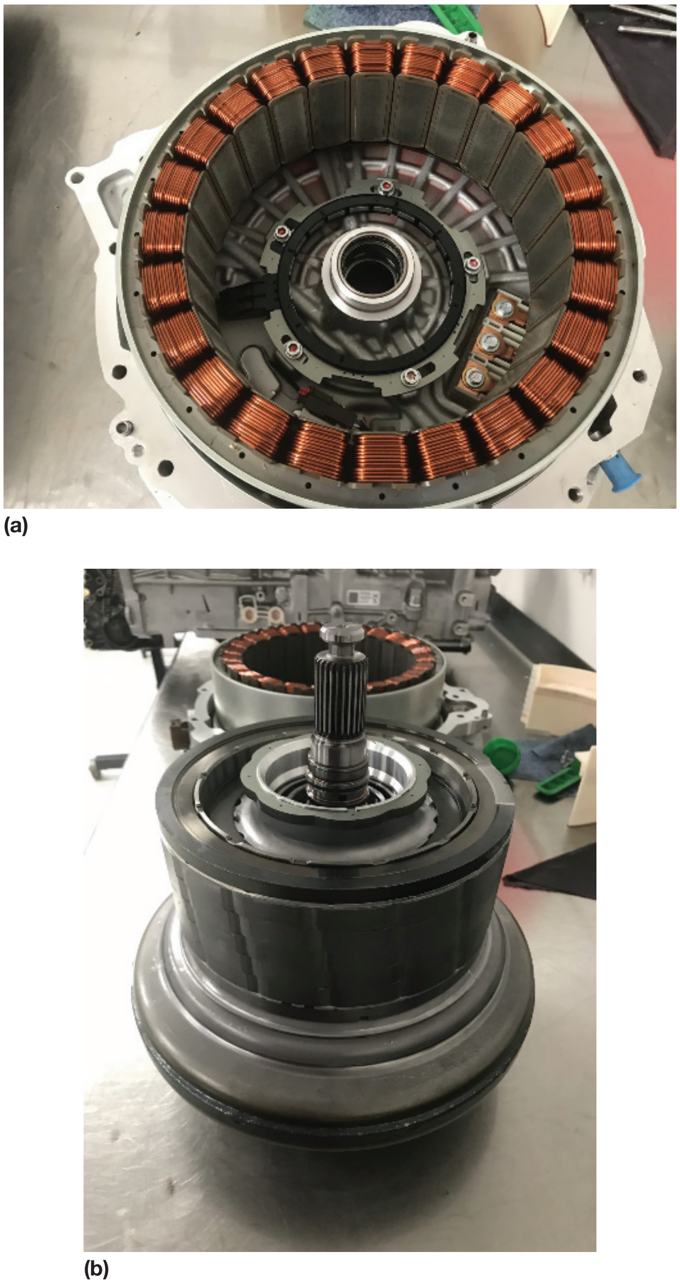


FIGURE 131–12 (a) The motor windings attached to the housing after the rotor has been removed. (b) The rotor and torque converter assembly after being separated from the winding.

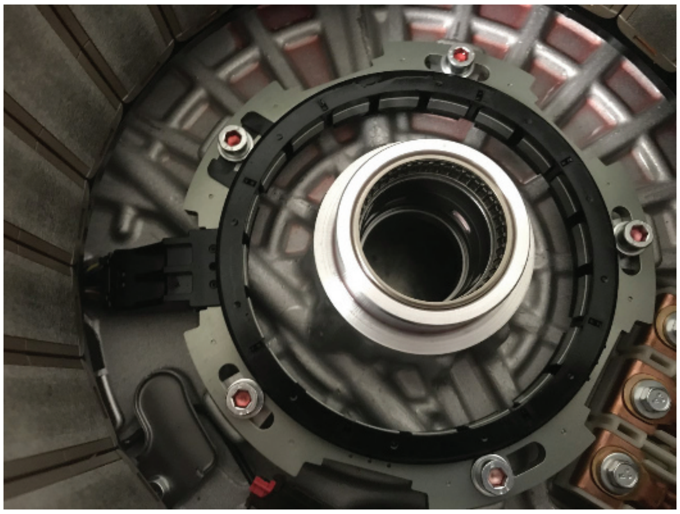


FIGURE 131–13 The resolver is the black and gray electrical sensor bolted to the housing at the bottom of the motor housing.

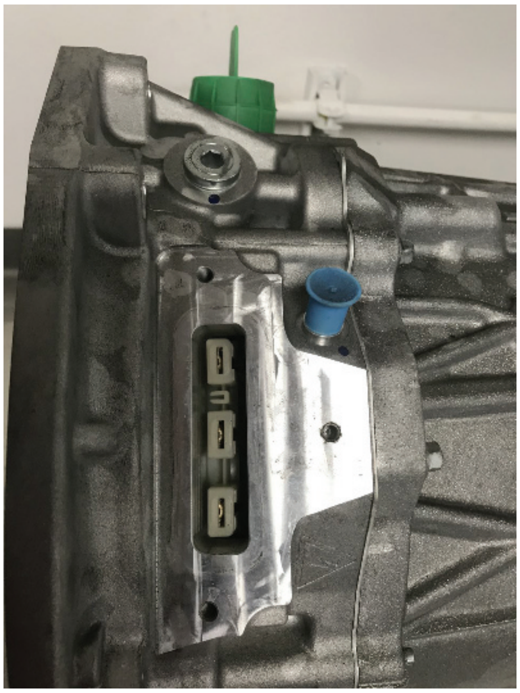


FIGURE 131–14 The three large flat connectors allow the electric motor to be connected to the ISC via the high-voltage cables.

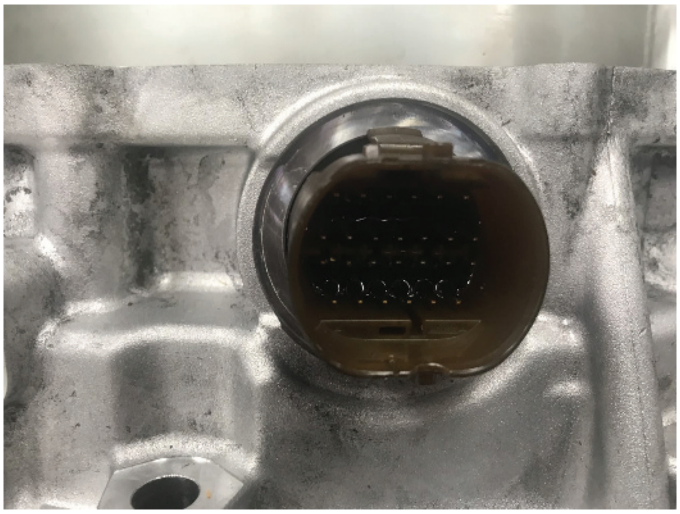


FIGURE 131–15 The low-voltage connector is for transmission control and monitoring

- Toyota Venza
- Toyota Camry Hybrid
- Lexus CT200h
- Toyota Highlander
- Toyota RAVA Hybrid
- Lexus RX400h and RX450h

DESCRIPTION The power-split transaxle is a series-parallel hybrid technology. During most phases of vehicle operation, the system is operating as both series and parallel at the same time. While the control system is complex, the basic transaxle is very simple in design as it is built around a single planetary gear set (power-split device) and two electric motor/generators, called MG1 and MG2. ● **SEE FIGURE 131–16**.

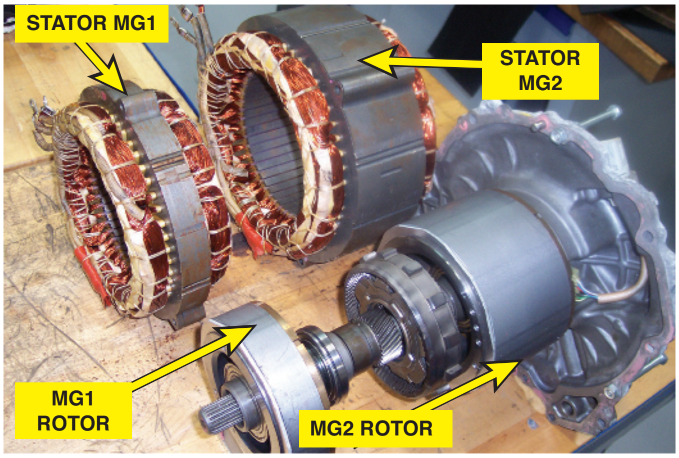


FIGURE 131–16 The Toyota Hybrid System uses two electric motor/generators (MG1 and MG2) and an ICE connected together by a power-split device, which is a simple planetary gear set.

A planetary gear set is composed of three main components:

1. Ring gear
2. Planet carrier
3. Sun gear

In the power-split transaxle, a large electric motor/generator (MG2) is directly attached to the transaxle final drive and the planetary ring gear. The ICE is connected to the planet carrier, and the small electric motor/generator (MG1) is connected to the sun gear. ● **SEE FIGURE 131–17**.

The planetary ring gear always turns in the same direction as the drive wheels and its speed is directly proportional to vehicle speed. In other words, if the ring gear is not moving, the vehicle is not moving. The power-split device is so named because the ICE (attached to the planet carrier) splits its torque output between the sun gear (MG1) and the ring gear (MG2 and drive wheels).

The gear ratio of the planetary gear set causes the ICE to send 72% of its torque to the ring gear and the remaining 28% to the sun gear. The torque split percentages remain the same regardless of what mode the transaxle is operating in because they are determined by the number of teeth on the planetary ring gear and the sun gear. ● **SEE FIGURE 131–18**.

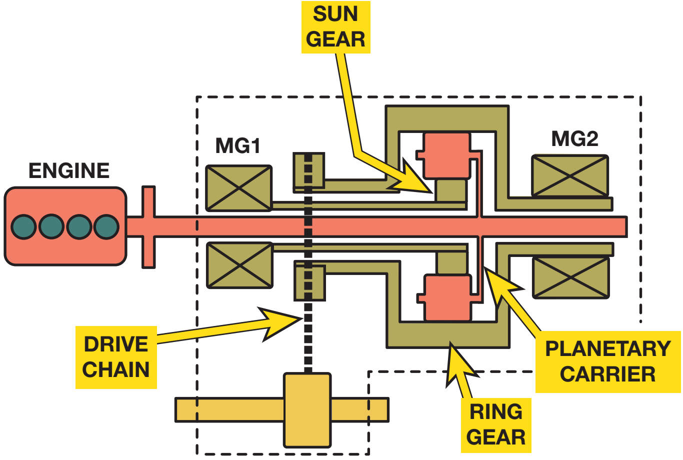


FIGURE 131–17 The power-split device from the Toyota Hybrid System. Note the vehicle will only move when MG2 (and the ring gear) is turning.

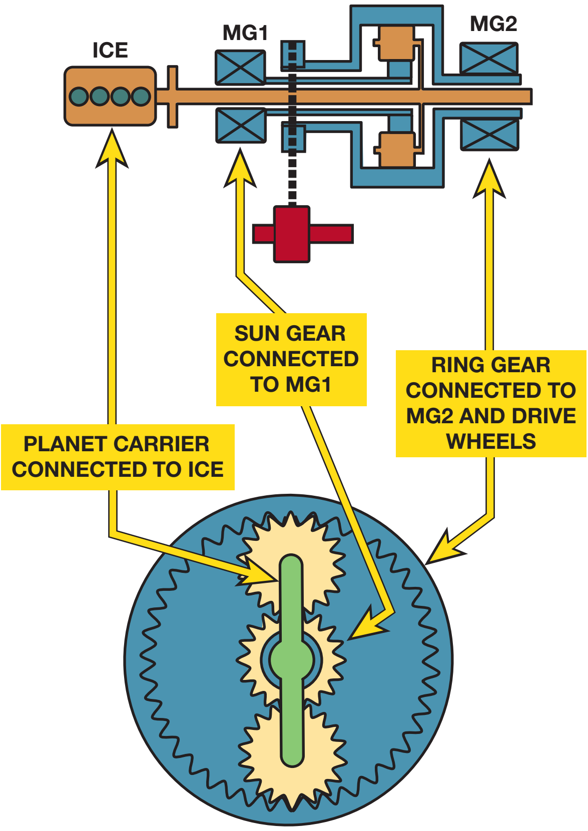

ICE
MG1
MG2
SUN GEAR CONNECTED TO MG1
RING GEAR CONNECTED TO MG2 AND DRIVE WHEELS
PLANET CARRIER CONNECTED TO ICE

FIGURE 131–18 The planetary gearset used in the Toyota Hybrid System has 2.6 times the number of teeth in its ring gear as it has in its sun gear. This means that the ICE (attached to the planet carrier) will send 72% of its torque to the ring gear (drive wheels) and 28% of its torque to the sun gear (MG1).

While torque split percentages are always the same, power split percentages will vary depending on the RPM of the various components. Horsepower is the rate at which work is performed and is a function of torque and RPM. If a shaft has torque applied to it, but remains at zero RPM, no work is being performed and no horsepower is transmitted through the shaft. The same principle applies to the torque split planetary gear set. If the sun gear is stationary, it will still receive 28% of the torque of the ICE, but all of the engine horsepower will be directed through the ring gear and on to the drive wheels.

OPERATION

- **Vehicle Stopped**. When the vehicle is stopped, nothing is happening within the vehicle drive system. The ICE is shut off, and both electric motor/generators are shut off as well. There are circuits within the vehicle that will use electrical energy from the auxiliary battery, but the drive system itself is effectively inert. The Toyota hybrid system does not use an auxiliary starter, but instead uses the MG1 for starting under all conditions. ● **SEE FIGURE 131–19**.
- **Light Acceleration**. When the vehicle is driven at low speeds and light acceleration, it is driven by MG2 alone. ● **SEE FIGURE 131–20**. This is because the electric motor is more efficient than the ICE at low vehicle speeds. Current from the high-voltage (HV) battery is sent through the inverter and on to MG2 to move the vehicle. A special graph, known as a monograph, shows the speed relationship between the various elements. When the engine is stopped (0 RPM), MG2 is turning forward (+), and this causes MG1 to turn backward (–). ● **SEE FIGURE 131–21**.

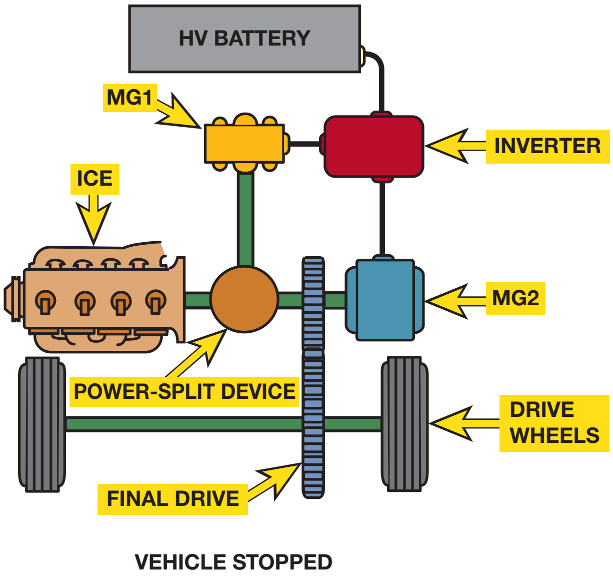


FIGURE 131–19 When the vehicle is stopped, the ICE is shut off along with both motor/generators.

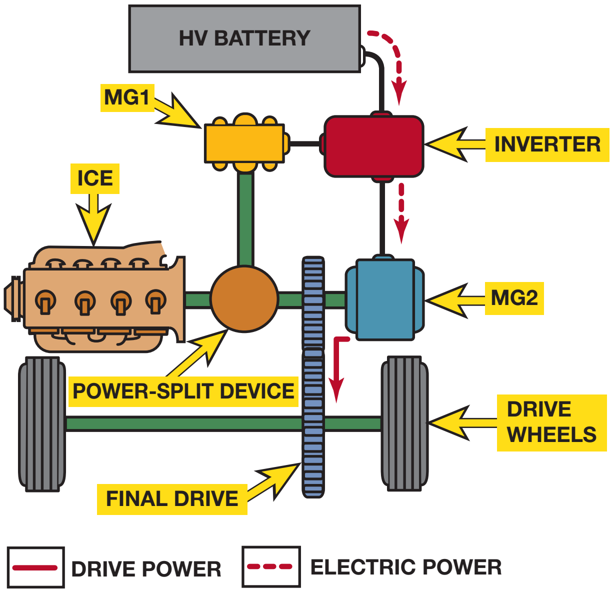


FIGURE 131–20 Under light acceleration, power is sent to MG2 to move the vehicle.

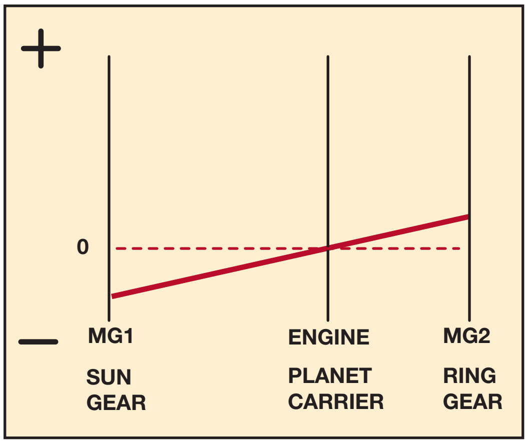


FIGURE 17–21 Under light acceleration, the engine is stopped (0 RPM), MG2 is turning forward (+), and MG1 is turning backward (–).

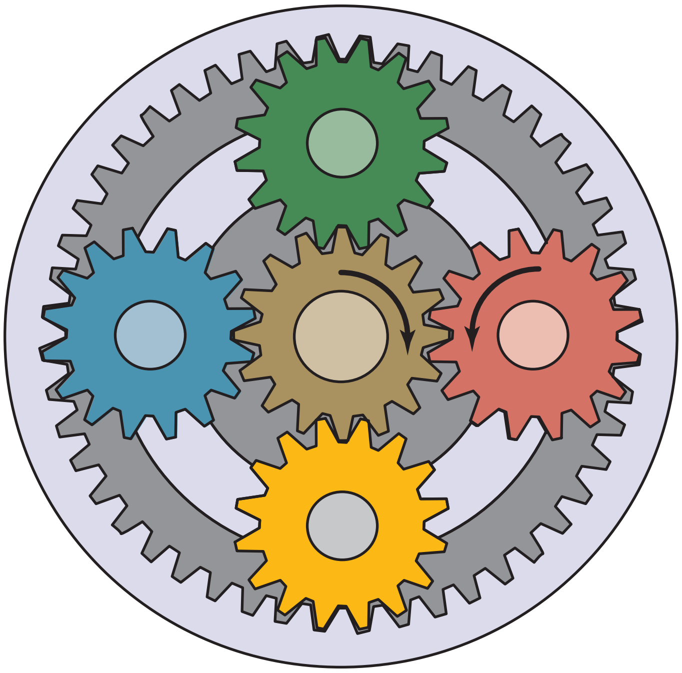


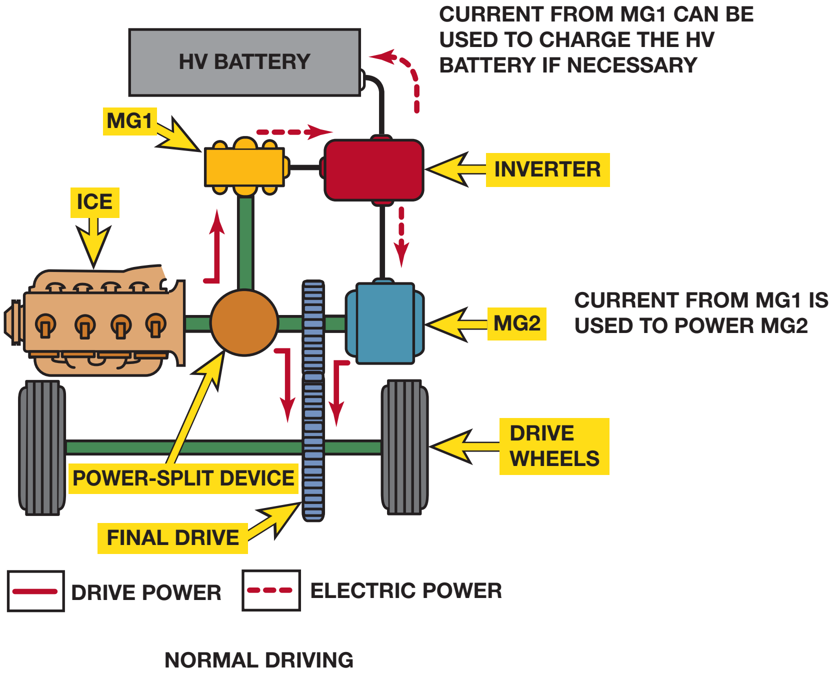
FIGURE 131–22 To start the ICE, MG1 (sun) acts as a motor and turns clockwise (CW), causing the planet carrier (attached to the ICE) to also turn CW.

- **Normal Driving**. When higher vehicle speeds are required, the ICE must be started so that its output can be combined with that of MG2. The ring gear is already turning clockwise as the vehicle travels in a forward direction. Since the planet carrier (attached to the ICE) is stationary, the sun gear (driven by MG1) is used to drive the planet carrier clockwise and start the ICE. Current from the HV battery is directed through the inverter and operates MG1 as a motor, turning clockwise and spinning the ICE up to 1000 RPM for starting. ● **SEE FIGURE 131–22**.

Once the ICE is started, MG1 operates as a generator, but turns in the counterclockwise direction. ICE output is now divided or "split" between the drive wheels (ring gear) and MG1 (sun gear). Power generated by MG1 is either directed to MG2 to help move the vehicle or is used to recharge the HV battery, if necessary. ● **SEE FIGURES 131–23 AND 131–24**.

- **Full-Throttle Acceleration and High-Speed Cruise**. When greater acceleration is required, both MG2 and the ICE continue sending torque to the vehicle drive wheels, but MG2 can also receive power from the HV battery to increase its output. As demand increases further, the ICE speed is increased for more output. To enable an increase in ICE speed, the sun gear (MG1) must rotate in a clockwise direction. It is during these times that MG1 can be configured as a motor and will draw power from MG2 during a phase known as *energy recirculation*. ● **SEE FIGURES 131–25 AND 131–26**.
- **Deceleration and Braking**. As the vehicle is decelerating, MG2 is configured as a generator. The kinetic energy (energy of movement) of the vehicle is converted into electrical energy by MG2. The ICE and MG1 are shut off, and current from MG2 is sent through the inverter and is used to recharge the HV battery. ● **SEE FIGURE 131–27**.
- **Reverse**. If reverse is selected, power is sent from the HV battery to the inverter and on to MG2. MG2 operates in

FIGURE 131–23 Normal driving—the ICE is now running and some of its torque is used to drive MG1. Electricity generated by MG1 is used to power MG2 or recharge the HV battery.


HV BATTERY
CURRENT FROM MG1 CAN BE USED TO CHARGE THE HV BATTERY IF NECESSARY
MG1
INVERTER
ICE
MG2
CURRENT FROM MG1 IS USED TO POWER MG2
DRIVE WHEELS
POWER-SPLIT DEVICE
FINAL DRIVE
DRIVE POWER
ELECTRIC POWER
NORMAL DRIVING

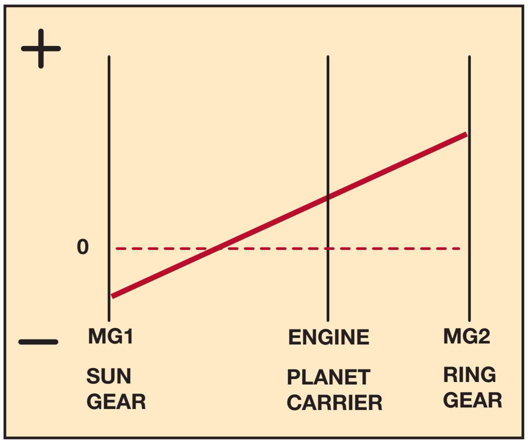


FIGURE 131–24 Normal driving—the engine is running, MG2 is turning forward (+), and MG1 is turning backward (–).

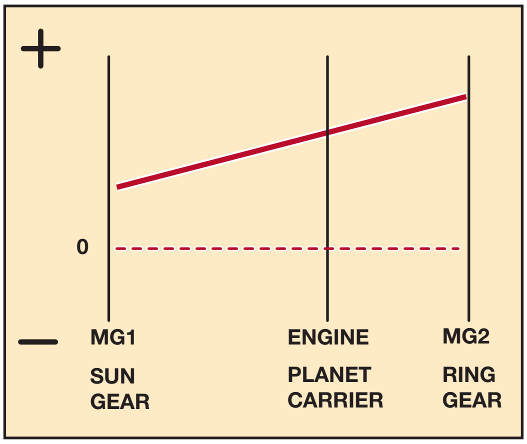
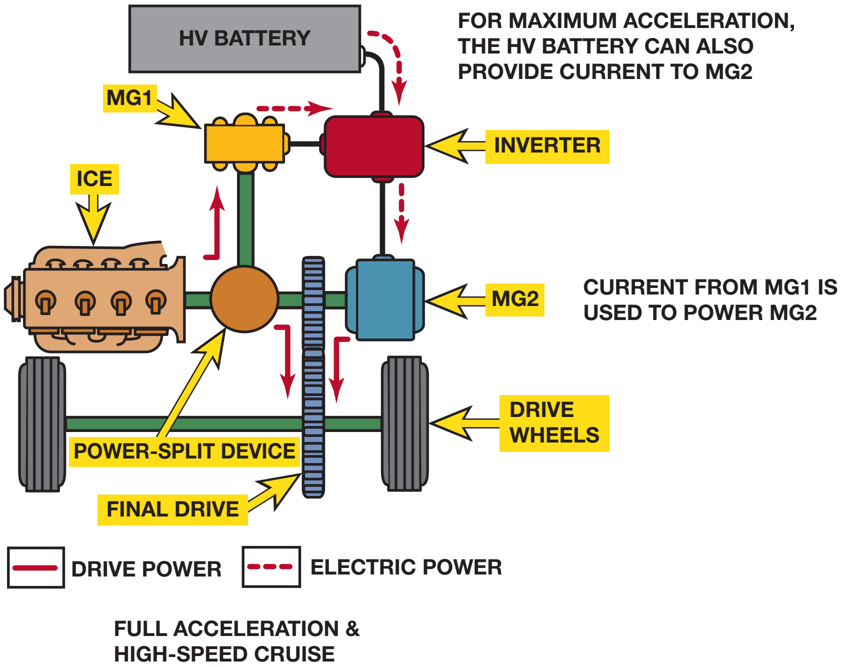


FIGURE 131–26 Full-throttle acceleration and high-speed cruise—this graph shows MG1 acting as a motor using power from MG2. This increases the speed of the ICE, allowing it to produce higher output.

FIGURE 131–25 Full-throttle acceleration and high-speed cruise—with greater demand for acceleration, power from MG1 is combined with power from the HV battery to generate higher output from MG2. It is also possible to configure MG2 as a generator and send its power to MG1 (which then acts as a motor).


HV BATTERY
FOR MAXIMUM ACCELERATION, THE HV BATTERY CAN ALSO PROVIDE CURRENT TO MG2
MG1
INVERTER
ICE
MG2
CURRENT FROM MG1 IS USED TO POWER MG2
DRIVE WHEELS
POWER-SPLIT DEVICE
FINAL DRIVE
DRIVE POWER
ELECTRIC POWER
FULL ACCELERATION & HIGH-SPEED CRUISE

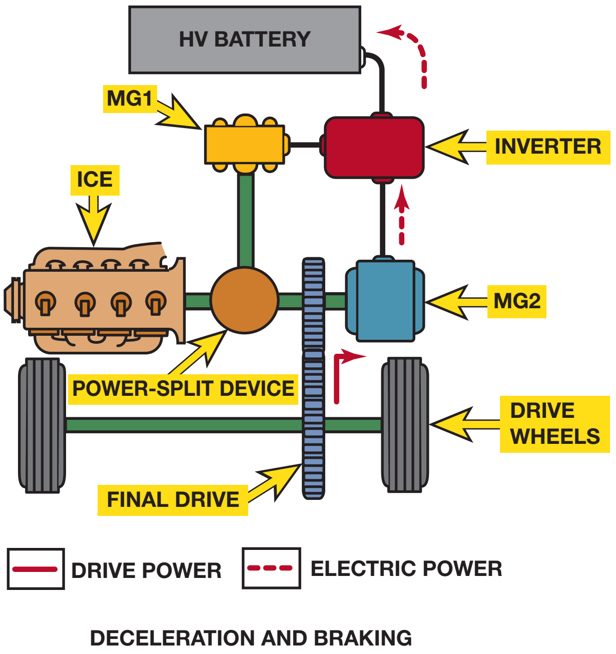


FIGURE 131–27 Deceleration and braking—MG2 is configured as a generator and recharges the HV battery.

the reverse direction to back up the vehicle, but the other components in the drive system are turned off at this time. The ICE does not run when the vehicle is being driven in reverse. ● **SEE FIGURE 131–28**.

CONSTRUCTION The Toyota power-split transaxle is built with an aluminum case composed of two major assemblies. These are known as the MG1 assembly and the MG2 assembly, and each houses its respective motor/generator.

Each of the motors/generators performs two functions:

- MG1—Used to crank the ICE and generate electrical current to charge the high-voltage battery.
- MG2—Used to propel the vehicle and to charge the high-voltage battery during deceleration.

Each of these major assemblies has its own water jacket for cooling the motor/generator windings in the housing. There are two water jacket unions installed in each major assembly, and these send coolant to the motors from the separate inverter cooling system. ● **SEE FIGURE 131–29 A AND B**.

The following components are assembled on a common axis:

- Internal combustion engine (ICE)
- MG1
- Power-split device
- MG2
- Oil pump

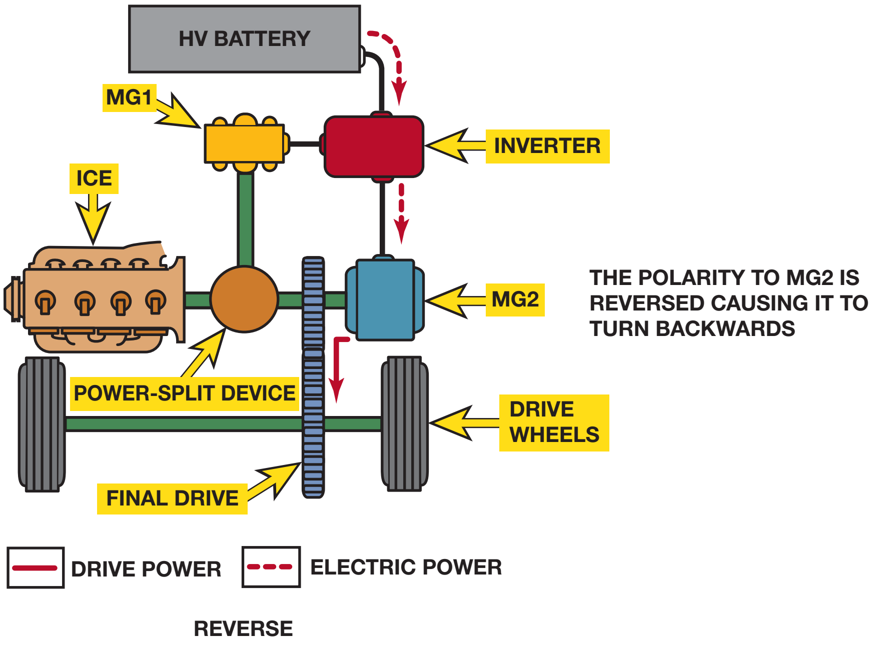
The final drive is housed between the two major assemblies and utilizes a conventional open differential for sending torque to the front-drive wheels. A chain drive attaches the ring gear of the power-split device to the counter drive gear, which drives the counter driven gear that is meshed with the ring gear of the differential assembly. ● **SEE FIGURE 131–30**.

This system does not use a conventional clutch or torque converter. With this design, there is no need to disconnect the engine from the input shaft. This is because the engine can turn at any speed while the vehicle is stopped (ring gear is stopped) by using MG1 (sun gear) as a generator. The ICE is connected directly to the transaxle input shaft using a damper disc mechanism. ● **SEE FIGURE 131–31**.

The transaxle oil pump is housed in the rear of the MG2 assembly and is attached to the input shaft from the ICE. ● **SEE FIGURE 131–32**. The oil is circulated by the pump only when the ICE is running.

When the vehicle is driven by MG2 only, the transaxle is splash-lubricated by the movement of the final drive gears. The transaxle for the 2001–2003 Prius has a cable-operated parking lock mechanism. This was replaced with an electrically actuated mechanism starting with the 2004 model year. ● **SEE FIGURE 131–33**.

SERVICE Service procedures to be performed at specified intervals include changing the transaxle oil and the coolant for



THE POLARITY TO MG2 IS REVERSED CAUSING IT TO TURN BACKWARDS

FIGURE 131–28 Reverse—MG2 alone is used to move the car in reverse. This is accomplished by reversing the direction of MG2.

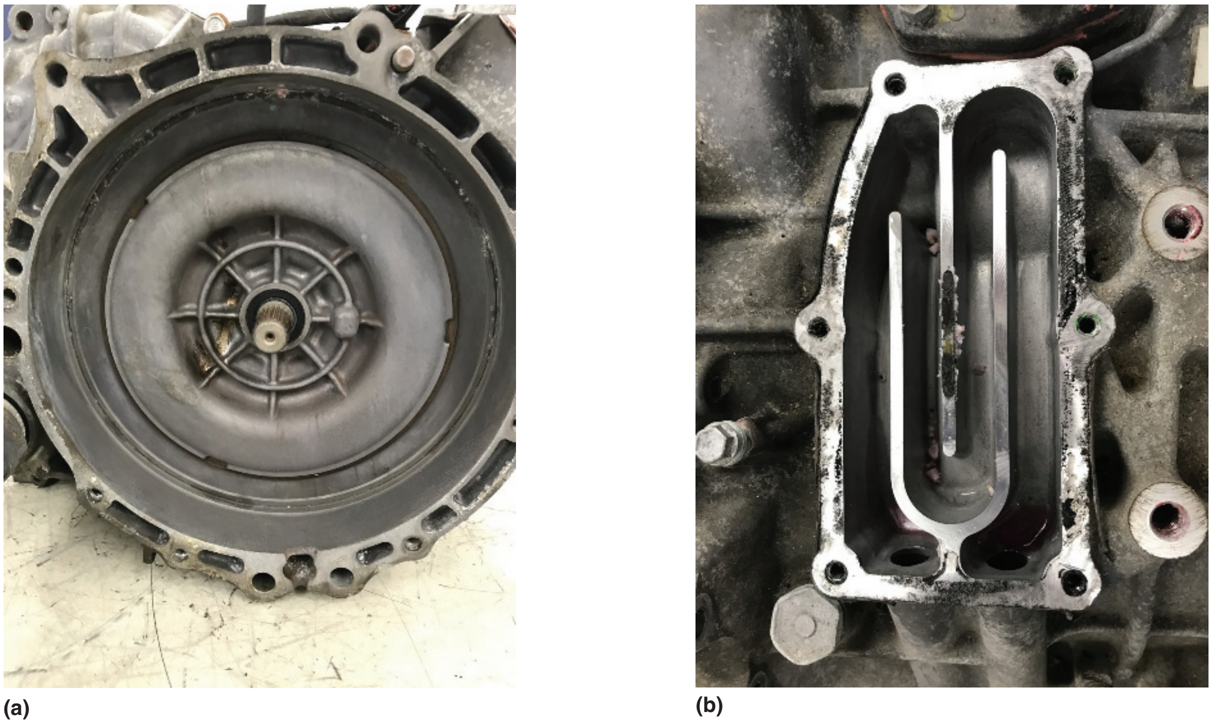


FIGURE 131–29 (a) Coolant is circulated under the ring in the bellhousing area to remove heat generated by MG1. (b) Coolant is circulated in the passages near the rear of the transmission to remove heat generated by MG2.

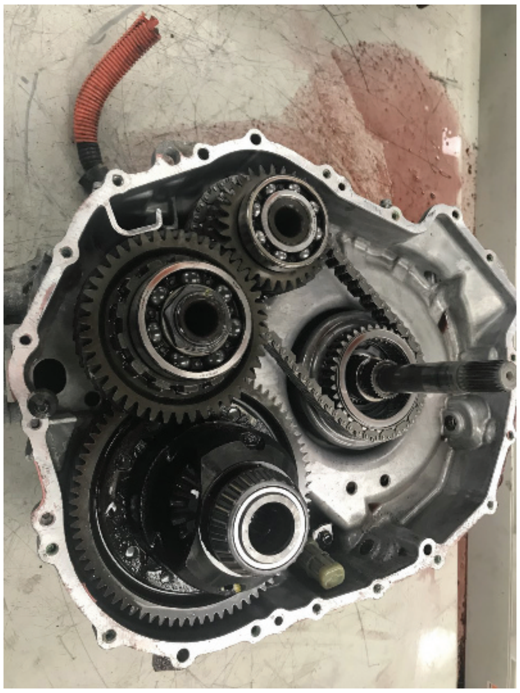


FIGURE 131–30 The view of the configuration of the final drive assembly after the front cover has been removed.

the inverter (high-voltage) system. There are drain plugs for both at the bottom of the transaxle assembly. The transaxle oil is refilled through a hole in the front of the case, with the level being brought up to a specified distance from the bottom of the hole. The coolant is refilled at the reservoir that is located on the inverter assembly and must be bled properly before placing the vehicle back into service. Always use the recommended fluids and procedures when servicing any vehicle.

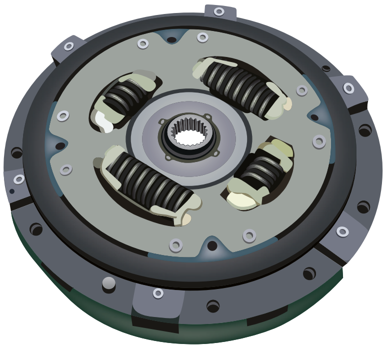


FIGURE 131–31 The flywheel and clutch assembly serve as the dampener between the engine and transmission.

NOTE: The fastest and most reliable way to refill the inverter cooling system is to use an airlift fluid exchange machine. This pulls the cooling system into a vacuum and then injects the coolant into the evacuated system. This method fills the system quickly and eliminates air bubbles.

HYBRID TRANSMISSION DIAGNOSIS

STEPS INVOLVED When diagnosing a hybrid electric vehicle (HEV) transmission concerns, perform the following steps:

STEP 1 The first step is to verify the customer complaint.

STEP 2 Check the fluid level and condition.

STEP 3 Check for stored diagnostic trouble codes (DTCs).

STEP 4 Check for any related technical service bulletins (TSBs).

STEP 5 Check scan tool data including checking the adaptive values.

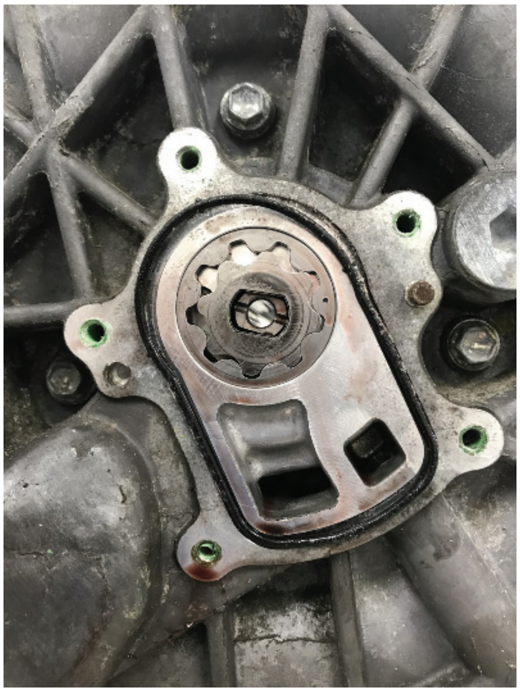


FIGURE 131–32 With the cover removed, the transmission oil pump is visible on the rear of the transmission.

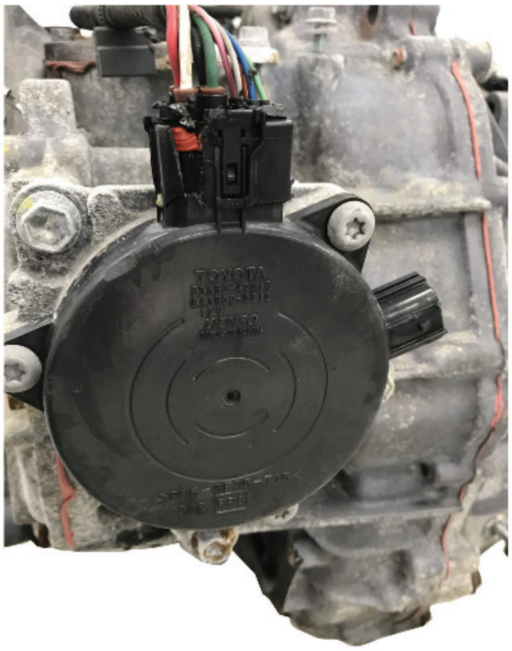


FIGURE 131–33 The electronic actuated park lock mechanism is mounted externally beginning with the 2004 model year.

STEP 6 Perform visual inspections, including checking for recent accident damage, previous repairs, or other issues.

STEP 7 Perform bidirectional control of the transmission using a factory or an enhanced aftermarket scan tool to check operation. This helps to establish if the issue is inside or outside of the transmission/transaxle.

STEP 8 Locate and correct the root cause of the problem.

Always follow the specified diagnostic and repair procedures for the vehicle being serviced.

ELECTRIC VEHICLE TRANSMISSIONS

ACCELERATION VS TOP SPEED Most production electric vehicles use a single-speed transmission. ICEs need many gears because they have a narrow RPM window within which they can operate efficiently. For electric motors, that window is much wider, so a single-speed works for both low-end acceleration and highway driving. It does require some compromise, and so EV manufactures usually design their system for optimum low-end acceleration instead of top speeds. Most electric vehicles have a top speed of 110–125 MPH (180–200 km/h). At top speed the electric motor RPM is 10000 and 18000 RPM, depending on the make and model.

SINGLE-SPEED GEARING The objective of the motor and drivetrain is improving the conversion rate of battery power to actual wheel power. Every one percentage point in energy conversion efficiency translates into 2% more range. Most all-electric vehicles are equipped with just a single speed transmission/transaxle, yet are capable of delivering outstanding performance and acceptable range with motor torque of up to 230 lb-ft (315 Nm) and peak power of 188 HP (140 kW).

FORD MUSTANG MACH-E BorgWarner is producing an Integrated Drive Module (iDM) being used in the Ford Mustang Mach-E. The iDM consists within one compact assembly including the following components:

- Electric traction motor
- Single-speed gearbox
- Thermal-management system (liquid cooling)
- Motor and power electronics

The iDM uses parallel axis gearing, instead featuring a concentric design with outputs on the same axis as the electric motor, resulting in a more compact package.

CHEVROLET BOLT The Chevrolet Bolt drive unit consists of an electric motor and final drive assembly. ● **SEE FIGURE 131–34**.

The electric motor is a permanent-magnet synchronous AC motor. It is rated at (150 kW) and has a maximum rotation speed

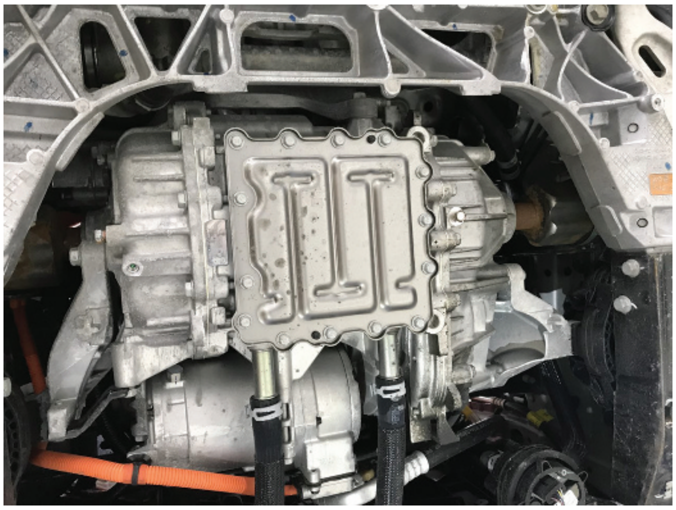


FIGURE 131–34 The electric motor and final drive assembly installed in a Chevrolet Bolt.

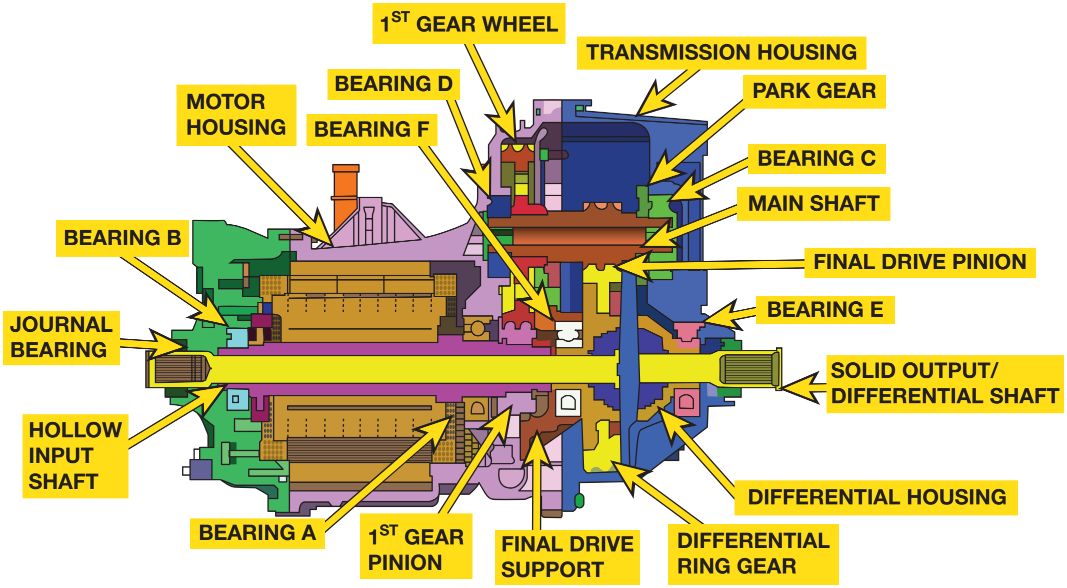

1^{ST} GEAR WHEEL
TRANSMISSION HOUSING
BEARING D
PARK GEAR
MOTOR HOUSING
BEARING F
BEARING C
MAIN SHAFT
BEARING B
FINAL DRIVE PINION
BEARING E
JOURNAL BEARING
SOLID OUTPUT/ DIFFERENTIAL SHAFT
HOLLOW INPUT SHAFT
DIFFERENTIAL HOUSING
BEARING A
1^{ST} GEAR PINION
FINAL DRIVE SUPPORT
DIFFERENTIAL RING GEAR

FIGURE 131–35 A CATIA drafting of a Chevrolet Bolt electric motor and final drive assembly.

of 8810 RPM (2017 model year specifications). The final drive section of the drive unit consists of the drive gear on the output end of the electric motor, the main shaft, and the ring gear that is mounted on the differential assembly. ● **SEE FIGURE 131–35**.

The final drive assembly provides a gear reduction of 7.05:1 between the electric motor and the drive wheels. The drive unit is internally lubricated and cooled using Dexron HP transmission fluid. ● **SEE FIGURE 131–36**.

The heat is transferred out of the transmission to an external radiator using coolant. ● **SEE FIGURE 131–37**.

The drive unit is completely serviceable following the specified procedures and General Motors-supplied special tools.

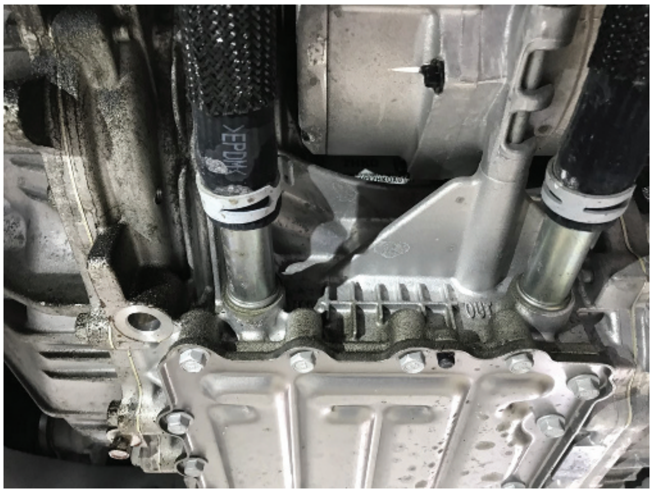


FIGURE 131–37 Coolant enters through the hose on the left, travels through the passageway absorbing heat, and exits to the radiator through the hose on the right.

ACDelco
DEXRON
DEXRON-HP
NET CONTENTS
1qL/32
10-4101
19331925

FIGURE 131–36 Dexron HP synthetic transmission fluid is specified for the Bolt final drive assembly.

NISSAN LEAF At the heart of LEAF's powertrain is its three-phase AC electric motor. It produces 40 kilowatts of power and can produce maximum torque within 0.1 seconds. This motor has a permanent magnet rotor core with high-density stator winding. It produces 206.5 pound-feet of torque and weighs 129 pounds. ● **SEE FIGURE 131–38**.

A resolver is incorporated to input rotor position and speed to the Vehicle Control Module (VCM). Resolver calibration data to correct for variations in manufacturing is encoded on the traction motor housing. ● **SEE FIGURE 131–39**.

Instead of a conventional transmission, the LEAF incorporates a reducer that transfers the torque from the traction motor to the drive wheels. The reducer directs the motor's output to provide ideal torque at both low- and high-motor speeds. Compact and lightweight, the reducer minimizes energy loss due to friction. The LEAF's reducer is connected to the electric drive motor. Its components include the input gear, main gear, main shaft, final gear, differential, and parking unit. ● **SEE FIGURE 131–40**.

Nissan is not currently servicing any of the internal parts for the electric motor assembly; however, there is a procedure for

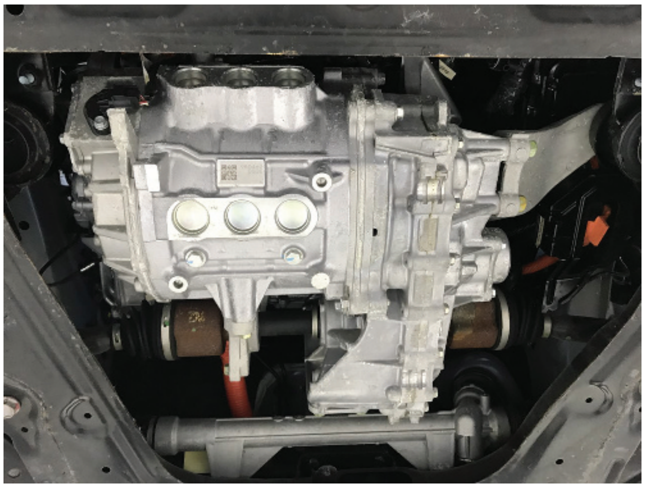


FIGURE 131–38 The electric motor assembly and reducer installed in a 2011 Nissan Leaf.

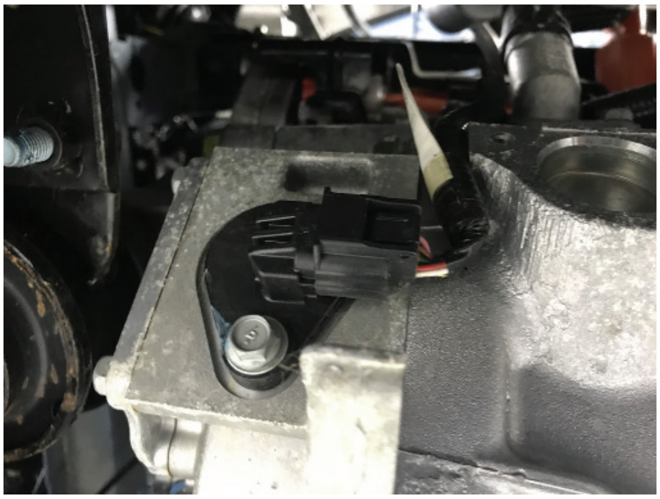


FIGURE 131–39 The external connection for the resolver.

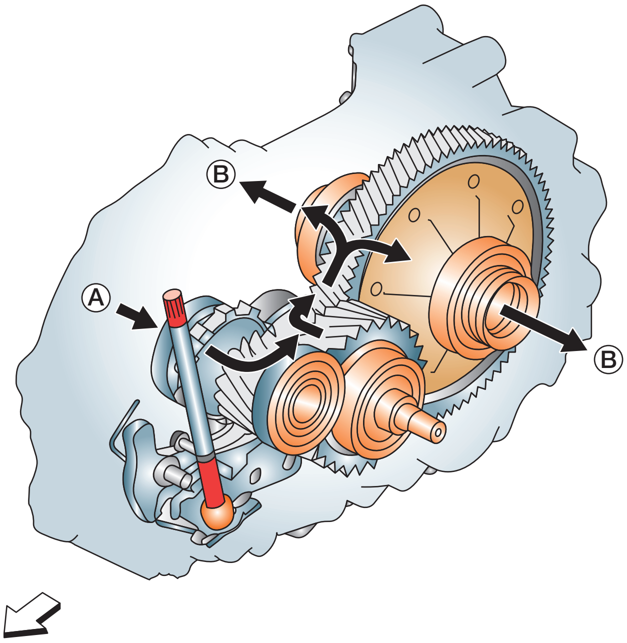


FIGURE 131–40 Power flow through the reducer.

repairing the reducer. According to the periodic maintenance schedule, the oil level in the reducer must be inspected. If the fluid level is found to be low, it should be filled to the desired level with Nissan genuine Matic Fluid S. The reducer holds approximately 1.1 liter of lubricant.

FREQUENTLY ASKED QUESTION

What Happens When You Shift to Neutral?

When neutral is selected, does it just disconnect the power connections? Or is the motor free to spin? In neutral, there is no power being supplied to the electric traction motor. The motor is never disconnected.

REVIEW QUESTIONS

1. What are the differences in FWD, RWD, and AWD powertrain configurations?
2. Explain how the transmission delivers torque and optimizes fuel economy.
3. Explain how the Toyota power-split system delivers power to the drive wheels.
4. How is the Chevrolet Bolt transmission lubricated and cooled?
5. Describe the operation of a single-speed transmission in a typical electric vehicle.

CHAPTER QUIZ

1. In a GM two-mode hybrid electric vehicle, when can the vehicle be powered by electric mode alone?
   a. During the first mode
   b. During the second mode
   c. During either the first or second mode
   d. During heavy load conditions regardless of mode
2. Modifications to automatic transmissions used in hybrid vehicles include ____________.
   a. electric auxiliary transmission fluid pumps
   b. modified torque converter lockup schedule
   c. hydraulic impulse storage accumulator
   d. All of the answers are correct

3. In a Toyota/Lexus hybrid electric vehicle, how is reverse achieved?
    - **a.** The ICE reverses direction and powers the drive wheels
    - **b.** MG2 is used to power the vehicle in reverse
    - **c.** MG1 is used to power the vehicle in reverse
    - **d.** Either b or c depending on model and year
4. A FWD hybrid electric vehicle with an electric rear axle ______________.
    - **a.** has all-wheel drive capabilities
    - **b.** uses a special inverter
    - **c.** has a separate resolver and temperature sensor for the rear axle unit
    - **d.** All of the answers are correct
5. The final drive assembly in an electric vehicle transmission assembly ______________.
    - **a.** transfers torque from the electric motor to the drive wheels
    - **b.** reduces motor speed to produce ideal torque at low and high speeds
    - **c.** provides for a parking mechanism for the assembly
    - **d.** All of the answers are correct
6. What is the first step when diagnosing a hybrid vehicle transmission?
    - **a.** Check the fluid level
    - **b.** Verify the customer concern
    - **c.** Check for trouble codes
    - **d.** Check for Technical Service Bulletins (TSBs)
7. In a Toyota/Lexus hybrid electric vehicle, what is the purpose of MG1?
    - **a.** Start the ICE
    - **b.** Charge the HV battery
    - **c.** Provide additional power to MG2
    - **d.** Both answers a and b are correct
8. The oil pump in the Toyota/Lexus power-split hybrid system ______________.
    - **a.** only turns when the ICE is operating
    - **b.** is located in the rear cover of the transmission behind MG2
    - **c.** only turns when MG2 is operating
    - **d.** Both answers a and b are correct
9. The electric motor in the Ford/Lincoln 10R80 MHT transmission provides ______________.
    - **a.** stop-start capabilities
    - **b.** extra power
    - **c.** extra low-speed torque
    - **d.** All of the answers are correct
10. How many forward speeds does the typical electric vehicle transmission have?
    - **a.** One
    - **b.** Two
    - **c.** Three
    - **d.** Four or more

Chapter

132

AUTOMATIC TRANSMISSION/ TRANSAXLE DIAGNOSIS AND IN-VEHICLE SERVICE

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain the process of diagnosing transmission problems.
- Describe how to diagnose transmission fluid leaks.
- Discuss the procedures for performing in-vehicle service.

KEY TERMS:

Diagnostic trouble codes (DTCs) 1682 • Technical service bulletins (TSBs) 1683

TRANSMISSION PROBLEM DIAGNOSIS

VERIFY THE CUSTOMER CONCERN The first step is to verify the customer concern. The customer should be asked the following questions in an effort to determine as much about the problem as possible:

- What exactly seems to be the concern? (Ask the customer to be as detailed as possible.)
- When did the problem first appear?
- Under what conditions do the symptoms occur? (Do they occur first thing in the morning? After the vehicle has been driven for a while?)
- Describe under what driving conditions the problem is noticed, such as when accelerating or while coasting to a stop or some other condition.
- Has the vehicle been serviced recently, such as a fluid change?

FLUID CHECK The first step in diagnosing any problem is to test drive the vehicle and verify the customer complaint (concern). Before test driving the vehicle, check the level and condition of the automatic transmission/transaxle fluid. Follow the procedure for checking the level as published in the owner's manual or factory information. ● **SEE FIGURE 132–1**.

CHECKING FLUID LEVEL WITH A DIPSTICK To check transmission fluid with a dipstick, check the procedure stamped on the dipstick. The usual procedure includes the following steps:

STEP 1 Park the vehicle on a level surface, apply the parking brake securely, and place the gear selector in park or neutral as recommended by the manufacturer. Start the engine and let the temperature of the transmission come up to operating temperature.

STEP 2 Apply the service brakes firmly and move the gear selector to each of the operating ranges. Leave the selector in each position long enough for each gear to become completely engaged.

STEP 3 Return the selector lever to park or neutral, depending on the transmission. Leave the engine running at idle speed.

STEP 4 Clean any dirt from the dipstick cap and remove the dipstick.

STEP 5 Wipe the dipstick clean and return it to the filler pipe, making sure that it is fully seated.

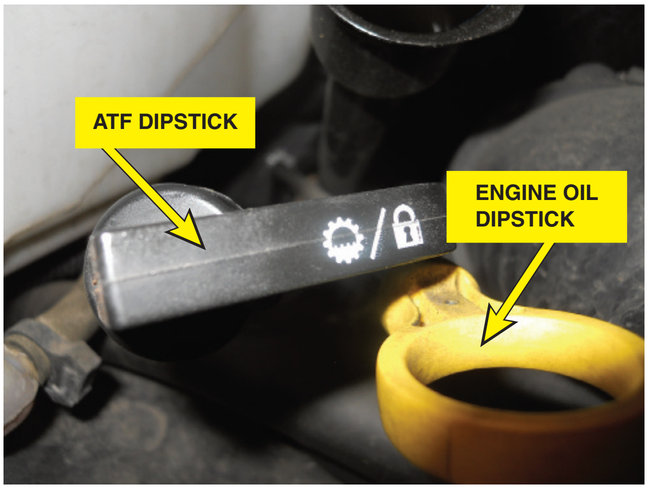


FIGURE 132–1 A typical automatic transmission dipstick (fluid level indicator). Many use a clip to keep it from being forced upward due to pressure changes inside the automatic transmission. A firm seal also helps keep water from getting into the fluid, which can cause severe damage to the clutches and bands.

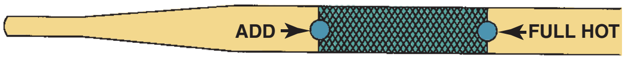


FIGURE 132–2 The "add" mark on most automatic transmission dipsticks indicates the level is down 0.5 quart (0.5 liter). Always follow the instructions stamped or printed on the dipstick.

STEP 6 Pull the dipstick out again and read the fluid level. ● **SEE FIGURE 132–2**.

Carefully grip the end of the dipstick between two fingers to get an indication of the fluid temperature.

- **a.** If it feels cold, use the COLD marks.
- **b.** If it feels warm, the correct fluid level will be between the HOT and COLD marks.
- **c.** If it is too hot to hold onto, use the HOT marks.

STEP 7 Replace the dipstick completely into the filler tube.

CHECKING FLUID LEVEL WITHOUT A DIPSTICK Some units do not use dipsticks. Fluid level is checked by following the procedure stated in the service information. When checking sealed units, a general procedure is to bring the transmission to operating temperature, and then remove the fluid level plug. Fluid will trickle or weep out of the plug if the level is correct.

- If it runs out, the level is high.
- If there is no fluid, the level is low.

Some manufacturers require a special procedure or tool in order to check the fluid level of their sealed transmissions, so it is wise to review their fluid-checking procedures. A general procedure follows.

To check transmission fluid level on a vehicle without a dipstick, perform the following steps:

STEP 1 Check service information for the correct checking procedure.

STEP 2 Check the transmission temperature using a scan tool. This is very important and the vehicle will usually need to be driven for several miles before the specified fluid temperature is achieved. ● **SEE FIGURE 132–3**.

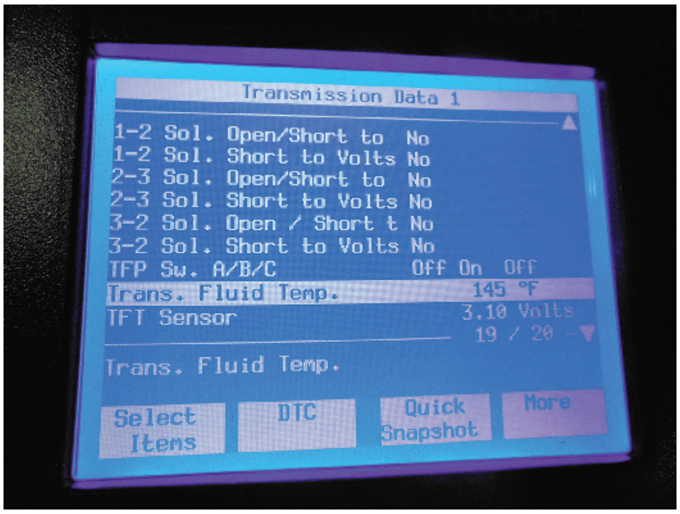

```
Transmission Data 1
1-2 Sol. Open/Short to  No
1-2 Sol. Short to Volts No
2-3 Sol. Open/Short to  No
2-3 Sol. Short to Volts No
3-2 Sol. Open / Short t No
3-2 Sol. Short to Volts No
TFP Sw. A/B/C            Off On  Off
Trans. Fluid Temp.           145 °F
TFT Sensor                3.10 Volts
                             19 / 20
Trans. Fluid Temp.
```

FIGURE 132–3 The temperature of the automatic transmission fluid is displayed on a factory or factory-level scan tool. It may require that the vehicle be driven under a load for the fluid to reach the specified temperature and can often be achieved by simply allowing the engine to idle.

TECH TIP

Quick-and-Easy Automatic Transmission/Transaxle Diagnosis

An experienced technician told the beginning technician that automatic transmission/transaxle diagnosis is often very easy. For example:

- **If the vehicle does not move in drive or reverse,** remove the transmission/transaxle for service because the problem is likely mechanical rather than hydraulic (valve body) or electrical (computer, solenoids, or sensors). If the unit will not power the vehicle, the unit will more than likely require removal for a thorough mechanical inspection and repair.
- **If the vehicle moves, but does not shift correctly,** the problem is likely electrical (computer, solenoid, or sensor) or hydraulic (valve body) rather than mechanical. This is usually true because if the vehicle is able to move forward and backward, the major mechanical components, though not in like-new condition, are at least able to function. Therefore, correcting the nonmechanical problem should be the technician's first consideration.

STEP 3 Locate and carefully remove the fluid level plug. Note that the level plug can be small, like a pressure check plug, or large, like a conventional plug. The plug can be located in the transmission case or on the bottom or side of the pan.

STEP 4 If fluid drips or seeps from the hole, the level is correct. Add additional fluid of the correct type until the level is correct. If necessary, add additional fluid by pumping it into the fill port located at the side of the case or up through the fluid level checking plug opening.

TEST DRIVE When test driving the vehicle, try to drive the vehicle under the same conditions that the owner noticed the problem.

To ensure a thorough diagnosis, the vehicle should be driven under a variety of conditions to see if it functions correctly, including the following:

1. **From a stop, and accelerated slowly until at highway speed.** This will check if all shifts are occurring and at the correct speeds.
2. **Note how the shifts feel.** The shifts may be too harsh or too soft. This could indicate a fluid pressure problem, or a worn clutch, bands, or accumulator.
3. **Note when the shifts occur.** The shifts may occur too early or too late.
4. **Use all gear selections.** Often a different element of clutch is used for manual gears compared to the same gear when the gear selector is in drive (D). Note any differences that may help in identifying the source of the problem.

COMMANDING SHIFTS Many automatic transmission test tools or scan tools can be used to actually cause the automatic transmission/transaxle to shift electrically. The tester is connected to the electrical connector at the automatic transmission/transaxle after disconnecting the factory connector. To perform this simple test, perform the following steps:

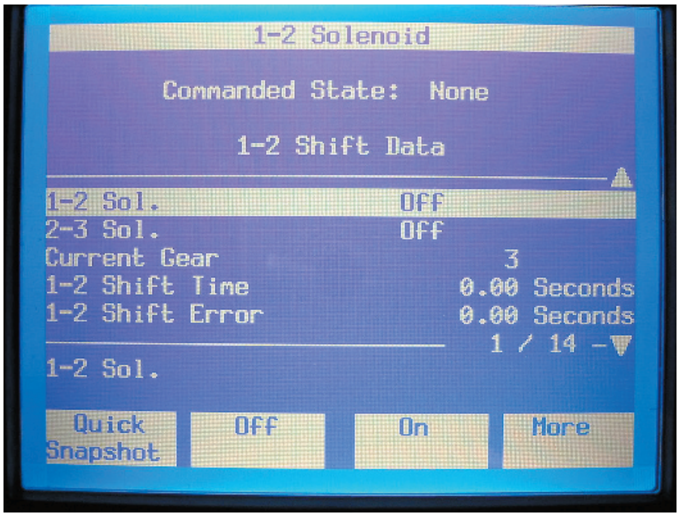
STEP 1 Safely hoist the vehicle.

STEP 2 Start the engine.

STEP 3 Place the gear selector in the drive position and use the tester or scan tool to command the various shift solenoids to actuate.

Results: If the shift occurs when commanded, the hydraulic system is functioning. If the tester commands a shift to occur and a shift does not occur, the service technician knows that the problem is either in the solenoid itself or the hydraulic system that actuates the clutch or band to accomplish the shift. ● **SEE FIGURE 132–4**.

CAUTION: A scan tool or special tester can be used to command shift while an assistant is driving the vehicle instead of on a hoist as stated above. If commanding a shift when driving, use extreme care as some shift may be harsh and damage to the vehicle could occur if the commanded shift occurs at too high a vehicle speed.



```
1-2 Solenoid

Commanded State:  None

1-2 Shift Data

1-2 Sol.                Off
2-3 Sol.                Off
Current Gear              3
1-2 Shift Time          0.00 Seconds
1-2 Shift Error         0.00 Seconds
                          1 / 14
1-2 Sol.
```

FIGURE 132–4 Most factory or factory-level scan tools are capable of bidirectional control of the automatic transmission or transaxle.

CHECK DIAGNOSTIC TROUBLE CODES If there are any **diagnostic trouble codes (DTCs)** stored in the memory of the vehicle computer, then a problem has been detected that should be corrected before further testing. ● **SEE CHART 132–1** for transmission-related diagnostic trouble codes.

A weak or missing engine cylinder can cause the vehicle to lack power, jerk, and hesitate. These symptoms are often blamed on an incorrectly shifting or slipping automatic transmission/transaxle. If a P0300 diagnostic code (random engine misfire code) is set, repair the cause of the misfire before trying to diagnose the transmission.

SCAN DATA A scan tool can display information about the various sensors and components that can assist the service technician in determining the cause of many automatic transmission/transaxle problems.

A properly operating engine should display the following readings with the engine at idle and operating in closed loop.

- **Engine coolant temperature (ECT)**—between 180 and 215°F (82 and 102°C)
- **Throttle position (TP) sensor**—usually between 0.5 and 4.5 volts and varying directly with throttle movement
- **Accelerator pedal position sensor (APPS)** —usually two or more sensors on differing scales (0.4 to 4.6 volts) and varying with accelerator pedal movement
- **Fuel injector pulse width**—1.5 to 3.5 ms
- **Upstream oxygen sensor (O2S)**—voltage varying between 200 and 800 mV
- **Air–fuel ratio sensor(s) (if equipped)**—scan tool to read fairly low and steady
- **Transmission fluid temperature**—less than 275°F (135°C)
- **Brake switch—**scan data to show a change when brake pedal is pressed and released
- **Manifold absolute pressure (MAP) sensor**—with the engine idling in park or neutral, the voltage should be within 0.88 and 1.62 volts or between 102 and 109 Hz for a Ford MAP sensor
- **Mass airflow sensor (MAF)**—warm engine in park with no load typically reads grams per second within 20% of the engine's liters of displacement, a 3.5 liter engine will show fairly close to 3.5 g/s of airflow at idle
- **Vehicle speed (VS) sensor**—source can vary: derived from ABS wheel speed sensors, output speed sensor of transmission, or a dedicated sensor on transmission or transfer case
- **Idle speed**—check for normal idle speed; vehicles with electronic throttle control are usually 2% to 3% open at warm idle in park and vehicles with IAC (idle air control) valves are typically 10 to 30 steps if stepper motor type or 250 to 400 milliamps if linear
- **Shift solenoids**—check for the proper voltage and current of the shift solenoids using a factory or factory-level scan tool

Observe the operation of the command for the shift solenoids and the TCC solenoid while driving the vehicle. This information confirms that the computer is commanding the

TRANSMISSION-RELATED DTCs

P0703	Brake switch input circuit
P0705	Transmission range sensor circuit problem (PRNDL input)
P0706	Transmission range sensor circuit range or performance
P0707	Transmission range sensor circuit low input
P0708	Transmission range sensor circuit high input
P0710	Transmission fluid temperature sensor problem
P0711	Transmission fluid temperature sensor range or performance
P0712	Transmission fluid temperature sensor low input
P0713	Transmission fluid temperature sensor high input
P0715	Input or turbine speed sensor circuit problem
P0716	Input or turbine speed sensor circuit range or performance
P0717	Input or turbine speed sensor circuit no signal
P0720	Output speed sensor circuit problem
P0721	Output speed sensor circuit range or performance
P0722	Output speed sensor circuit no signal
P0725	Engine speed input circuit problem
P0726	Engine speed input circuit range or performance
P0727	Engine speed input circuit no signal
P0728	Gear 6 incorrect ratio
P0730	Incorrect gear ratio
P0731	Gear 1 incorrect ratio
P0732	Gear 2 incorrect ratio
P0733	Gear 3 incorrect ratio
P0734	Gear 4 incorrect ratio
P0735	Gear 5 incorrect ratio
P0736	Reverse incorrect ratio
P0740	Torque converter clutch system problem
P0741	Torque converter clutch system performance or stuck off
P0742	Torque converter clutch system stuck on
P0743	Torque converter clutch system electrical
P0745	Pressure control solenoid problem
P0746	Pressure control solenoid performance or stuck off
P0747	Pressure control solenoid stuck on
P0748	Pressure control solenoid electrical
P0750	Shift solenoid A problem
P0751	Shift solenoid A performance or stuck off
P0752	Shift solenoid A stuck on
P0753	Shift solenoid A electrical
P0755	Shift solenoid B problem
P0756	Shift solenoid B performance or stuck off
P0757	Shift solenoid B stuck on
P0758	Shift solenoid B electrical
P0760	Shift solenoid C problem
P0761	Shift solenoid C performance or stuck off
P0762	Shift solenoid C stuck on
P0763	Shift solenoid C electrical
P0765	Shift solenoid D problem
P0766	Shift solenoid D performance or stuck off
P0767	Shift solenoid D stuck on
P0768	Shift solenoid D electrical
P0770	Shift solenoid E problem
P0771	Shift solenoid E performance or stuck off
P0772	Shift solenoid E stuck on
P0773	Shift solenoid E electrical

CHART 132–1

Transmission/transaxle-related diagnostic trouble codes (DTCs). For transmission-related diagnostic trouble codes for vehicles older than 1996, check service information on how to retrieve and read the codes.

operation; it does not mean that the solenoids are working correctly. Therefore, if the scan data indicates that a particular solenoid is being commanded on and nothing occurs, then the problem could be caused by a defect with the following:

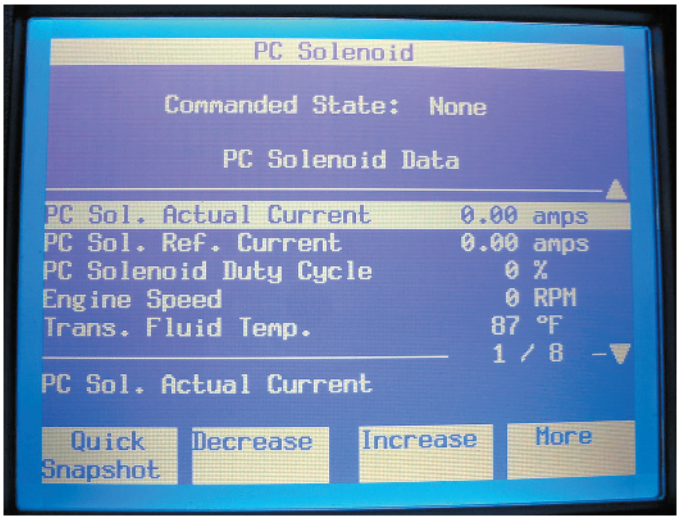
1. Hydraulic component (clutch, band, etc.)
2. Solenoid
3. Fault in the wiring to the solenoid or from the solenoid to the PCM or TCM

● **SEE FIGURE 132–5.**

Use a scan tool to check the engine operation values and inputs that could affect transmission operation. ● **SEE CHART 132–2.**

CHECK TECHNICAL SERVICE BULLETINS According to studies performed by automobile manufacturers, as many as 30% of the vehicles can be repaired following the information, suggestions, or instructions concerning replacement parts found in a **technical service bulletin (TSB)**. Before an accurate search of a TSB can be performed, the technician must know the following information about the vehicle under service:

- Make, model, and year of the vehicle
- Engine size and VIN
- Transmission type
- Federal, high-altitude, or California emissions
- Build date (sometimes)



```
PC Solenoid
Commanded State:  None
PC Solenoid Data
PC Sol. Actual Current      0.00 amps
PC Sol. Ref. Current        0.00 amps
PC Solenoid Duty Cycle         0 %
Engine Speed                   0 RPM
Trans. Fluid Temp.          87 °F
                            1 / 8
PC Sol. Actual Current
```

FIGURE 132–5 A Tech 2 scan tool is able to display shift solenoid current. Use this information and check service information for the specified current to help diagnose shift solenoid-related faults.

INPUT SENSOR	TYPICAL VALUE
Throttle position (TP) sensor	0.5–4.5 volts (0% to 100%)
Mass airflow (MAF) sensor	3–7 grams per second at idle
Oxygen sensor (O2S)	200–800 mV and changing rapidly
Turbine shaft speed (TSS) sensor	Should be the same as the engine speed
Transmission fluid temperature (TFT) sensor	−40 to 300°F (−40 to 150°C)
Transmission range (TR) sensor	P, N, R, D, L (or 2, 1)
Overdrive switch (if equipped)	On or off
Barometric pressure (BARO) sensor	Varies with weather and altitude
Accelerator pedal position (APP) sensor	0% to 100%
Brake pedal position (BPP) switch	On or off

CHART 132–2

Typical automatic transmission/transaxle sensor values as displayed on a scan tool.

- Current hard codes
- History or soft codes
- PCM/TCM part number for applicable module flash

Diagnostic trouble codes must be known before searching for TSBs because bulletins often include information on solving problems that involve a stored code.

TRANSMISSION/TRANSAXLE IDENTIFICATION The identification of the transmission/transaxle can sometimes be a challenge.

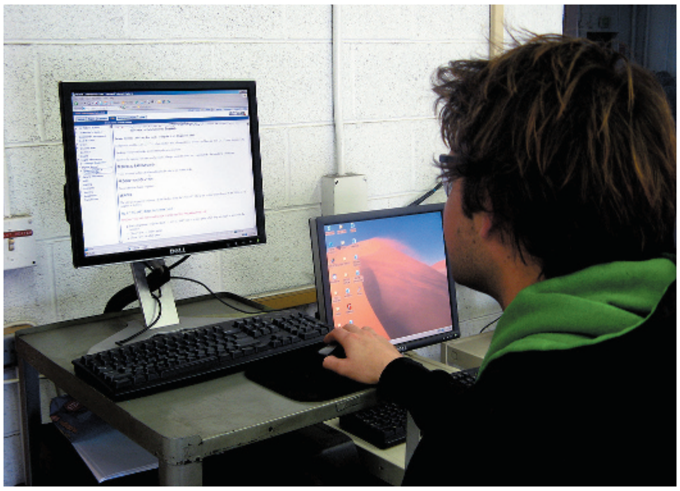


FIGURE 132–6 Checking service information for how to perform diagnosis on an automatic transmission fault is a wise step.

TECH TIP

You'd Ask a Friend, Wouldn't You?

If you were stuck on a difficult transmission problem, you would probably ask a technician friend for ideas. Think of the service information as a friend with some inside information. It is written by the people who know how the system works in detail.

Such advice is available in service information. If the technician follows the recommended steps, chances are excellent of finding the problem—just like getting the advice of an experienced technician. ● **SEE FIGURE 132–6**.

CASE STUDY

The Stalling Impala

The owner of a Chevrolet Impala complained that the vehicle would occasionally stall when slowing to a stop. The problem only occurred after at least 20 miles and occurred more frequently in warm weather. The owner also indicated even though this vehicle was equipped with an automatic transmission it felt like the clutch not being depressed on a manual transmission. Thankfully, the service technician was aware of this common problem and installed a new torque converter clutch solenoid.

When the original solenoid got hot, it became stuck in the applied position. Even though the voltage was removed from the solenoid when the brakes were applied, the solenoid and the torque converter clutch (TCC) remained applied. ● **SEE FIGURE 132–7**.

Summary:

Complaint—The owner of the vehicle complained that the engine would stall when slowing to a stop, but only after the car was driven for 20 miles or further.
Cause—A defective torque converter clutch (TCC) solenoid.
Correction—Replacing the TCC solenoid cured the engine staling problem.

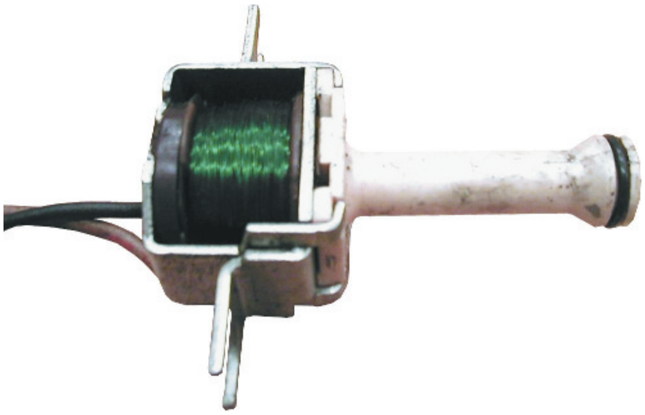


FIGURE 132–7 A torque converter clutch (TCC) solenoid. This TCC can be replaced on a General Motors vehicle without having to remove the transmission/transaxle from the vehicle.

Check service information to determine the identification of the unit based on one or more of the following:

- Vehicle identification number
- Engine (transmissions can vary internally based on engine size)
- Regular production option (RPO) code
- Transmission/transaxle identification plate information
- Pan shape and/or number of bolts used on the pan

STALL TESTING THE TORQUE CONVERTER

A stall test is often performed to verify the proper operation of the torque converter.

CAUTION: Some vehicle manufacturers do not recommend performing a stall test because it can be dangerous if the brakes were to fail during the test and it places stress on the engine. Always follow the manufacturer's recommended service procedures.

Performing a stall test includes the following steps:

STEP 1 Drive the vehicle until normal operating temperature is achieved.

STEP 2 Check the stall speed specifications for the vehicle being serviced and connect a tachometer to the engine.

STEP 3 With your left foot firmly applied to the brake pedal, move the shift selector in the drive position and depress the accelerator pedal to the floor. Observe the maximum engine speed. This engine speed is the stall speed. ● **SEE FIGURE 132–8.**

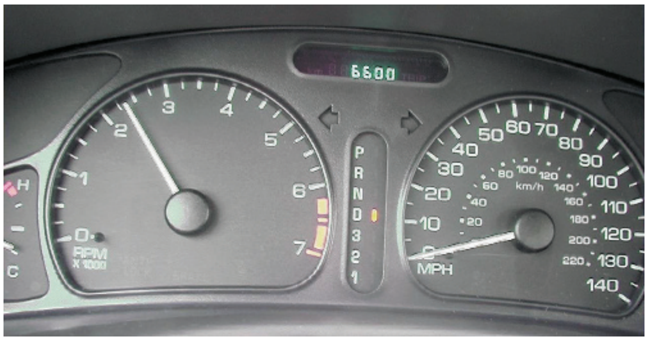


FIGURE 132–8 This 4-cylinder General Motors vehicle has a stall speed of about 2350 RPM. Notice that the gear selector is in drive and the speedometer is reading zero.

TECH TIP

Using the Wrong ATF Could Cause Shifting Problems

If the incorrect automatic transmission fluid has been used, such as during a previous repair, the following problems could occur:

- Hard shifts
- Slipping
- Shudder (feels like a vibration similar to driving over a rippled road surface)

If any of these conditions are present, check with the customer to find out if the transmission had been recently serviced or if the customer added new fluid or some additive. Often, some of the above concerns can be solved by replacing fluid with the specified fluid.

STEP 4 Release the accelerator as soon as possible to avoid the possibility of overheating the automatic transmission fluid. Repeat the test with the gear selector in reverse.

NOTE: Checking the stall speed in reverse is just a double check. This is done because the line pressure is higher in reverse and, as a result, the higher pressure will hold clutches better and keep them from slipping. A slipping forward clutch could cause the engine speed to be higher than normal and would affect the recorded stall speed.

STEP 5 Compare results with the specifications:

- *If the engine speed is higher than specifications,* then a holding clutch or band is slipping.
- *If the engine speed is lower than specifications,* then the torque converter is defective (one-way clutch or stator is slipping) or the engine is not producing normal power output.

Both conditions can result in reduced vehicle performance and slow acceleration.

NOTE: There are many other possible causes of poor performance or sluggish acceleration besides a fault with the automatic transmission/transaxle. The stall test is just one test that can be performed to help narrow the problem to the root cause.

TRANSMISSION FLUID LEAK DIAGNOSIS

VISUAL INSPECTION

To locate a leak from an automatic transmission/transaxle, the first step is to perform a thorough visual inspection. Start by checking the fluid level:

- If too high, then the fluid loss could be caused by it being overfilled and forced out of the vent opening located at the top of the unit.
- If too low, a fluid leak is the most likely cause and should be corrected as soon as possible to prevent damage, wear, or harm to the transmission/transaxle parts due to low fluid level.

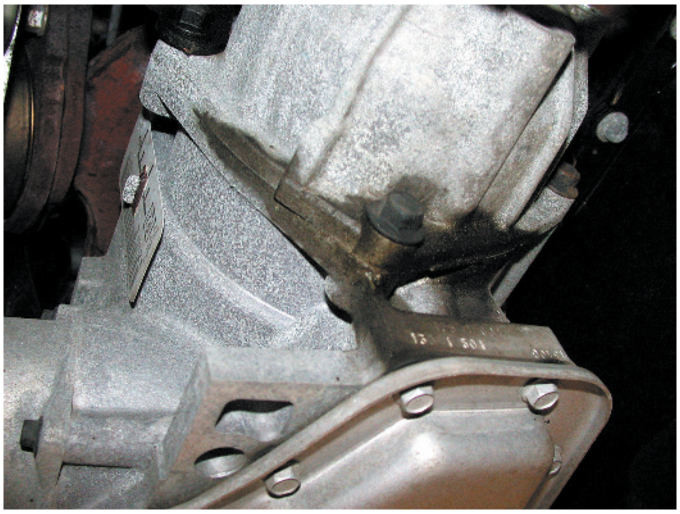


FIGURE 132–9 Sometimes the location of a transmission fluid leak is easy to see, but with others it can be difficult to find the exact location. Look closely at places where O-rings or gaskets are used, as these are the most common areas where fluid leaks occur.

Perform a visual inspection using the following steps:

STEP 1 Use a trouble light and start the visual inspection under the hood and look for signs of fluid leakage on the top of the unit. Because fluids flow downward due to gravity, the fluid will be most likely seen from underneath the vehicle; however, the source could be at or the near the top.

STEP 2 Hoist the vehicle safely and look for the highest and most forward place where fluid is seen. Due to gravity and the forward movement of the vehicle, leaking fluid will travel downward and toward the rear. ● **SEE FIGURE 132–9**.

DYE TESTING Often the exact location of a fluid leak is difficult to locate. Using a dye designed for ATF and a black light is an effective method to locate ATF leaks. To check for leaks using a dye, perform the following steps:

STEP 1 Add a small bottle of dye that is designed for use in ATF into the dipstick tube using a transmission funnel.

CAUTION: Do not use dye designed for use in coolant or air-conditioning systems or severe harm can occur to the automatic transmission/transaxle.

STEP 2 Drive the vehicle until the fluid has reached normal operating temperature.

STEP 3 Safely hoist the vehicle.

STEP 4 Using a black light, look for the highest and most forward place where a greenish stain appears. This is the source of the leak. ● **SEE FIGURE 132–10**.

TORQUE CONVERTER CLUTCH DIAGNOSIS The torque converter clutch is usually applied above 30 MPH (48 km/h) when the automatic transmission/transaxle is in second, third, or overdrive gear, depending on the vehicle speed and the throttle position. It is often difficult to distinguish between a normal shift and the application of the torque converter clutch. The torque converter clutch (TCC) may not even be applying due to a fault in the computer sensors, wiring, or the TCC solenoid.

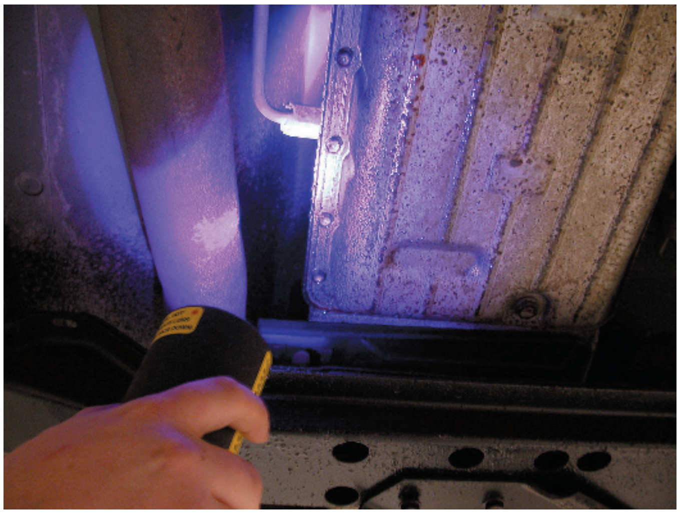


FIGURE 132–10 A black light being used to locate the source of an automatic transmission fluid leak.

NOTE: If the torque converter clutch does not apply, a drop in fuel economy of 3 to 4 miles per gallon is commonly reported. If the TCC fails to apply on an automatic transmission/transaxle, the automatic transmission fluid is likely to become overheated due to the torque converter slip. The higher fluid temperature can cause the automatic transmission/transaxle to fail.

TECH TIP

Vibration—Engine or Transmission?

A vibration is often difficult to diagnose. One method is to separate (unbolt) the torque converter from the engine drive flex plate. Push the torque converter as far toward the transmission/transaxle as possible, then start the engine. If the vibration is gone, the problem is due to a fault in the torque converter, pump assembly, or other component that is constantly rotating with the engine running. If the vibration is still present, then the cause is due to an engine or accessory problem.

TECH TIP

Look at the Command and the Engine Speed

Using a scan tool is very helpful when diagnosing automatic transmission problems. However, the display often shows when the shift has been commanded and may not show if the shift or the TCC engagement actually occurred. To help ensure that the shifts have in fact occurred, also watch the engine speed. Many factory or enhanced scan tools can also display the engagement speed. A slow engagement is usually caused by worn clutches. Check service information for the exact parameters and range of proper operation for the vehicle being diagnosed.

To test for proper operation of the torque converter clutch, simply drive the vehicle and watch either the tachometer on the dash or connect a scan tool to observe the engine RPM:

STEP 1 Drive the vehicle until the engine has reached normal operating temperature.

STEP 2 Drive the vehicle on a flat, level road away from any traffic about 50 MPH (80 km/h).

STEP 3 While maintaining constant speed with your right foot on the accelerator, gently apply the brake pedal with your left foot to open the electrical circuit for the torque converter clutch through the brake switch. The TCC will disengage and the RPM should increase about 150 to 250 RPM and then drop back when the brake pedal is released. This RPM change is evidence that the TCC is, in fact, working. If the torque converter clutch is not operating, consult the factory information for the exact procedures to follow.

NOTE: If the temperature of the automatic transmission fluid (ATF) is too high, the computer will modify the shift pattern (usually disabling overdrive) and engage the TCC at slower speeds in an attempt to drop the temperature of the ATF to less harmful temperatures. Also if the temperature is too low, the PCM may not allow lockup and may limit the number of forward gears available until the transmission fluid warms up. This computer control of the shifting may be noticeable to the driver as a fault.

RANGE CHARTS All vehicle manufacturers publish range charts that indicate which holding device is used for each gear selection. Knowing which component is being used for each gear helps the service technician determine the cause of a failure or problem. **SEE CHART 132–3**.

PRESSURE TESTING Pressure testing involves connecting a pressure gauge to pressure taps located on the outside of the automatic transmission/transaxle. ● **SEE FIGURE 132–11**.

CASE STUDY

The Customized Van Story

The owner of a customized General Motors van equipped with an electronically controlled automatic transmission (4L80-E) complained that the automatic transmission downshifted into second gear and stayed in second gear whenever the headlights were turned on. The transmission shifted okay when the headlights were turned off. After hours of troubleshooting, including the replacement of the vehicle computer (which did not help), the technician discovered that 4 volts DC were on the one wire leading from the vehicle speed (VS) sensor to the vehicle computer whenever the headlights were turned on. Obviously, there was a short to voltage between a light wire and the sensor wire. Instead of totally disassembling the van, the technician decided to replace the wire with a new one, and the problem was solved. The 4 volts DC apparently shut down the computer. With both solenoids A and B off, the transmission was in second gear. This is the default gear or the limp-in-mode gear for this transmission. After replacing the wire, the automatic transmission returned to normal operation:

Summary:

Complaint—The customer stated that whenever the headlights we on, the transmission would not shift. The transmission worked fine if the headlights were turned off.

Cause—A wiring fault caused a four-volt DC current to be applied to the vehicle speed sensor wiring.

Correction—A new wire was run and this corrected the default gear from being used when the headlights were on.

RANGE	GEAR	2-4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3-4 CLUTCH	LO-ROLLER CLUTCH	LO-REV. CLUTCH
Park-Neutral									
Overdrive	First Gear	Applied	Holding		Applied	Holding	Applied	Holding	
	Second Gear	Applied	Third Gear		Applied	Holding	Applied		
	Third Gear		Applied		Applied	Holding			
	Fourth Gear		Applied		Applied				
Drive	First Gear	Applied	Holding	Applied	Applied	Holding	Applied	Holding	
	Second Gear		Applied	Applied	Applied	Holding			
	Third Gear			Applied	Applied	Holding			
Manual 2nd	First Gear	Applied		Applied	Applied	Holding		Holding	
	Second Gear			Applied		Holding			
Manual 1st	First Gear			Applied		Holding		Holding	Applied
Reverse	Reverse		Applied						Applied

CHART 132–3

This typical range chart shows the forward clutch is applied in all forward gears. Notice that if the low-reverse clutch were to fail, it would prevent the vehicle from moving in both reverse and forward.

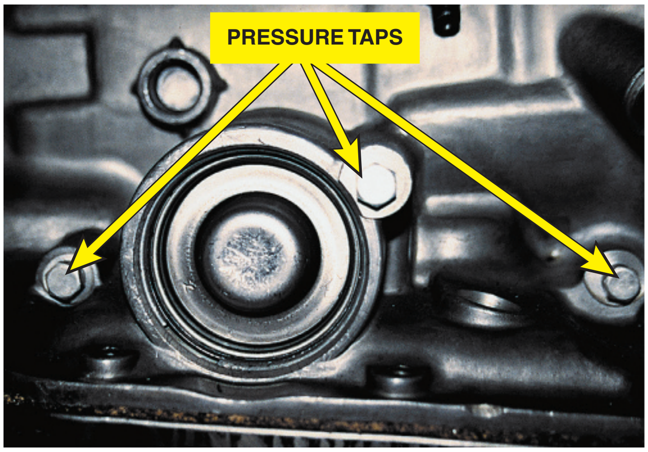


FIGURE 132–11 The locations (taps) for connecting a pressure gauge to measure the pressure of the various hydraulic circuits are usually found on the side of the automatic transmission/transaxle. Check service information for the exact locations for the vehicle being tested.

GEAR SELECTION	IDLE (PSI)	WIDE OPEN THROTTLE (WOT) (PSI)
Park (P)	54–60	54–60
Reverse (R)	100–105	250–300
Neutral (N)	54–60	54–60
Drive (D)	54–87	240–250
Low (L)	84–87	240–250

CHART 132–4

A pressure chart for the Ford 6F50N/GM 6T70 transaxle.

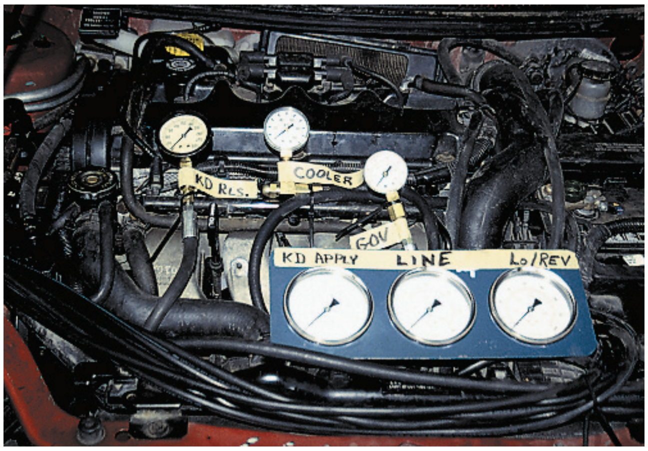


FIGURE 132–12 Six pressure gauges are installed on this vehicle to show students how the pressures vary and how the gauges can be used to find faults or possible problem areas before the unit is removed and disassembled.

After connecting the pressure gauge(s) to the transmission/transaxle, start the engine and select the gear being monitored. Check service information for the specified pressures.

● **SEE CHART 132–4** for a typical pressure chart.

If the pressure is not within specifications, then the technician knows that the fault is internal and usually involves either removing the valve body, or in many cases, removing the automatic transmission/transaxle from the vehicle. ● **SEE FIGURE 132–12.**

TRANSDUCERS Pressure switches are used to verify that solenoids and/or valves have done their job. They do not read actual pressure as they are usually controlled by a spring rated at a certain number of pounds. A transducer-equipped vehicle will usually provide an actual pressure reading on a scan tool. Many vehicles with variable line pressure will have a transducer.

IN-VEHICLE SERVICE

PAN REMOVAL Check service information for the exact procedure to follow when removing the pan. Some transaxles are equipped with a side pan that either may nor may not be needed to be removed when serving the assembly. The usual procedure includes the following steps:

STEP 1 Hoist the vehicle safely.

STEP 2 Place a large drain pan under the transmission/transaxle pan.

STEP 3 Loosen all of the fasteners except for those at one end. Allow the pan to drop down slightly at one end allowing fluid to drain into the drain pan.

● **SEE FIGURE 132–13.**

STEP 4 After the fluid has stopped flowing from the pan, carefully remove the last retaining bolts, slowly lower the pan, and allow any remaining fluid to flow into the drain pan.

STEP 5 Dispose of or recycle the used automatic transmission fluid according to state or local laws.

STEP 6 Remove all of the oil pan bolts except for two at one end. This will allow the pan to drop and empty most of the ATF into the drain container without falling. After most of the ATF has drained, remove the remaining bolts and remove the pan.

STEP 7 Inspect the inside of the pan for excessive friction material and wear metals (such as lead and copper from bushings). Use a magnet to check for steel particles, which would indicate serious wear to major components. ● **SEE FIGURE 132–14.**

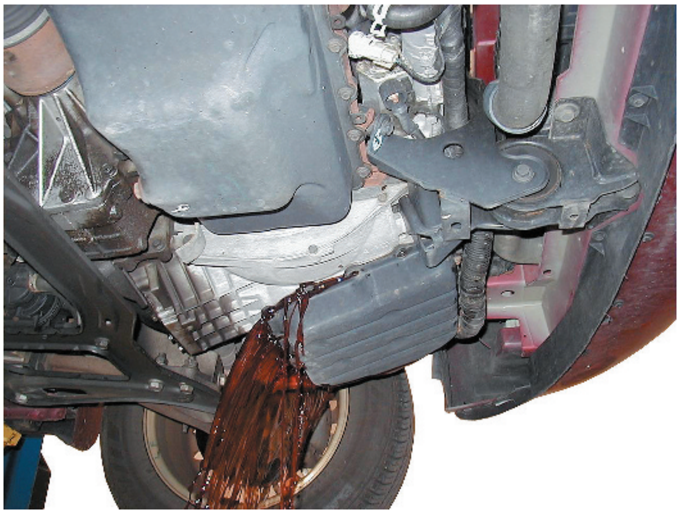


FIGURE 132–13 Draining the fluid from an automatic transaxle by allowing the fluid to flow into a container after most of the retaining bolts have been removed.

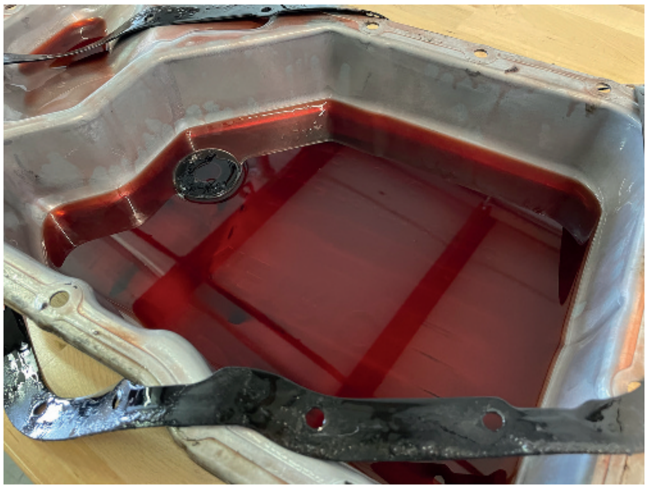


FIGURE 132–14 This is a normal amount of wear material in the bottom of an automatic transmission pan.

FREQUENTLY ASKED QUESTION

What Is Wrong When My Automatic Transmission Does Not Upshift?

The following examples can cause the automatic transmission/transaxle to fail to upshift:

- A *defective governor* (if so equipped) will often not allow any automatic transmission/transaxle to shift out of first gear or stuck in high gear.
- A *defective vacuum modulator* (if so equipped) or misadjusted *throttle valve* will often delay the shift until a very high speed is achieved.
- A *fault in the PCM, TCM, or a speed sensor* on electronically controlled automatic transmissions/transaxles will occur when one gear, usually second or third, is selected and the unit will not shift out of that gear.

WARNING

The automatic transmission fluid may be hot enough to cause personal injury. Wear protective clothing and avoid contact with the hot fluid.

NOTE: The presence of metal particles in the pan of an automatic transmission/transaxle does not necessarily mean that a part(s) has failed or needs to be replaced. Some wear is normal. If there are a lot of metallic particles in the pan, then this may be an indication of severe gear failure that may require replacement. Use a magnet to check for steel particles. Ask the advice of an experienced transmission expert, if in doubt, about whether the wear should be considered "normal."

FILTER REPLACEMENT Check service information for the exact procedure to follow when replacing the filter. Most are retained by a clip or a bolt. ● **SEE FIGURE 132–15**.

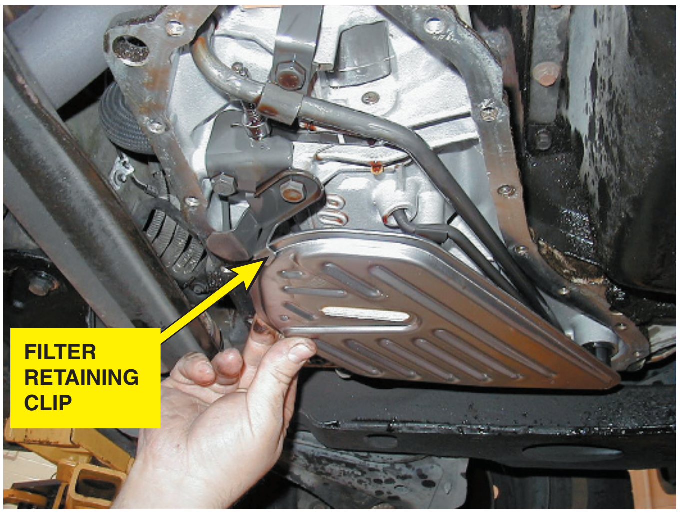


FIGURE 132–15 Always check that the filter is secured by a clip or other fastener to keep it from dropping out of location.

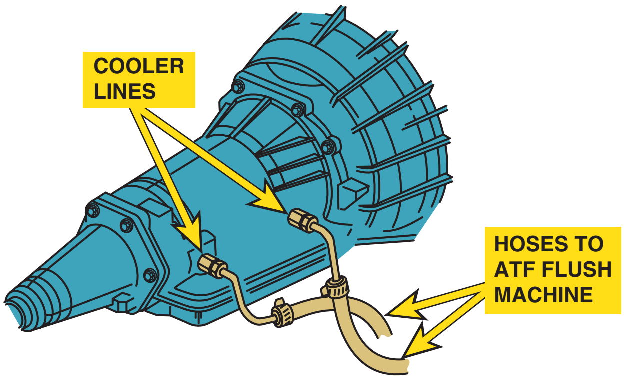


FIGURE 132–16 A fluid exchange machine uses the engine and the transmission pump to force the fluid into the machine where the old fluid is used to push against a diaphragm, which then forces new fluid back through the transmission. A sight glass is used to show the technician the fluid, so the process can be stopped when only clean, new fluid is seen flowing through the cooler line.

CAUTION: Extra or missing O-rings on filter necks and/or cracked or mispositioned filter filler necks cause many problems. The pump may intermittently ingest air, leading to transmission or driveability complaints such as rough idle or an engine stalling condition.

FLUSHING ATF The following are ways to flush automatic transmission fluid:

1. Connect the cooler lines to a machine that exchanges the old fluid with new fluid. ● **SEE FIGURE 132–16**.
2. Use a machine to draw out the old fluid though the filler tube and then refill it with clean fluid.
3. Use a machine that attaches to the pump inlet after the pan and filter have been removed. The machine uses its own pump to force all of the old fluid from the transmission or transaxle.
4. Drain and refill. Using this method, recommended by Honda and Acura, means that about 3 quarts are being replaced. The vehicle should be driven and the drain and refill formed another two times.

Most experts recommend that the filter be replaced, so the pan should be removed (except for Honda and Acura) and the filter replaced after any of the above methods are used. ● **SEE FIGURE 132–17**.

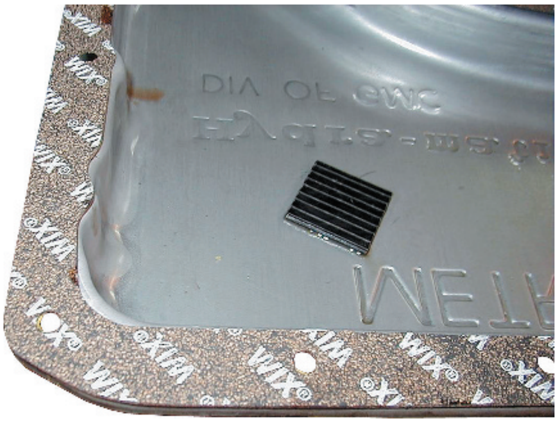


FIGURE 132–17 In this case, the cork-rubber gasket is glued to the pan and is ready to be installed. The retaining bolts need to be tightened in sequence, but be aware that overtightening will cause a leak. Also, some manufacturers recommend using only an RTV sealer, but never use an RTV sealer and a gasket together.

TECH TIP

Use Old Headlights to Check Wiring

The proper operation of any electronically controlled automatic transmission/transaxle depends on having electrical power available to operate the solenoids. Before removing the unit from the vehicle, use a headlight to check if there is enough current being sent to the unit. Unplug the electrical connection that supplies 12 volts, usually from the ignition switch. Use a headlight and attach wires to the ground and the bright filament terminals.

Attach one test lead from a headlight to the terminal that supplies 12 volts to the unit. Attach the other lead from the headlight to a good clean chassis or transmission ground such as the case. Turn ignition key on, engine off (KOEO), and observe the headlight.

- If the headlight is dim, there is a voltage drop between the source (battery) and the transmission feed. Check the wires directly leaving the ignition switch or transmission control relay. If the headlight is still dim, replace the ignition switch or transmission feed relay. ● **SEE FIGURE 132–18**.
- If the headlight is off, then there is an open circuit between the battery and the transmission/transaxle. Follow electrical troubleshooting procedures to find and repair the open circuit.
- If the headlight is bright, there is enough voltage and current being supplied to the transmission/transaxle to correctly operate all of the solenoids. ● **SEE FIGURE 132–19**.

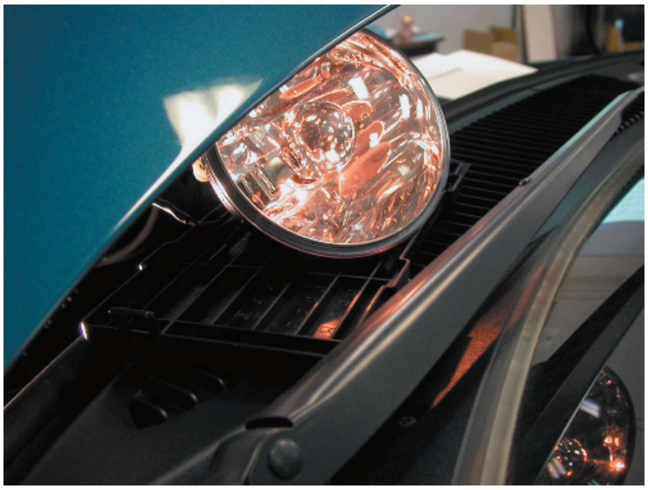


FIGURE 132–18 A dim headlight indicates excessive resistance between the battery and the electrical connector to the automatic transmission/transaxle.

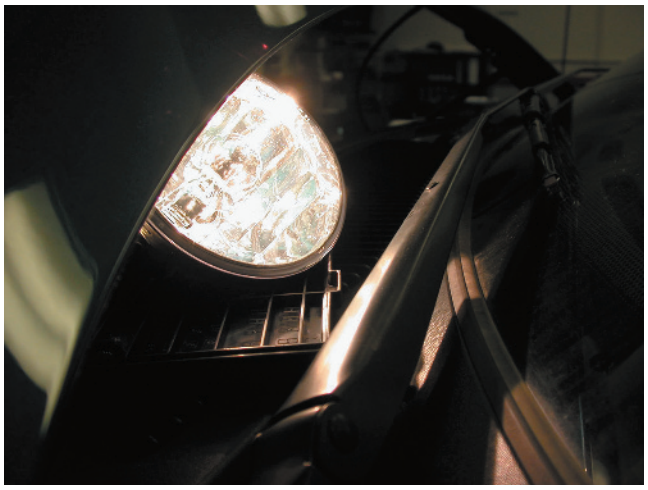


FIGURE 132–19 A bright headlight indicates that there should be sufficient current flow available at the automatic transmission/transaxle to operate all the solenoids correctly.

LINKAGE ADJUSTMENT The linkage between the shift selector and the automatic transmission should be checked for proper adjustment whenever there is a transmission-related problem. The linkage may need to be adjusted to compensate for worn linkage components. Before adjusting the linkage, check the engine and transmission/transaxle mounts carefully because a defective mount is a common reason for needing a linkage adjustment.

REVIEW QUESTIONS

1. What tests can be performed on an automatic transmission/transaxle to determine any faults while the unit is still in the vehicle?
2. How does a defective torque converter clutch solenoid cause the vehicle to stall when the vehicle is slowing to a stop?
3. How is the ATF level determined on a transmission/transaxle that does not have a dipstick?
4. How is a pressure test of the mainline and other pressures of an automatic transmission/transaxle performed?
5. What precautions have to be used when stall testing?

CHAPTER QUIZ

1. Technician A says that the PCM should be checked for any stored diagnostic trouble codes when diagnosing a transmission fault. Technician B says that technical service bulletins (TSBs) should be checked whenever there is a transmission-related customer concern. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. A vehicle is being tested using a scan tool. Technician A says that the throttle position (TP) sensor should read between 0 and 1 volt. Technician B says that a factory or factory level scan tool is needed to check for proper voltage and current of the shift solenoids. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. An electronically controlled overdrive automatic transmission is equipped with a transmission fluid temperature sensor. Technician A says that the shifts may be changed if the fluid temperature is too high. Technician B says that overdrive may be disabled if the transmission fluid temperature is too high. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. A scan tool can be used to _____________.
   - **a.** check for stored diagnostic trouble codes
   - **b.** command a shift
   - **c.** check for transmission-related sensor information
   - **d.** All of the above
5. Caution should be used when performing a stall test because _____________.
   - **a.** it could increase the temperature of the ATF
   - **b.** it could be hazardous if the brakes fail
   - **c.** it puts a strain on the engine
   - **d.** All of the above
6. An electronically controlled automatic transmission was tested using a pressure gauge and the pressures were below specifications. Technician A says that a defective torque converter is the likely cause. Technician B says that a defective shift solenoid could be the cause. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Technician A says that two bolts should be loosened and the other bolts removed when removing the pan of an automatic transmission. Technician B says that if there is any friction material found in the pan, the transmission needs to be overhauled. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
8. Fluid leaks can be checked using _____________.
   - **a.** visual inspection
   - **b.** dye added to the ATF
   - **c.** a black light
   - **d.** All of the above
9. Fluid exchange can be performed using _____________.
   - **a.** drain and refill three times
   - **b.** a machine that replaces the ATF through the cooler lines
   - **c.** a machine that forces the old fluid out, using a pump inside the machine that is attached to the fluid inlet after removing the transmission pan and filter
   - **d.** Any of the above
10. Two technicians are discussing inspection of the transmission pan. Technician A says that some friction material at the bottom of the pan is normal. Technician B says that if any metal parts stick to a magnet then further investigation is needed to determine the cause. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

Chapter

133

AUTOMATIC TRANSMISSION/ TRANSAXLE UNIT REPAIR

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Explain how to verify the need for unit repair.
- Discuss the steps involved in removing the automatic transmission/transaxle.
- Discuss the steps involved in disassembling the automatic transmission/transaxle.
- Describe how to reassemble an automatic transmission/transaxle.
- Discuss how to flush the cooler and torque converter.
- Discuss dynamometer testing the automatic transmission/transaxle.
- Describe how to reinstall the automatic transmission/transaxle.
- Describe road testing.

KEY TERMS:

Air pressure check 1698 • Holding fixture 1694 • Tag number 1693

VERIFY THE NEED FOR UNIT REPAIR

VERIFY THE FAULT It is not unusual for a transmission or transaxle to be removed from the vehicle when the fault could have been repaired with the unit still in the vehicle. Or the fault could be due to an electrical or engine-related fault outside the transmission/transaxle. Check with all of the following to be sure that the unit needs to be removed from the vehicle:

- A knowledgeable technician
- Service information
- A hotline service provider, such as Identifix (www.identifix.com)

Use these resources to verify that the fault is inside, not outside, the unit.

IN-VEHICLE REPAIRS Not all mechanical faults require that the automatic transmission/transaxle be removed from the vehicle. Faults that can usually be repaired with the unit still in the vehicle include any valve-body-related concerns.

● **SEE FIGURE 133–1.**

Depending on the transmission/transaxle, it may be possible to disassemble and repair many mechanical components of the unit while it remains in the vehicle. Parts and components that may be replaced with the transmission/transaxle still in the vehicle include

- Pressure switches
- Transmission range switch
- Turbine and output speed sensors
- Extension housing gasket
- Drive axle seals
- Valve body replacement

Check service information for details on what can be replaced with the unit in the vehicle.

IDENTIFY THE UNIT Before removing the transmission/transaxle for replacement or repair, be sure that the unit is properly identified. This identification is critical because of the following:

1. The final drive ratio in transaxles can vary depending on the application; and using the wrong unit can cause shifting and other issues such as gear ratio–related diagnostic trouble codes.
2. The internal gear ratios can vary depending on exact application of the unit.

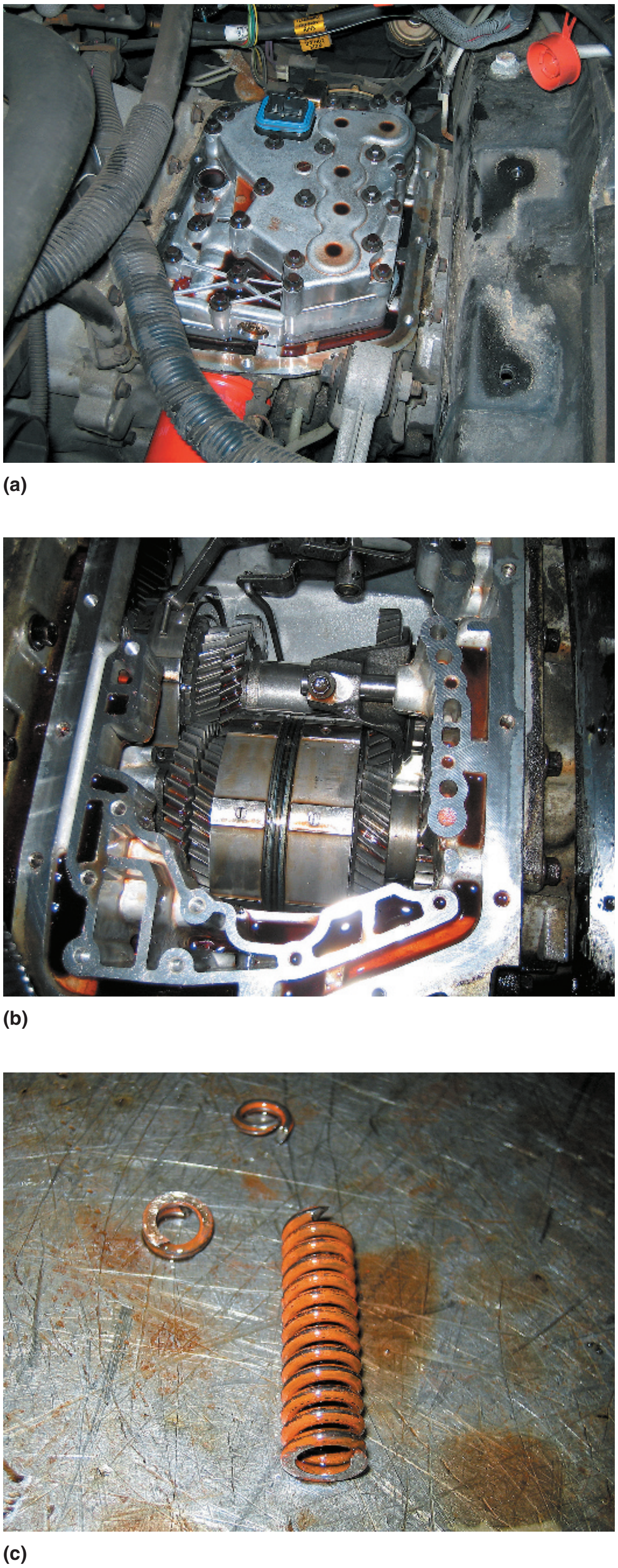


FIGURE 133–1 (a) This Saturn did not shift correctly and one technician was ready to replace the unit; however, another technician thought that the problem could be due to a fault in the valve body. (b) Removing the valve body shows the nonplanetary gears used in the Saturn automatic transaxle. (c) The valve body was disassembled and a broken pressure regulator spring was found to be the cause of the customer concern.

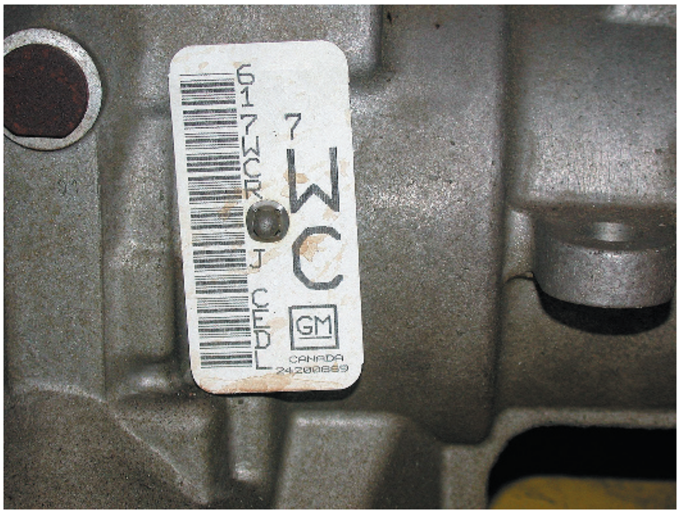


FIGURE 133–2 A transmission identification number on the side of the unit. The information on this tag is needed when ordering parts, as there are often several versions of the same transmission used in similar vehicles and the differences could affect the parts needed.

3. Sometimes the vehicle identification number (VIN) is needed to obtain the correct parts, but more often the transmission/transaxle identification number, also called the **tag number**, is the identification needed to be assured of ordering and receiving the proper parts.

   ● **SEE FIGURE 133–2**.

REMOVING THE AUTOMATIC TRANSMISSION/TRANSAXLE FOR SERVICE

STEPS INVOLVED Removing an automatic transmission/transaxle from a vehicle includes many steps to avoid doing damage to the vehicle or personal harm. Always follow the vehicle manufacturer's recommended procedures. Most procedures include the following steps:

STEP 1 Disconnect the negative (−) battery cable from the battery. This prevents the possibility of an accidental short circuit that could damage the vehicle or cause a spark that could start a fire.

STEP 2 Hoist the vehicle safely and drain the fluid from the unit.

STEP 3 Disconnect the driveshaft or drive axle shafts.

STEP 4 Disconnect all cooler lines, linkage, and electrical connections. Be sure to label each to ensure proper reinstallation. Also be sure to label all electrical connectors so that they can be reinstalled in the proper location.

STEP 5 Disconnect the torque converter from the flex (drive) plate of the engine.

STEP 6 Support the engine before disconnecting the automatic transmission/transaxle. ● **SEE FIGURE 133–3**.

STEP 7 Remove the transmission/transaxle mounting fasteners.

STEP 8 Support the transmission/transaxle on a jack and remove the attaching bolts at the bell housing of the engine. ● **SEE FIGURE 133–4**.

STEP 9 Remove the transmission/transaxle from the vehicle.

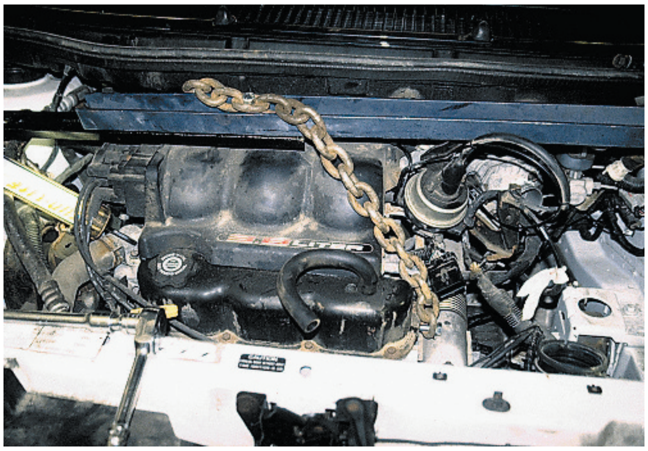


FIGURE 133–3 A chain and holding fixture being used on this front-wheel-drive vehicle to support the engine when the transaxle is removed.

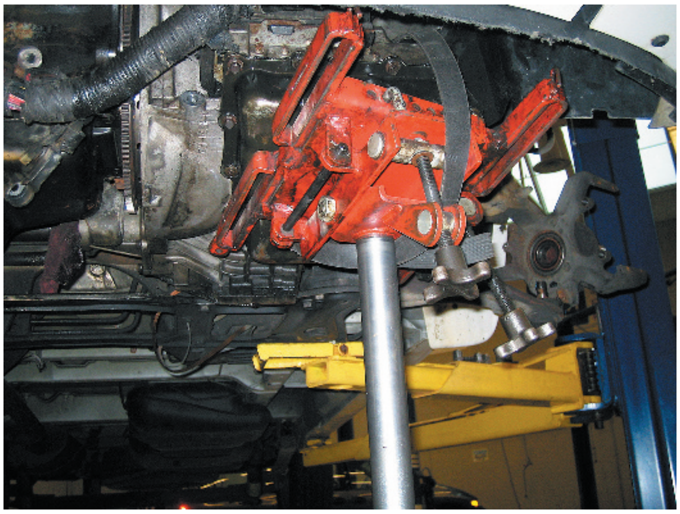


FIGURE 133–4 A transaxle being supported by a transmission jack prior to removal of the unit from underneath the vehicle.

AUTOMATIC TRANSMISSION/ TRANSAXLE DISASSEMBLY

MOUNT TO HOLDING FIXTURE For best results, the automatic transmission/transaxle should be attached to a **holding fixture** that allows the unit to be rotated yet properly supported during disassembly and reassembly. ● **SEE FIGURE 133–5**.

TORQUE CONVERTER CHECKS Remove the torque converter and drain the fluid by tipping it so the fluid runs out into a suitable container. Check the torque converter for the following:

- Visually check for wetness that could indicate a leak such as at the welded seam.
- Check for damage to the pump drive tags.
- Inspect the hub for seal and wear.
- Check that the one-way clutch of the stator is working.
- Check for end play of the stator. ● **SEE FIGURE 133–6**.

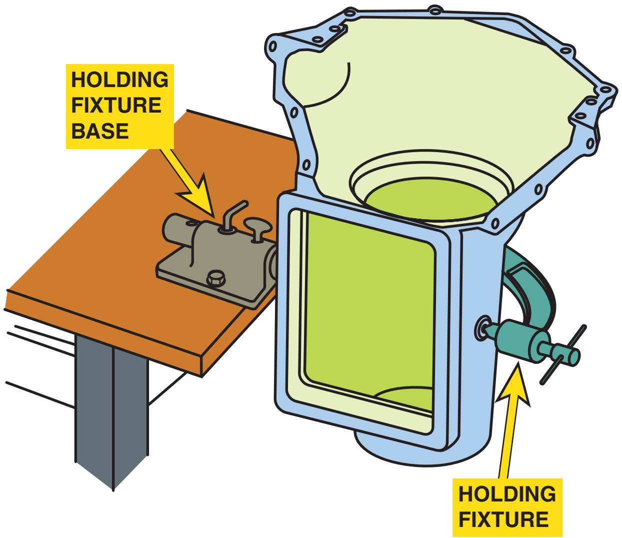


FIGURE 133–5 A holding fixture makes working on a transmission easier.

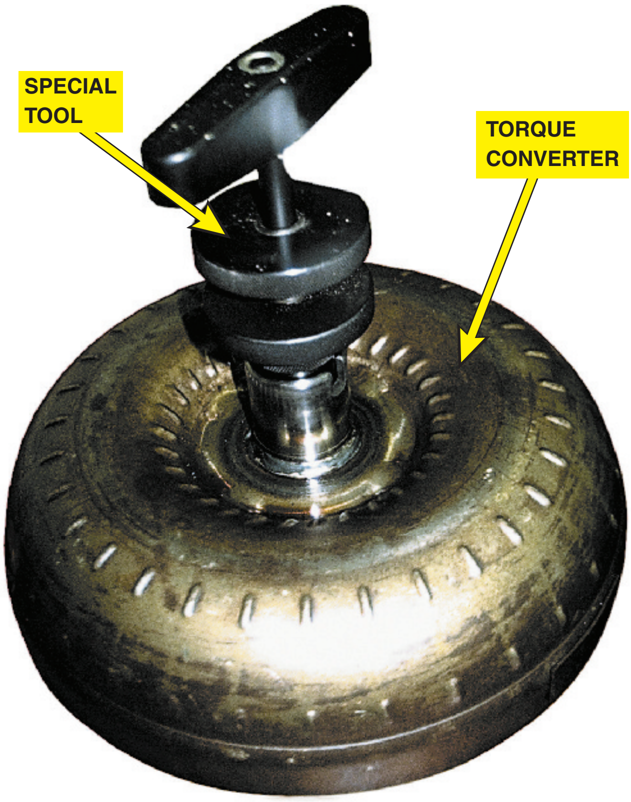


FIGURE 133–6 A special tool being used to check the end play of the stator inside the torque converter.

TECH TIP

Check the Flex Plate

After removing the transmission or transaxle, carefully inspect the flexplate for the following faults:

1. Cracks
2. Warpage
3. Stripped starter ring gear teeth

TECH TIP

Replace the Torque Converter

Many automotive transmission/transaxle experts recommend that the torque converter be replaced when the automatic transmission is rebuilt or replaced. This is because the torque converter is generally considered to be the "garbage pit" of the entire unit in that it often collects wear particles from the clutches and bands that can cause future problems. According to remanufacturers of torque converters, the majority of the torque converters being returned as cores have little, if any, friction material remaining for the torque converter clutch. ● **SEE FIGURE 133–7**.

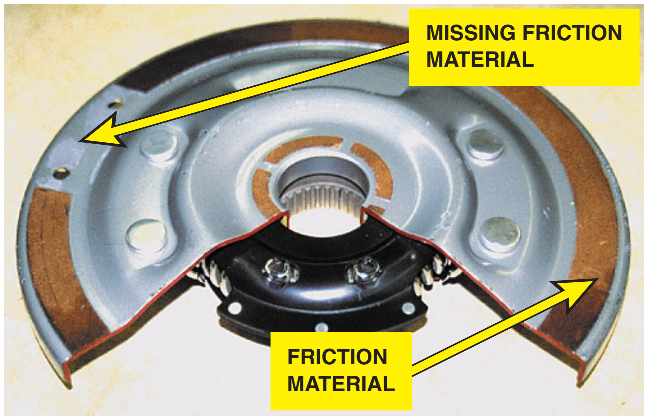


FIGURE 133–7 A cutaway of the torque converter clutch showing the paper-thin friction material.

VALVE BODY Remove the valve body and the internal electronic components found in many units. Before the valve body fasteners are removed, the following items need to be performed or checked:

1. Disconnect the manual valve linkage and "rooster comb."
2. Carefully loosen the valve body bolts starting from the outside and working toward the center or help prevent distortion.
3. Remove the lower part of the valve body.
4. Remove the separator plate. ● **SEE FIGURE 133–8**.
5. Check and note the location of all check balls in the upper valve body.
6. Carefully check the operation of all shift valves by using a plastic tool or compressed air to move the valves in their bores. All valves should be free to move and should return to the home position by spring pressure. ● **SEE FIGURE 133–9**.

To service a valve body, disassemble all the parts, identify them for reassembly, and check the valve body with a precision straightedge.

PUMP ASSEMBLY Remove the pump assembly using the proper removal tool to avoid damaging it. ● **SEE FIGURES 133–10 AND 133–11**.

Check the pump for wear by checking service information for the recommended procedure and specifications. ● **SEE FIGURE 133–12**.

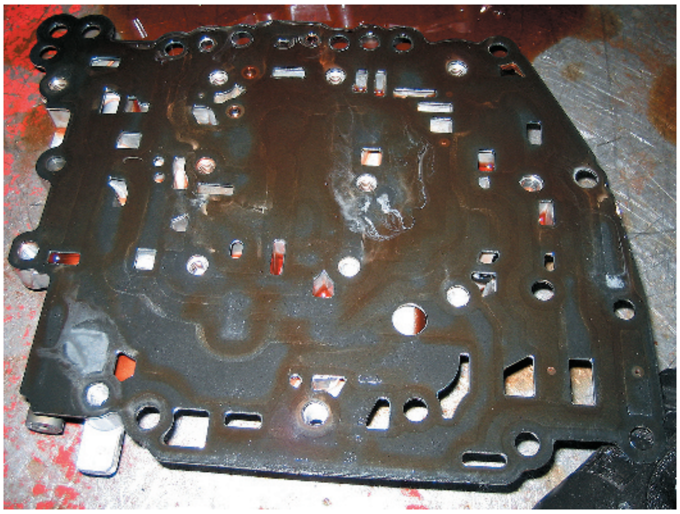


FIGURE 133–8 A typical separator plate. Check holes over check balls to make sure that the metal balls have not caused damage to the separator plate during operation.

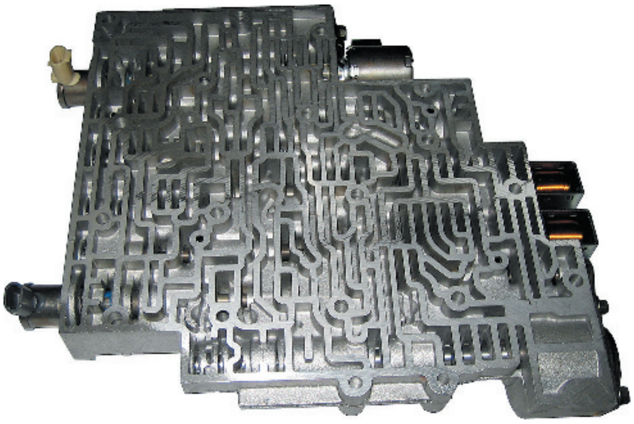


FIGURE 133–9 Check that all valves are free to move, and look for signs that the valves have caused wear to the valve bore. This causes fluid to leak around the valves, which can also cause shifting problems. If the bore is found to be worn, then the valve body will require repair using specialized tools or replacement.

TECH TIP

The Valve Body Cardboard Trick

To help remember where each bolt goes in the valve body, draw an outline of the valve body on cardboard and then stick the bolts through the cardboard in the position where they were removed. Often the lengths of the bolts are different, so this method saves time and helps prevent possible harm to the valve body of the case of the transmission/transaxle when reassembling the unit.

UNIT DISASSEMBLY Before disassembly, measure input shaft end play. Some transmissions require the measurement of output shaft end play. Always check service information for the specified procedures to follow.

The usual disassembly procedure includes

1. Removal of snap rings
2. Compressing of clutch pistons most often using special tools
3. Removal of bands (if equipped)

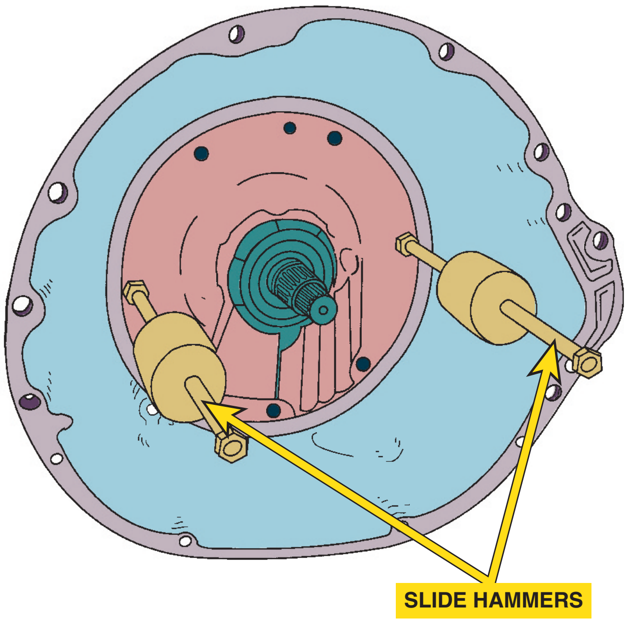


FIGURE 133–10 Two slide hammers are often used to remove a pump from older automatic transmissions.

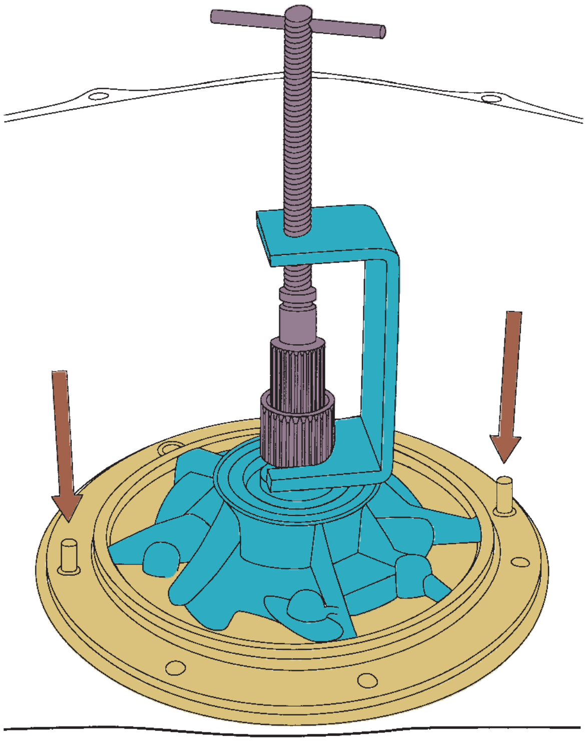


FIGURE 133–11 A special puller is usually specified to remove aluminum pumps from automatic transmission/transaxles. Alignment pins (arrows) are used to properly align the gasket and pump on the case during reassembly.

4. Removal of solenoids
5. Disconnecting and labeling of all interior wiring

Note the condition of all of the following so that any parts needed can be ordered:

- One-way clutches
- Clutches and bands (if used)
- Accumulators and springs
- Trust washers
- Snap rings

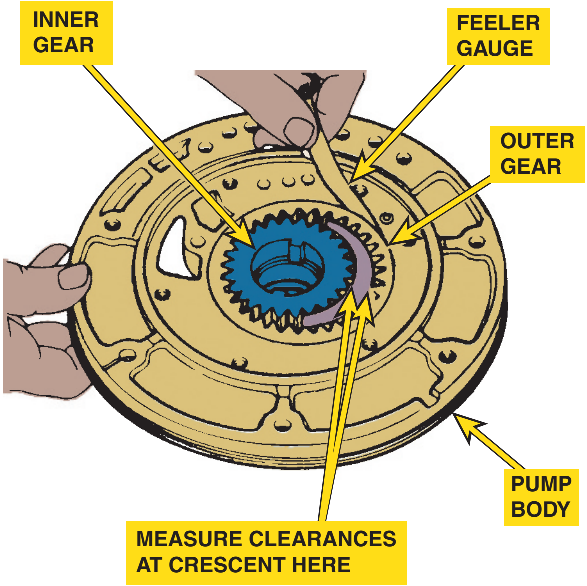


FIGURE 133–12 Checking a transmission pump assembly for wear using a feeler gauge. Compare the reading to factory specifications.

TECH TIP

A Picture Is Worth a Thousand Words

During disassembly, note items such as direction of snap rings front and back and clock position of the snap ring openings. Instead of taking numerous detailed notes, use a digital or phone camera and take pictures as the unit is being disassembled. Then the photos can be reviewed during reassembly to be sure that everything is installed in the same position as it was when it was disassembled.

- Servos and springs
- Planetary gear sets
- Final drive assembly on transaxles
- Shift and pressure control solenoids

Save the old gaskets to match with the new ones. Clean all parts in a solvent that removes all gum, varnish, dirt, and grease. Rinse clean parts in hot, running water, and then immerse them in clean mineral spirits or a similar solvent to separate water from the parts. Finish cleaning by blow drying with low-pressure, filtered, compressed air. Once clean, inspect the valve body and its components for the following:

- Scored, cracked, or burred plugs and valves
- Broken, bent, or worn springs
- Scored or rusted bores
- Plugged or restricted fluid passages
- Bent or rusted separator plates
- Stuck check valves
- Bent manual valves
- Cracked castings and distorted or nicked mating surfaces.

Shiny areas on valve lands indicate friction between the spool valve and body. On steel valves, these areas can be polished carefully with 400- to 600-grit wet or dry sandpaper, crocus cloth, or polishing stone. Take care not to round off the edges of the valve lands while polishing. Aluminum valves cannot be polished. If a valve needs polishing, the bore it rides in also requires servicing. Polish the valve bore by inserting and turning loosely rolled wet or dry sandpaper or crocus cloth. Attach a piece of crocus cloth to a slotted dowel rod or bent welding rod to reach the bottom of a deep bore. Rewash and dry any valves and bores that are polished.

After polishing and washing, lubricate the spool valve with ATF and slide it into its bore to check fit and operation. The valve should slide back and forth freely of its own weight.

CAUTION: Do not use cloth shop cloth as lint can cause a sticking shift valve.

CLUTCH PACKS Begin disassembling a clutch pack by removing the snap ring that holds the discs in the housing. Remove the snap ring from most clutches by prying one end of it free from its groove with a small screwdriver. Then, slide the screwdriver around the drum and the snap ring removes easily. ● **SEE FIGURE 133–13**.

FRICTION DISC INSPECTION Wipe each friction disc with a dry, lint-free cloth and inspect for the following:

- Excessive wear
- Cracks in the lining material
- Charred, burned, or glazed lining surface
- Pitting, flaking, or scoring
- Chips or particles embedded in the lining
- Scoring or burns on disc serrations
- Distortion and/or warping

Friction discs tend to discolor in use, which is normal. However, if any friction disc shows signs of one or more of the defects above, replace the entire set. Replace the set of friction discs if they do not fit freely in the clutch hub serrations (grooves) or if there is wear or damage to their splines.

STEEL DISC INSPECTION Clean steel discs by wiping with a dry, lint-free cloth and, once clean, inspect each disc for the following:

- Uneven heat discoloration
- Surface scuffing or scoring

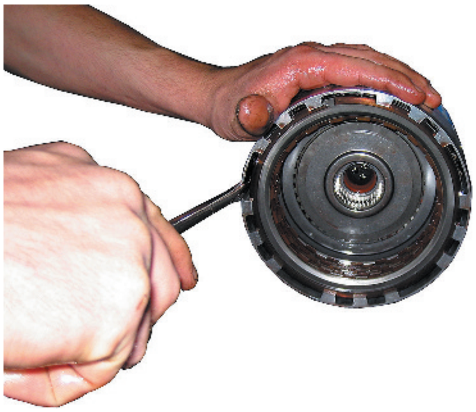


FIGURE 133–13 A straight-blade screwdriver can help remove the snap ring that is used to retain the frictions and steels in the clutch pack.

- Drive lug damage
- Distortion and/or warping

Replace the entire set of steels if you note a rough surface or there is uneven or spotty discoloration on any of the discs. Also replace steel discs if they do not fit freely into the clutch drum tang notches.

CLUTCH PISTON REMOVAL AND INSPECTION To remove the snap ring holding the clutch piston in place, compress the piston return springs using the proper compressor tool. Always check service information for proper procedure. ● **SEE FIGURE 133–14**.

Tightening a nut onto the shaft draws the fingers of the tool down, compressing the spring, and allowing the snap ring to be

TECH TIP

Smooth Is In; Rough Is Out

It used to be common practice in the automatic transmission business for the rebuilder to use sandpaper to "roughen up" the surface of the steel discs to achieve a good clutch apply. This is not true now. Sanding creates grooves and sharp peaks that decrease the oil film between the paper on the friction plate and the steel plates. There should be a thin oil film between the paper and the steel to create a holding bond and make it possible for a clutch pack to apply and release thousands of times without wear. Therefore, for consistent shifts and a long-lasting transmission/transaxle, do not sand the steel discs. Steels are often replaced with new steels along with new friction discs during an overhaul.

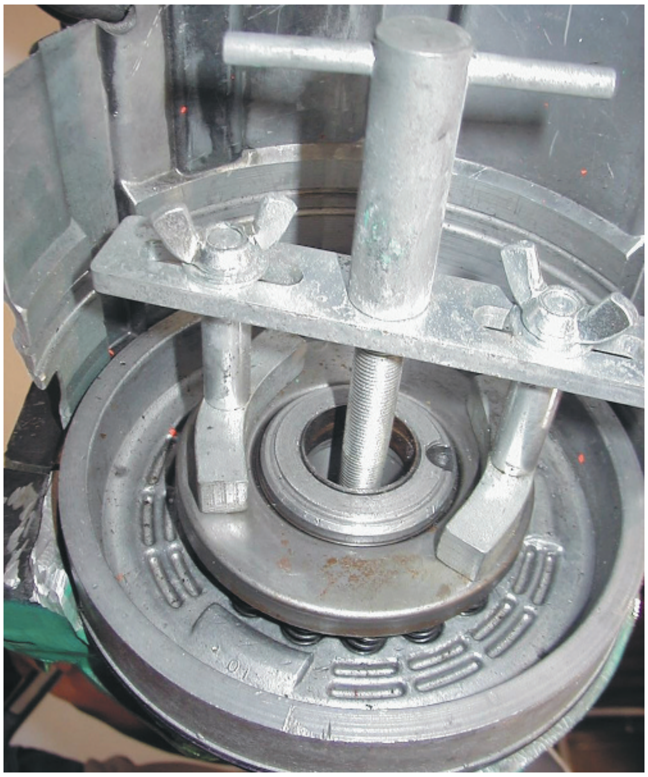


FIGURE 133–14 A compressor tool is usually necessary to compress the springs of the clutch piston to remove the snap ring.

removed. After removing the snap ring, release and remove the spring compressor, then remove and inspect the return springs.

RETURN SPRING INSPECTION Coil springs should be straight and provide proper pressure. Check for broken, distorted, or collapsed springs. If one or more of the springs requires replacement, discard them all and install a complete set of new springs.

NOTE: Individual return springs are often colored coded as to their location. Make note of the color and number of return springs for ease of reassembly.

Some coil springs are permanently attached to their retaining collar and can only be serviced as a set. There will be vacant spring seats in some applications. This allows the manufacturer to use the same piston but vary the number and location of springs to precisely match spring return rate to the requirements of a particular vehicle. In these cases, reinstall return springs in exactly the same location.

CLUTCH PISTON INSPECTION Remove the clutch piston from the hub. The drag of the piston seal can make it hard to remove the piston from its bore. Should this be the case, apply low-pressure compressed air through the hydraulic apply hole in the housing to force the piston from its bore.

CAUTION: Always use care when using compressed air as it can be very dangerous. Use regulated air pressures set to a maximum 35 PSI (240 kPa) and a rubber-tipped nozzle. Always wear safety glasses when checking valves and actuators using compressed air.

Do not use high air pressure and be careful to avoid pinching your hand or dropping the piston as it pops from its bore. Once you remove the piston, check for the following:

- Cracks or scoring in the piston bore
- Nicks, scores, burrs, or signs of wear on the piston
- Seal damage
- Fluid passage obstructions or restrictions

If the piston contains a check valve, make sure it is functional. Remove and discard seals.

HUBS, DRUMS, SHELLS, AND PLANETARIES Clutch hubs, drums, and shells transfer the torque load to the various combinations of planetary gear set members to provide different gear ratios. Hubs, drums, shells, and planetaries are *hard parts* that do not wear out under normal conditions, so they can be reused unless they are damaged. ● **SEE FIGURE 133–15**.

Carefully check drums and shells for cracks before reusing. Wash with solvent, dry with compressed and filtered air, and then inspect. Planetary gear sets should be checked for proper pinion gear end play and compared to factory specifications. ● **SEE FIGURE 133–16**.

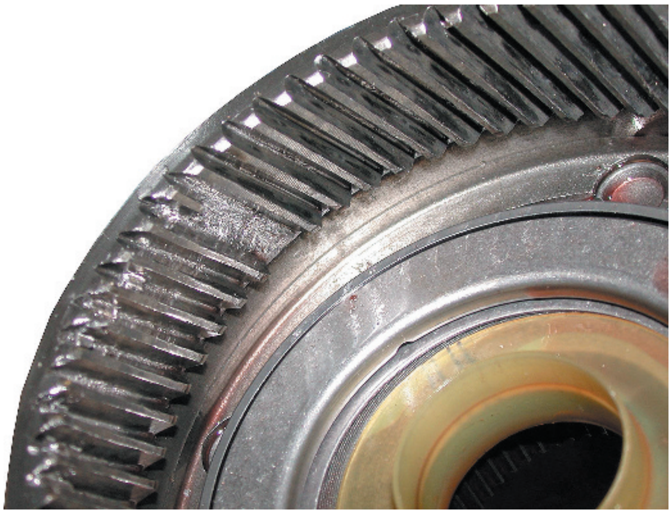


FIGURE 133–15 The ring gear has damaged gear teeth. This entire planetary gear set must be replaced because the damage also affected the gear teeth of the planetary pinion gears and the sun gear.

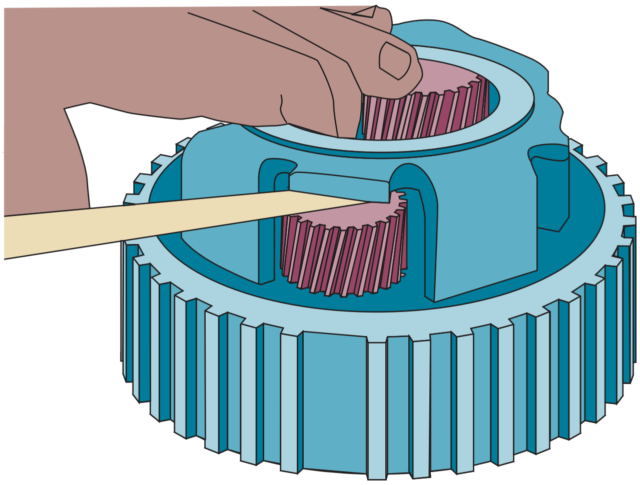


FIGURE 133–16 Pinion gear end play can be checked using a feeler gauge.

REASSEMBLING AN AUTOMATIC TRANSMISSION/ TRANSAXLE

CLUTCH ASSEMBLY Before assembling a clutch assembly, soak all friction plates in automatic transmission fluid (ATF). This should be done for as long as possible to allow the friction material to absorb the automatic transmission fluid. Check service information for the exact order of assembly and assemble each clutch pack.

AIR PRESSURE CHECKS Reassembly of an automatic transmission/transaxle involves assembling the various subassemblies, such as a clutch pack clearance, before final assembly is completed. ● **SEE FIGURES 133–17 AND 133–18**.

If the clutch pack clearance is not correct, often one clutch pack component is a selective member. The selective component could be any of the following:

- Reaction plate
- Pressure plate
- Thrust washer
- Snap ring

After making the needed changes, the clearance should be rechecked to be sure it is within factory specifications.

An **air pressure check** uses air to apply clutches and/or bands to verify that components such as clutch packs perform correctly. The air takes the place of the ATF under pressure when

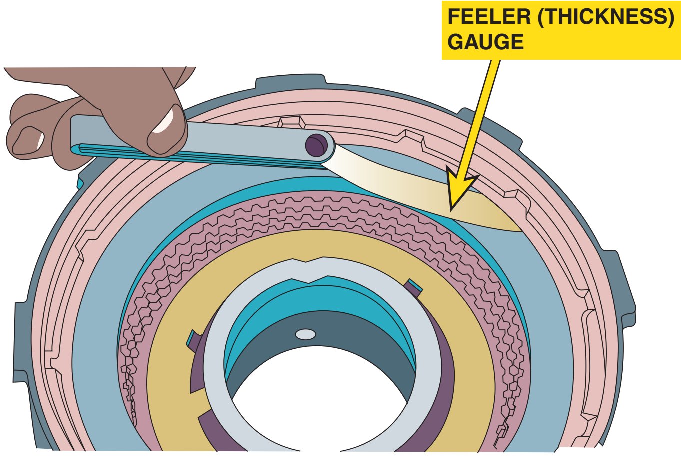


FIGURE 133–17 All clutch packs should be checked for proper clearance. Here, a feeler (thickness) gauge is used to check the clearance to make sure it is within factory specifications.

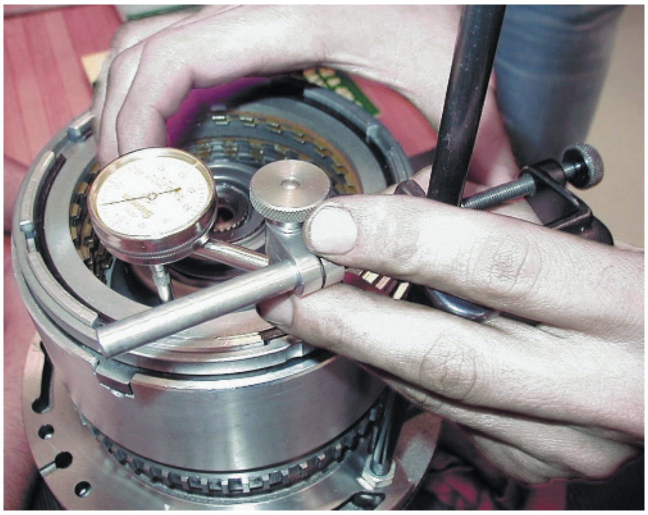


FIGURE 133–18 Checking clutch pack clearance using a dial indicator. This method is used when a feeler gauge cannot be inserted to check for proper clearance.

it is being used in the vehicle. Air checking a unit includes the following steps:

STEP 1 Use the factory service information regarding where to air check and what the results should be.

STEP 2 Use a rubber-tipped air nozzle and regulate the air supply to about 35 PSI (240 kPa).

STEP 3 A typical result is a dull thud or clunk heard when air pressure is applied to a clutch pack or servo piston. ● **SEE FIGURE 133–19**.

STEP 4 When the air pressure is removed, the unit should release. If there is a seal leak, air can usually be heard hissing from around the seal. ● **SEE FIGURE 133–20**.

BUSHINGS All bushings should be inspected and replaced if necessary. ● **SEE FIGURE 133–21**.

ONE-WAY CLUTCHES Always double check that all one-way roller clutches are installed correctly. The transmission will not work correctly if the one-way clutch is installed upside down. Check service information for the exact method to use to ensure that they are installed correctly. ● **SEE FIGURE 133–22**.

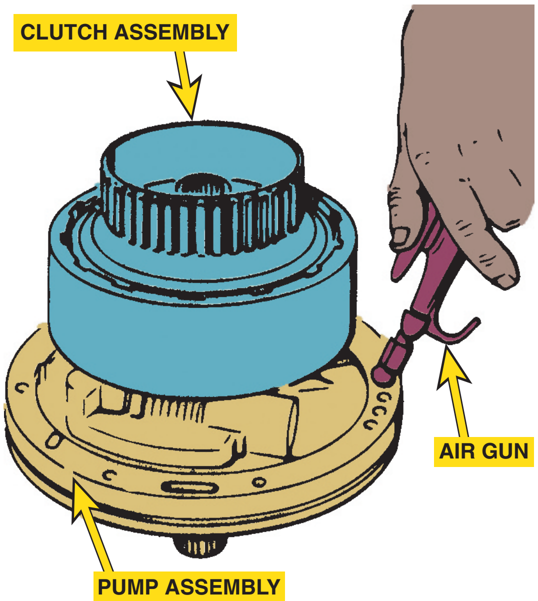


FIGURE 133–19 Air testing a clutch pack before installing it into an automatic transmission or transaxle.

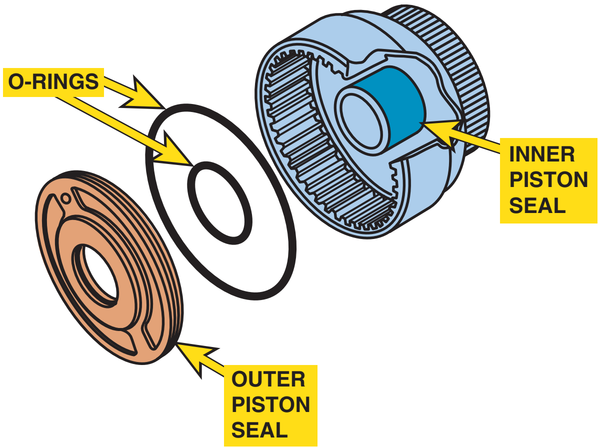


FIGURE 133–20 Both the inner and outer seals are checked when air testing a clutch pack assembly.

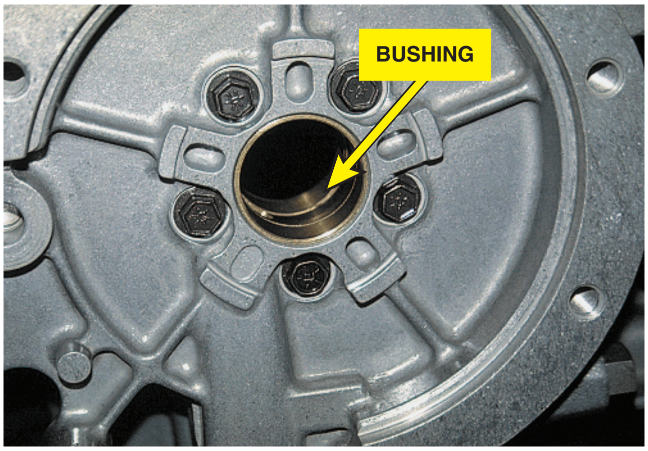


FIGURE 133–21 A typical brass bushing used in an automatic transmission.

SPECIAL TOOLS Special tools are often specified by the vehicle manufacturer. These tools allow the service technician to disassemble and reassemble the transmission/transaxle more easily without harming the unit. ● **SEE FIGURE 133–23**.

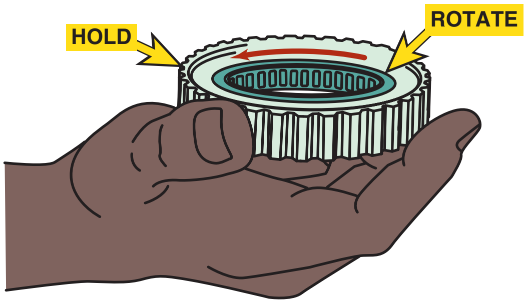


FIGURE 133–22 Service information states that this one-way roller clutch should be installed as shown. Check by holding the outer race so that the inner race is free to rotate counterclockwise as shown.

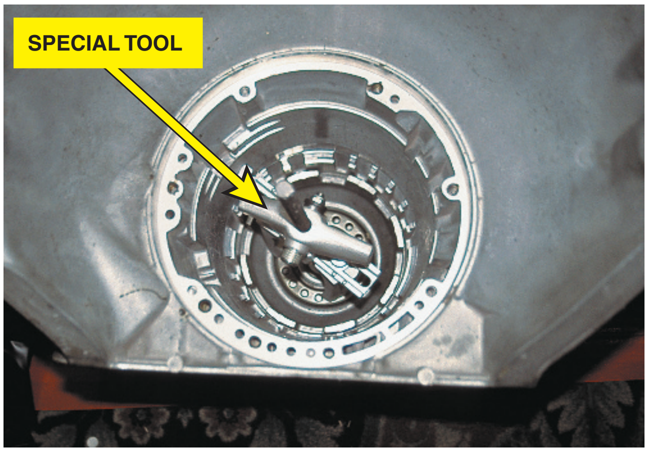


FIGURE 133–23 A special clamp makes removal and reinstallation of this clutch pack easier.

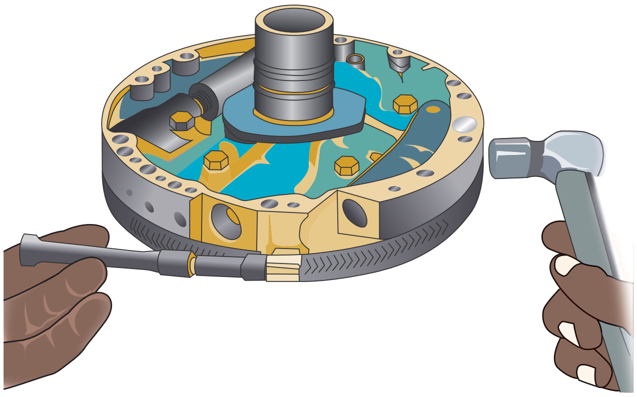


FIGURE 133–24 Using an alignment clamp to assemble both pump halves. To ensure proper alignment, many experts recommend lightly tapping the outer edges of the pump while tightening the clamp.

PUMP ASSEMBLY Follow the vehicle manufacturer's recommended procedures. For example, a special clamp is often necessary to properly assemble a pump. ● **SEE FIGURE 133–24**.

END PLAY CHECKS Perform all end play checks during assembly to ensure that the unit was properly assembled and that the proper internal clearances are achieved. ● **SEE FIGURE 133–25**.

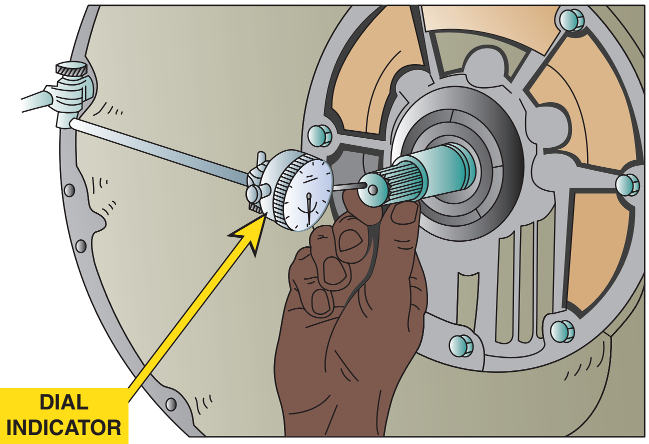


FIGURE 133–25 A dial indicator being used to measure the end play of an input shaft. If the end play is not within factory specifications, the unit may not have been assembled correctly.

TECH TIP

Avoid Using Red Assembly Lube

Assembly lube is used during the reassembly of automatic transmissions. If red assembly lube is used on seals, it may look like an automatic transmission fluid leak when the transmission gets hot and the lube melts. If you use blue, green, brown, or clear assembly lube, then the color will immediately identify it as assembly lube. ● **SEE FIGURE 133–26**.

Many transmissions have been disassembled because the service technician thought that the red liquid dripping from parts of the transmission was automatic transmission fluid when, in fact, it was only assembly lube that melted and ran when the transmission reached normal operating temperature.

FIGURE 133–26 Blue assembly lube.

VALVE BODY CHECKS The valve body can be checked using a tester especially designed for this purpose. Adapters are available for all commonly serviced automatic transmissions/transaxles, and the pressure gauges that are part of the tester are used to monitor the movement and flow through the valve body.

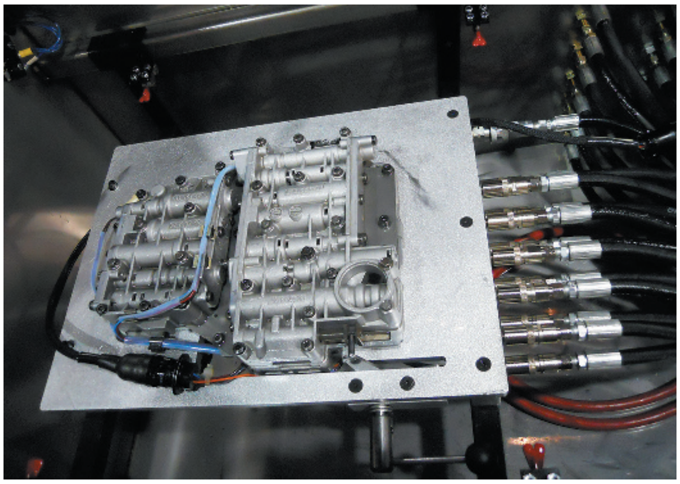


FIGURE 133–27 A valve body being tested on a valve body tester. While it takes some setup time to adapt each valve body to the proper hoses, this type of machine can find valve body problems before the transmission/transaxle is installed in the vehicle.

TECH TIP

Change the Bolts and Washers

When reassembling an automatic transmission, always replace the pump bolts and sealing washers to avoid the possibility of a leak. A leak in the area of the pump can cause quite a headache for the technician because the entire assembly must be removed from the vehicle again to fix it.

This unit also heats the automatic transmission fluid so that the valve body is being tested under the same conditions as will be occurring in the vehicle. It is easier to repair a fault with the valve body than wait until the valve body and the transmission are installed in the vehicle. ● **SEE FIGURE 133–27**.

CAUTION: It is critical that the valve body be torqued in the proper sequence to the correct specification to avoid warpage which could cause a sticking valve.

FLUSHING THE COOLER AND TORQUE CONVERTER

PURPOSE All vehicle manufacturers recommend that the automatic transmission fluid cooler be checked for proper flow and, if not, then it should be replaced whenever a replacement or overhauled automatic transmission/transaxle is installed in a vehicle. Most vehicle manufacturers are recommending to flush the cooler. Cooler can be flushed using special machines that pulsate ATF through the cooler. Solvent can be used to clean the varnish that flushing with ATF will not remove. Always follow the instructions that come with flushing machines or solvent containers.

NOTE: At least 2 quarts (liters) of ATF should flow through the cooler every 30 seconds or the cooler and/or the lines are restricted. ● SEE CHART 133–1 for the placement of the cooler-out lines on common transmissions/transaxles.

COOLER-OUT LINES	
TRANSMISSION	**COOLER-OUT LINE ON THE TRANSMISSION/TRANSAXLE**
GENERAL MOTORS	
125 (3T40)	Bottom
THM-180	Bottom
THM-200/200-4R	Top
THM-325/325-4L	Bottom
THM-350	Bottom
THM-400 (4L80)	Bottom
THM-440-T4 (4T60)	Bottom
THM-700-R4 (4L60)	Bottom
FORD	
A4LD	Bottom
AOD	Top
ATX	Bell housing end
AXOD	Top
C3, C4, C5, C6	Front
CHRYSLER	
904, 727	Front
42RLE	Bottom is one to cooler
41TE	Right side is one to cooler
62TE	One farther from bell housing is one to the cooler
IMPORT BRANDS	
Honda	Over the bell housing
Jatco (RWD) (Various Makes and Models)	Front
Mitsubishi	Inner
Renault	Top
Nissan RL3F01A	Top
Nissan RL4F02A	Front
Subaru	Top of the differential
Toyota FWD	Top
Toyota RWD	Front

CHART 133–1

The location of the cooler-out lines varies by vehicle and transmission/transaxle. Check service information for location of the cooler lines on the vehicle being serviced.

DYNAMOMETER TESTING THE AUTOMATIC TRANSMISSION/TRANSAXLE

A rebuilt automatic transmission/transaxle can be tested on a dynamometer powered by

- An electric motor (● **SEE FIGURE 133–28.**)
- A gasoline engine (● **SEE FIGURE 133–29.**)

Most dynamometers are equipped with pressure gauges so the operation of the unit can be checked before being installing in the vehicle.

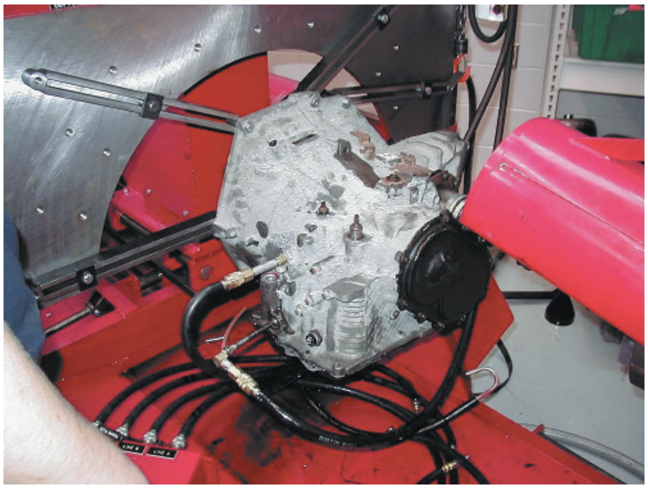


FIGURE 133–28 An electric motor-driven dynamometer being used to check the operation of a 41 TE transaxle.

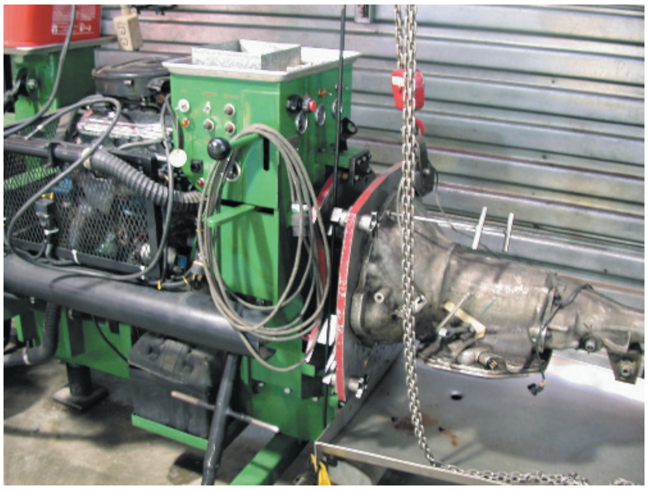


FIGURE 133–29 A gasoline-powered dynamometer being used to test a rear-wheel-drive automatic transmission.

REINSTALLING THE AUTOMATIC TRANSMISSION/TRANSAXLE

DOUBLE CHECK END PLAY After the unit has been reassembled and all end play checks indicate that the unit is properly assembled, reinstall the automatic transmission/transaxle in the vehicle. Many experts recommend that new transmission/transaxle mounts be installed to assure proper driveshaft/drive axle shaft angles.

NOTE: New mounts are particularly important if the unit was leaking automatic transmission fluid (ATF). The ATF can soften and deteriorate the rubber used in the mounts.

TORQUE CONVERTER INSTALLATION Before installing the unit into the vehicle, flush the torque converter with clean ATF. Carefully install the torque converter onto the input shaft being sure to fully engage the following:

- Pump gear
- Stator splines
- Turbine splines

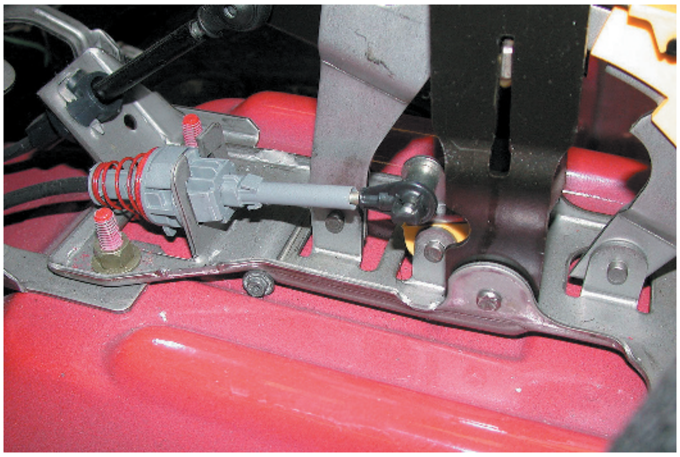


FIGURE 133–30 Check the linkage for proper adjustment so that the shift interlock works correctly and the PRNDL is aligned with the transmission range switch.

TRANSMISSION/TRANSAXLE INSTALLATION Check service information for the exact procedure to follow when installing an automatic transmission/transaxle. The following are the steps often specified:

- inspect engine core plugs and replace as required.
- Check and replace as needed the rear crankshaft seal.
- Check and correct as needed the dowel pins, dowel pin holes on the back of the engine block.
- Check the engine to transmission mounting surfaces.
- Carefully install the unit and use a torque wrench to torque the bolts to the bell housing.
- Attach the torque converter to the flex (drive) plate.
- Reattach all electrical connections, linkages, and cooler lines. ● **SEE FIGURE 133–30**.
- Lower the vehicle and add enough ATF to properly fill the unit. Consult factory information for the recommended amount, to avoid under- or overfilling.

ROAD TEST

FAST LEARN THE PCM/TCM Start the engine and check the level of the ATF. For an electronic transmission/transaxle to operate correctly, a "fast learn" or a "quick learn" should be performed

TECH TIP

Install a Transmission Cooler

An auxiliary transmission fluid cooler is recommended by most experts to help keep the temperature from becoming excessive, especially when towing or performing other heavy-duty vehicle operation. ● **SEE FIGURE 133–31**.

Most experts recommend that the cooler be connected so that the hot fluids travel through the auxiliary cooler and then through the factory cooler and return to the transmission/transaxle. Using this method of plumbing allows the radiator to warm the transmission fluid in cold weather as well as provide additional cooling of the fluid when the fluid temperature is high.

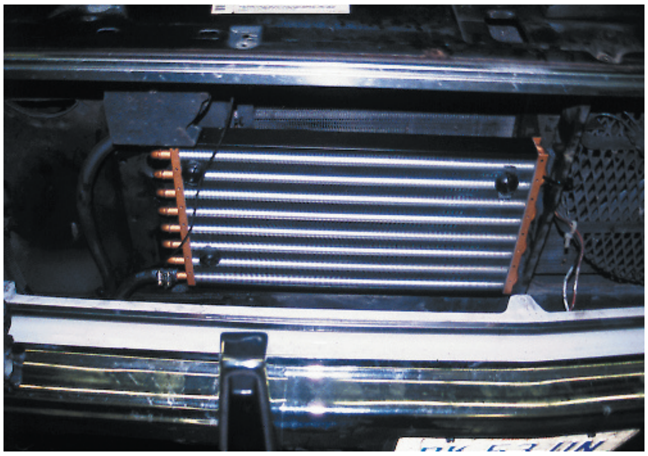


FIGURE 133–31 An auxiliary automatic transmission fluid cooler installed on a Chevrolet pickup truck used to haul a car trailer.

with a scan tool before the vehicle is driven. This action will get the adaptive settings close to what they should be and will help prevent damage to the unit if this procedure is not done.

TECH TIP

If the Torque Converter Is Dropped, Replace It

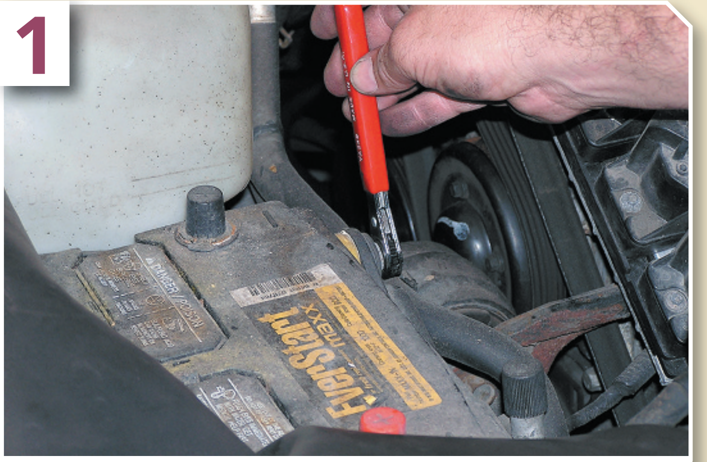
Torque converters include plastic thrust plates, which are very strong under the compressive forces of normal torque converter operation. However, if a torque converter is dropped, even from a distance of less than 6 inches (15 cm), the thrust washer can easily break, ruining the torque converter. Even though torque converts look strong and feel heavy, handle them as if they are glass.

In addition, Chrysler has a torque converter burnishing mode that can be activated on the scan tool for some models.

ROAD TEST PROCEDURE Carefully test drive the vehicle, checking for proper operation and shift points. Hoist the vehicle and check for any possible ATF leaks before returning the vehicle to the customer.

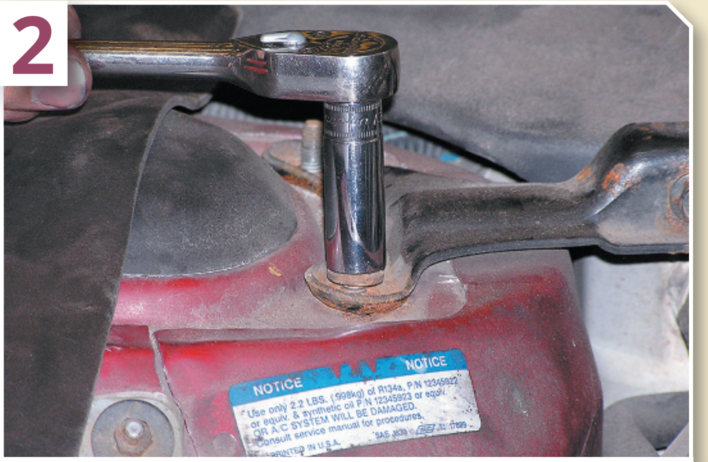
TRANSAXLE REMOVAL

1



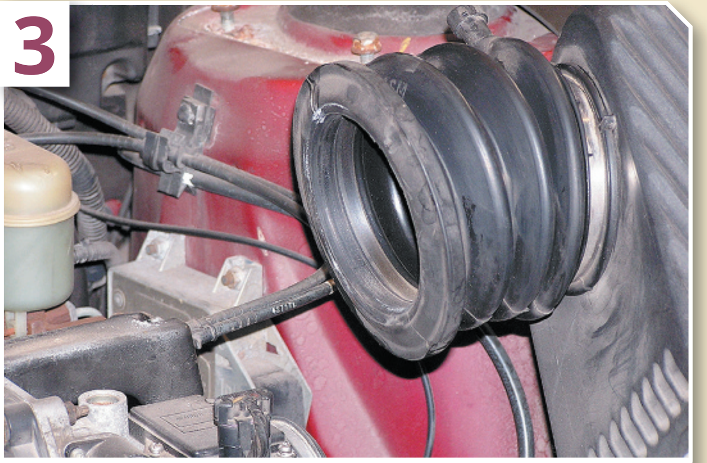
For safety purposes, remove the negative battery cable before starting the removal procedure.

2



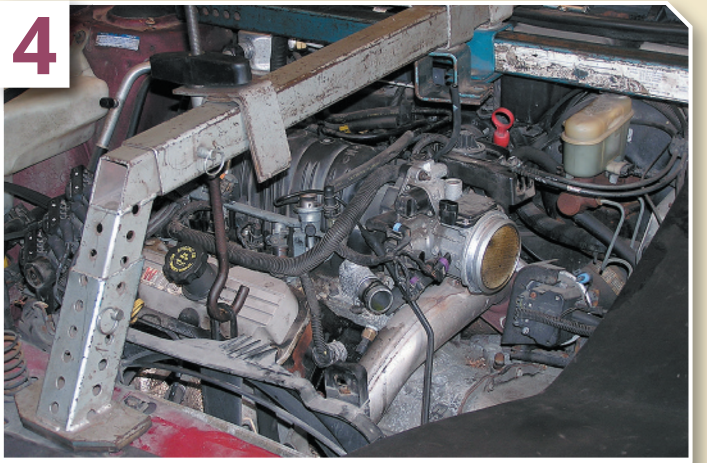
Remove engine bay cross members that may interfere with access to the transaxle fasteners.

3



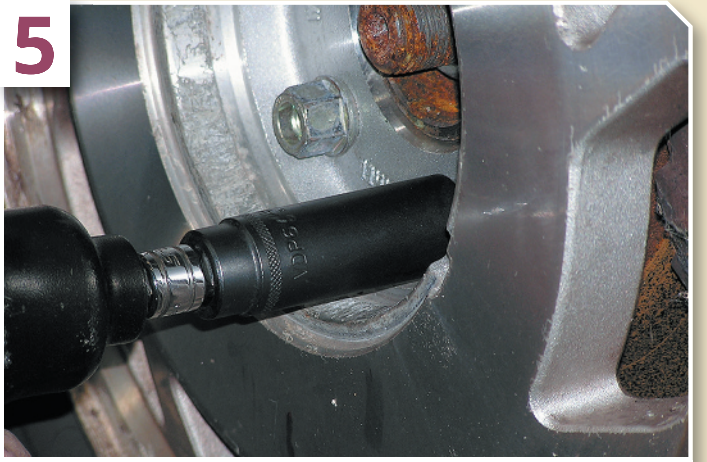
Remove the air intake and air filter assembly, which is covering the transaxle in this vehicle.

4



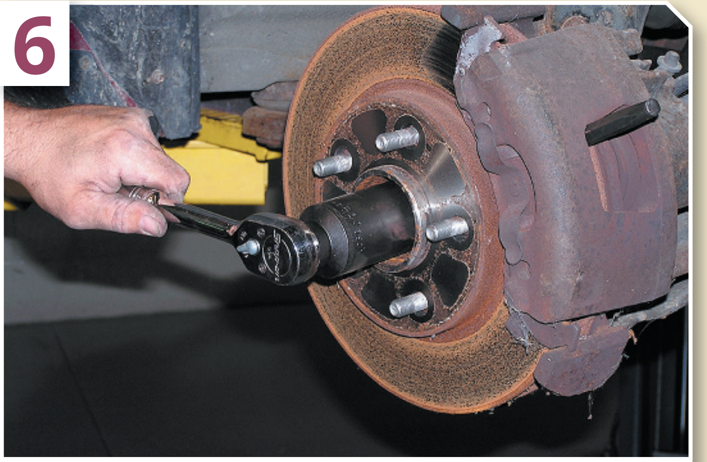
Install a support for the engine.

5



Safely hoist the vehicle and remove the wheels.

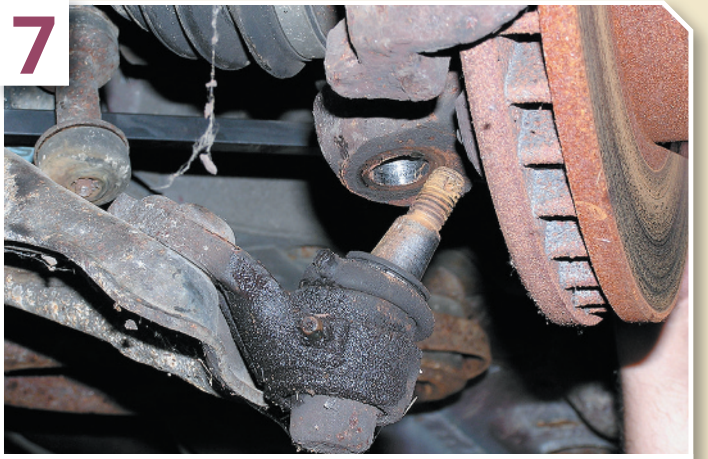
6



Remove the retaining nut from the drive axle shaft.

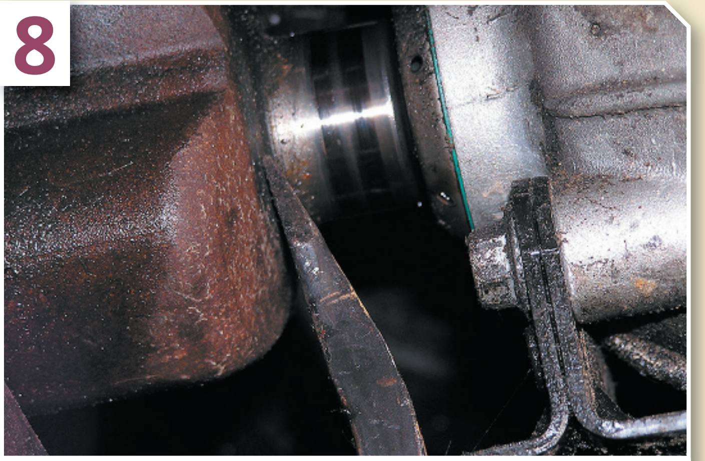
STEP BY STEP

7



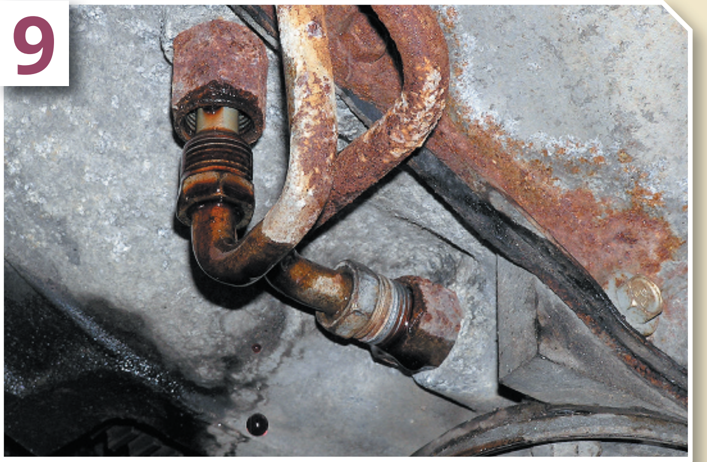
Disconnect the lower ball joint on the front-wheel-drive vehicle to allow removal of the drive axle shaft.

8



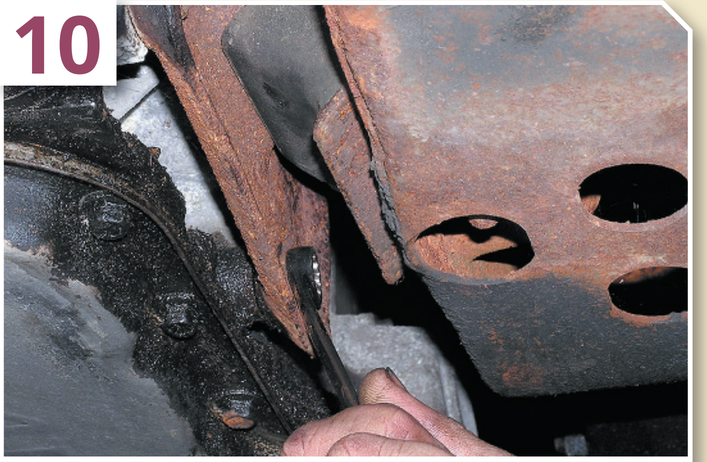
Remove the drive axle shaft from the transaxle using a pry bar.

9



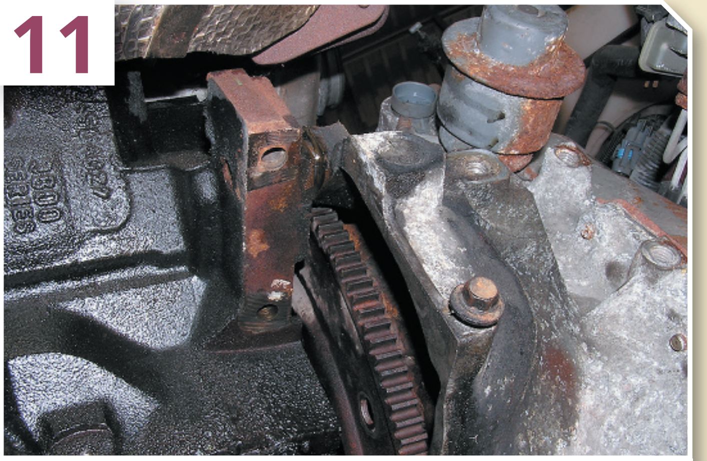
Disconnect the cooler lines from the transaxle using a line wrench.

10



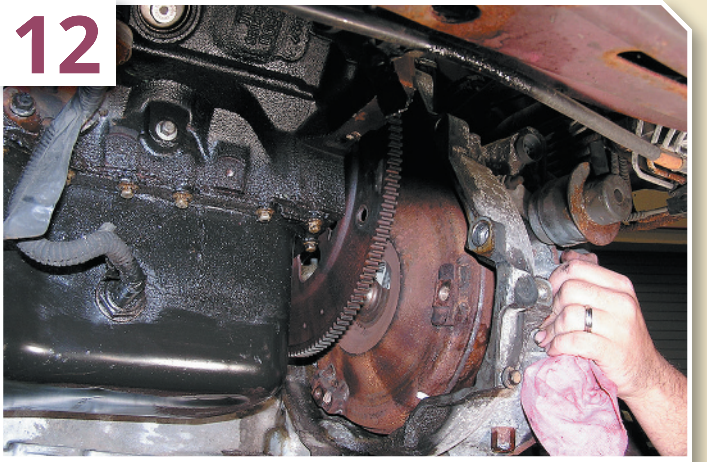
Unbolt the torque converter from the flexplate, then remove the transaxle mounts.

11



With the transaxle supported on a transmission jack, remove the retaining bolts from the bell housing.

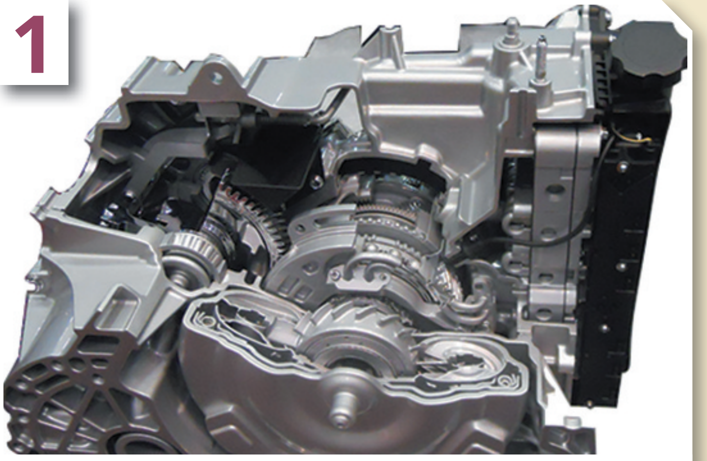
12



Carefully remove the transaxle from the vehicle.

6T70 TRANSAXLE DISASSEMBLY AND ASSEMBLY

1

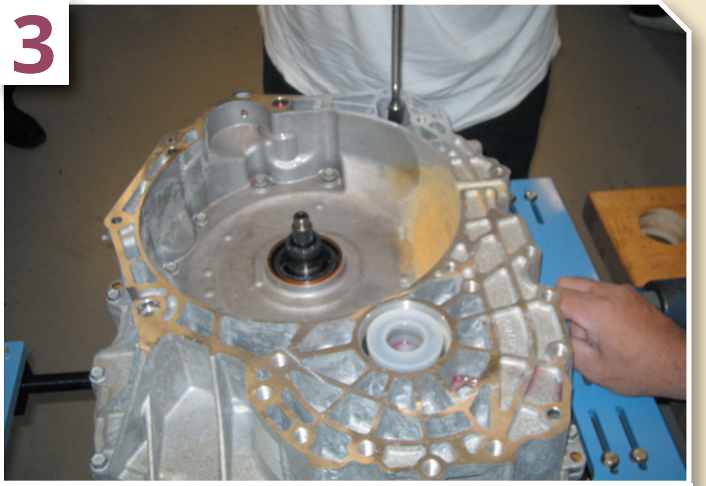


The GM 6T70 6 forward speed transaxle was a joint venture with Ford and therefore is similar to the 6F50.

2

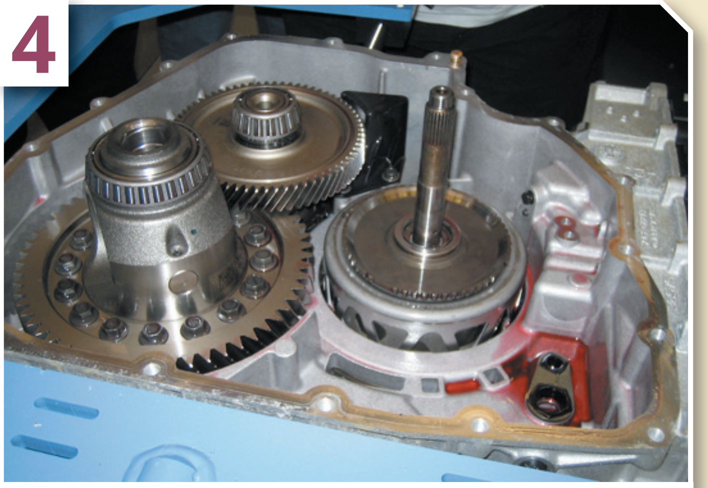
A unique thin torque converter is used to help reduce the overall length of the transaxle.

3



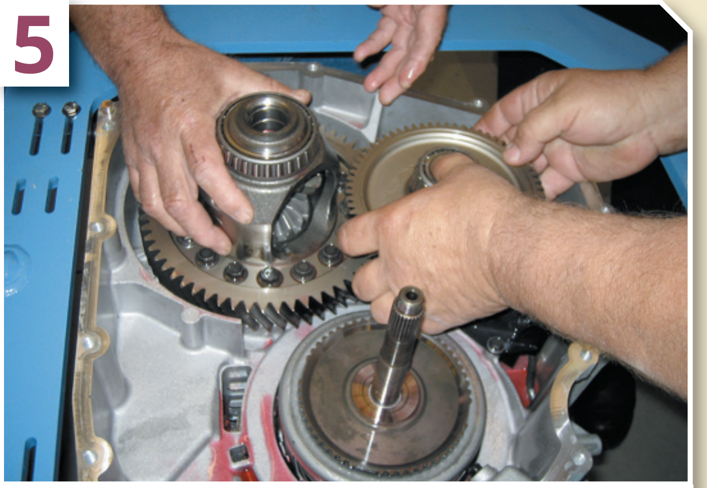
After removing the torque converter, the housing is being removed.

4



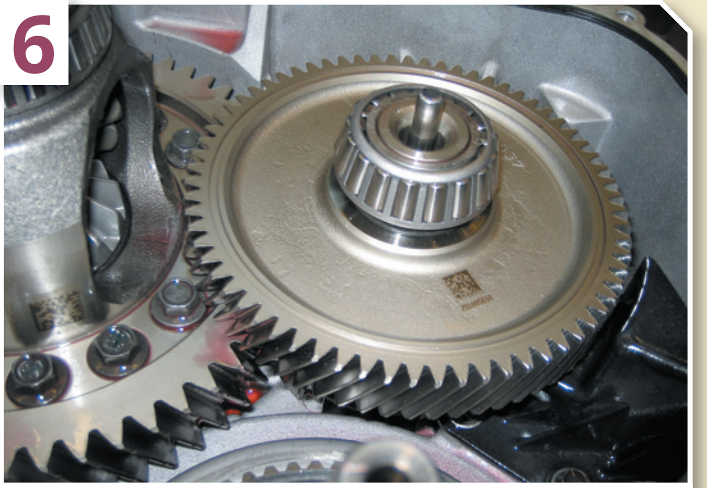
The final drive assembly is exposed after the housing has been removed.

5



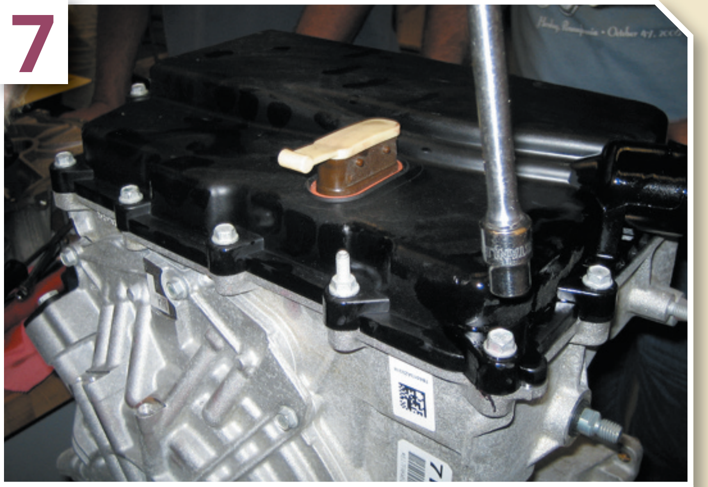
The final drive is easily lifted out after the housing has been removed.

6



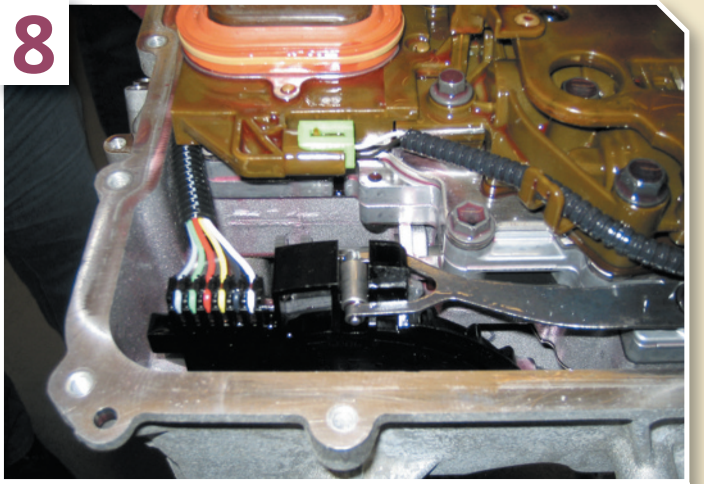
Note the tapered roller bearing used in the final drive assembly component.

7



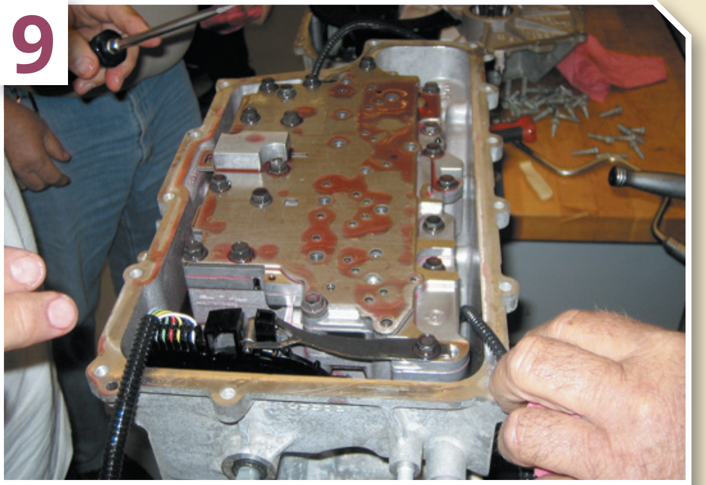
The transaxle is rotated and the plastic side cover is removed.

8



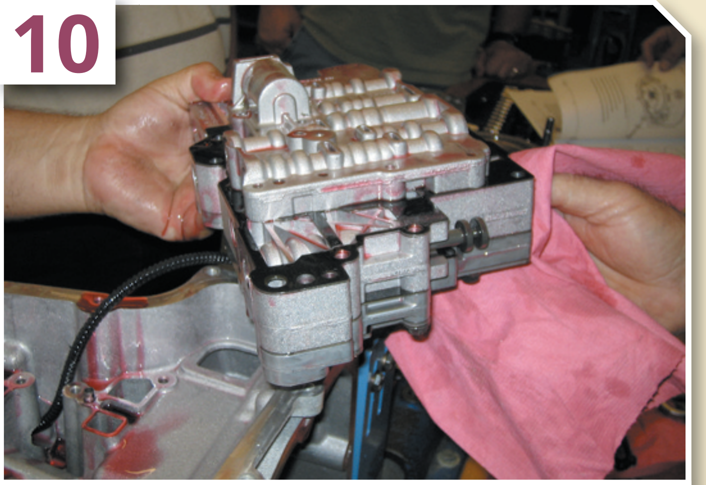
Under the side cover is the valve body and integrated solenoid assembly.

9



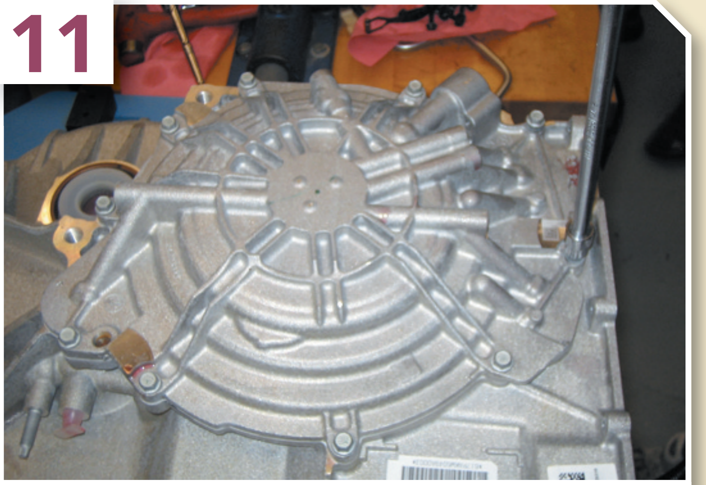
Under the plastic electrical solenoid assembly is the valve body assembly.

10



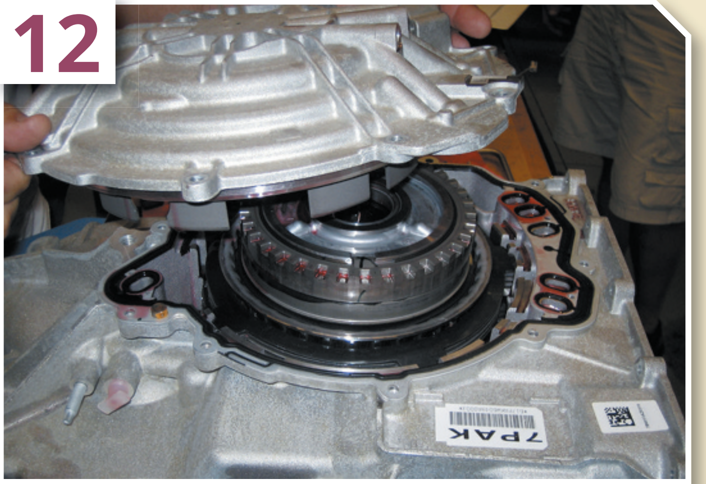
Removing the valve body assembly.

11



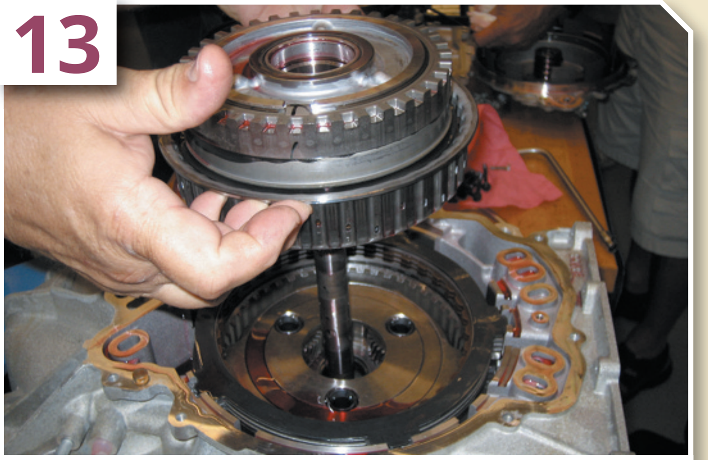
Turning the assembly around, showing the end cover.

12



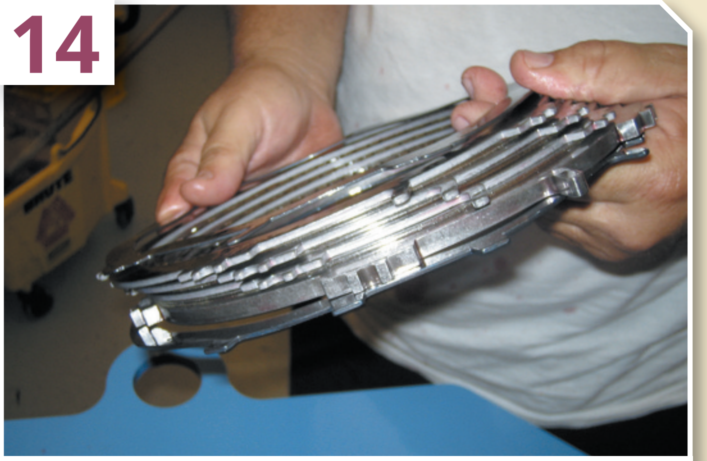
Removing the end cover shows the clutch packs and planetary gear set.

13



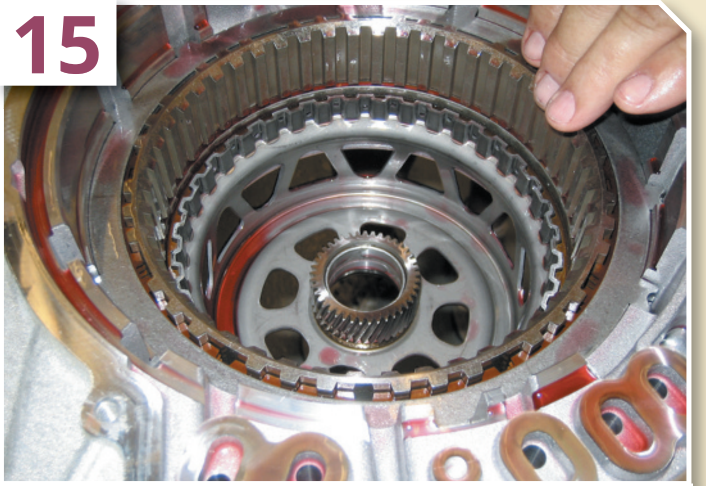
Removing the first of five clutch packs (two driving and three holding).

14



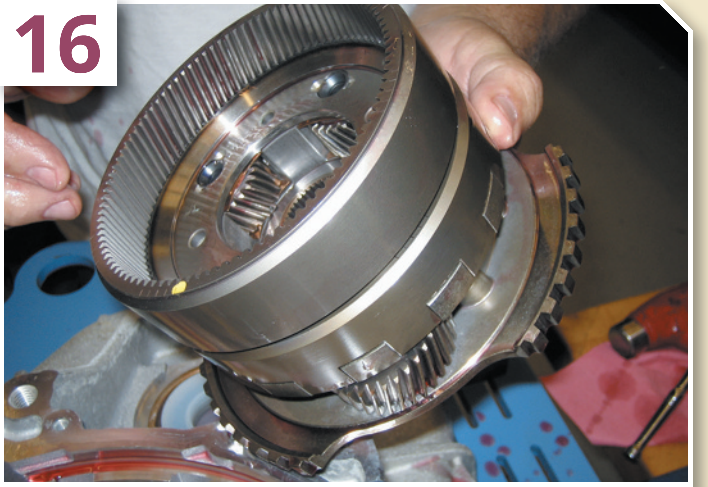
A typical clutch pack in a 6T70 showing the selective thickness steel used to determine clutch pack clearance.

15



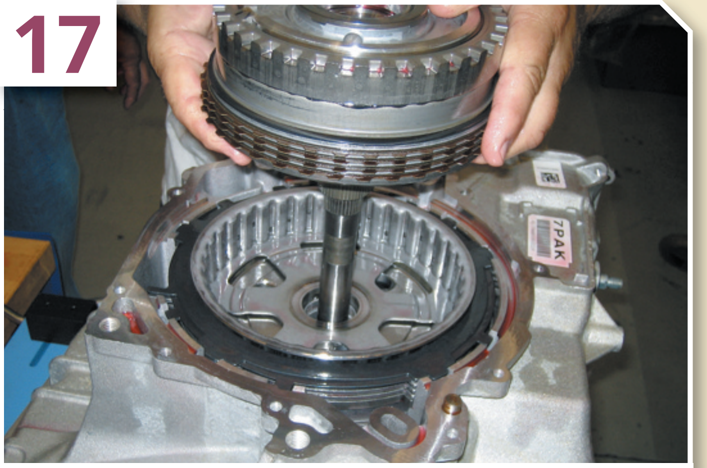
A view down into the case where multiple clutch packs are found.

16



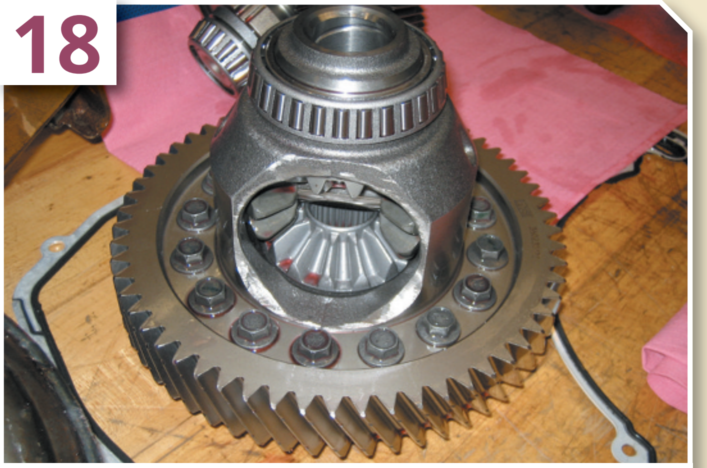
The output planetary gear set with four pinions used on 6T70 units. The 6T75 version uses a five pinion carrier and a reinforced case.

17



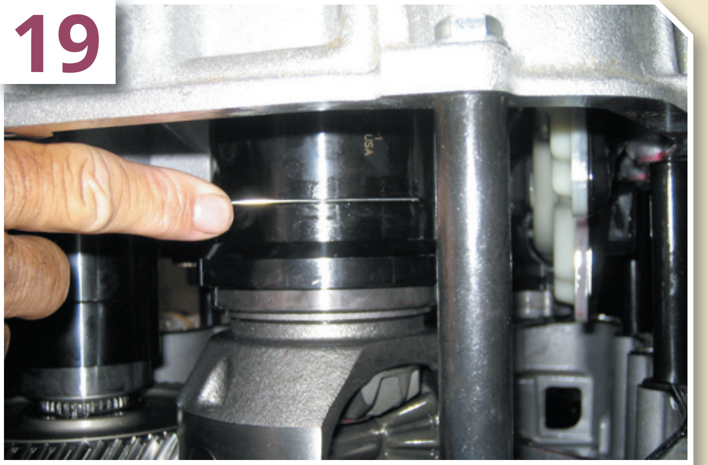
Reassembly of the clutches. Check service information for specified clutch pack clearance.

18



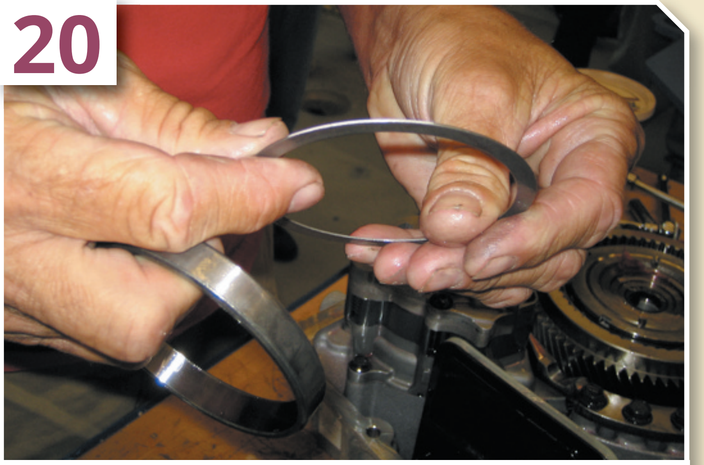
Notice that the final drive is equipped with tapered roller bearings, which means that the preload must be adjusted.

19



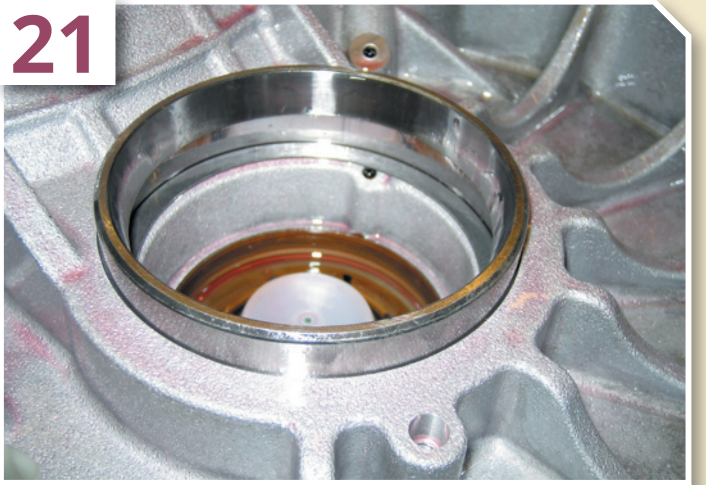
A special set of spacers and blocks used to determine the preload needed. A feeler gauge is then used to measure the clearance.

20



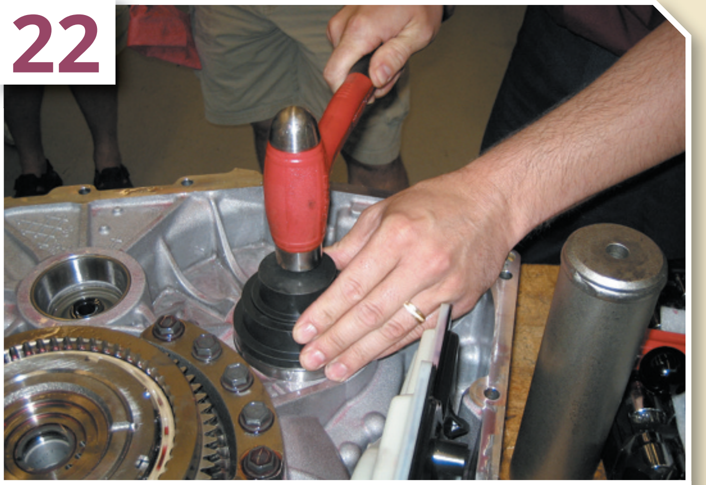
Following the procedure in service information, the designated thickness of shim is selected, which is placed under the bearing race in the bearing packet.

21



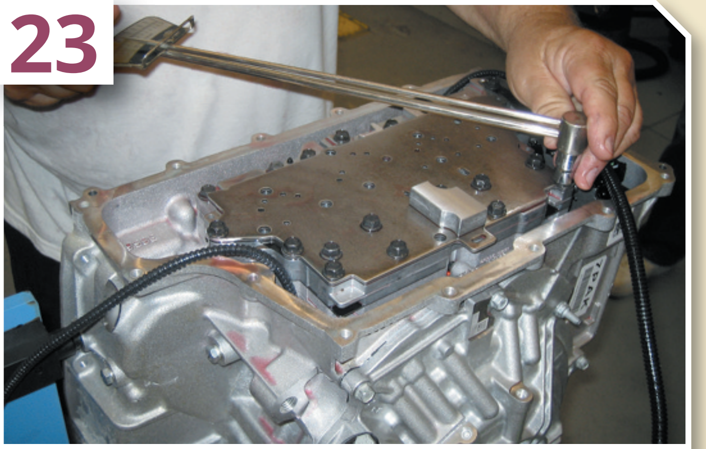
The selective shim and race before the race is driven into position.

22



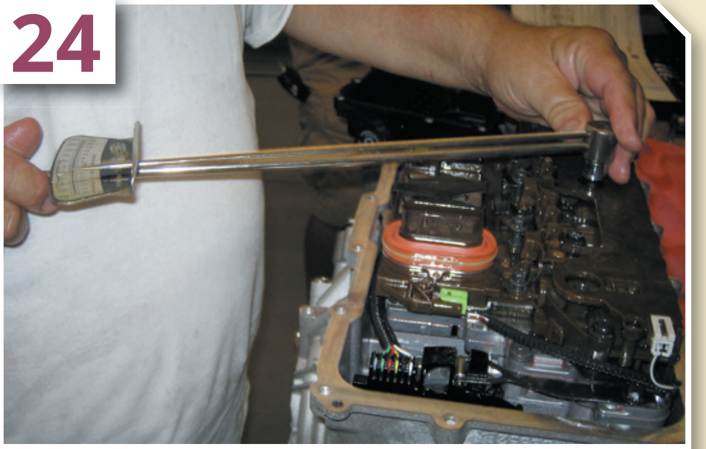
Driving the race into position using the specified driver.

23



Reassembly of the valve body being sure that all fasteners are tightened to factory specifications.

24



The solenoid assembly is replaced as an assembly only if defective and all the fasteners need to be torqued to factory specifications.

REVIEW QUESTIONS

1. What are the typical operations needed when disassembling an automatic transmission/transaxle?
2. What are two methods of checking a clutch pack?
3. Why is it important to perform an end play check of an automatic transmission/transaxle during the reassembly process?
4. Why is it important to flush the automatic transmission fluid cooler when a rebuilt or replacement automatic transmission/transaxle is being installed in a vehicle?
5. Why should assembly lube NOT be red in color?

CHAPTER QUIZ

1. The technician should use ___________ to verify the need for unit repair.
   - **a.** service information
   - **b.** the owner's manual
   - **c.** the parts catalog
   - **d.** Any of the above
2. What is the first step required when removing an automatic transmission or transaxle?
   - **a.** Remove the pan so all of the fluid is drained from the unit
   - **b.** Disconnect the negative battery cable
   - **c.** Disconnect the torque converter from the flexplate
   - **d.** Remove the cooler lines
3. Friction discs should be ___________ before being installed.
   - **a.** sanded
   - **b.** soaked in ATF
   - **c.** surface roughed up
   - **d.** All of the above
4. Technician A says that the torque converter should be separated from the flex (drive) plate before removing the automatic transmission/transaxle. Technician B says that the clutches should be installed “dry” when replacing the frictions and steels in a clutch pack. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
5. Air pressure checking is used to test ___________.
   - **a.** clutch packs
   - **b.** transmission filters
   - **c.** TCC solenoids
   - **d.** shift valves
6. Technician A says that all friction and steel plates in a clutch pack should be replaced during an overhaul. Technician B says that the automatic transmission fluid cooler should always be flushed when a unit is rebuilt or replaced. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Which of these requires transmission removal if it needs to be replaced?
   - **a.** Range switch
   - **b.** Speed sensors
   - **c.** Valve body
   - **d.** Converter clutch
8. Most dynamometers are equipped with ___________ so the operation of the unit can be checked before being installed in the vehicle.
   - **a.** pressure gauges
   - **b.** a drive shaft
   - **c.** a powertrain control module (PCM)
   - **d.** All of the above
9. How much transmission fluid should flow through the cooler?
   - **a.** 2 quarts every 30 seconds
   - **b.** 1 quart per minute
   - **c.** 2 quarts per minute
   - **d.** 2 pints per minute
10. Road testing the vehicle should include ___________.
    - **a.** performing a fast learn procedure
    - **b.** checking for proper shifting
    - **c.** checking for any leaks
    - **d.** All of the above

SECTION XV

SPECIALTY ASE CERTIFICATION CONTENT

CHAPTERS

134 Parts Specialist (P2)
135 Service Consultant (C1)
136 Exhaust Systems Specialist (X1)

Chapter 134

PARTS SPECIALIST (P2)

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the terminology of a typical automotive parts business.
- Discuss the general operations of a typical automotive parts business.
- Describe the customer relations and sales skills needed by a parts specialist.
- Explain how to identify a vehicle, including the VIN, body style, and paint codes.
- Demonstrate basic knowledge of the systems common to every vehicle.
- Describe catalog and information system skills that a parts specialist must have.
- Explain inventory management, including physical inventory, stock rotation, and parts returns.
- Describe merchandising strategies.

KEY TERMS:

Aftermarket parts 1711 • Backorder 1712 • Charge policy 1713 • Core charge 1718 • Customer satisfaction 1714 • Customer satisfaction survey 1714 • End cap 1720 • FIFO (first-in-first-out) stock rotation 1718 • Footnote 1717 • Housekeeping 1713 • Impulse item 1719 • Inventory discrepancy form 1718 • Invoice 1712 • Jobber parts 1711 • Loss leader 1720 • Lost sales report 1718 • Original equipment manufacturer (OEM) parts 1711 • OSHA 1711 • Outside purchase 1718 • Parts bulletins 1717 • Point of purchase (POP) 1719 • Purchase order (PO) 1712 • Reference materials 1718 • Return policies 1714 • Safety Data Sheet (SDS) 1712 • Sales objections 1715 • Seasonal item 1719 • Special order 1712 • Stock order 1712 • Stocking fee 1712 • Subscription-based electronic information retrieval systems 1717 • Supersession bulletin 1718 • Technical service bulletin (TSB) 1718 • Upselling 1716 • Vehicle identification number (VIN) 1716 • Warehouse distributor 1711 • Warranties 1714

DEFINITIONS AND TERMINOLOGY

PARTS SPECIALIST Automotive parts specialists must learn the skills needed to work competently in a retail or jobber parts store. Automobile parts specialists must possess knowledge about a wide range of vehicle component systems for all makes and models. They must also have customer relations, sales, merchandising, vehicle identification, cataloging, and inventory management skills.

OEM PARTS **Original equipment manufacturer (OEM) parts** are manufactured by the same company that produced the original part used in assembly of the vehicle. Vehicle dealer parts departments carry OEM parts as well as some parts and supplies manufactured by other companies.

JOBBER PARTS **Jobber parts** (or **aftermarket parts**) are not made by the original manufacturer of the vehicle. The aftermarket industry makes up about 80% of the parts used in vehicle repair. A jobber store purchases manufacturer goods at wholesale prices, usually through a **warehouse distributor** and then sells products to consumers at retail prices.

OSHA The U.S. Congress passed the **Occupational Safety and Health Administration (OSHA)** act into public law in 1970.

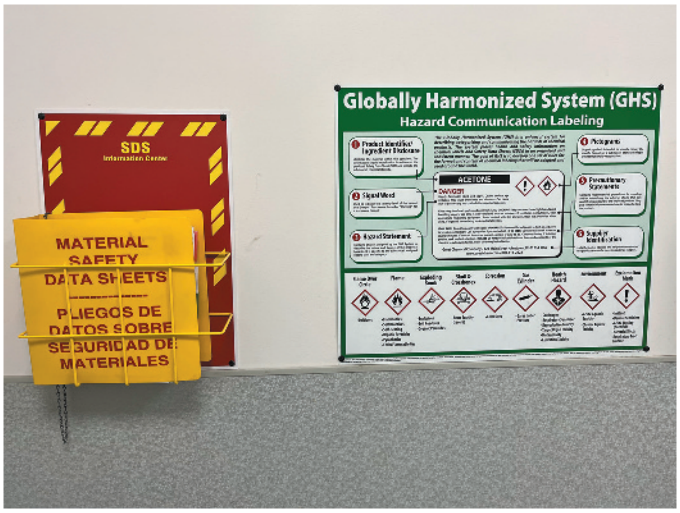

Globally Harmonized System (GHS)
Hazard Communication Labeling
SDS
Information Center
MATERIAL SAFETY DATA SHEETS
PLIEGOS DE DATOS SOBRE SEGURIDAD DE MATERIALES

FIGURE 134–1 The SDS and Globally Harmonized System (GHS) information are displayed in a parts store. The GHS includes health, physical, and environmental hazards as well as SDSs.

Workers must be familiar with OSHA standards regarding health and safety in the workplace.

SAFETY DATA SHEETS (SDS) A **Safety Data Sheet (SDS)** is provided by manufacturers for all chemicals used in industry. The SDS includes warnings and precautionary information about hazardous materials. OSHA requires that SDSs "shall be maintained and kept in a readily accessible area." Any SDSs received with shipments or received separately should be placed in a local SDS binder or file. ● **SEE FIGURE 134–1.**

PARTS INDUSTRY TERMINOLOGY The parts industry has many terms relating to ordering, stocking, selling, or returning parts:

- The **invoice** lists all parts by name and is used to track inventory and purchases for billing purposes.
- A **purchase order (PO)** is used to enable a store or business to purchase parts. It describes the component and the quantity being purchased along with billing information.
- A **stock order** is used to order more parts from the supplier on a routine basis.
- A **backorder** is for parts ordered from a supplier but not shipped due to them being out of stock.

GENERAL PARTS OPERATIONS

DISCOUNTS, PRICES, AND PERCENTAGES Businesses often offer discounts and special sales to promote customer interest. Parts specialists might be expected to calculate such discount. A discount is often expressed in percentages such as "20% off." To calculate the percentage discount, perform the following steps:

STEP 1 Convert the percentage to a decimal number by moving the decimal two places to the left. For example, 5% becomes 0.05 and 20% becomes 0.20.

STEP 2 Multiply this decimal number by the price to get the amount of the discount. 20% of $50 = $10 (or 0.20 × $50).

STEP 3 Subtract $10 from $50 to get the discounted price of $40.

FREQUENTLY ASKED QUESTION

How Is Margin Determined?

All businesses must earn money from every sale in order to pay their employees, rent on the building, as well as insurance and other expenses. It is typical in the automotive parts business for each level in the parts distribution chain to earn a 35% (or higher) margin on the parts handled. For example, take a part that costs the manufacturer $5 to produce:

- **First level** The manufacturer needs to make money and sells the part to a warehouse distributor for $10 (50% margin).
- **Second level** The warehouse distributor sells the part to a parts store and adds its markup, usually 35%. To determine what the parts store pays, divide $10 by 0.65. This equals $15.38.
- **Third level** The parts store wants to make a 35% margin, so the cost that it paid ($15.38) is divided by 0.65 = $23.66, which is a 35% margin. This $23.66 is the price that retail customers pay for the part.

This formula works for all amounts.

Percentages are also used to calculate the markup value of parts being sold. If the cost is $55 and the percentage of markup is 10%, then multiply 55 × 10% = $60.50.

NOTE: Financial calculators and computers can handle these calculations, and most likely the store's system will perform these calculations automatically.

SPECIAL ORDERS AND STOCKING FEES A **special order** is placed whenever a customer purchases a part that the business does not normally keep in stock. A customer who places a special order may be asked to pay shipping or handling charges, which may be based on the purchase price. If a customer returns a part, a **stocking fee** may be charged based on the original purchase price. For example, if a customer returns a $50 component and is charged a 5% restocking fee, 5% of $50 is $2.50 and subtracting $2.50 from $50 equals $47.50.

UNIT CONVERSIONS AND MEASURING Parts specialists should have a working knowledge of units of measurement, measuring, and converting from conventional to metric units. For example, engine displacement can be specified in either cubic inches or liters. Converting liters to cubic inches or cubic inches to liters is performed by dividing the volume value of cubic inches by 61 (liters = cubic inches/61).

A ruler, dial caliper, or micrometer might be needed to verify the size and fit of a replacement part, so parts specialists should know how to use and read these tools.

ALPHA, NUMERIC, AND ALPHANUMERIC SEQUENCES An alphanumeric listing is a series of numbers and letters starting from the left digit and working across to the right. If the part numbers are the same but there are slightly different versions of the part, then the order sequence might continue with an A, B, C suffix.

CASH, CHECKS, AND CREDIT/DEBIT/GIFT CARDS Cash sales are more profitable than credit card sales because there are no credit card charges or additional paperwork. Processing sales with other forms of payment differs only in the payment method. Follow these steps when accepting payment using a personal check:

1. Get a driver's license number and write it on the check.
2. Compare the license photo ID to the customer's appearance.
3. Use a check verification process.
4. Apply store endorsement to the check before placing it in the cash drawer.
5. Post the check number.

Credit cards and debit card concerns include the following:

- Make sure the credit/debit card belongs to the customer.
- Check the information on the credit/debit card against the customer's photo ID.

E-COMMERCE E-commerce refers to the process of buying or selling products or services over the Internet. E-commerce sales involve the following:

1. The online order is received.
2. The order is processed using the store's back-office system.
3. The customer is notified that the order has been received.
4. A request for fulfillment is sent to the warehouse.
5. The order is picked from stock at the warehouse.
6. The order is packed at the warehouse.
7. The order is shipped from the warehouse.
8. A shipping notification is sent to the customer.
9. The customer receives the order.

REFUNDS AND CREDIT INVOICING Parts specialists need to be familiar with the store's **charge policy** to provide the best customer service. If a sale needs to be voided or credited, parts specialists should know the steps necessary to complete this action. The procedure for refunds should be specific to the business and to the specific processor.

HOUSEKEEPING SKILLS **Housekeeping** relates to keeping all areas of the business clean and orderly; everyone in a parts store must have housekeeping skills. Lost sales can result from a disorderly and sloppy appearance. Countertops, shelves, and displays should all be neat and clean. Good housekeeping leads to a safe, clean, and productive environment. The following are some general housekeeping guidelines:

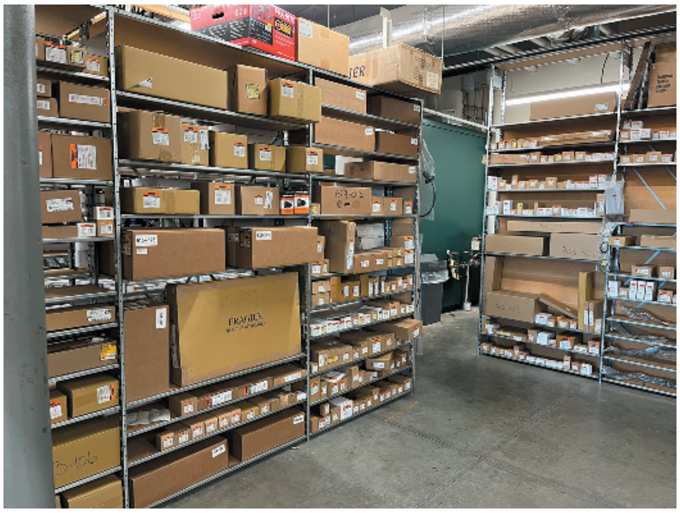


FIGURE 134–2 Even areas customers do not see should be clear of clutter to provide a path for employees to walk.

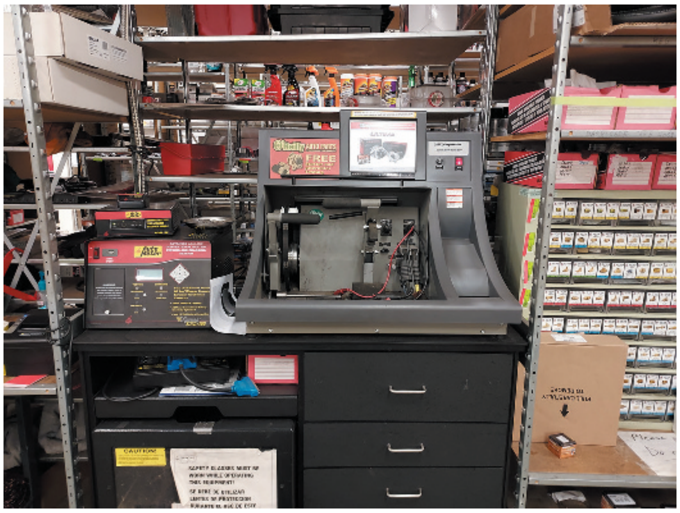


FIGURE 134–3 Most parts stores offer starter and alternator testing as part of their customer service policy.

- Keep aisles and walkways clear of tools, equipment, and other items. ● **SEE FIGURE 134–2.**
- Make sure that garbage containers are conveniently located and emptied regularly.
- Keep all lights in working order.

ADDRESS CUSTOMER CONCERNS Parts specialists should always sell the right parts to customers. This may involve educating the customer about the parts being bought and the importance of related items or tasks to be performed in combination with the parts installation. If a customer comes in for a starter while carrying a pair of jumper cables, the wise parts specialist will ask: "What is the problem that makes you think you need a starter motor?" The specialist may also mention that the battery or wiring could be the problem. ● **SEE FIGURE 134–3.**

PROPER SAFETY PRACTICES All parts specialists must maintain a safe environment to avoid personal injury or damage to the merchandise or customers. Safety includes the following:

- Learning about all safety precautions.
- Applying this safety precaution knowledge while working by developing safe working habits.
- Receiving training on how to lift heavy objects. Some heavy components should be moved with handling equipment like a forklift.

Following safety practices results in protecting employees and customers from harm.

POTENTIAL SECURITY RISKS Expensive items should be displayed behind the counter in locked cases. Parts specialists should give thought as to what is displayed near entrances and exits to avoid theft. It is best to use a video surveillance system and keep the areas around entrances clear.

FREQUENTLY ASKED QUESTION

What Is a Customer Satisfaction Survey?

A **customer satisfaction survey** is a study of customers' perceived satisfaction with a product or service. A completed survey provides answers for a list of questions that a company has concerning its products or services. Identifying unhappy customers is as important as identifying extremely happy ones (i.e., potential advocates). Parts stores can use a number of survey websites to help determine their level of customer satisfaction.

CUSTOMER RELATIONS AND SALES SKILLS

CUSTOMER SATISFACTION **Customer satisfaction** is defined as the customer's overall feeling of satisfaction with an interaction with the store. Customer satisfaction recognizes the difference between customer *expectations* and customer *perceptions*. Satisfaction may develop quickly or may be refined over time.

APPEARANCE All aspects of the parts specialist's appearance, including clothing, personal hygiene, and outward demeanor, create a first impression with customers. First impressions affect the level of trust achieved. It is harder to convey a message effectively if the customer is distracted by some aspect of the parts specialist's appearance. Thus the parts specialist should always have a professional appearance.

ACKNOWLEDGING AND GREETING CUSTOMERS From the moment customers walk through the door until they leave, employees should welcome and acknowledge them in a friendly manner. Parts specialists should not hold personal conversations with one another when a customer is at the counter. The first step toward making customers feel noticed is to make eye contact with them and say "Good morning/afternoon" and "I'll be with you in a few minutes." Customers should be waited on in the same order in which they came into the store.

HANDLING DIFFICULT CUSTOMERS When confronted with a difficult customer, consider doing the following:

- Listen. It is important to allow the customer to explain the problem or concern even if it involves a long and drawn-out story.
- Do not get angry. Remember that the customer is upset at the situation, not at the parts specialist.
- Ask questions. Seek clarification of the problem and determine the variables involved.
- Show empathy. Attempt to understand what the customer is experiencing.
- Determine the most appropriate solution to the problem. Use creativity and follow company policies to create a positive outcome for both the customer and the business.
- Follow up. Restate what has been decided and how the situation is being resolved. Ask the customer whether they have any further questions.
- End on a positive note. Thank the customer for their understanding. Bid them farewell in an enthusiastic manner so they remember the professional manner used to resolve their problem. Customers are more likely to remember the end of an interaction than the beginning.

UNDERSTANDING WARRANTIES AND RETURN POLICIES Parts specialists should help customers understand the terms of sale, such as cash or credit sales. **Warranties** are almost always offered by the part manufacturer. Some warranties are for 30 to 90 days or for one year after purchase. An extended warranty may apply to parts such as batteries or tires. A lifetime warranty may be offered on products that can be returned with proof of purchase at any time after the sale for a replacement. **Return policies** vary by store. For example, for some companies, electrical and electronic parts are sometimes not returnable for reimbursement.

ANSWERING THE TELEPHONE The telephone is a powerful tool for sales, information gathering, and relationship building. A telephone call is often the first point of contact a customer has with the store. Creating a good first impression helps establish positive feelings about the store. Some useful telephone tips include the following:

1. Answer calls promptly and be prepared to handle them. Answer at the second ring if possible. When the telephone rings longer, callers get the feeling that no one is available and that their call is an intrusion.
2. Have paper and pens handy to take notes. Use a computer-based customer system for reference. Get the caller's name and number as soon as possible, and summarize the conversation briefly at the end—especially mentioning any commitments that need to be followed up on.
3. The best way to answer a business call is for the parts specialist to simply state their name or department and ask, "How may I help you?"
4. Use proper titles for people when communicating. If in doubt about whether to use a customer's first name, call the person by the more formal Mr. or Ms. If they prefer that their first name be used, they will say so. It is better to be a little too formal than overly familiar.
5. "Thank you" is the most powerful phrase in human relations. Express appreciation regularly. Some companies use it as a greeting: "Thank you for calling Jones Buick." A "Thanks for calling" at the end of a conversation is also a strong customer satisfaction booster.
6. Keep the conversation businesslike. Nothing turns off a customer or caller like forgetting their name. If this happens, simply say, "I'm sorry, I didn't get your name, sir/ma'am. Would you please repeat it?"
7. Speak clearly and distinctly. Avoid using speaker phone.
8. Do not allow "dead air." When dead air occurs, callers have no idea what is going on and are often annoyed if the silence persists.
9. Take messages cheerfully and accurately. Get customers' full names and correct spelling by asking callers to spell their names. Also ensure their correct telephone number is recorded.
10. Try to picture customers on the phone. Physically smiling somehow travels through the telephone line via voice tones.

FIGURE 134–4 Smiling while talking on the telephone conveys a positive attitude to customers.

TECH TIP

How to Handle Customers When Times Are Busy

Sometimes the phone will ring while the parts specialist is waiting on a customer. When no one else is available to answer the phone, the parts specialist should ask the customer to stand by and then answer the phone, requesting the caller to hold. The parts specialist should never pick up the phone and press the hold button without talking to the caller. If it appears that the call will take some time, the parts specialist should try to explain to the caller that they are with another customer at the moment. Return the call as soon as possible or tell the caller to call back in a few minutes.

Keep a mirror by the telephone to remember to smile. It really does come through to callers. ● **SEE FIGURE 134–4**.

11. When the phone rings, the first thing all associates should think is, "There's an opportunity on the phone—here we go!" It's time to smile, breathe, and project energy and enthusiasm with a heartfelt greeting.
12. Make sure the conversation is finished before hanging up. If the parts specialist initiated the call, the parts specialist should take responsibility for ending it. Use conclusion words such as, "Thank you for the help."
13. When leaving a message on a customer's voicemail, be sure to state the following:
    - Your name
    - The time and day of the call
    - A brief explanation of why the call was made
    - A phone number
    - When the customer can reach the parts specialist
14. Don't let a telephone call interrupt an important live conversation. One concern of many customers is having their discussion with a parts specialist interrupted by a phone call. If a phone call must be answered, always indicate this to the customer in a polite way. Ask the caller if they are able to hold. If they are not, they should be called back promptly.

HANDLING DIFFICULT PEOPLE ON THE PHONE

Here are some tips for handling upset callers:

STEP 1: Try to understand why they are upset. Three common causes of anger or frustration arise from people feeling that

- They are not valued or important
- They are helpless
- "It" just isn't fair

STEP 2: Try diffusing their anger or frustration with statements or questions such as the following:

- "Help me to understand." This encourages customers to explain why they are upset. Do not try to defend or argue with their perceptions—they know what they feel, even if it does not make a lot of sense.
- Express empathy by saying, "I can understand feeling that way." Do not say "I know exactly what you mean," because that may not be true. Instead, convey an idea of what they might be feeling.
- Ask, "What would be a good solution from your point of view?" This begins to shift the conversation away from the venting of emotion toward solution seeking.

Always ask, "Is this a convenient time to talk?" If it really is not a good time, let the caller know and arrange another time to talk that would be more convenient. Then arrange a callback.

SELLING RELATED ITEMS

If a customer comes into the store to purchase a product, the parts specialist should suggest buying related items. Selling related parts when a customer buys a particular part can boost sales. For example, when selling brake pads, suggest Brake Clean to prevent brake dust from going airborne, brake pad silencing gel or spray, and caliper slide lube. ● **SEE FIGURE 134–5**.

HANDLING SALES OBJECTIONS

Sales objections may occur when a customer has a problem with the price or item. Wise parts specialists should say: "Why do you feel that way?" This approach politely tries to find out the customer's real objection. By explaining the features and benefits of the product, the customer may understand the price better. Parts specialists should understand different customer types and determine their needs. Customers may need to be convinced that a repair can and should be performed sooner rather than later if safety is involved.

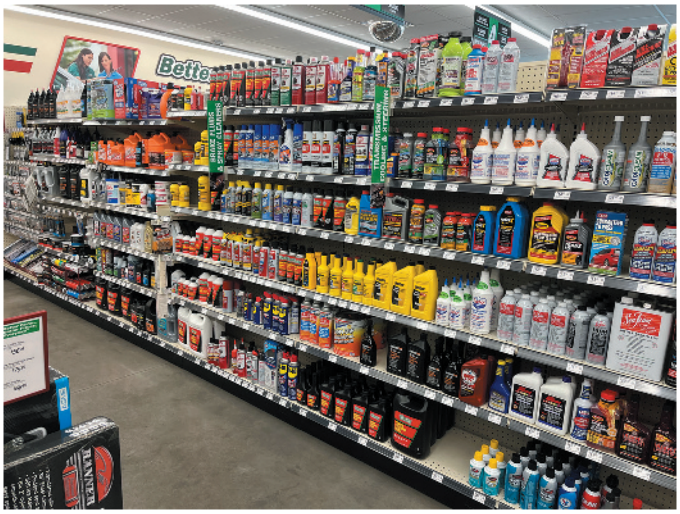
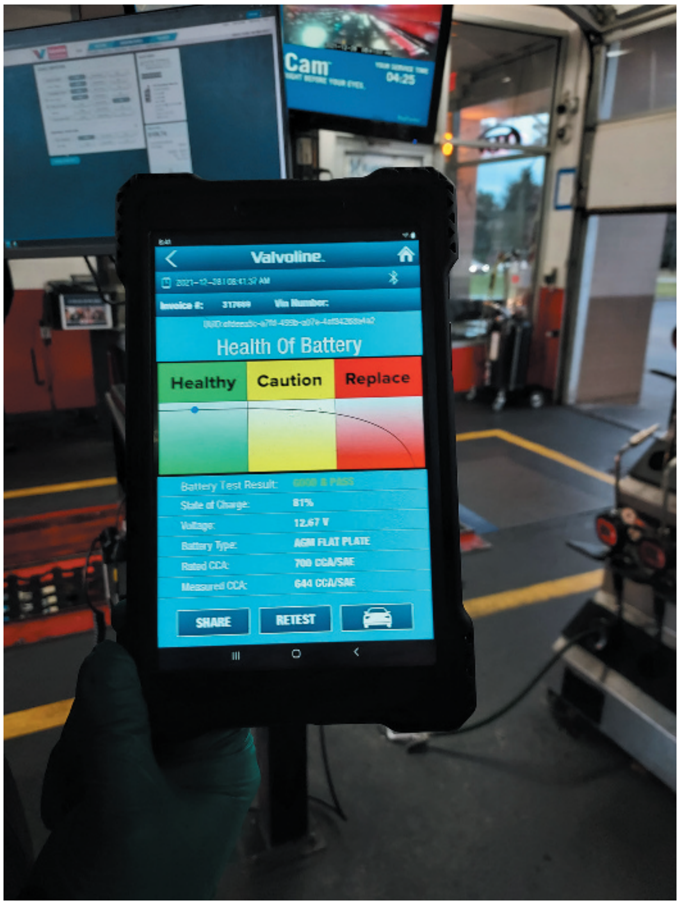


FIGURE 134–5 Products that are related are often arranged together so customers see related items while shopping.



Battery Test Result: GOOD & PASS
State of Charge: 81%
Voltage: 12.67 V
Battery Type: AGM FLAT PLATE
Rated CCA: 700 CCA/SAE
Measured CCA: 644 CCA/SAE

FIGURE 134–6 Many parts stores are able to test batteries for their retail customers.

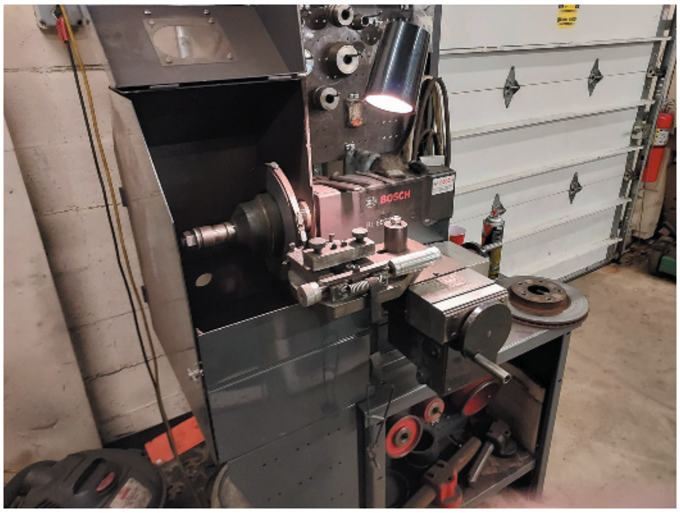


FIGURE 134–7 Many parts stores are also equipped to handle brake drum and rotor machining.

FREQUENTLY ASKED QUESTION

What Is Meant by "Upselling"?

Upselling refers to the attempt to increase sales above and beyond what the customer first wanted. For example, parts specialists could suggest that brake cleaner would also be helpful when they sell brake pads to a retail customer. Other examples of upselling include

- Recommending a funnel and gloves to a customer purchasing engine oil and an oil filter.
- Recommending a new accessory drive belt to a customer purchasing an alternator.
- Recommending a new battery or battery cable to a customer purchasing a new starter.
- Recommending microfiber cloths to a customer purchasing wax or polish.

Additional sales help the store be more profitable by increasing the total revenue of the store.

PROMOTING SALES AND STORE SERVICES Parts specialists should always promote sales and store services. For example, if a customer asks for brake pads, let the customer know that the store has a machine shop service that can machine the rotors. If a customer is purchasing tires, suggest mounting, balancing, and wheel alignment service. If the store does not do this, recommend a reputable shop that can. ● **SEE FIGURES 134–6 AND 134–7.**

CLOSING THE SALE Closing the sale means getting a commitment from the customer. Parts specialists need to overcome objections customers may have to purchasing at that time. For example, to help close a parts sale, a parts specialist could tell the customer:

- "This part has very good reliability."
- "This special price will end soon."
- "This is the best price."
- "This product has a longer warranty."

PRODUCT APPLICATION INFORMATION AND VEHICLE IDENTIFICATION

Proper selling techniques help customers leave the store with the part they need. To get the correct part, parts specialists must obtain the right vehicle information, including the following:

- year
- make
- model
- engine
- drive line

Sometimes, additional information such as the wheel or tire size, wheelbase, presence or absence of air conditioning, or the 17-character **vehicle identification number (VIN)** may be needed from customers when researching their parts needs. Having the right information will ensure the customer is sold the correct parts. ● **SEE FIGURE 134–8.**

Although every vehicle manufacturer assigns various letters or numbers within these 17 characters, there are some constants, including

- The first number or letter designates the country of origin.
- The model of the vehicle is commonly the fourth and/or fifth character.
- The eighth character is often the engine code.
- The tenth character represents the model year (MY) on all vehicles.

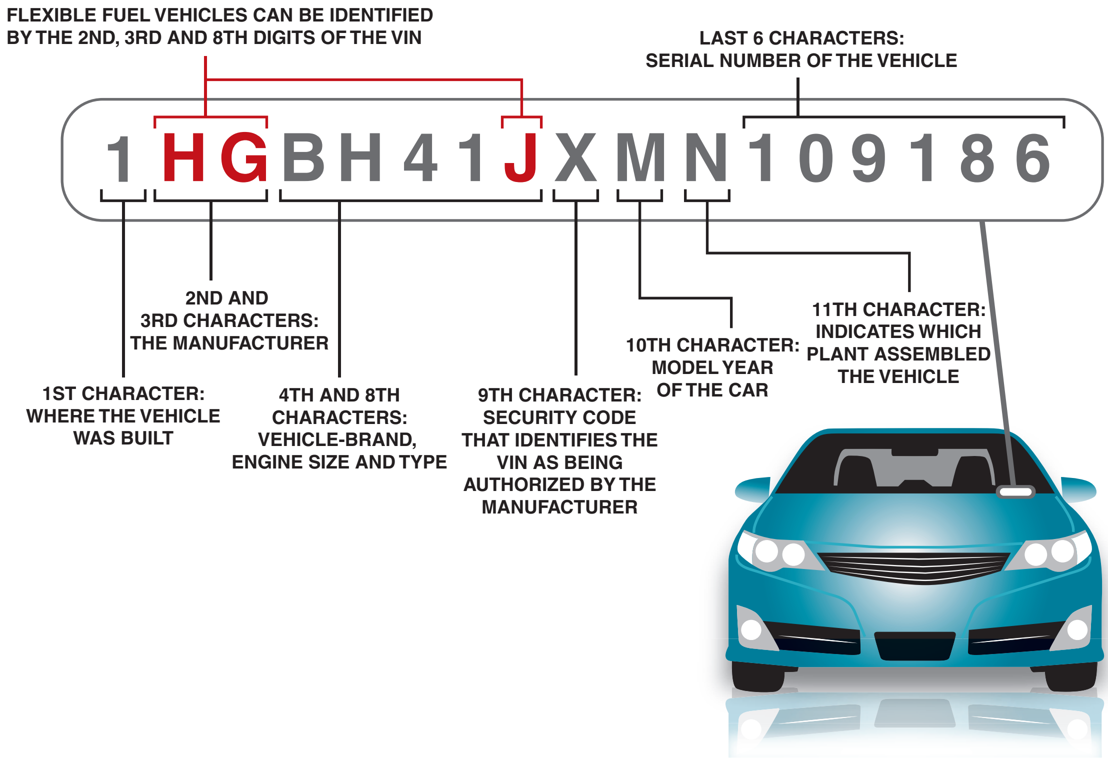

FLEXIBLE FUEL VEHICLES CAN BE IDENTIFIED BY THE 2ND, 3RD AND 8TH DIGITS OF THE VIN
LAST 6 CHARACTERS: SERIAL NUMBER OF THE VEHICLE
1 H G B H 4 1 J X M N 1 0 9 1 8 6
2ND AND 3RD CHARACTERS: THE MANUFACTURER
11TH CHARACTER: INDICATES WHICH PLANT ASSEMBLED THE VEHICLE
10TH CHARACTER: MODEL YEAR OF THE CAR
1ST CHARACTER: WHERE THE VEHICLE WAS BUILT
4TH AND 8TH CHARACTERS: VEHICLE-BRAND, ENGINE SIZE AND TYPE
9TH CHARACTER: SECURITY CODE THAT IDENTIFIES THE VIN AS BEING AUTHORIZED BY THE MANUFACTURER

FIGURE 134–8 Explanation of the VIN code located on the dash visible through the windshield and also on the driver's side door pillar.

Parts specialists should also know how to find the following additional information about the vehicle:

- Vehicle build date
- Vehicle-specific options
- Body style and chassis type
- Paint color codes

VEHICLE SYSTEMS KNOWLEDGE

Parts specialists should have a basic knowledge of vehicle systems and components. Review the chapters in ● **CHART 134–1** for more information.

CATALOG/INFORMATION SYSTEM SKILLS

CATALOGING SYSTEMS Parts specialists must be familiar with digital and/or online cataloging systems. **Subscription-based electronic information retrieval systems** serve both the OEM and the aftermarket. Program jobbers like NAPA, CARQUEST, AutoZone, and Advance Auto contract for the use of electronic parts systems to make information retrieval faster, easier, and up-to-date.

USING THE PROPER RESOURCE TO IDENTIFY PARTS To obtain the correct replacement part, often the owner or parts specialist must supply additional, specific information. For example, when parts are ordered for a differential assembly, the exact axle specification must be determined. OEMs use differentials from more than one axle manufacturer. Each OEM has its own individual ratios, parts, service procedures, and specifications.

Engine Mechanical Parts	Chapter 15
Cooling Systems	Chapters 17–18
Fuel Systems	Chapters 74–76
Ignition Systems	Chapters 68–69
Exhaust Systems	Chapters 21 and 136
Emission Control Systems	Chapters 80–82
Manual Transmissions	Chapters 121–122
Automatic Transmissions	Chapters 128–133
Drive Train Components	Chapters 123–126
Brakes	Chapters 93–107
Suspension, Steering, Wheels, and Tires	Chapters 108–118
Heating and Air-Conditioning Systems	Chapters 60–66
Electrical Systems	Chapters 36 and 41–42
Battery, Charging, and Starting Systems	Chapters 47–52
Miscellaneous	Chapters 8–9 and 14

CHART 134–1

Chapters containing information regarding vehicle systems information and parts identification.

INTERPRETING ADDITIONAL INFORMATION Parts specialists must refer to an online catalog to reference additional information, determine parts exceptions, or find alternative parts. A **footnote** is used to provide additional information for multiple applications. The footnotes themselves are important and should be referenced systematically in order to define parts.

Parts bulletins inform the parts store personnel about technical changes to a part. New vehicle information is found on parts bulletins. A **technical service bulletin (TSB)** alerts parts specialists of technical information regarding the part and any new model information. A **supersession bulletin** alerts parts specialists of a superseded part.

CONSULTING ADDITIONAL REFERENCE MATERIAL

Besides parts catalogs, other **reference materials** provide information to parts specialists. These include

- New item bulletins
- Product information bulletins, which contain specific information about a product, such as a defect or a unique method of installation
- Correction bulletins, which refer to catalog errors due to keystroke errors or incorrect parts numbers
- Parts specification guides, which help determine correct parts based on their dimensions, and electrical connections
- Illustrated part guides, which help parts specialists identify the correct replacement part if the original part number is not known or the old part is not available for inspection
- Cross-reference lists and supersession lists, which offer replacement part numbers if earlier issued parts are no longer available

IDENTIFYING TERMINOLOGY AND ABBREVIATIONS

The Society of Automotive Engineers (SAE) releases practices for nomenclature (parts names) in the industry. Parts specialists must be familiar with these and the OEM counterpart names if used. OEMs include aids for using these information-retrieval systems. These include an abbreviation list, which can be helpful since abbreviations can often have more than one meaning. For example:

- OD can mean overdrive or outside diameter.
- AC can mean alternating current or air conditioning.

INVENTORY MANAGEMENT

LOST SALES REPORTING

The main benefit of a **lost sales report** is to spot trends in the parts business. This type of report shows new part numbers that the store does not stock along with older part numbers that are increasingly in demand. Some part numbers have an instant demand, such as those found in some newer vehicles. Other parts grow in demand. The store owner or buyer must investigate not only part numbers that are selling, but also those that they do not stock.

VERIFYING INCOMING AND OUTGOING MERCHANDISE

A shipment order must be carefully picked, packaged, and documented. The packing list or slip is included with each shipment. This slip contains a detailed description of all parts included in the shipment. A separate packing list can be placed in each part of a shipment, but often a single all-inclusive list is packaged with or secured to the first part of a multiple-part shipment.

KNOWING REASONS FOR PHYSICAL INVENTORY

Physical inventory should be performed once a year, when all the stock is counted on the shelves and checked to determine what is actually in the store versus what the computer system shows. This helps keep the computer inventory current and can help provide customers with faster and more accurate parts service. Some parts stores perform inventory on one product line per month as part of a continuous process; others do a complete inventory every year. A physical inventory may show whether parts are missing from the store and whether some part numbers have been incorrectly invoiced.

IDENTIFYING AND REPORTING INVENTORY DISCREPANCIES

After a physical inventory has been completed, any discrepancies must be recorded and logged into the computer system. The cause of the discrepancy needs to be identified (e.g., wrong stock numbers, stolen products, transfers to other stores, incorrect part numbers, or quantities of parts picked off the shelf). Parts specialists must attempt to eliminate discrepancies by using an **inventory discrepancy form**. Such forms should be kept for future reference. When a discrepancy is discovered in the inventory, the records need to be changed.

STOCK ROTATION

Stock rotation means selling older stock ahead of newer stock. This can be done by placing older parts or chemicals in front on shelves where they are visible and where customers can easily select them. This **FIFO (first-in-first-out) stock rotation** prevents older stock from getting an aged appearance. ● **SEE FIGURE 134–9**.

OUTSIDE PURCHASES

An **outside purchase** is a non-stocking part that has been ordered from an outside supplier. A part that repeatedly appears on a lost sales report and needs to be special ordered or that appears on outside purchase reports should be considered as a candidate for normal stock.

CORE HANDLING

A **core charge** is a charge that is added when the customer buys a remanufactured component like a starter or alternator. The core charge is refunded to the customer when the old core is returned. To make sure that customers return the core, the store should charge the core charge to the customer upfront when the rebuilt component is purchased.

PRODUCT PACKAGING

Parts specialists need to be knowledgeable of how various products are packaged to bill and sell them. The term *EACH* is for a single item. A *CARTON* or *CASE* is several parts that are packaged together and sold as a unit. The term *PAIR*

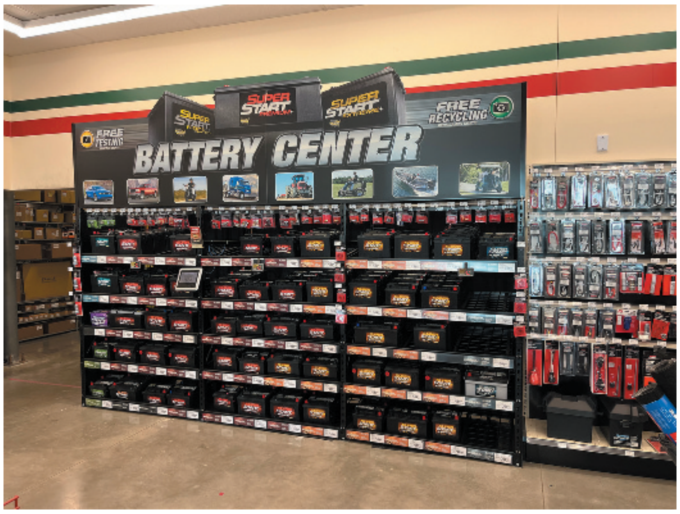


FIGURE 134–9 Batteries are one example of a product that shops need to keep up to date because batteries lose capacity over time. Most batteries have a date sticker, which can help parts specialists determine when batteries have been on the shelf unsold for a period of time.

is two of something. *SET* is two or more compatible items. A *KIT* is a package of parts used to rebuild a component. For example:

- Brake pads are sold as one unit in one box.
- Shocks are sold as individual units.
- Engine oil is shipped by the case but can be sold by the quart.

RETURNS AND EXCHANGE PARTS Freight charges may be added to emergency-order parts to cover the cost of special transportation to the store. Some parts have a restocking fee that is charged to the customer when a product is returned for a refund. Broken kits may not be acceptable for refund, or if a kit is accepted for refund, it must be checked to ensure the kit is resalable, with no missing or damaged parts. Exchange parts must be inspected for resalable condition.

CASE STUDY

The Case of the Overwhelmed Parts Store Manager

The manager of a locally owned and operated automotive parts store felt overwhelmed every day. It seemed as if there was always more to do. Plus, the store was hard to keep looking clean because many of the part cores were dirty and often leaked fluids. The parts manager saw an advertisement for an automotive expo nearby that offered both technical as well as management training sessions. The parts store manager signed up to attend the management classes. During one management session, the parts manager learned one important lesson:

> *"Nothing should be on the floor that does not have to be on the floor."*

Everything should be placed off the floor and on shelves or in cabinets, and only those items that are heavy, such as a brake lathe, should be on the floor. By keeping almost everything else off the floor, cleaning is made easier and the store appears neat and clean for a longer period of time.

After returning from the expo, the parts manager spent about a week making a place for everything and putting everything in its place. Now instead of placing cores on the floor or on the steps leading to the upper level of shelving, the parts manager purchased plastic bins and placed the cores in the plastic bins on a shelf. Larger cores, such as rack and pinion assemblies, were kept on a shelf and off the floor. After about a week, the parts manager finally had a handle on the store. By keeping almost everything off the floor, cleaning was a lot easier. Customers even noticed that the store always looked clean and neat.

Summary:

Complaint—The parts store always seemed to be messy and was hard to keep clean, making the parts manager feel overwhelmed.

Cause—Almost everything, especially cores, were on the floor of the parts store, making it difficult to clean and keep clean.

Correction—The parts store manager learned to keep the store looking clean by keeping almost everything off the floor.

INVENTORY TURNOVER Inventory turnover is crucial to maintain profitability. When inventory sits for too long, it can eventually become wasted inventory that is no longer salable, which hurts profitability. When ordering and stocking inventory, the product turnover and sale likelihood must be considered.

MERCHANDISING

POINT-OF-PURCHASE The best place for a display is in an open area near the front of the store. An attractive display will catch customers' eyes when they enter. A display should be large and appealing to the customer. This can be accomplished by building the display out of the product being sold with the intent of the customer picking the item from the display. Many times, the OEM of a product will send a display kit, which is assembled in the store. Often included with such kits are shelves, banners, signs, and handouts. Displays are also often built near the cash register as a **point of purchase (POP)** display, so that customers notice the product when they pay. ● **SEE FIGURE 134–10**.

PRICE DISPLAY PRODUCTS The practice of display pricing is to feature an item that is specially priced as a display in an open part of the store or department. Along with the display is a noticeable sign that calls out the special pricing. The product that is specially priced may remain in its assigned shelf position, but this additional display lets customers know the part is on sale. A customer is more likely to notice a display with a posted price than notice a specially priced item on the shelf in its normal position. This type of display and pricing is also used to introduce new items. A vendor may also choose to put up a display when certain items are overstocked. This helps promote the item and possibly leads to increased sales.

IDENTIFYING SEASONAL, IMPULSE, AND RELATED ITEMS A **seasonal item** is something that is stocked only at certain times of the year or throughout the entire year but not in large quantities. For example, dry gas is an alcohol-based product used to remove moisture from fuel lines and tanks on gasoline-fueled vehicles in the winter months. Batteries fail more often in the winter, so more of them should be kept in stock during the winter months. An **impulse item** is a product that the customer

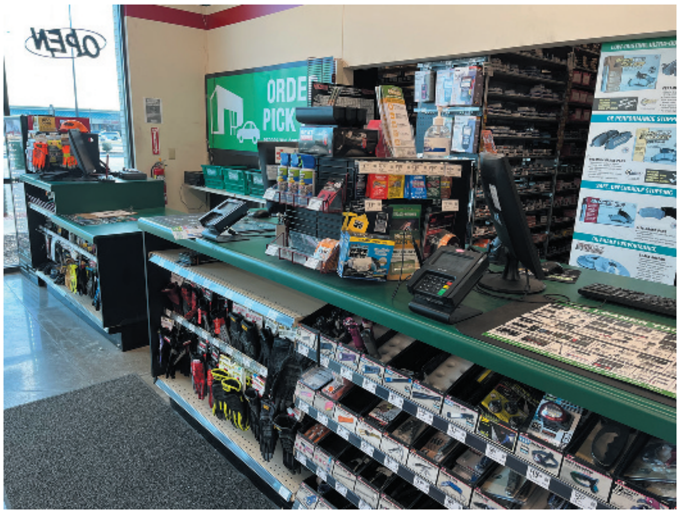


FIGURE 134–10 The point of sale is often another place where a potential sale can be made by displaying small and popular items near where customers pay.

TECH TIP

End Caps

An **end cap** is a rack or counter at the end of a store aisle used to display promotional or sale items. Studies repeatedly show that end caps sell better than in-aisle displays of the same product(s). Frequent rotation of products displayed on end caps rather than the regular shelves often makes economic sense because they grab customers' attention. ● **SEE FIGURE 134–11.**

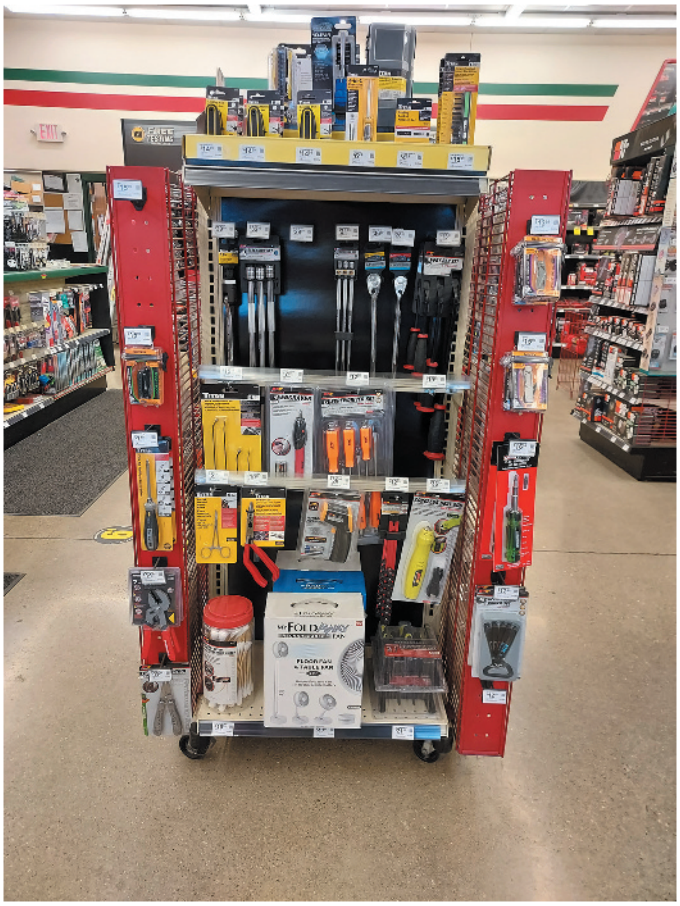


FIGURE 134–11 End caps are a highly visible location where select products are showcased.

FREQUENTLY ASKED QUESTION

What Is a Loss Leader?

A **loss leader** is a product that is sold for less than the usual or expected price in an effort to entice customers to visit the parts store to purchase the item. Once customers are in the store, they often purchase other items or services that are not highly discounted. It is these purchases of the higher-priced items that make selling a loss leader at a discount worth it to the store.

buys to fill a want rather than a need. Some examples of impulse items include

- speakers
- phone adapters and cables
- chrome accessories
- interior items like extra cup holders or seat covers

FREQUENTLY ASKED QUESTION

What Is included in the Parts Specialist (P2) Test?

Test Specifications and Task List Automobile Parts Specialist (Test P2) include

CONTENT AREA	NUMBER OF QUESTIONS IN THE TEST
A. General Operations	10 (13%)
B. Customer Relations and Sales Skills	11 (15%)
C. Vehicle Systems Knowledge	40 (53%)
D. Vehicle Identification	3 (4%)
E. Catalog and Information Systems Skills	6 (8%)
F. Inventory Management	3 (4%)
G. Merchandising	2 (3%)
Total = 75 Questions	100%

REVIEW QUESTIONS

1. How are discounts, selling prices, and percentages calculated?
2. What is the value of housekeeping skills?
3. What is a VIN code?
4. What reference materials are available to parts specialists?
5. How is a warranty processed?

CHAPTER QUIZ

1. A customer comes into the store while a parts specialist is on the telephone with another customer. Which of the following should the parts specialist do?
   - **a.** Finish with the telephone customer first.
   - **b.** Put the telephone customer on hold and wait on the walk-in customer.
   - **c.** Acknowledge the walk-in customer and finish with the telephone customer.
   - **d.** Finish with the telephone customer before greeting the walk-in customer.
2. To obtain the correct part, parts specialists should know how to locate what vehicle information?
   - **a.** Vehicle options
   - **b.** VIN
   - **c.** Build date
   - **d.** All of the above
3. Parts specialists should have a basic knowledge of which of the following?
   - **a.** Computer programming
   - **b.** Excel spreadsheets
   - **c.** Vehicle systems
   - **d.** Store shelving systems
4. Which of the following plays a role in creating a positive first impression for customers?
   - **a.** Clothing
   - **b.** Personal hygiene
   - **c.** Outward demeanor
   - **d.** All of the above
5. What is the purpose of an end cap?
   - **a.** To hide the end of the shelf
   - **b.** To showcase merchandise
   - **c.** To store unneeded parts
   - **d.** Any of the above
6. Parts catalogs are normally available in ___________ format.
   - **a.** digital
   - **b.** online
   - **c.** paper
   - **d.** Either a or b
7. Which of the following is NOT a topic of the parts specialist P2 ASE certification test?
   - **a.** Customer relations
   - **b.** Tire repair
   - **c.** Vehicle identification
   - **d.** Merchandising
8. Parts Specialist A says that there is no reason to use a lost sales report. Parts Specialist B says that many stores use a lost sales report to analyze parts that do not sell very well. Which specialist is correct?
   - **a.** Parts Specialist A only
   - **b.** Parts Specialist B only
   - **c.** Both Specialists A and B
   - **d.** Neither Specialist A nor B
9. Which of the following parts orders would be considered a special order?
   - **a.** An order placed once a week
   - **b.** An order for a part the store does not normally stock
   - **c.** An order for new customers only
   - **d.** An order intended only for store employees
10. To provide the most effective product sales promotion, where should the product display be placed?
    - **a.** Less than 3 feet high
    - **b.** Near the stocking area
    - **c.** Above eye level
    - **d.** Where it can be seen

Chapter

135

SERVICE CONSULTANT (C1)

LEARNING OBJECTIVES:

After studying this chapter, the reader should be able to:

- Discuss the communication and customer relations skills required of a service consultant.
- Discuss how to project a professional image as a service consultant.
- Describe how to greet customers.
- Discuss how to write work orders.
- Describe how to handle customer complaints.
- Explain effective service sales skills.
- Discuss automotive product knowledge needed for service consultants.

KEY TERMS:

Appointment 1730 • Appointment log 1730 • Communication 1722 • Customer satisfaction 1727 • Estimate 1729 • Ethics 1728 • Eye contact 1725 • Five basic needs 1728 • Listening 1722 • Nonverbal communications 1723 • Repair order log 1730 • Service history 1727 • Service pricing menu 1729 • Trust 1730 • Vehicle safety certification label 1731 • Voice inflection 1722 • Work order (repair order) 1725

COMMUNICATION AND CUSTOMER RELATIONS

Communication refers to the process of sending and receiving messages with other people. If the outcome of the communication is not what we intended, the communication was not effective. Communication is a vital skill for service consultants. Two basic types of communication include listening and talking.

LISTENING TO CUSTOMERS

Listening to customers is more difficult than it may seem. A person speaks at the rate of 150 to 200 words per minute, yet we talk privately to ourselves at the rate of 1,300 words per minute. The problem is that our brain may start talking to us before the other person has finished speaking. Good listening requires that we focus our attention on those speaking to us. The following are tips for being a good listener:

- Be attentive; concentrate and focus on the speaker.
- Show interest about what other people think and feel.
- Show understanding and demonstrate empathy.
- Balance input; do not dominate conversations.
- Do not finish the sentence for the other speaker or interrupt.
- Paraphrase what was said to ensure accurate understanding.
- Share positive comments.
- Make eye contact when appropriate.
- Control body language; try not to show impatience or disapproval.

When service consultants listen to customers it shows they care about and respect their questions and concerns. However, it takes practice and dedication to improve listening skills. Listening is a skill that must continuously be developed, but by focusing on customers and on what they are saying, misunderstandings are less likely.

TALKING TO CUSTOMERS

Voice inflection refers to the variation in pitch, timing, or loudness of the voice. Problems with voice inflection can be amplified by the telephone. To improve voice inflection, try the following:

- Record yourself.
- Ask friends for their honest assistance.
- Make a conscious effort to improve.
- Keep listening to yourself. It is easy to slip back into old habits. Excellent voice inflection takes practice!

FREQUENTLY ASKED QUESTION

What Is the Circle of Communication?

The *circle of communication* involves two individuals transmitting and receiving messages in an easy-to-understand way. ● **SEE FIGURE 135–1.**

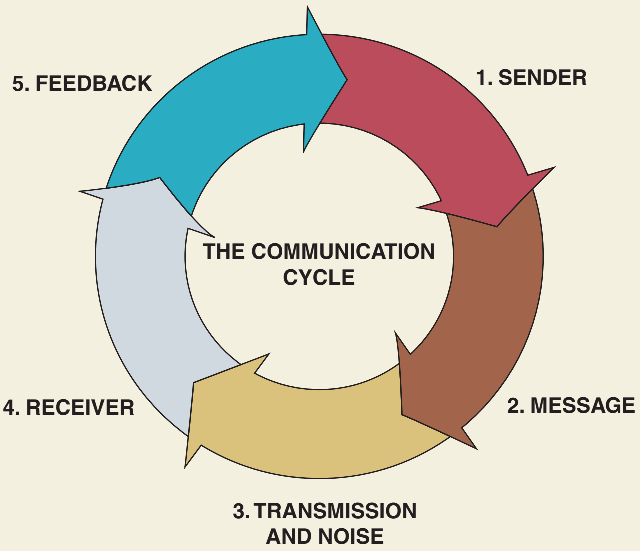


FIGURE 135–1 The circle of communication includes the sender transmitting a message and the receiver understanding it, as well as responding and providing feedback.

NONVERBAL COMMUNICATION **Nonverbal communication** includes such things as:

- Eye contact/lack of focus
- Gestures
- Body movements
- Mannerisms
- Posture

Having one's arms crossed or looking at other things rather than paying attention to what is being discussed can result in communication problems. Body language can override poor verbal communication, but there are generally no words that can override poor body language.

A customer's nonverbal communication may indicate that they are not interested in or do not believe or understand what is being said. If this type of nonverbal communication occurs, consider doing the following:

- Ask questions, which would require the customer to pay attention and express their lack of understanding, plus it demonstrates interest in what they think.
- Give the customer options rather than just ask them what they want, such as saying, "Would you prefer to have this work done all at the same time or spread out over several weeks?"

TELEPHONE COMMUNICATION A telephone call is often the first point of contact a customer has with the shop. A phone call therefore creates a first impression in customers' minds about the shop, its efficiency, and employees' communication skills, friendliness, and expertise. However, on a phone call, people interact without the visual feedback that helps us assign meaning to spoken messages. The following are some tips for using the telephone professionally:

1. Answer promptly. An answer after two rings or less conveys efficiency and a willingness to serve. The best way for service consultants to answer a business call is to simply state their name or department and ask, "How may I help you?"
2. Have paper and pens handy to take notes. Use a computer-based customer system for reference. Get the caller's name and number as soon as possible, and summarize the conversation briefly at the end—especially mentioning any commitments that need to be followed up on. ● **SEE FIGURE 135–2.**
3. Use proper titles for people when communicating. If in doubt about whether to use a customer's first name, call the person by the more formal Mr. or Ms. If they prefer that their first name is used, they will say so. It is better to be a little too formal than overly familiar.
4. Express appreciation regularly. Some companies use it as a greeting: "Thank you for calling Jones Buick." A "Thanks for calling" at the end of a conversation is also a strong customer satisfaction booster. It reassures customers that their calls are not an intrusion.
5. Keep the conversation businesslike. Nothing turns off a customer or caller like forgetting their name. If this happens, simply say, "I'm sorry, I didn't get your name, sir/ma'am. Would you please repeat it?"
6. Some service consultants find it helpful to list "Words to Use" and "Words to Avoid" on a card so that it is available for easy reference. ● **SEE CHART 135–1.**
7. Speak clearly and distinctly and avoid using speaker phone.
8. Do not allow "dead air." When dead air occurs, callers have no idea what is going on and are often annoyed if the silence persists.
9. Take messages cheerfully and accurately. Get customers' full names and correct spelling. If the name isn't clear, ask the caller to spell it. Also ensure their correct telephone number is recorded.
10. Smile. Smiling while speaking on the phone creates a friendly tone.

FIGURE 135–2 When answering the phone, be sure to have paper and pen or pencil handy.

WORDS TO USE	WORDS TO AVOID
Please	Can't
Yes	Never
May I	Don't tell me no
Consider this	You have to
Do	Don't
Let's negotiate	Not our policy
Will	Won't
Thank you	Not my job
Appreciate	Problem
Can	Sorry
Use customer's name	Slang (honey, etc.)
Would you like	We'll try
Opportunity	Haven't had time
Challenge	I don't know
Regret	Hang on for a second

CHART 135–1

A list of suggested words to use compared to a list of words to avoid when talking to customers.

11. When the phone rings, the first thing all associates should think is, "There's an opportunity on the phone—here we go!" It is time to smile, breathe, and project energy and enthusiasm with a heartfelt greeting.
12. Make sure the conversation is finished before hanging up. If the service consultant initiated the call, it is their responsibility to end it. Use conclusion words such as, "Thank you for the help." If the service consultant received the call, the caller should be finished before hanging up.
13. Don't let a telephone call interrupt an important live conversation. One concern of many customers is having their discussion with a service consultant interrupted by a phone call. If the service consultant must answer the phone call, ask the caller to hold. If they are not able to hold, call them back promptly.

VOICEMAIL Most shops use some form of voicemail system. Service consultants must be comfortable using such systems. When leaving a voicemail, do the following to increase customer responsiveness:

- Speak clearly and slowly. Service consultants should provide their name, the name of the company, the day and date, and the time.
- State the reason for the call.
- Suggest to the customer what the next step should be. Do they need to call back or wait for more information?
- Leave appropriate contact information and indicate when they can return the call. Provide contact information again, including a phone number.
- Close with a positive farewell.
- Remember that when leaving a voicemail, time may be short, so be as brief and to the point as possible.
- Customers may become frustrated with having to talk to "a machine" when they have a question or problem. When answering complaints about voicemail, do not dismiss the complaint as being unimportant. Ask questions to find out what really went wrong.

TECH TIP

How to Handle an Upset Customer

Here are some tips for handling upset customers:

STEP 1 Try to understand why they are upset. Three common causes of anger or frustration arise from people feeling that:

- They are not valued or important
- They are helpless
- "It" just is not fair

STEP 2 Try diffusing their anger or frustration with statements or questions such as the following:

- "Help me to understand." This encourages customers to explain why they are upset. Do not try to defend or argue with their perceptions—they know what they feel, even if it does not make a lot of sense.
- Express empathy by saying, "I can understand feeling that way." Do not say "I know exactly what you mean," because this may not be true. Instead, convey an idea of what they might be feeling.
- Ask, "What would be a good solution from your point of view?" This begins to shift the conversation away from the venting of emotion toward solution seeking.
- Always ask, "Is this a convenient time to talk?" If it really is not a good time, arrange another time to talk that would be more convenient. Then arrange a callback.

EMAIL/TEXT The ability to communicate with customers is one of the most critical aspects of the service business. Other than direct contact, communication can also be by email or text message. Ask the customer which method they prefer. Many prefer the quick and easy text message, whereas others prefer talking on the phone.

TECH TIP

Email Etiquette

Email etiquette includes the following:

- Double check grammar, spelling, and punctuation
- Avoid long and detailed emails. If an email conversation has exceeded two emails on both sides already, call that person instead.
- Writing in a very friendly manner can come across as too casual, whereas a formal approach can seem too impersonal. Try to write as if addressing a close business contact.
- Reply to emails from others promptly.

CASE STUDY

Telling the Customer It Will Be Ready in an Hour

A customer called to check on the status of their vehicle in the shop for a timing belt replacement. The service consultant checked with the technician and found out that the vehicle would be ready in about 15 minutes. However, the service technician told the service consultant to tell the customer that it would be ready in an hour. This way, the customer would be very happy when it was ready sooner rather than later than promised. Plus, the extra time allowed the technician plenty of time for a test drive to confirm that the repair was successfully completed.

Summary:

Complaint—Customer wanted their vehicle back as soon as possible.
Cause—The repair would be completed in less than 30 minutes, but the technician wanted to be sure so told the service consultant to tell the customer it would be ready in an hour.
Correction—The customer was notified that the repair was done before the hour was up, making the customer very happy.

PROJECTING A PROFESSIONAL IMAGE

Customers notice the personal appearance of service consultants and other team members as well as the appearance of the service center. Appearances often give customers a feeling about the care the service center will give to their vehicle. To convey a professional image, service consultants should be clean and neatly dressed.

When a service consultant projects a "whatever it takes" attitude and shows interest in solving the customer's needs, the customer will be more at ease and be more receptive to the service consultant's recommendations and suggestions. Try to keep the conversation on the subject, ask questions, and listen to let the customer know that the shop cares about them and their vehicle concerns.

NOTE: When all team members are committed to a set of common goals, they can contribute in positive ways to the success of the team. Customer service has a direct impact on the ability of employers to hire employees, provide wages, and offer promotions. In fact, vehicle manufacturers place great importance on the customer satisfaction index rating at their dealerships.

GREETING CUSTOMERS

Follow these steps when greeting customers:

1. Recognize the customer's presence by smiling and cheerfully saying "Hello," even when the service center is very busy. Smiling helps customers relax and feel more comfortable. Remember, they are in an unfamiliar area, one that they may view as being a negative place to visit. If customers are recognized and made to feel comfortable, they are more likely to be patient and wait until they can be helped.
2. Make **eye contact** with customers. In American culture, eye contact conveys sincerity and interest. Avoiding eye contact may suggest a lack of concern or lack of honesty. Customers may perceive that a customer service provider is not interested in what they are saying if they do not periodically make eye contact with them.

NOTE: When dealing with people from other cultures, customer service providers should be aware of cultural differences. In many other cultures, avoiding eye contact is a sign of respect. Be sensitive to others, but use eye contact whenever possible.

3. Service consultants should introduce themselves and state their position at the shop or dealership. Explain what will be happening and the steps that will occur, so the customer is aware of what to expect. For example, the customer needs to know that an accurate estimate may not be possible until a diagnostic procedure has been performed. Let customers know that the shop will contact them after diagnostic procedures have been performed to inform them of the results plus any other additional information.
4. Mention and repeat each step so the customer is assured that the shop is doing exactly what it said would be done. Customers do not like surprises, and while the news is often not good news, keeping customers informed is the best way to avoid misunderstandings.

Customers may be nervous when entering a shop or any other business where they know they may have to spend a great deal of money. Being professional at all times helps customers know that they are in good hands. Ask if they understand what will be done to their vehicle, try to answer all their questions accurately, and avoid using slang terms that may be misunderstood.

WRITING WORK ORDERS

PRIMARY JOB The primary job of a service consultant is to write an effective and accurate **work order** (also called a **repair order**) with repair/service authorization, warranty repair, and customer follow-up. Most dealerships and shops use an electronic repair order system. The process may differ from shop to shop. Some considerations include

- If this is a new client or a new vehicle, missing information may need to be gathered.
- If this is an existing customer (i.e., one that is already in the database), verify the customer information and update it if needed.
- It is very important to capture the customer concern exactly the way the customer states it. For example, if the customer states that their vehicle runs rough, shakes, and sputters when they give it gas from a stop, we know there is an engine running problem. So, the service consultant would enter "Engine Diagnostic" and then the exact customer statement. Determine whether it is a predetermined service such as a brake inspection or tire rotation.

FREQUENTLY ASKED QUESTION

What Is the Purpose of the Pre-Service Inspection?

The service consultant, or another designated person, should perform a quick visual inspection of the vehicle before service work is performed to check for any preexisting body damage or other faults. Any issues found should be brought to the attention of the customer and noted on the work order. If, for example, worn or damaged tires are found, it may be time to recommend that they be replaced during this service visit. The primary reason for the pre-service inspection is to protect the shop from claims of damage that were not caused when the vehicle was under the control of the shop. Many shops have installed cameras to record all views of the vehicle, making a physical inspection unnecessary.

The work order includes:

- Customer details such as name and address
- Vehicle make, model, and year
- Vehicle identification number (VIN)
- Odometer reading
- Date
- Customer concern information
- Cause of the problem(s)
- Correction for the problem(s)
- Hours of labor
- Parts used for the repair

The repair order should always include all of the information pertaining to the customer, vehicle, and cost of repair. The most important part is the VIN. There may be many white Chevrolets, but there is only one vehicle that matches a particular VIN. Repair orders are legal documents that can be used as evidence in the event of a lawsuit. Make sure the information is complete and accurate when filling out a repair order and store it in a safe place or electronically on a secure computer network.

TECH TIP

Listen to the Entire Story

It is important to allow the customer to explain the problem or concern even if it involves a long and drawn-out story. Customers often provide important clues about the problem if the technician or the service advisor is carefully listening. For example, the customer could say that during the previous day before the problem started that the "kid next door slammed the driver's door shut." This one clue could be the root cause of a problem that otherwise would be very difficult to locate. Try to avoid talking or adding to what the customer is saying, no matter how difficult that may be.

DETERMINE THE CUSTOMER'S PRIME CONCERN The service consultant needs to know the customer's main concern for their vehicle on this visit to the shop. To help determined this, ask questions such as:

- What is your main concern?
- Why are you here today?
- What can we do to help?
- When does the problem occur?
- How often does it occur?
- What does it sound like?
- What does it feel like?

Follow with more focused questions that help zero in on the customer concern. These questions could provide additional information such as what type of road the vehicle was being driven on when the problem occurred or whether the vehicle was towing something when the problem happened. The purpose of these additional questions is to gather as much information as possible for the technician so that the root cause can be found and corrected.

CONFIRM WHAT IS EXPECTED When speaking with customers, do not use unnecessary technical jargon. When discussing issues with customers, do the following:

- Speak clearly and concisely.
- Always start with a diagnosis to confirm the fault.
- List the procedures that should be followed according to the online service information to pinpoint the root cause followed by the service procedure.
- State that the repair will be confirmed to assure that the original concern has been addressed.

DOCUMENT THE WORK ORDER The complaint or concern is why the customer brought the vehicle in for service. The service consultant enters the technician's diagnosis on the work order based on the concern. To properly verify the concern:

- Make sure the customer's complaint and the service writer's repair order description are understood before starting work.
- Make sure the correct operation of the system is understood by the customer or the service consultant.
- Check the online service information to verify all aspects of normal system operation.
- Once the repair is complete, provide a short, concise statement about the cause of the concern and the correction or repair necessary to solve the customer's original concern or complaint. ● **SEE FIGURE 135–3.**

THE THREE Cs The three "Cs" are Concern, Cause, and Correction. Remember that each of these sections needs to be written up as concisely and completely as possible. For example:

- **Concern:** The vehicle overheats within about 10 minutes of vehicle operation from a cold start, no matter whether it is hot or cold outside. The coolant is full and protected to −30°F. The engine was started and engine temperature was monitored with a temperature gun. The temperature exceeded the specified 195°F thermostat opening temperature and still did not open at 205°F.

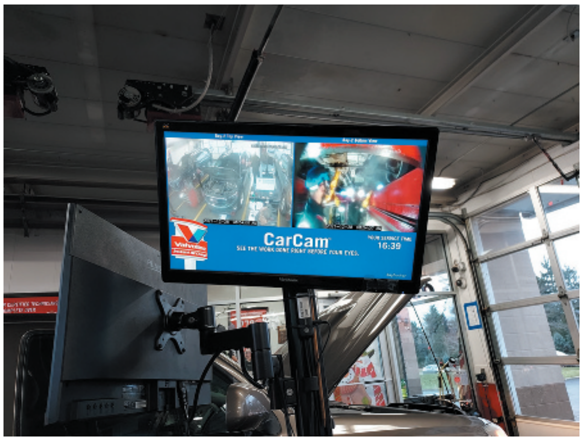


FIGURE 135–3 Some shops are equipped with cameras that show the work being done so customers can view their vehicle while service is being performed. Some shops are equipped with glass between the waiting area and the service area for the same reason.

- **Cause:** Thermostat faulty, not opening at specified temperature. Removed, no external damage noted.
- **Correction:** Replaced the thermostat with a new thermostat. Using a scanning tool, retested and determined that thermostat starts to open at 205°F, which is within specifications.

VEHICLE SERVICE HISTORY Good customer relations require knowing the **service history** of the vehicle. Having service history information available allows the service consultant to track previous service work and to recommend future maintenance. This helps avoid misunderstandings that can occur, such as the request from a customer for an alignment when the actual problem is a vibration that an alignment may not correct. Therefore, be sure that the customer is aware that the shop will try to fix the concern rather than selling parts or service procedures.

SCHEDULED MAINTENANCE NEEDS After reviewing the vehicle service history, the service consultant can suggest any needed maintenance. Multipoint inspections cover many vehicle systems and should be completed at regular intervals. What is inspected and the inspection results should be documented on the work order or on a separate inspection checklist.

CUSTOMER LOUNGE AREA Show the customer a comfortable location where they can wait for the diagnosis or service. Offer the customer a snack or beverage while they wait. The furnishings and cleanliness of the client reception area should be constantly monitored. Often, these areas become cluttered and are not noticed by those working in the area. Try to look at service areas as customers would if they were seeing the area for the first time.

ALTERNATIVE TRANSPORTATION OPTIONS A service consultant may need to offer alternative transportation options to the customer. Car rental sources are often found near repair shops and dealers. Many of these businesses can pick up the customer from the shop. Some shops provide substitute transportation or pay the rental depending on the situation. A free loaner vehicle may be provided under some circumstances involving a warranty repair, liability, or other special consideration. Many shops and dealers provide shuttle service for customers. When shuttling a customer, the following should be adhered to:

- Radios should be off or light music/news stations should be on. Always ask clients what they would like to listen to.
- The climate-control settings should be set to make clients comfortable; again ask clients what they would prefer.
- Ask whether they need to make any special stops while on the way to their destination.

HANDLING CUSTOMER COMPLAINTS

CUSTOMER SATISFACTION **Customer satisfaction** is defined as the customer's overall feeling of satisfaction with an interaction with an automotive service and repair facility. Customer satisfaction recognizes the difference between customer *expectations* and customer *perceptions*. Satisfaction may develop quickly or may be refined over time. Customers have many concerns, and the task of the service consultant is to reduce the stress of vehicle service and to create a pleasant customer experience, while providing current information and helping to solve customers' vehicle repair concerns.

EXAMPLES OF CUSTOMER SERVICE Customer service may involve the following:

1. Calling the customer by name
2. On-time delivery of repaired vehicles
3. Courtesy
4. Enthusiasm
5. Demonstrating care for the customer
6. Excellent follow-up
7. Empathy in handling customer complaints and questions
8. Well-explained repairs
9. Suggesting a less expensive option

CUSTOMER NEEDS Every customer has different needs. While what the customer wants is frequently hard to identify and may

FREQUENTLY ASKED QUESTION

What Is a Customer Satisfaction Survey?

A customer satisfaction survey is a study of customers' perceived satisfaction with a product or service. A completed survey provides answers for a list of questions that the company has concerning its products or services. A survey can also help determine inactive leads. The general purpose of customer satisfaction surveys is to assess how satisfied customers are with different aspects of the product/service. Identifying unhappy customers is as important as identifying extremely happy ones (i.e., potential advocates).

occasionally be unrealistic, all customers have the following **five basic needs**:

- **Service.** Customers expect the service they think is appropriate for the level of purchase they are making. A small, spontaneous purchase may have a smaller service need than a large purchase that has been carefully planned and researched. Exceeding customers' expectations, such as under-promising and over-delivering, is beneficial for businesses as it often results in repeat sales and free word-of-mouth advertising.
- **Price.** People and businesses want to use their financial resources as efficiently as possible. Many products previously considered unique are now considered commodities. This makes the component price even more important to customers.
- **Quality.** Customers want the products they purchase to be durable and functional until they decide to replace them. This requirement of quality mandates that manufacturers and distributors produce products that live up to customers' expectations of durability. Customers are much less likely to question price if they are doing business with a company that has a reputation for producing high-quality products.
- **Action.** Customers need action when a problem or question arises. Customers like to think that they are an important priority and that when a need or question arises, someone will be ready and waiting to help them.
- **Appreciation.** Customers need to know that the shop appreciates their business. Service consultants can convey this appreciation in many ways. Saying "thank you" to the customer through their words and actions is a good starting point. Additionally, letting them know their business is appreciated conveys a positive message.

EXCEEDING CUSTOMERS' EXPECTATIONS To begin attempting to exceed customers' expectations, try the following:

- Become familiar with customers. Get to know who they are and why they do business at the shop. Find out their likes and dislikes.
- Ask customers what their expectations are. Find out what they see as the benefit of doing business at the shop.
- Tell customers what they can expect. Convey to customers a commitment to them.
- Live up to their expectations. Follow through by accomplishing what was promised.
- Always deliver a consistent service. Customers like to know that they will have the same positive experience every time they interact with the shop.

One important key to exceeding customers' expectations is to remember that expectations are always changing.

ETHICS IN CUSTOMER SERVICE Most individuals periodically face ethically challenging situations. **Ethics** are a set of principles that govern the conduct of an individual or group. Sometimes ethical decisions are easy to recognize and are perceived as popular choices of behavior by the people around us. At other times, the spectrum of potential choices falls into gray areas in which the "right" or "wrong" course of action is difficult or nearly impossible to identify.

There are really no shortcuts when it comes to telling the truth and determining an appropriate course of action. Individuals in business must be seen by those around them as honest or they will not succeed for long. The bottom line in decision making is that individuals must face the consequences of their decisions—good or bad. When faced with an ethically challenging situation, ask the following questions:

- Is it legal?
- Is it fair?
- How do I feel about it?
- Would the court of public opinion find my behavior incorrect?
- Am I fearful of what those I trust would say about my actions?

The above questions can be quite revealing when attempting to choose an ethical course of action. This is not to suggest that ethically challenging situations are easily resolved. Analyzing a situation may make the appropriate decision easier to identify.

One final consideration regarding ethical behavior is that it is not always popular to do the right thing. Maintaining individual integrity and an organization's reputation will better enable all involved to choose the most appropriate course of action.

WHY ARE SOME CUSTOMERS DIFFICULT? Customers may be perceived as challenging for reasons such as the following:

- They are visibly upset about something.
- The facility did not repair their vehicle correctly.
- They do not have expertise regarding the specific product or situation.
- They are quiet and noncommunicative.
- They are impatient.
- They have difficulty making decisions.

Every customer should be the most important person at the moment. They come into our shops with past experiences, perceptions, expectations, frustrations, the stresses of daily life, and the desire for us to show that we value them as customers. Customer service providers also bring their own unique backgrounds to an interaction. The difference between customers and customer service providers is that the customer service provider is responsible for building the bridge of communication.

AVOIDING DIFFICULT CUSTOMER INTERACTIONS The following are some tips for avoiding difficult customer interactions:

1. Respect the customer's time. Stay focused on the customer.
2. Do not impose bad or negative mood on anyone else.
3. Recognize regular customers with a smile and try to learn their names. It is not too much for regular customers to expect they would be remembered from one interaction to another. Giving someone a look of recognition is a great place to start. Try for one week to call everyone by name, including coworkers. This may increase the morale in the work area. People usually choose to do business with people who they like.
4. Avoid destructive remarks. Jokes that seem creative and "smart" may seem inappropriate to customers. In the long run, destructive remarks are just that—destructive.
5. Go the extra mile for customers. It is refreshing to do business with someone who offers to do a little something extra and carries through a project to the end.

FREQUENTLY ASKED QUESTION

What Should Service Consultants Do When They Are Wrong?

Customer service providers are only human and may make mistakes. When service consultants believe that they have made a mistake, they should try the following:

- Examine the behavior and words. Try to look at the situation from the customer's point of view.
- Observe the customer's reaction. Is the customer visibly upset? Does the customer seem surprised or hurt by the service consultant's actions?
- Admit the mistake. Regardless of whether it was an error in information or judgment, it is always best to acknowledge it.
- Apologize for the actions or error. Express regret about the problem to the customer, but do not make excuses for why it occurred.
- Find a solution and implement it. The most effective way to undo the improper treatment of a customer is to create an effective solution and to put it into effect as quickly as possible.

HANDLING DIFFICULT CUSTOMERS When confronted with a difficult customer, consider the following:

1. **Listen.** Allow customers to express their concerns or to share their side of the story.
2. **Try not to take it personally.** Remember that the customer is upset at the situation, not at the service consultant personally.
3. **Ask questions.** Seek clarification of the problem. Determine the variables involved.
4. **Show empathy.** Attempt to understand what the customer is experiencing.
5. **Solve the problem.** Determine the most appropriate solution to the situation. Use creativity and follow company policies while seeking to create a positive outcome for both the customer and the business.
6. **Follow up.** Restate what has been decided and how the situation is being resolved. Ask the customer whether they have any further questions.
7. **End on a positive note.** Thank the customer for their understanding. Bid them farewell in an enthusiastic manner so that they remember the professional manner used to resolve their problem. Customers are more likely to remember the end of an interaction than the beginning.

SALES SKILLS

ESTIMATES The service consultant is the first person to discuss concerns customers have about their vehicle and is ultimately responsible for writing up the repair order and providing the initial estimate of repair. An **estimate** is the suggested service cost to the customer, which is determined by the service consultant. It is the estimate of what the expected service costs will be. Labor time guides list how much time will be involved in performing a standard or warranty-related service or repair. Flat-rate servicing costs are usually derived from a labor time guide. The writeup is the same as a repair order. The service estimate can be part of the repair order or a separate document.

SERVICE PRICING A **service pricing menu** provides a quick reference for service consultants to identify and accurately quote the cost for the most common repairs that the shop performs. It is a valuable tool to help service personnel quickly and accurately provide estimates for common light, medium, and heavy repairs. Preventive maintenance is one of the easiest items to sell to every customer because it is based on the manufacturer's scheduled vehicle maintenance.

NOTE: The service consultant should sell only what is needed. Be sure that the repairs and services recommended are based on sound practices.

COST OF REPAIR AND APPROVAL All work must be documented on the work order. It is important to have the customer's approval before working on the vehicle. This approval must be in writing or verbal approval if the telephone call is documented with the telephone number and time when the call was made. The customer could refuse to pay for unapproved repairs. In some areas, customers legally do not have to pay if they did not sign the repair order first.

These are very important steps, and if done correctly, they help build customer loyalty and avoid possible misunderstandings when the work has been completed.

SHOP MANAGEMENT SOFTWARE Shop management software allows shop owners and service consultants to evaluate work, prepare estimates, sell and buy vehicle parts, and control the whole operation using one integrated computer system. Garage software is convenient for all businesses as it offers multiple functionalities. It includes service assessment and vehicle tracking and generates point-of-sale invoices.

SUBLET PROCEDURES A sublet repair is a repair (or a part of a repair) performed by another person or company outside the shop. For example, an engine needing repair that also has a defective or leaking radiator would be repaired by the original repair facility, but the radiator may be sent to a specialty radiator repair shop. The radiator repair cost is entered on the work order as a sublet repair. Radio repair, radiator repair, and glass replacement are all examples of sublet repairs.

TECH TIP

Separate "Needed" from "Suggested"

The service consultant should always separate items into

- Service that is required because the part or system no longer meets factory specifications.
- Service that is suggested because those items are close to the end of their service life or are in need of replacement based on the extensive and informed experience of the technician.

ESTABLISH COMPLETION EXPECTATIONS The **appointment** is the best time to discuss when the customer will get their vehicle back. The appointment is the earliest point in the repair process where the customer expectations can be addressed. Appointments provide customer preferential treatment, effective shop management, qualified technician availability, bay space availability, proper equipment available, permits pre-ordering of parts, determine client's initial concerns, and allows more time for new customers.

The **appointment log** is created by the service consultant to record all the vehicles that are scheduled to come in on a particular day. There are now computer-generated logging and scheduling systems.

MANAGE AFTER-HOURS VEHICLES A drop off box with a write-up envelope can manage after-hours vehicle drop offs. The customer fills out a form and places the keys and form in an envelope and drops it in the opening of a locked box. Extending the business hours is another way to accommodate customers who work late.

MONITOR REPAIR/SERVICE PROGRESS A **repair order log** (or daily work control log) is used to track the repair and completion process or the lead time for each repair order. It provides an overview of all the vehicles that are in the shop on a given day.

DOCUMENT SERVICES PERFORMED/DECLINED An inspection form is a useful guide when conducting a vehicle inspection. By following the checklist, all the components can be tested in a systematic way to ensure that they are operational or serviceable. It also becomes a record for the shop to bring a customer's attention to needed service, or if a customer declines repairs, shows that the shop made the customer aware of them.

TRUST Once the service is completed, the results should be reviewed with the customer to confirm that the repairs have successfully resolved the customer's concerns and that the vehicle has been returned to the condition in which it was received. It is important to accurately communicate with the customer so they have a decent understanding of the service that was completed and so that any remaining questions are answered. This conversation should be based on **trust** and the relationship built with the customer during their experience with the shop. The service consultant must make sure the vehicle service was completed in a timely manner to maintain satisfied customers.

Having a conversation with the customer also gives the customer an opportunity to add something to the project that they may have forgotten. The added items may include those that were suggested at the time the work order was written. Once the original job has been completed, the customer may wish to have the additional work done when the vehicle is already at the shop.

THANK YOU NOTE Place a business card in the customer's car with a written thank you on the back. This little item seems as if it would not be important to customers, but it helps personalize the vehicle repair. Instead of a faceless service technician, the business card and/or note makes the transaction a personal one and helps build customer loyalty.

PRODUCT KNOWLEDGE

VEHICLE SYSTEMS KNOWLEDGE The service consultant should have a basic knowledge of vehicle systems and components. There is too much to cover within this chapter, but this text has other chapters that contain that information. ● **CHART 135–2** lists the subject areas and the related chapters to study.

Engine Systems (Includes Computer Controls, Mechanical, Cooling, Fuel, Ignition, Exhaust, Emissions Control, and Starting/Charging)	Chapters 15, 17, 21, 47, 49, 51, 80–82
Drive Train Systems (Includes Computer Controls, Manual Transmission/Transaxles, Automatic Transmission/Transaxles, and Drive Train Components)	Chapters 121–126, 128
Chassis Systems (Includes Computer Controls, Frames, Brakes, ABS, Traction Control, Suspension, Steering, Wheels, Tires, and TPMS)	Chapters 93, 105, 107–109, 111
Body Systems (Includes Computer Controls, Body Components, Glass, Heating and Air Conditioning, Electrical, Restraint and Accessories)	Chapters 46, 56, 57, 60

CHART 135–2

Correlation chart for where vehicle system knowledge is found in this text.

SERVICES/MAINTENANCE INTERVALS Online service information provides a systematic procedure and identifies special tools, safety precautions, and specifications relevant to the maintenance task. Maintenance and lubrication information includes topics such as:

- Maintenance reminder reset procedures
- Specified oil and other lubricant specifications
- Chassis lubrication points
- Component location
- Tire rotation methods
- Periodic vehicle inspection services (items to check and time/mileage intervals)
- Maintenance item part numbers, such as oil and air filter numbers, and specifications, such as oil capacity and tire pressures

WARRANTY, SERVICE CONTRACTS, BULLETINS, AND CAMPAIGNS/RECALLS Service consultants need to be familiar with the warranty of a vehicle that has one to be able to answer any questions customers may have. All new vehicles are provided with a warranty document when the vehicle is delivered.

NOTE: No vehicle manufacturer provides warranty coverage for tires. Tires are only covered for defects by the tire manufacturer.

Some shops or dealers sell a service contact through an insurance company and documents are also issued by the seller. These contracts like Car Shield generally require preapproval of repairs.

Service campaigns and recalls are usually conducted by original equipment manufacturers (OEMs) when a safety issue is discovered with a particular vehicle. Recalls are costly because they may require the repair of an entire model or production run of vehicles. This could involve many thousands of vehicles. Depending on the nature of the problem, recalls can be mandatory and enforced by law, or OEMs may choose to voluntarily recall these vehicles.

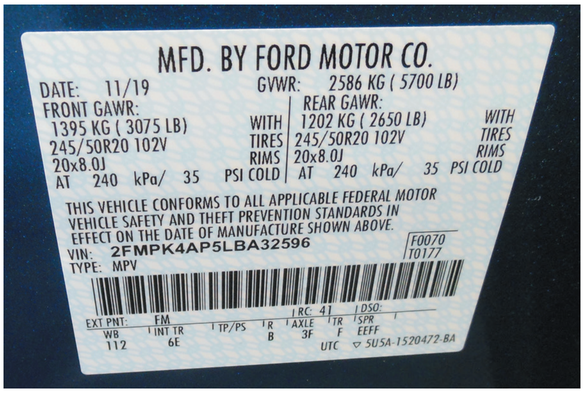
The service consultant should use the online service information to check for technical service bulletins for any concerns that enter the shop. Also check for recall campaigns or use the NHTSA website at https://www.nhtsa.gov/recalls by inputting the VIN.

The recall notice is sent to the customer and the OEM dealer. The service information indicates what campaigns are covered for that vehicle by VIN, but not the specific vehicle notice.

VEHICLE IDENTIFICATION Service work requires that the vehicle, including the engine and accessories, be properly identified. The most common identification is the make, model, and year of the vehicle. The VIN provides most of the information needed for identification.

Since 1981, all vehicle manufacturers have used a VIN that is 17 characters long. Although every vehicle manufacturer assigns various letters or numbers within these 17 characters, there are some constants, including

- The first number or letter designates the country of origin.
- The model of the vehicle is commonly the fourth and/or fifth character.



MFD. BY FORD MOTOR CO.
DATE: 11/19 GVWR: 2586 KG (5700 LB)
FRONT GAWR:
1395 KG (3075 LB) WITH TIRES RIMS
245/50R20 102V
20x8.0J
AT 240 kPa/ 35 PSI COLD
REAR GAWR:
1202 KG (2650 LB) WITH TIRES RIMS
245/50R20 102V
20x8.0J
AT 240 kPa/ 35 PSI COLD
THIS VEHICLE CONFORMS TO ALL APPLICABLE FEDERAL MOTOR VEHICLE SAFETY AND THEFT PREVENTION STANDARDS IN EFFECT ON THE DATE OF MANUFACTURE SHOWN ABOVE.
F0070
T0177
VIN: 2FMPK4AP5LBA32596
TYPE: MPV
EXT PNT: FM
WB 112
INT TR 6E
TP/PS
R B
RC: 41
AXLE 3F
TR F
DSO:
SPR EEFF
UTC
▽ 5U5A-1520472-BA

FIGURE 135–4 A typical vehicle safety certification label showing the front and rear gross axle weight rating (GAWR).

- The eighth character is often the engine code.
- The tenth character represents the model year (MY) on all vehicles.

A **vehicle safety certification label** is attached to the left side pillar post on the rearward-facing section of the left front door. This label shows the month and year of manufacture, the VIN, as well as the gross vehicle weight rating (GVWR), which is the maximum weight of a vehicle as specified by the OEM. The gross axle weight rating (GAWR) is the maximum weight that an axle can support and is usually followed by "FR" for front axle and "RR" for rear axle. ● **SEE FIGURE 135–4.**

REVIEW QUESTIONS

1. What are some effective communication skills?
2. What is an example of a professional image?
3. How does a service consultant handle a customer complaint?
4. What is found on an accurate repair order?
5. List some examples of nonverbal communications.

CHAPTER QUIZ

1. A service consultant receives a phone call from a customer. Which of these must the service consultant do before they hang up?
   - **a.** Answer all other calls
   - **b.** Make sure the customer was finished
   - **c.** Make sure they made their point
   - **d.** Pause for two seconds of dead air before hanging up
2. Two service consultants are discussing alternative transportation options for customers. Service Consultant A says that the shop should always provide alternate transportation for a customer under all circumstances. Service Consultant B says that many car dealers have vehicle rental companies nearby to help with transportation needs. Which service consultant is correct?
   - **a.** Service Consultant A only
   - **b.** Service Consultant B only
   - **c.** Both Consultants A and B
   - **d.** Neither Consultant A nor B
3. Which of these is a good reason for reviewing the vehicle service history?
   - **a.** It keeps the cost of repair low
   - **b.** It helps address concerns
   - **c.** It maximizes shop profits
   - **d.** To repeat the service
4. The performance of maintenance and service activities depends on the shop's ability to ______________.
   - **a.** read and interpret trouble codes from memory
   - **b.** interview vehicle owners with an open mind
   - **c.** research and apply technical information
   - **d.** quickly interpret schematics and parts diagrams
5. Service Consultant A says that appearance is the image we present to the public. Service Consultant B says that a first impression is not all that important if we use a smile. Which service consultant is correct?
   - **a.** Service Consultant A only
   - **b.** Service Consultant B only
   - **c.** Both Consultants A and B
   - **d.** Neither Consultant A nor B
6. Changes need to be made to a previously authorized work order. Service Consultant A says only the service manager must approve the changes. Service Consultant B says the customer needs to approve the changes. Which service consultant is correct?
   - **a.** Service Consultant A only
   - **b.** Service Consultant B only
   - **c.** Both Consultants A and B
   - **d.** Neither Consultant A nor B

7. A work order is also called a(n) _____________.

a. invoice
b. repair order
c. technical service bulletin
d. None of the above

8. All customers have basic “needs.” Which of these is NOT one of the needs listed in this chapter?

a. Service
b. Water
c. Price
d. Appreciation

9. The _____________ gives the country of origin and the vehicle model year.

a. VECI label
b. vehicle registration
c. VIN
d. Any of the above

10. Which of these is the best time to discuss when the customer will get their vehicle back?

a. During write-up
b. At the cashier
c. When making the appointment
d. During the quality assurance review

Chapter

136

EXHAUST SYSTEMS SPECIALIST (X1)

LEARNING OBJECTIVES:

After studying this chapter the reader should be able to:

- Discuss the purpose and function of an automotive exhaust system.
- Discuss the components of an automotive exhaust system.
- Describe exhaust system mounting hardware.
- Describe how to inspect the exhaust system.
- Discuss exhaust system repairs.
- Explain exhaust emission control systems.
- Discuss the exhaust system fabrication process.
- Discuss MIG welding.
- Discuss oxy-acetylene welding.
- Discuss flame types.

KEY TERMS:

Backpressure 1733 • Backfire 1743 • Carburizing flame 1743 • Catalytic converter 1734 • Clamps 1735 • Custom bending 1739 • Exhaust manifold 1733 • Flashback 1742 • Hangers 1735 • Heat shield 1735 • Metal inert gas (MIG) 1741 • Muffler 1735 • Neutral flame 1743 • Oxidizing flame 1743 • Pattern bending 1739 • Pipe adapter 1735 • Powertrain mounts 1738 • Program card 1739 • Resonator 1735 • Slip joint 1737 • Tap test 1734 • Tailpipe 1735 • Vehicle Emissions Control Information (VECI) 1738 • Weld pool 1741

EXHAUST SYSTEM

PURPOSE AND FUNCTION The job of the automotive exhaust systems is to rid the internal combustion engine (ICE) of spent gases (the gases are left over from the burning of the hydrocarbon fuel, with oxygen, and nitrogen). The ICE draws in the fresh air charge that is needed for combustion and uses the exhaust system to remove what has been spent. Exhaust gases must be removed with as little resistance as possible. The cylinders will not fill with the proper air charge if combustion gas pressure builds up in the exhaust system.

Backpressure is the resistance to exhaust gas flow in the system, which is often due to restrictions, such as exhaust pipe blockage, mufflers, catalytic converters, or resonators. Exhaust systems that do not remove exhaust gases efficiently may have unwanted backpressure.

EXHAUST SYSTEM COMPONENTS

EXHAUST MANIFOLD The **exhaust manifold** bolts directly to the cylinder head and mates with the cylinder head exhaust ports. Inline engines are equipped with a single exhaust manifold, while "V" design engines have one exhaust manifold for each cylinder head. ● **SEE FIGURE 136–1**.

EXHAUST MANIFOLD REMOVAL The exhaust manifold must be cool before being removed. Penetrating spray is often needed on the mounting fasteners to get the nuts or manifold bolts off of the cylinder head. Some vehicles have secondary air injection (SAI) tubes and a check valve that may have to be removed. Often

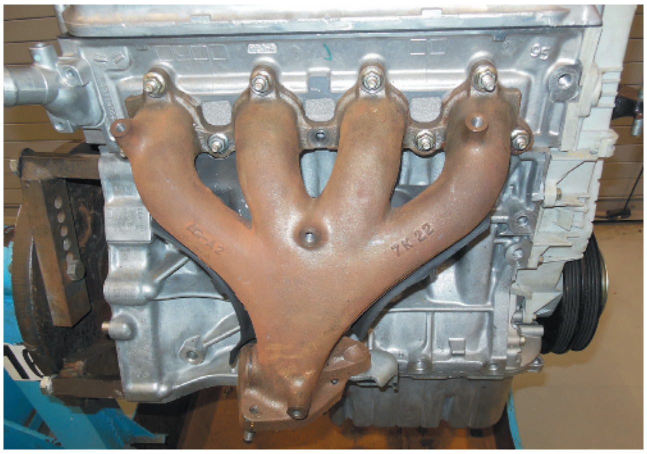


FIGURE 136–1 An exhaust manifold on a four-cylinder engine.

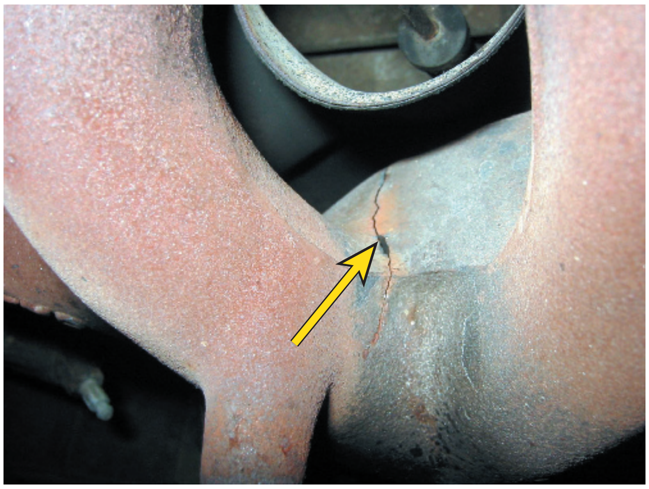


FIGURE 136–2 A cracked exhaust manifold is often hard to see because the manifold is covered by a heat shield.

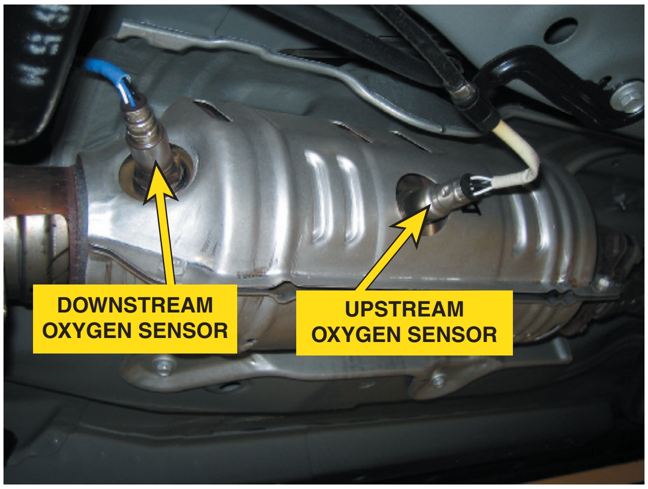


FIGURE 136–3 Upstream and downstream oxygen sensors are used to monitor the operation of the catalytic converter.

there will be tubing for the exhaust gas recirculation (EGR) that also needs to be removed.

EXHAUST MANIFOLD INSPECTION Carefully examine the exhaust manifold for cracks or other damage. ● **SEE FIGURE 136–2**.

Depending on the design of the manifold, some areas get hotter than others. Thoroughly clean off all dirt and old gasket material from the mating surface of the exhaust manifold. Check the cylinder head mating surface of the exhaust manifold using a straight edge and a feeler gauge and compare to the manufacturer specifications. If the mating surface of the exhaust manifold is warped or damaged, it may be necessary to resurface it or replace the exhaust manifold. Sometimes a gasket is available for these applications, which may take up for the warpage or damage. Also inspect the manifold studs for any corrosion or damage. Replace or repair the studs as needed.

CATALYTIC CONVERTER The **catalytic converter** converts harmful exhaust emissions into non-harmful compounds. The converter structure contains small amounts of rhodium, palladium, and platinum. When the converter is heated by the exhaust gasses, the three elements act as catalysts and convert the exhaust gases of hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) into harmless emissions such as water (H_2O), carbon dioxide (CO_2), and nitrogen (N_2). The catalytic converter can be clogged if an overly rich air fuel mixture overheats the converter and melts the substrate brick. The catalytic converter substrate or brick can melt or break into pieces if the engine over-fuels due to a misfire or defective oxygen sensor or air-fuel ratio (AFR) sensor.

The catalytic converter monitor of OBD II uses an upstream and downstream oxygen sensor to test catalyst efficiency. When the engine burns a lean air–fuel mixture, higher amounts of oxygen flow through the exhaust into the converter. The catalyst materials absorb this oxygen for the oxidation process, thereby removing it from the exhaust stream. If a converter cannot absorb enough oxygen, oxidation does not occur. The oxygen content after the converter is monitored by the downstream oxygen sensor. ● **SEE FIGURE 136–3**.

Some methods of testing the catalytic converter include the following:

- Use an infrared thermometer to determine whether a catalytic converter is working. The outlet temperature should be around 10% hotter than the inlet temperature. When the catalytic converter is not working, the inlet temperature is hotter than the outlet temperature.
- The **tap test** involves tapping on the catalytic converter with a rubber mallet. If the substrate inside the converter is broken, the converter will rattle.
- When the catalytic converter is being tested for contamination and operation, use a scan tool that can access mode 6 and look at the test results for each of the catalyst monitors. When using mode 6, research must be done for the specific codes that the manufacturer uses to identify each catalyst monitor, as well as the coding for the actual results.
- A digital storage oscilloscope (DSO) can be used to compare the upstream and downstream oxygen sensor patterns to determine whether the catalyst is working efficiently.

FREQUENTLY ASKED QUESTION

How Long Must a Shop Keep a Removed Catalytic Converter?

An aftermarket installer can only keep a catalytic converter after it has been removed from a vehicle for 15 days. In 1986, the U.S. Environmental Protection Agency (EPA) issued new guidelines for the construction, efficiency, and installation of aftermarket catalytic converters. EPA guidelines state that replacement converters may be installed only in the following situations:

1. Vehicles manufactured prior to 1996 must have more than 50,000 miles, and a legitimate need for replacement must be established and documented.
2. In cases of OBD II-equipped vehicles (1996 and later), the original equipment manufacturer's 8-year/80,000-mile warranty must have expired, and a legitimate need for replacement must be established and documented.
3. The vehicle is missing a converter.
4. A state or local inspection program has determined that the existing converter needs replacement.
5. Please note that federal law prohibits removal or replacement of a properly functioning original equipment catalytic converter.

MUFFLER The **muffler** is used in the exhaust stream to help quiet the sound of engine combustion. The muffler is a can or container with an inlet and an outlet pipe attached. Inside the muffler is a series of baffles designed to deflect the exhaust inside the muffler. The baffling or deflecting of the exhaust gases inside the muffler quiets the sound of combustion before the gases move out of the tailpipe.

In an exhaust system, pressure pulses create sound waves that travel down the exhaust pipe and into the muffler. The sound waves enter a reverse-flow muffler (most common type) through the center tube, bounce off the back of the muffler, and are reflected through a hole into the muffler main body. Then, they pass through more holes into another chamber and turn and exit the muffler outlet. Mufflers are designed so that the size of their chamber, tubes, and baffles allow the sound waves to cancel each other out, reducing engine noise. There are also straight-through mufflers that use perforations inside the muffler to break up the pulsations and glass insulation inside the muffler to absorb some of the pressure pulses. Straight-through mufflers are less restrictive and are used for performance-based engines. They do not reduce sound level as well as reverse-flow mufflers and may not be legal in your state.

NOTE: Some mufflers use a small hole in the lower rear part to drain accumulated water. About a gallon of water is produced in the form of steam for each gallon of gasoline burned. The water vapor often condenses on the cooler surfaces of the exhaust system unless the vehicle has been driven long enough to fully warm the muffler above the boiling point of water.

UNIVERSAL MUFFLER A universal muffler may require cutting existing pipes, pipe adapters, and new clamps and hangers. Using an original equipment manufacturer (OEM) exact fit replacement muffler eliminates the need for pipe adapters. A **pipe adapter** is used to connect nonstandard exhaust components to existing OEM components like the one used to connect the catalytic converter to the existing exhaust systems or connect one size pipe to another.

RESONATOR The **resonator** is similar to a muffler and is usually connected in the exhaust stream before the muffler. The resonator helps to quiet the sound of combustion before the exhaust gases reach the muffler.

TAILPIPE The **tailpipe** is the last pipe in the exhaust system; it carries the exhaust fumes out from under the vehicle and into the atmosphere.

EXHAUST SYSTEM MOUNTING HARDWARE

PURPOSE Mounting hardware is used to attach the exhaust system to the vehicle using brackets hangers and clamps.

CLAMPS **Clamps** are U-bolts that come in different sizes that correspond to the pipe diameter that secure the slip joint connections that are attached to some exhaust system components. Clamps may also be used to attach hangers in some applications. Ensure the inside pipe is fully inserted in the slip joint connection and the clamp is positioned around both pipes, but not too close to the edge of the outer pipe. Position the clamp so that the ends of the U-bolt will not contact other components or snag objects that may pass under the vehicle. Tighten the clamp only enough to secure the connection. Overtightening may distort the pipes, causing an exhaust leak.

HANGERS **Hangers** are O-ring or fabric devices that attach to brackets mounted on the underside of the vehicle to support the exhaust system. Some are welded to the exhaust system. Hangers can also be made of reinforced fabric that are bolted or clamp to the exhaust system. Hangers must be flexible enough to allow the exhaust system to expand as it gets hot and move with the torque of the engine. The hangers also isolate the vehicle from vibrations in the exhaust system. When installing exhaust system components, make sure to take the necessary steps to properly position them. Hangers should be used to support the exhaust system and not pull or force the exhaust system into position. Hangers that are used this way will be under constant stress and most likely break.

HEAT SHIELDS **Heat shields** are used to protect the underbody of the vehicle from excessive heat created by the exhaust system. Heat shields are usually riveted or screwed into the bottom of the vehicle floor pan above the exhaust system. ● **SEE FIGURE 136–4**.

EXHAUST SYSTEM INSPECTION

VISUAL INSPECTION Exhaust system inspection starts by raising and safely supporting the vehicle. Visually inspect the exhaust system for physical damage, holes, cracks, separated components, bulging muffler seams, and broken or missing clamps and hangers. A catalytic converter that appears bluish or brownish indicates that it has been overheated. Wiggle the exhaust system at various points to look for excessive movement caused by broken or cracked connections or broken or missing hangers. Tap on the exhaust system components with a mallet. An exhaust component in good condition will make a solid metallic sound, while a component that is worn out will have a dull sound. Rattling noises can be caused by loose heat shields, loose clamps, or an exhaust pipe interfering with another exhaust component. When tapping on the muffler or catalytic converter, listen for the sound of loose rust particles.

DIAGNOSING NOISE The first step in diagnosing a noise or exhaust leak under the vehicle is to discuss the noise with the vehicle owner because the owner or driver is the best resource to find out the nature of the noise. Exhaust system components can fail due to physical or chemical damage. The exhaust system is subject to damage and wear from dirt, stones, water, and other road hazards. It can also rot out from the inside from moisture or internal corrosion from poor combustion. Many vehicles are driven short distances, so the exhaust system never gets warm enough to evaporate the moisture. Whether caused by physical or chemical damage, the result is cracks, holes, or other damage to the exhaust system that can cause excessive noise and can allow harmful exhaust gases to enter the passenger compartment. Exhaust system damage can result in a restriction. A blockage can be caused by physical damage, such as a dented exhaust pipe, or clogged muffler, resonator, or catalytic converter. A restriction can also be caused by a collapsed inner exhaust pipe.

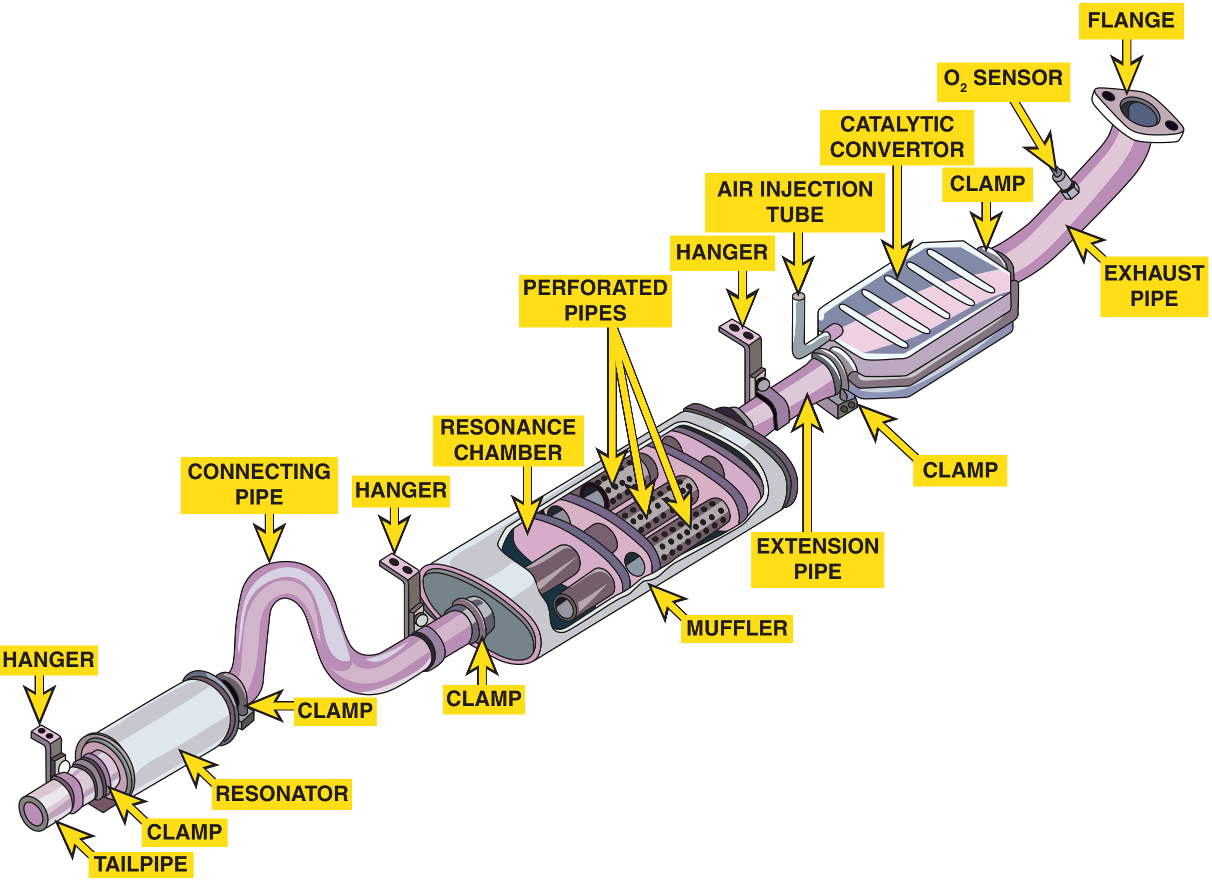


FIGURE 136–4 An exhaust system has many individual parts Each has its own purpose and function, and all must be working as designed.

WARNING

Engine exhaust contains carbon monoxide (CO), which can cause headache, nausea, and drowsiness, and if enough is inhaled, it can even result in unconsciousness and death. Any exhaust system damage that results in exhaust leakage must be repaired as soon as possible.

TECH TIP

A Rubber Mallet Is a Technician's Friend and Helper

Some vehicles use double wall tubing for exhaust pipes. The inside tube can collapse or rust inside the outer tube and cause a restriction, even when the outer tube looks good. Tap on the exhaust pipes with a rubber mallet and listen for rattling or rust breaking loose, which would indicate a problem inside the pipe. A restricted exhaust system can cause low power, poor fuel economy, and, if it is completely clogged, the engine may not run at all.

CHECKING FOR EXHAUST LEAKS Black streaks or soot on the outside of a component can be signs of leakage. If the source of exhaust leakage is not seen, start the vehicle and listen carefully for exhaust leaks at all joints and seals. Never overlook any welded connections because they can crack and leak as well. A small exhaust leak will make a hissing or popping noise. A significant exhaust leak can show up as a diagnostic trouble code (DTC) set for a poor-performing turbocharger or catalyst.

A tapping sound that may sound like valve train noise can be an exhaust leak at the exhaust manifold connection to the cylinder head. To check for leaks, perform the following steps:

STEP 1 Use a rag to block off the exhaust flow from the tailpipe. If the exhaust system is not leaking, pressure will build and force the rag out of the pipe. If there are leaks in the exhaust, hissing will be heard from the exhaust system through the leaks. It may be necessary to have an assistant perform this test (block off the tailpipe with a rag) while the technician listens for exhaust leaks.

STEP 2 Use a technician's stethoscope to help pinpoint small leaks while this test is being performed.

STEP 3 Use a smoke machine with an exhaust pipe adapter to fill the exhaust system with smoke. With the engine off, any signs of smoke will be pinpointed.

ELECTRONIC LEAK DETECTOR TESTING Obtain an electronic exhaust gas leak detector, which can be purchased at a reasonable cost. The first step is to test for a known gas such as at the tailpipe to verify the tester is capable of measuring gas. Raise the vehicle on a lift or safety stands using a floor jack and go down the exhaust system from the turbocharger to the tailpipe and look for leaks. If any leaks are found, take the necessary steps to repair the exhaust system.

SOAPY WATER TESTING FOR EXHAUST LEAKS Obtain an empty spray bottle and mix water and a small amount of dish washing detergent to make a soapy water solution. Raise the vehicle on a lift or safety stands using a floor jack and check the exhaust system starting at the turbocharger. Spray the joints and pipe looking for soapy bubbles. If any leaks are located, take the necessary steps to repair the exhaust system.

EXHAUST SYSTEM BACKPRESSURE Excessive exhaust system backpressure can cause poor engine breathing due to a clogged or restricted exhaust system. A low power complaint with a whistling sound may indicate an exhaust system restriction. High exhaust backpressure can cause several destructive engine operating conditions, including the following:

- High exhaust valve temperatures can be caused by an inadequate flow of fresh intake air over the exhaust valve, especially during the valve overlap period. High exhaust valve temperatures can cause a valve to burn, resulting in an engine misfire.
- Overheating of cooling systems can be caused by transfer of heat energy from slow-moving exhaust gases lingering near the exhaust ports into the cylinder head.
- Excessive crankcase pressure can result from exhaust gas pressure retained in the cylinder that will leak past piston rings and enter the crankcase.
- Increased engine blow-by gases can cause the combustion gases to leak past the piston rings into the crankcase.
- High exhaust emissions due to poor combustion quality can be caused by high exhaust backpressure.
- Low turbocharger boost pressure caused by high exhaust backpressure. Turbine speed is dependent on the pressure drop between the turbine inlet and outlet, and high exhaust pressure reduces the pressure differential across the turbine. This causes turbocharger speed and boost pressure to fall.

TESTING BACKPRESSURE Two methods can be used to check for exhaust system backpressure:

1. **Vacuum Measurement at Intake Manifold** A vacuum gauge measures engine vacuum with the engine running and installs to a port on the intake manifold. To measure engine backpressure, install a vacuum gauge into an intake manifold port. At idle, the vacuum will be from 17 to 22 inches of mercury (in. Hg). Raise the engine speed by opening the throttle by hand or with a scan tool to about 2,000 to 2,500 RPM. When the engine is kept at a constant speed, the manifold vacuum on the gauge will drop gradually if there is a restriction. ● **SEE FIGURE 136–5**.
2. **Exhaust Manifold Pressure Measurement** Back pressure can be measured directly by installing a pressure gauge into an exhaust opening. A manometer is the best gauge to use for this test. The upstream oxygen or air fuel ratio sensor is a convenient place to install the pressure gauge. Using a modified or discarded oxygen sensor is an easy way to connect the gauge. The maximum backpressure should be less than 1.5 PSI (10 kPa) at idle and less than 2.5 PSI (17 kPa) at 2,500 RPM.

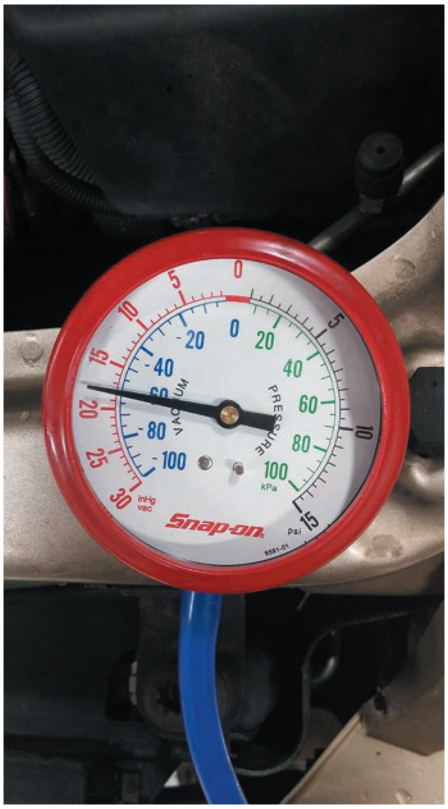


FIGURE 136–5 A vacuum gauge can be used to determine whether an engine has an exhaust restriction.

EXHAUST SYSTEM REPAIR

RUST AND CORROSION Always wait until the exhaust system is cool to the touch before beginning exhaust system repairs to help avoid possible personal injury. The greatest hindrance found during exhaust repair is rust and corrosion. To help address rust and correction problems, keep in mind the following:

- Nuts rust solid to clamps, and exhaust manifold studs and other components rust together at their connection points.
- Threaded fasteners that must be reused can be soaked with penetrating oil or heated for removal.
- Always use six-point sockets to remove exhaust fasteners, as a 12-point socket will round off the corners of a corroded fastener.
- Support the exhaust system with a tall jack (safety) stand and remove the necessary clamps, fasteners, and hangers from the component being replaced.
- Remove the nuts from the exhaust manifold studs, and pull the pipe flange away from the studs.
- Remove the exhaust pipe from the catalytic converter and remove the exhaust pipe from the vehicle.
- Inspect the exhaust manifold studs for corrosion. It is a good idea to replace the studs.

Many exhaust system components use a **slip joint** connection. These connections use an inner pipe that fits inside an outer pipe or an inner pipe that fits inside the muffler. When separating

TECH TIP

Use a MIG Welder

A time-saving option is to use the stud welding attachment that is available on some MIG welders. With this tool, a new stud can be welded to the exhaust manifold without removing the manifold from the vehicle.

these connections, be careful not to damage the parts that are not being replaced. On these types of connections, if the part that is being replaced is the inner pipe, the pipe can be cut in half just outside the outer pipe using a hacksaw, air chisel. or cutoff wheel. Cut a slit in the remaining part of the pipe, which will allow it to be pulled from the muffler or outer pipe. There are slitting tools that can be attached to air tools that are used for this purpose. When replacing the muffler outer pipe, use the slitting tool to cut the outer pipe open, which will allow it to be removed from the inner pipe.

If replacing a component that has been welded together, is not necessary to weld the replacement component in place. Adapters are available that allow a slip joint connection and clamps to be used to secure the component. When installing a new pipe into an old muffler outer pipe, the new pipe may not fit because the muffler or outer pipe opening was distorted, damaged, or overtightened. A cone-shaped pipe-shaping tool and a hammer can be used to make the pipe opening round. A pipe expander can also be used to smooth out or enlarge the diameter of the pipe. Install the expander and tighten the bolt with the socket ratchet until the pipe has been enlarged. Install clamps and hangers, but do not tighten them yet if installing a new exhaust pipe using a new gasket at the exhaust manifold. Replace the exhaust pipe flange nuts with brass, which will not rust to the studs. Make sure the exhaust system is properly aligned and there is enough clearance between the system and all underbody components. Tighten all clamps and hangers, but do not overtighten clamps because this could distort the pipes and create a leak. Install any heat shields or other components that were removed. Start the engine and check for leaks.

POWERTRAIN MOUNTS Broken **powertrain mounts** can cause stress on the exhaust system to wear and even cause components to break. Exhaust system hangers are designed to allow normal system movement with the torque of the engine. If a broken mount allows the powertrain to move more than intended, the exhaust system can be damaged. On a rear-wheel-drive (RWD) vehicle, to inspect the mounts, carefully raise the engine just high enough to remove weight from the mount. This will place a slight tension on the mount to see if it is broken. Repeat this process at the transmission to relieve pressure on the rear mount reattached to the cross member. On a front-wheel-drive (FWD) vehicle, perform the same procedure by raising the powertrain at support points along the subframe. With the weight removed from the mount, look for signs of cracking or splitting in the rubber section. ● **SEE FIGURE 136–6**.

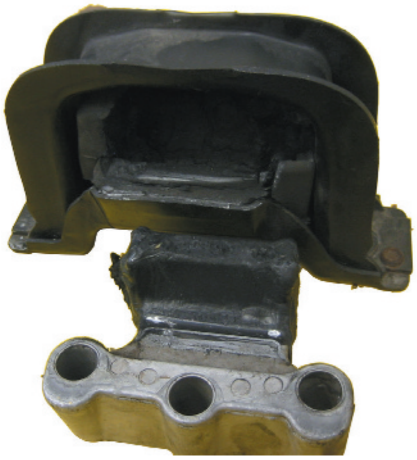


FIGURE 136–6 All powertrain mounts should be carefully inspected for damage. This mount has separated from the support frame and needs to be replaced.

POSITION	DEFINITION
1	Country of Origin
2	Manufacturer
3	Vehicle Brand/Type
4	GVWR/Brake System/Body Style
5/6	Line Chassis/Series
7	Restraint System
8	Engine
9	Check Digit
10	Model year
11	Plant Location
12–17	Plant Sequence Number

CHART 136–1

The VIN showing the information given by each character.

EXHAUST EMISSION CONTROL

VEHICLE IDENTIFICATION NUMBER The vehicle identification number (VIN) is a 17-character code that identifies the vehicle. In 1981, the National Highway Traffic Safety Administration of the United States standardized the format. It required all on-road vehicles sold to contain a 17-character VIN. ● **SEE CHART 136–1**.

VEHICLE EMISSIONS CONTROL INFORMATION (VECI) The **Vehicle Emissions Control Information (VECI)** label is located under the hood of the vehicle. The VECI label (sticker) can be located on the bottom side of hood, the radiator fan shroud, the radiator core support, or the strut towers. The VECI label usually includes the following information:

- Engine identification
- Emissions standards that the vehicle meets
- Spark plug type and gap
- Valve lash, if adjustable
- Major emission control systems on the vehicle
- Emission calibration codes

VEHICLE EMISSION SYSTEMS The exhaust system specialist needs to have a working knowledge of emission control systems that are used on today's vehicles. This information can be found in other chapters. ● **SEE CHART 136–2.**

Catalytic converters	Chapter 86
SAI (AIR) systems	Chapter 85
EGR systems	Chapter 84
Oxygen sensors	Chapter 77

CHART 136–2

Chapters where detailed information about exhaust emission control devices and emission testing can be found.

TECH TIP

Always Comply with Exhaust System Repair Regulations

Any and all exhaust system repairs must comply with federal state and local laws including the following:

- Comply with the standards for the proper operation of the EGR, oxygen sensors, and turbocharger system, if equipped.
- Verify that the catalytic converter requirements are met for the type and location, as well as proper record keeping if a converter is replaced.
- Ensure that the exhaust system is routed correctly, and that the exhaust exits the vehicle according to regulations and is leak free.

EXHAUST SYSTEM FABRICATION

PIPE BENDING There are three methods of bending exhaust pipes:

1. **Program cards** are provided by the pipe-bending equipment manufacturer and contain all the information necessary to duplicate the exhaust pipes found on most vehicles. The number of the program card is found by looking up the make, model, year, and engine in the card catalog. There are separate cards for each pipe in the exhaust system. The program card lists the length and diameter of the pipe, the distance between the center of the bends, and the rotation and depth of the bends in degrees. There may also be remarks that describe bending instructions for peculiar applications. Using this information, the technician can make a pipe identical to the one originally installed by the vehicle manufacturer.
2. **Pattern bending** means measuring and comparing the old exhaust pipe to make a new one. This may be necessary when making a pipe for an older or low-production vehicle for which no program card exists.
3. **Custom bending** is necessary when there is no program card or existing pipe. Applications for which custom may be necessary include installing other than the original.

SAFETY TIP

Safety Precaution When Operating a Pipe Bender

When bending exhaust pipe, always follow the instructions from the bending tool manufacturer and the following:

- Always wear eye protection, gloves, and protective shoes or boots.
- Do not wear loose-fitting clothing that could be snagged by the machine or a pipe.
- Make sure the area around the machine inside the length of the pipe being bent is clear.
- The pipe will move as it is bent, so make sure that the pipe will not contact anything during the bending procedure.
- Do not operate the machine without the safety guards in place, and keep hands clear of the bending dies when the machine is in motion.
- Use caution when handling the ends of pipes that have just been cut, as they can be sharp.

PROGRAM BENDING To use a program card to bend pipe, perform the following steps:

STEP 1 Using make, model, year, and engine information, look up the program card in the card catalog for the pipe that is needed, and remove the card from the card file. Thoroughly read and understand all the information on the card before proceeding with the bending operation.

STEP 2 Select a straight length of pipe in the outside diameter listed on the program card, which is 12 inches longer than the cutoff point listed on the card.

STEP 3 Wipe the excess oil and dirt from the pipe and turn on the bending machine. Install the dies and back shoes on the machine that correspond with the pipe diameter and the radius of the first bend that will be made.

STEP 4 The die fits on the hydraulic ram that pushes against the pipe during the bending operation, while the back shoes mount on the swing gates and clamp the pipe in position during bending and also form the outside radius of the pipe.

STEP 5 Position the pipe on the machine, seam side up, and engage the die using the ram until the pipe is held firmly, with the greater portion of the pipe extending from the left side of the machine.

STEP 6 Using a sharpie pen, mark the points of the pipe where the bends will be made, as listed on the program card. At each point, position the marker on the pipe and then rotate the pipe until the mark is completely around the pipe. The last mark made is the final cutoff point for overall length.

STEP 7 Release the pipe from the machine and reposition it so it extends from the right side of the machine, seam side up, with the first bending mark between the back shoes. Engage the die until the pipe is firmly held in place. Position the rotation dial at the right end of the pipe, at least 12 inches from the final bend. Rotate the dial so that the indicator points to zero, which should also line up with the pipe seam. Secure the dial to the pipe.

STEP 8 Adjust the depth-of-bend setting on the machine according to the program card. Operate the machine until the bend is made. Some machines must be operated manually, while others will automatically make the bend, reverse the ram, and then stop, with the touch of a button.

WARNING

Read, understand, and follow all of the operating instructions of the pipe bender being used to help prevent personal injury.

PATTERN BENDING To use a pattern bending to bend pipe, perform the following steps:

STEP 1 Measure the outside diameter of the old pipe. Dies come in different radiuses, so fit the bends of the old pipe into various radius dies in that diameter until the necessary die is identified. Install that die and back shoes that will be used for the first bend on the pipe bending machine.

STEP 2 Measure the overall length of the old pipe and select a new pipe that is long enough for the job.

STEP 3 Place the new pipe in the bending machine and position it so the largest portion extends from the right side of the machine. Place the old pipe over the back shoes so that the center of the first bend is between the shoes. Push the new pipe from the left side of the machine until the end of the pipe lines up with the old pipe.

STEP 4 Position the first bend of the old pipe on top of the back shoes parallel with the new pipe, and gradually bend the new pipe until the bends of both pipes match. Retract the ram and move the pipe to the left. Place the old pipe on top of the back shoes and line up the center of the second bend with the center between the back shoes.

STEP 5 Line up the first bend on both pipes, then rotate the new pipe until it is parallel with old pipe. Clamp the new pipe into position with the die.

STEP 6 Position the second bend of the old pipe on top of the back shoes and gradually bend the new pipe until the die bends of both pipes match. Repeat bending operations until the last bend has been made. When all bends are completed, cut the pipe to match the length of the old pipe. Finish the ends of the pipe, as required. ● **SEE FIGURE 136–7**.

CUSTOM BENDING Since there is no program card or old pipe to use, inspect the area where the pipe is supposed to fit and try to visualize the pipe routing in relation to the components under the vehicle. Look for things like heat shields on the underside of the vehicle and old hangers that can indicate how the pipe was routed. Hold a length of stiff wire (welding rod works well) up to the exhaust system component to which the new pipe will be attached. Bend the wire to match the projected routing of the new pipe, making sure to allow enough clearance around other components. To make the new pipe, use the wire in the same manner as the old pipe described under pattern bending. Once the new pipe is made, perform a test fit under the vehicle to make sure the routing is as projected and that there will be no interference with other components.

END FINISHING Exhaust system components are connected in a variety of ways. A common type is the slip-joint connection, where an inner pipe fits inside an outer pipe. If both pipes are the same diameter, the end of one pipe must be made larger to fit over the other pipe. Other connections use gaskets and require that the end of the pipe be flared or flanged to make a good seal.

To expand, reduce, or flare the ends of exhaust pipes, pipe bending machines have swaging and expanding attachments. These attachments come with tooling that can end finish a pipe for any kind of connection. Besides the expansion for slip joint connections, other common end finishes are flares, flat flares, male ball joints, female ball sockets, flare flanges, and flat flanges.

Follow the manufacturer's instructions for pipe positioning, tooling combinations, and swaging and expanding procedures. If a flange is used to secure a pipe, such as an exhaust pipe to an exhaust manifold, be sure that the flange is installed before the end of the pipe is flared.

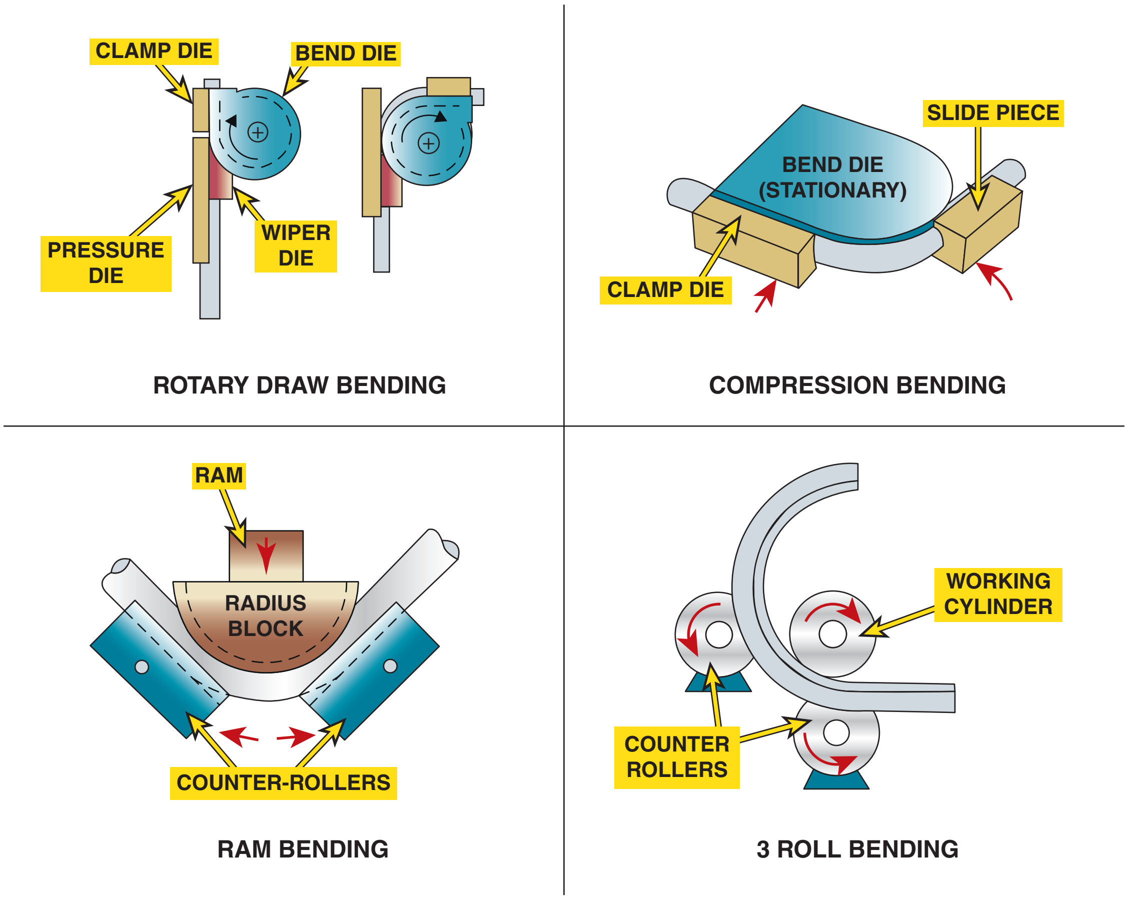


FIGURE 136–7 Exhaust pipe forming and bending can include rotary draw bending, compression bending, ram bending, or three roll bending.

MIG WELDING

TERMINOLOGY **Metal inert gas (MIG)** welding is an arc welding process that uses a continuous solid wire electrode heated and fed into the weld pool from a welding gun. The two base materials are melted together forming a joint. The gun uses a shielding gas around the electrode to protect the weld pool from oxidation. The MIG welder is currently used for welding panels and structural components together. MIG welding can repair high-strength steel without harming or weakening it.

OPERATION An arc is struck between the end of a wire electrode and the workpiece, melting both of them to form a puddle of molten steel, called the **weld pool**. The wire provides both the heat source due to the arc at the wire tip and filler metal. The wire is fed through a copper contact tube (contact tip) that conducts welding current into the wire. The weld pool is protected from the surrounding atmosphere by a shielding gas fed through a nozzle surrounding the wire. Shielding gas selection depends on the material being welded and the application and is usually CO_2 or argon or a combination. The wire is fed from a reel by a motor drive, and the welder moves the welding torch along the joint line. The process offers high productivity, as the wire is continuously fed. ● **SEE FIGURE 136–8**.

OXY-ACETYLENE WELDING

OPERATION Oxy-acetylene welding is used for welding, cutting, and heating to normalize metal, to shrink metal, to forge or shape metal, and to solder. The gases used for the oxyacetylene welding process are oxygen and acetylene. When mixed in the proper ratios using approved equipment, these two gasses produce a flame that is hot enough to melt most metals.

The welding and cutting set consist of the following:

- Oxygen cylinder
- Acetylene cylinder
- Hand truck to hold the cylinders
- Acetylene and oxygen regulators
- Hoses
- Welding torch (cutting attachment)
- Friction lighter

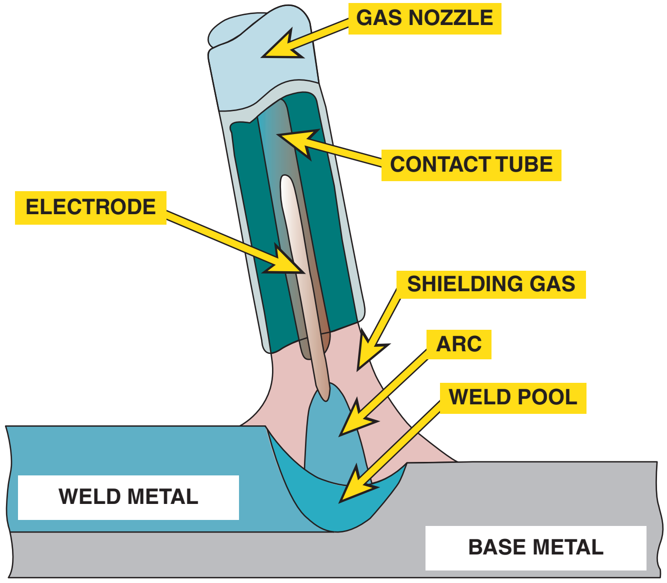


FIGURE 136–8 When using a MIG welder, create a weld pool and move the pool to create an even weld.

WARNING

If oxygen comes into contact with oil or grease, it will burst into flame. Make sure hands and gloves are free of oil and grease before handling any cylinders.

OXYGEN CYLINDER The oxygen cylinder is made from high-grade steel and is a seamless design and painted blue. They range in size from less than 20 cubic feet to greater than 300 cubic feet and contain compressed oxygen at pressures as high as 2,200 PSI (15,200 kPa). Cylinders have valves and are fitted with a screw on a steel cap that protects the cylinder valve. The safety cap MUST always be used during any cylinder movement or replacement. **SEE FIGURE 136–9**.

Open the cylinder valve and then close it before installing the regulator to clear the valve of any dirt. With the regulator installed, always crack the cylinder valve open first, then open it fully. This lessens the chance of recompression that is caused by high cylinder pressure entering the regulator, heating it up and damaging the regulator

ACETYLENE CYLINDER Acetylene cylinders are under pressure and are painted black or red. They are made of steel, have cylinder valves, and range in size from 10 to 400 cubic feet. The cylinders contain a porous filler material that is wetted with acetone and that allows the acetylene to safely be contained in the cylinder at 250 PSI (1,724 kPa). Always use an acetylene cylinder in the upright position so liquid acetylene is not drawn out of the tank. Only open the cylinder valve 1 to $1\frac{1}{2}$ turns, leaving the valve wrench on the valve if it has to be shut off quickly. Acetylene should never be used at a pressure that exceeds 15 PSI (103kPa) as it becomes highly unstable, which could cause it to decompose and explode.

REGULATORS The pressure in a full acetylene cylinder is about 250 to 2,200 PSI (1724 to 15,170 kPa) in a full oxygen cylinder. Regulators are used to adjust the high oxygen and acetylene pressures to lower working pressures for torch use. The regulator maintains a steady working pressure as the cylinder pressure drops. Regulators admit the high cylinder pressure through a valve, which is operated by a flexible diaphragm. When turning the regulator adjusting knob in or out, it causes a spring to operate the diaphragm to open or close the valve. When turning the adjusting knob in, the flow and pressure are increased. When turning it out, the flow and pressure are decreased.

Oxygen and acetylene regulators connect differently to their cylinders so they cannot be mixed up. Oxygen cylinder regulators have right-hand threads and acetylene cylinders use left-hand threads. There is a groove around fuel connections that indicates a left-handed thread. Finally, all acetylene regulator outlet (low-pressure) gauges have the gauge scales marked in red

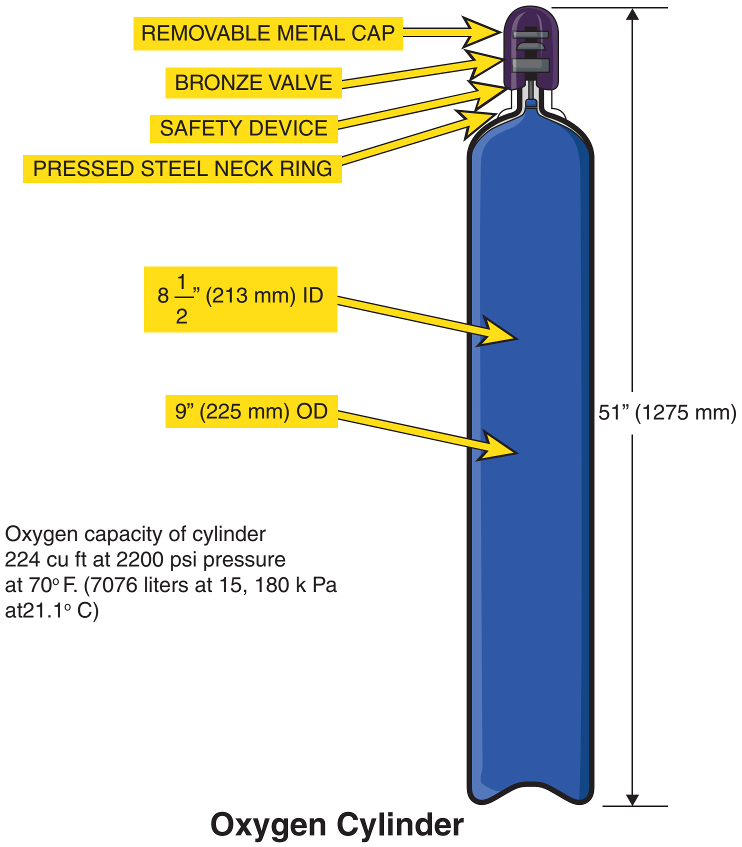

REMOVABLE METAL CAP
BRONZE VALVE
SAFETY DEVICE
PRESSED STEEL NECK RING
8 $\frac{1}{2}$" (213 mm) ID
9" (225 mm) OD
51" (1275 mm)
Oxygen capacity of cylinder
224 cu ft at 2200 psi pressure
at 70° F. (7076 liters at 15, 180 k Pa
at21.1° C)
Oxygen Cylinder

FIGURE 136–9 A cross-sectional view of an oxygen tank.

starting at 15 PSI (103 kPa). This is to act as a reminder not to use acetylene at pressures over that marked in red.

Before opening the supply cylinder, check the adjusting screw to see if it is released and then open the cylinder valve. To adjust the working pressure, the valves on the torch body should be opened slightly as the adjusting screw is turned to adjust the regulator pressure that is required for the job. When a regulator is not being used overnight or is idle for a long period, the pressure should always be relieved on the delivery pressure valve seat.

HOSES The cylinder regulators and torch are connected using double-line rubber hoses. Double-line hose is known as type VD. The oxygen line is green, and the acetylene or fuel line is red. Hoses are available in four sizes, 3/16-, 1/4-, 3/8- and 1/2-inch I.D. The different grades of double-line hose used for acetylene are as follows:

- Non-oil resisting rubber cover
- RM (carries both a non-oil and flame and an oil-resisting cover for use with all fuel gases and acetylene)

Grades R and RM should be marked for acetylene only. Grade T should be marked fuel or acetylene gas. All hoses are marked to their service level (light, standard, or heavy). The date of manufacture is also marked at a maximum working pressure (200 PSI) along with nominal I.D size and if it meets RMA/CGA IP-90 (Rubber Manufactures Association, Compressed Gas Association) specifications for rubber welding hose. The hose fittings are marked as right- or left-handed threads. Single line hose come in 3 grades: L, light duty, S, standard duty, and H, heavy duty. Hoses are limited to a working pressure of 200 PSI.

CHECK VALVES Acetylene and oxygen must mix to be combustible. This must only take place at the torch mixer or the torch tip. Due to improper operation, sometimes acetylene and oxygen can feed back into the hoses and cause combustion in the hoses or regulators. *Check valves* are installed between the hoses and the torch to prevent this back flow. Check valves must be used with all oxy-acetylene torches.

TORCH The torch consists of a handle, oxygen, and acetylene gas valves and a mixing chamber. Welding tips or a cutting attachment can be used with the handle to weld, heat, or cut metal. Oxygen and acetylene gas flow through tubes inside the handle that blend in the mixing chamber or tip. It is at the tip where the mixed gases are ignited. Oxygen and acetylene enter the torch at about equal pressures. The injector type is used when acetylene

FREQUENTLY ASKED QUESTION

What Is a flashback?

A **flashback** is a rapid high-pressure flame in the hose, which can occur if there are not any check valves or the check valves fail to operate due to improper installation. Once a flashback starts, check valves cannot stop it. The flashback arrestor connects the same as the check valves in the hose at the torch or regulator and contains a trap that is spring loaded that cuts off the gas flow in the event of a flashback. Both check valves and flashback arrestors should be included on every oxy-acetylene setup.

FREQUENTLY ASKED QUESTION

What Causes a Backfire?

A **backfire** can take place with improper torch operation. The flame will go out with a loud snap or pop. The torch valves should be turned off and connections and valves checked for leaks. If everything is normal, relight the torch. Backfires are caused by the following:

- The tip is touching the work.
- The tip is overheated or dirty.
- Gas pressure is too low.
- The torch head or tip are loose.
- The seal between the torch body and mixing chamber is leaking.

gas pressures measure less than 1 PSI (7kPa). The oxygen at high pressure pulls the acetylene into the mixing chamber.

FLAME TYPES

NEUTRAL FLAME The **neutral flame** is generally used for welding and burns about one part oxygen to one part acetylene. Adjust the torch until the inner cone is blunt and the feathery edges have disappeared. A typical neutral flame burns at 5900°F (3260°C).

OXIDIZING OR EXCESS OXYGEN FLAME The **oxidizing flame** is used for brazing and is obtained by opening the oxygen valve slightly more than the neutral flame. The inner cone gets shorter and pointed and it becomes somewhat purple in color. Flame temperature is about 6300°F (3482°C). ● **SEE FIGURE 136–10**.

CARBURIZING FLAME The high acetylene or **carburizing flame** is the one most commonly used by automotive technicians to heat parts or to solder. More acetylene is burned than oxygen, so the inner cone has a feather. The inner cone is also white. The envelope around the carburizing flame has the same look as the neutral flame and the temperature is about 5700°F (3154°C).

OXY-ACETYLENE TORCH SAFETY

- NEVER use acetylene gas at pressures higher than 15 PSI (103 kPa).
- NEVER use oil or grease on or around oxygen equipment.
- NEVER use oxygen or acetylene to blow dirt or dust off of equipment.
- ALWAYS use a flint striker to light the torch; never light a torch with matches or a butane lighter.
- When opening an oxygen or acetylene valve, always crack it open first.
- Make sure regulators have their adjusting screws released by turning them CCW before opening the cylinder valves.
- Stand to the side of the regulator, NEVER in front of it, when opening the cylinder valves.
- ALWAYS wear OSHA-approved welding goggles (shield) and gloves when using an oxy-acetylene torch.
- ALWAYS have a fire extinguisher handy when using an oxy-acetylene torch.
- ALWAYS replace the cylinder caps when finished using the cylinders.
- Do not rely on the cylinder color to identify the gas, because some welding equipment suppliers may use different color codes.
- ALWAYS use the right regulator for the gas.
- ALWAYS use cylinders in an upright position only.
- NEVER store gas cylinders in temperatures above 130°F (54°C)
- ALWAYS keep the valve wrench on acetylene cylinder valve when in use.
- ALWAYS be aware of others around when using a torch.
- ALWAYS open the valve a maximum of 1½ turns.
- NEVER carry butane lighters, matches, or other flammable objects while heating, welding, or cutting.
- NEVER store gas cylinders in temperatures above 130°F (54°C)
- NEVER let welding hoses come into contact with the torch flame or sparks from cutting.

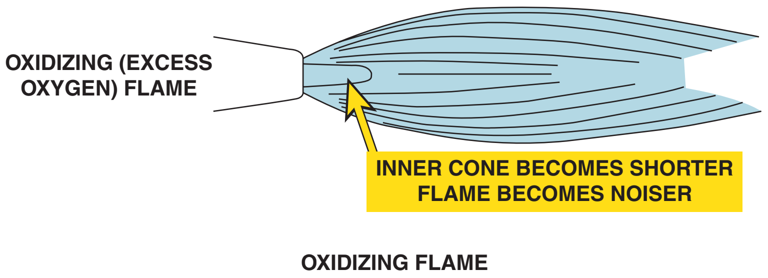
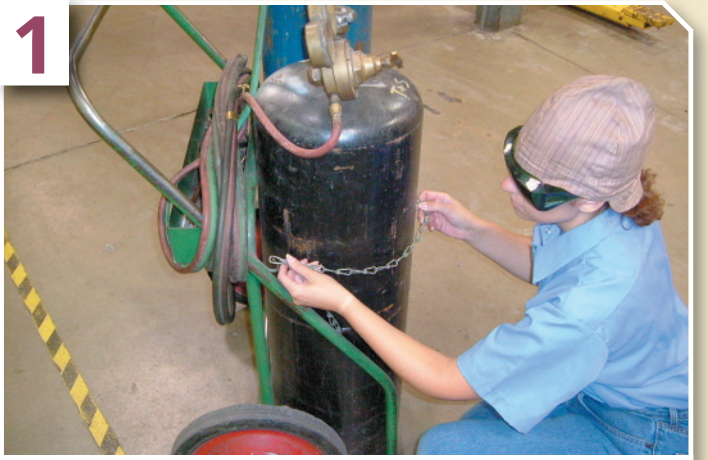


FIGURE 136–10 An oxidizing flame is hotter than a neutral flame and is identified by the short inner flame cone.

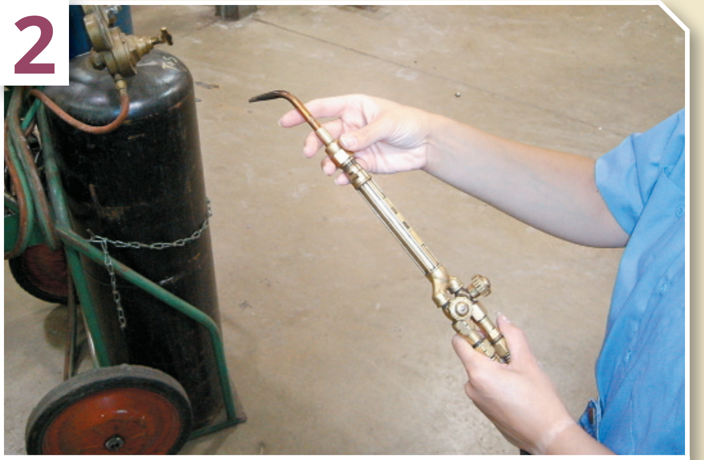
SETUP AND LIGHTING A TORCH

1



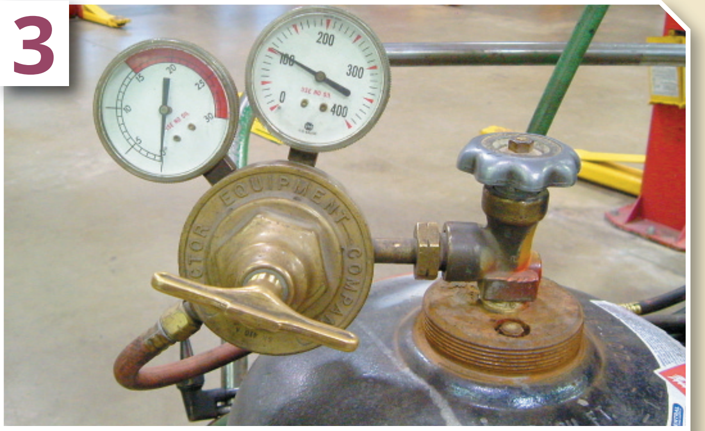
Inspect the cart and make sure the tanks are chained 1 properly before moving it to the work location.

2



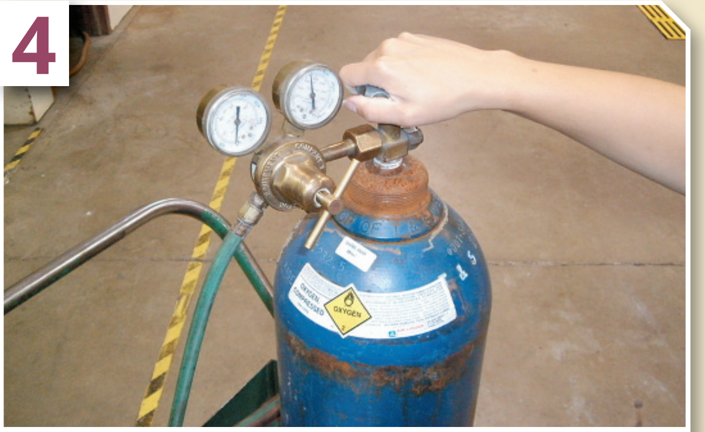
Start by attaching the appropriate work tip to the torch handle. The fitting should only be tightened hand tight. Make sure the valves on the torch handle are closed at this time

3



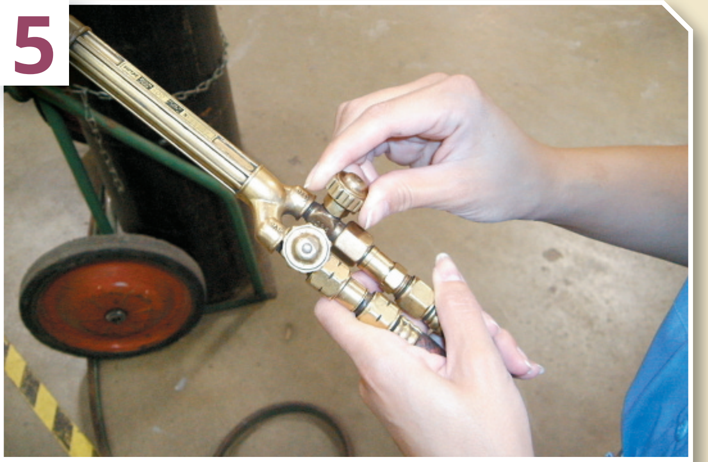
Each tank has a regulator assembly with two gauges. The high-pressure gauge shows tank pressure, and the low-pressure gauge indicates working pressure.

4



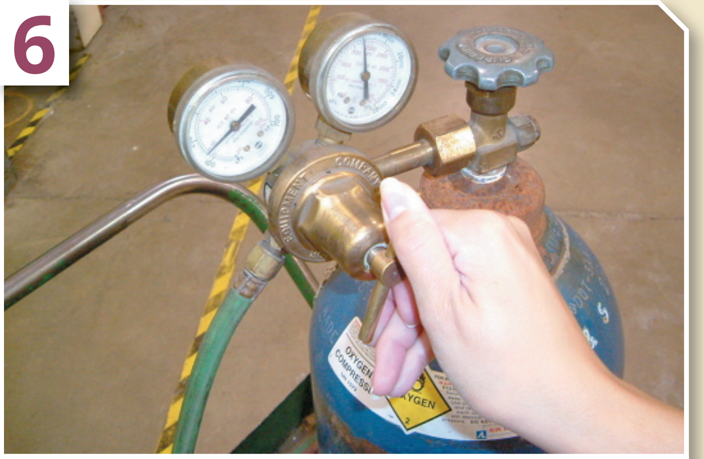
Open the oxygen tank valve fully open, and open the acetylene tank valve ½ turn.

5



Open the oxygen valve on the torch handle ¼ turn in preparation for adjusting oxygen gas pressure.

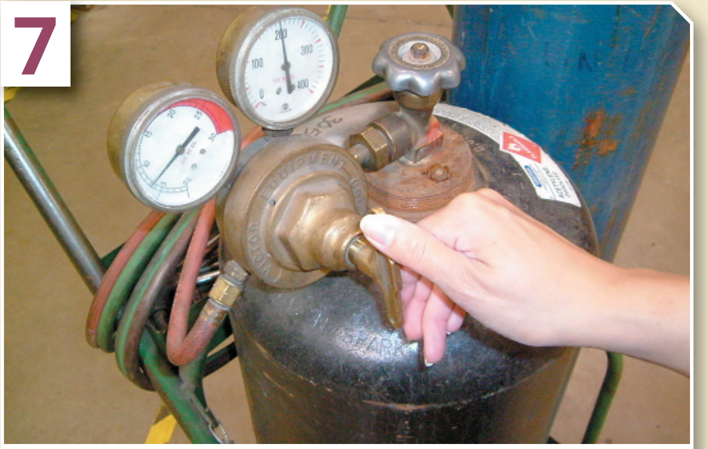
6



Turn the oxygen regulator valve clockwise and adjust oxygen gas pressure to 20 PSI. Close the oxygen valve on the torch handle.

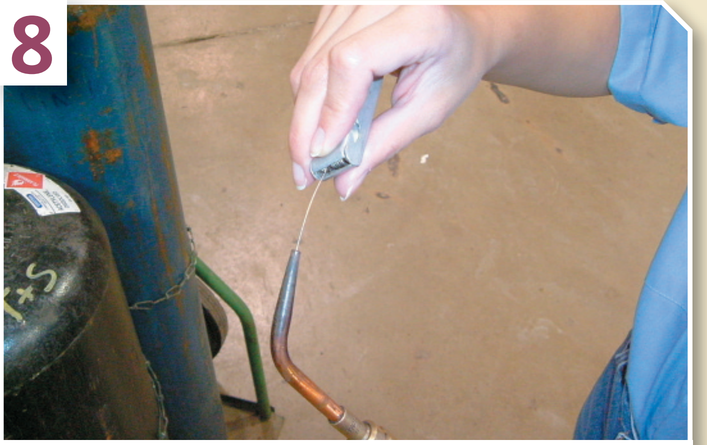
STEP BY STEP

7



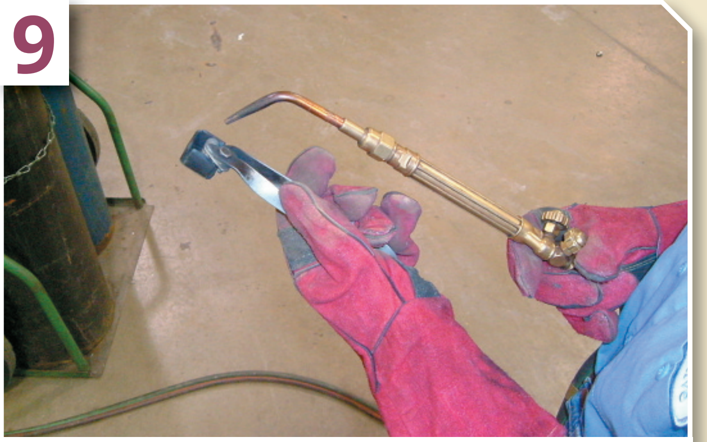
Open the acetylene valve on the torch handle ¼ turn and adjust acetylene gas pressure to 7 PSI. Close the acetylene valve on the torch handle

8



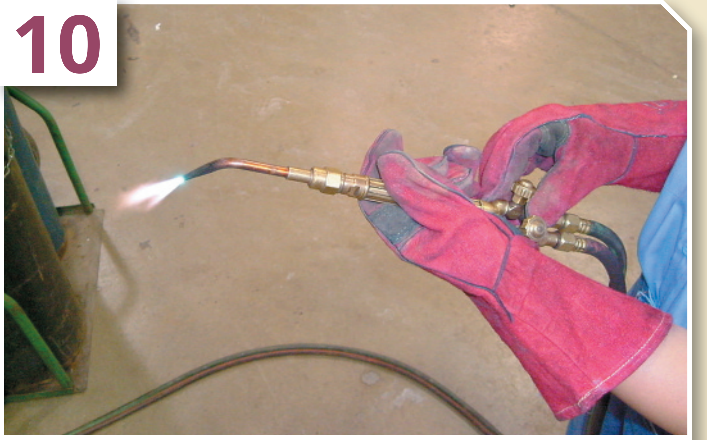
Open the oxygen valve on the torch handle ¼ turn and use an appropriate size tip cleaner to clean the tip orifice. Finish by closing the oxygen valve.

9



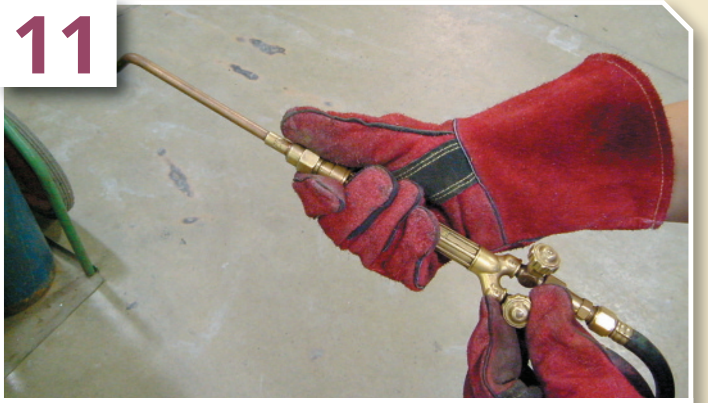
Put on leather gloves and open the acetylene valve on the torch handle ¼ turn Use a flint striker to ignite the acetylene gas exiting the torch tip.

10



Adjust the acetylene valve until the base of the flame just touches the torch tip. Slowly open the oxygen valve on the torch handle and adjust for a neutral flame (blue cone is well-defined).

11



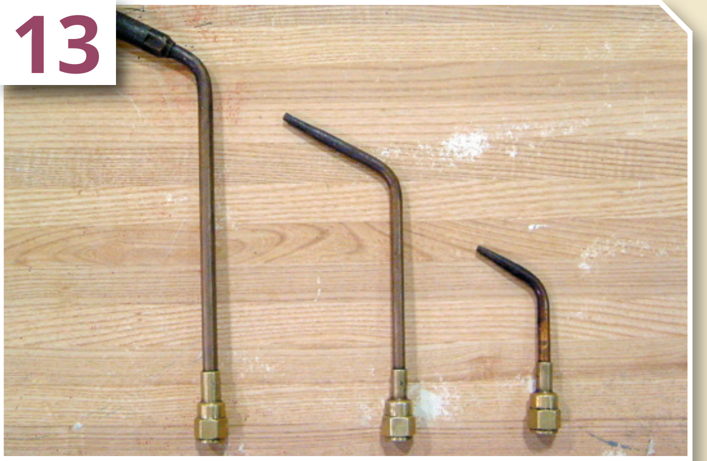
Once work is complete, extinguish the flame by quickly closing the acetylene valve on the torch handle. Be prepared to hear a loud “pop” when the flame goes out. Close the oxygen valve on the torch handle.

12

Close the valves on both tanks and turn the regulator handles counterclockwise until they no longer contact the internal springs. Open the gas valves briefly on the torch handle to release gas pressure from the hoses. Close the gas valves on the torch handle and put away the torch assembly.

HEATING METAL

13



Heating attachments include ordinary heating tips, middle and right and a “rosebud” (left). Ordinary heating tips work fine for most purposes, but occasionally the rosebud is utilized when a great deal of heat is needed

14

Note that while acetylene tank pressures are relatively low, the oxygen tank can be filled to over 2,000 PSI. This can represent a serious hazard if precautions are not taken. Be absolutely certain that the tanks are chained properly to the cart before attempting to move them!

15

Any time heating or cutting operations are being performed, be sure that any flammables have been removed from the immediate area. A fire blanket may be placed over floor drains or other objects to prevent fires. A fire extinguisher should be on hand in case of an emergency.

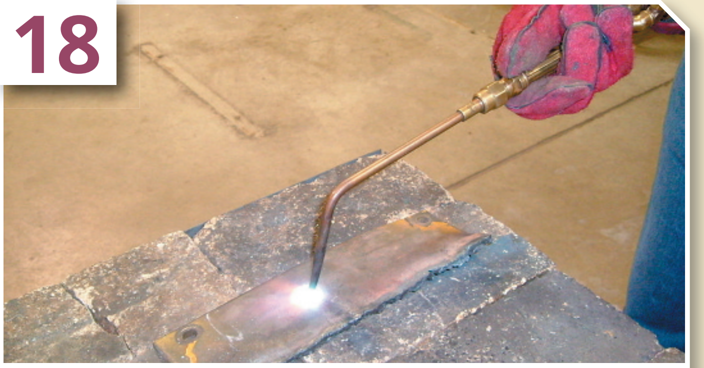
16

Be sure to wear appropriate personal protective equipment during heating and cutting operations.

17

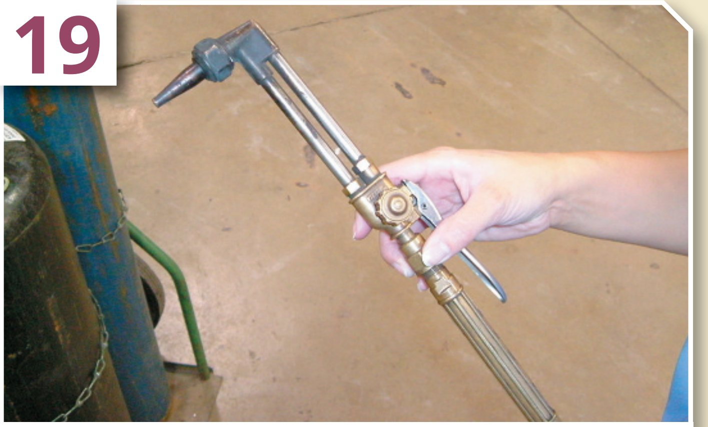
Note that heating operations should be performed over steel or firebrick. Never heat or cut steel close to concrete, as it could cause the concrete to explode.

18



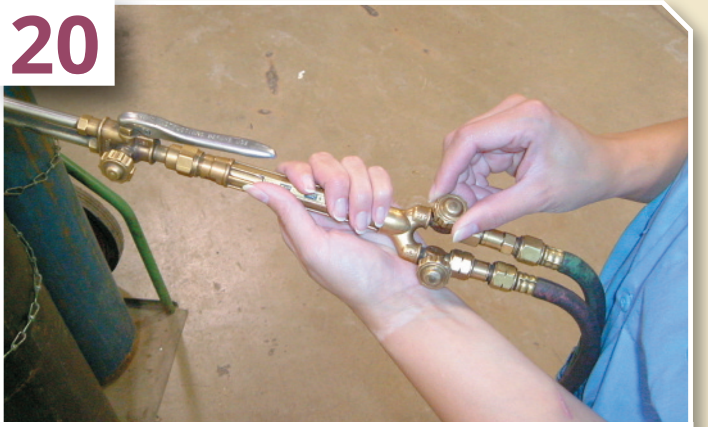
When heating steel, move the torch in a circular pattern to prevent melting of the metal. Don’t hold the torch too close to the work as this will cause a “snapping” or “backfire” that can extinguish the flame.

19



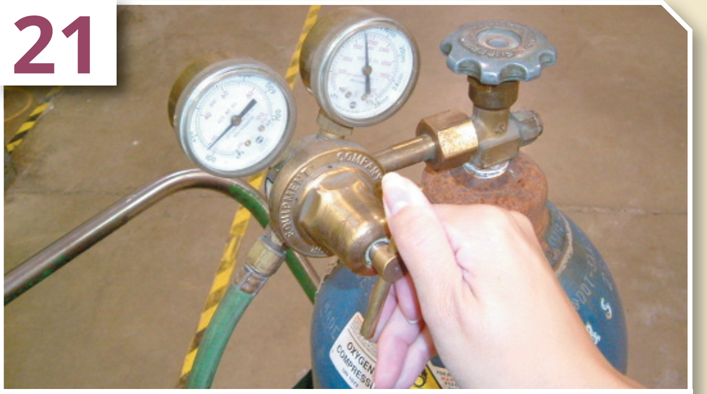
Affix the cutting attachment to the torch handle. Note that the cutting attachment has a cutting handle and a separate oxygen valve.

20



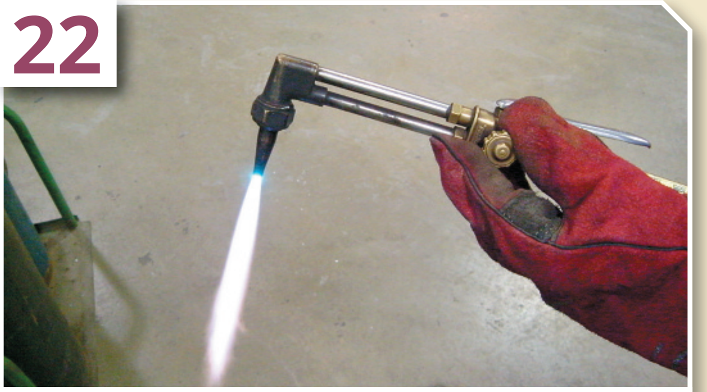
Fully open the oxygen valve on the torch handle. Oxygen flow will now be controlled with the valve on the cutting attachment.

21



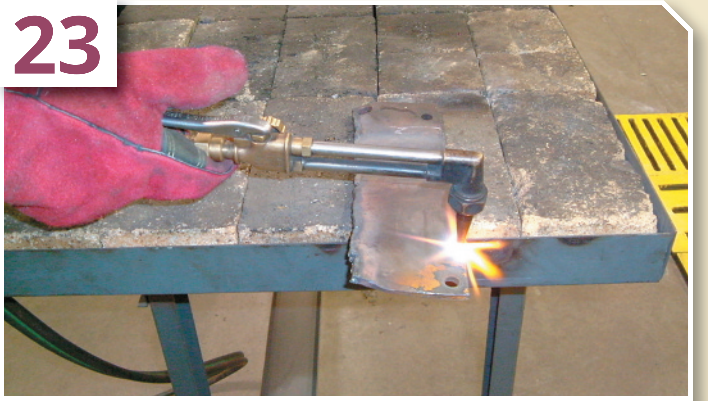
Oxygen gas pressure should be adjusted to 30 PSI whenever using the cutting attachment. Acetylene pressure is kept at 7 PSI.

22



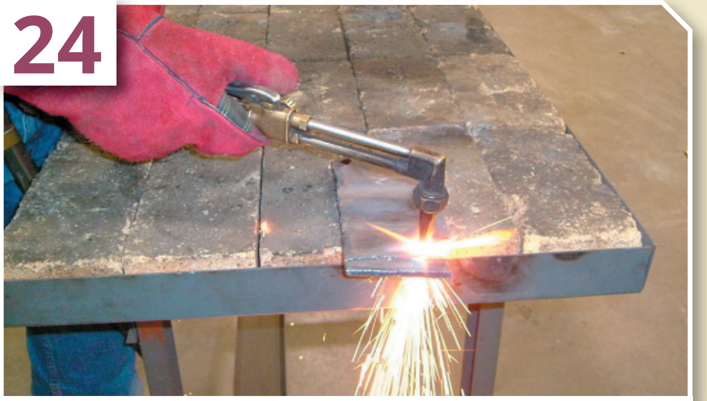
Open the acetylene valve on the torch handle ¼ turn and light the torch. Adjust the flame until its base just touches the cutting tip. Slowly open the oxygen valve on the cutting attachment and adjust the flame until the blue cone is well-defined.

23



Direct the flame onto a thin spot or sharp edge of the metal to be cut. This will build the heat quicker in order to get the cut started.

24



When the metal glows red, depress the cutting handle and move the torch to advance the cut. You will need to move the torch faster when cutting thinner pieces of steel. On thicker pieces, point the cutting tip into the direction of the cut.

REVIEW QUESTIONS

1. What are the components of an automotive exhaust system and subsystems?
2. What is found on an emissions label?
3. How is inspection done on engine/transmission mount condition and alignment?
4. What is the carburizing flame of a gas welding method?
5. What is a program card?

CHAPTER QUIZ

1. An engine makes a clicking like sound like a lifter, and all of the hydraulic lifters were recently replaced. Which of these could be the cause?
   - **a.** Leaking catalytic converter
   - **b.** Cracked exhaust manifold
   - **c.** Cracked intake manifold
   - **d.** Clogged exhaust pipe
2. A technician uses a vacuum gauge to check for an exhaust restriction. The vacuum is read at idle and then at 2,000 RPM. What result would indicate an exhaust restriction?
   - **a.** Vacuum increases
   - **b.** Vacuum falls
   - **c.** Reading stays the same
   - **d.** Reading climbs very slowly
3. Two technicians are discussing the small hole in the muffler. Technician A says that some mufflers have a small hole located in the rear at the bottom to drain out condensed water. Technician B says that you need to periodically drain the water using a vacuum pump. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
4. Which of these is the biggest concern when you find a rust hole in an exhaust system?
   - **a.** Exhaust gases escaping
   - **b.** High noise level
   - **c.** High exhaust emissions
   - **d.** Failing state inspection
5. On which vehicle label would you find emission calibration codes?
   - **a.** VIN (vehicle identification number)
   - **b.** Parts and accessories label
   - **c.** VECI (vehicle emissions control information) label
   - **d.** VSC (vehicle safety certification) label
6. A technician is in the process of removing the bolts on a catalytic converter. Technician A says that you should be using a six-point socket. Technician B says water pump pliers (slip joint) should be used at slip-joint connections to hold the pipe. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
7. Exhaust hangers are used to ___________ vibrations in the exhaust system.
   - **a.** focus
   - **b.** isolate
   - **c.** increase
   - **d.** remove
8. Which of these fabrication processes results in an exhaust pipe that duplicates the original pipe?
   - **a.** Pattern bending
   - **b.** Custom bending
   - **c.** Program card bending
   - **d.** Wire bending
9. Which of these welding methods uses carbon dioxide or argon gas?
   - **a.** MIG welding
   - **b.** Oxy-acetylene welding
   - **c.** Arc-welding
   - **d.** All of these
10. Which type of flame is used for soldering?
    - **a.** Neutral
    - **b.** Oxidizing
    - **c.** Carburizing
    - **d.** Soldering

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GLOSSARY

A-arm Another name for a control arm because it often looks like the letter A.

Aboveground storage tank (AGST) A type of oil storage.

Absolute humidity Absolute humidity is the measurement of the weight of the water vapor in a given volume of air.

Abutments All braking force is transferred through the caliper to the mount. The places where the caliper contacts the caliper mount are called the abutments, reaction pads, or ways.

AC coupling A signal that passes the AC signal component to the meter, but blocks the DC component. Useful to observe an AC signal that is normally riding on a DC signal; for example, charging ripple.

AC ripple voltage While it is normal to measure some AC voltage from an alternator, excessive AC voltage, called AC ripple, is undesirable and indicates a fault with the rectifier diodes or stator windings inside the alternator.

AC/DC clamp-on DMM A type of meter that has a clamp that is placed around the wire to measure current.

Accelerator pedal position (APP) sensor A sensor that is used to monitor the position and rate of change of the accelerator pedal.

Accumulator A temporary location for fluid under pressure.

Acid materials Pure water is neutral; on the pH scale, water is pH 7. Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the alkaline action will be. Acid materials have pH numbers from 1 through 6. The lower the number, the stronger the acid action will be.

Acoustic vehicle alerting system (AVAS) Electric vehicles and most hybrid electric vehicles emit a sound through a speaker in the front at low speeds to warn pedestrians that a moving vehicle is nearby. This system is called acoustic vehicle alerting system (AVAS).

Active balancing Active balancing is achieved when energy is drawn from the most charged cell and transferred to the least charged cells, usually through DC–DC converters.

Active grille shutters (AGS) Plastic shutters that open or close to control the airflow going under the hood. The primary function of the active grille shutters is to reduce the aerodynamic drag of the vehicle when closed.

Active mode When the TPM sensor inside the tire detects that the vehicle is traveling above 20 mph (32 km/h), the sensor transmits once every minute.

Active wheel speed sensors Active wheel speed sensors are called active because they require outside electrical power to operate.

Actuator cylinder The cylinder used to transfer movement from the clutch master cylinder to the throw-out bearing to apply or release the clutch.

Actuator An electromechanical device that performs mechanical movement as commanded by a controller.

Adaptive cruise control An adaptive cruise control, often called radar cruise control, uses radar, lasers, cameras, or a combination of sensors, to keep a constant distance from the vehicle ahead.

Adaptive Front Lighting Systems (AFS) Active front headlight system. A name for the system that causes the headlights to turn when cornering.

Additive package A number of chemicals that will help each other can be used for each of the additive requirements. The balanced additives are called an additive package.

Adhesive-lined heat shrink tubing A type of heat shrink tubing that shrinks to one-third of its original diameter and has glue inside.

Adjustable pedals Adjustable pedals, also called electric adjustable pedals (EAP), place the brake pedal and the accelerator pedal on movable brackets that are motor operated.

Adjustable wrench A wrench that has a moveable jaw to allow it to fit many sizes of fasteners.

Adsorption By a process called adsorption, the fuel vapor molecules adhere to the carbon surface. This attaching force is not strong, so the system purges the vapor molecules quite simply by sending a fresh airflow through the charcoal.

Advanced Engagement (AE) Starter When energized, the pinion shifts forward by the starter solenoid and engages with the engine's ring gear/flywheel, and immediately spins.

Advisor A role played by a mentor.

Advocate A role played by a mentor.

Aerated Aerated means air mixed with the oil.

Afterblow Afterblow is a term used to describe the operation of the blower motor after the ignition has been turned off. The purpose of afterblow is to dry the evaporator to help prevent the formation of mold and mildew in the evaporator case.

After-blow module An electrical control that will run the HVAC blower after the vehicle has been shut off. Its purpose is to dry the evaporator fins.

Aftermarket parts Referring to repair parts produced by companies other than OEM.

Aftermarket parts Replacement parts that are not manufactured by the original vehicle manufacturer.

Aftermarket Jobber parts are not made by the original manufacturer of your vehicle. These parts are also called aftermarket parts. The aftermarket industry makes up about 80% of the parts used in vehicle repair.

AFV Alternative fuel vehicle.

Agitation Parts washers are often used in place of soaking tanks. This equipment can move parts back and forth through the cleaning solution or pumps the cleaning solution over the parts. This movement, called agitation.

AGM The acid used in an absorbed glass mat (AGM) battery is totally absorbed into the separator, making the battery leak proof and spill proof.

Air compressor A piece of shop equipment that uses an electric motor to power an air compressor, which is stored in a pressure tank for use in the shop.

Air doors A system that contains the HVAC plenum, ducts, and air doors is called the air management system, or air distribution system, and controls the airflow to the passenger compartment

Air drill An air drill is a drill that rotates faster than electric drills (up to 20,000 RPM). Air drills are commonly used in auto body work when many holes need to be drilled for plug welding.

Air filter An air filter filters dirt from the air before it enters the intake system of the engine.

Air inlet Air inlet door is used to select outside or inside air inlet.

Air management system The system of solenoids and valves that control the flow of air from the secondary air injection system.

Air pressure check An air pressure check uses air to apply clutches and/or bands to verify that components such as clutch packs perform correctly.

Air ratchet An air-operated hand tool that rotates a socket.

Air spring A rubber fabric air-filled bag used to replace a spring.

Air suspension A type of suspension that uses air springs instead of steel springs.

Airbag An inflatable fabric bag that deploys in the event of a collision that is server enough to cause personal injury.

Air-blow gun A handheld nozzle attached to a compressed air hose to apply air pressure to a component or device.

Air-fuel ratio sensor A term used to describe a wide-band oxygen sensor.

Air-fuel ratio The ratio of air to fuel in an intake charge as measured by weight.

Air-injection reaction (AIR) An AIR pump that pumps air in a secondary air-injection system.

Alemite fittings Grease fittings are also called Zerk fittings (named for Oscar U. Zerk) or Alemite fittings (named for the manufacturer of early grease fittings).

Alert mode Alert mode is triggered if a rapid change in inflation pressure is detected. In alert (or rapid mode), the tire inflation pressure is sent about every second (every 800 milliseconds on some sensors).

Algorithm A series of mathematical calculations used to make precise determinations.

Alkaline A substance with a pH of higher than 7.

Alternator An electric generator that produces alternating current; also called an *AC generator*.

Aluminum Aluminum was the last of the three materials to be used for automotive bearings. Automotive bearing aluminum has small quantities of tin and silicone alloyed with it. This makes a stronger but more expensive bearing than either babbitt or copper-lead alloy.

Always Be Charging (ABC) The saying that many owners of electric vehicle mention when discussing charging at home. Due to the vehicle itself needing to keep the systems functional and within a temperature range, many owners simply keep their EV connected to the charging station when at home.

AM Amplitude modulation.

Amber ABS warning lamp The dash warning lamp that lights if a fault in the antilock braking system (ABS) is detected.

Ambient air temperature sensor This sensor is usually located at the front of the vehicle behind the grille but in front of the radiator. The purpose of this sensor is to detect the temperature of the outside air. This sensor is commonly called the ambient air temperature sensor.

Ambient side electrode This electrode is exposed to outside (ambient) air and is the signal electrode, also called the reference electrode or ambient air electrode.

American National Standards Institute (ANSI) American National Standards Institute, an organization that publishes safety standards for safety glasses and other personal protective equipment.

American Petroleum Institute (API) The American Petroleum Institute gravity, or API gravity, is a measure of how heavy or light a petroleum liquid is compared to water. The American Petroleum Institute (API), working with the engine manufacturers and oil companies, has established an engine oil performance classification. Oils are tested and rated in production automotive engines. The oil container is printed with the API classification of the oil.

American Society for Testing Materials (ASTM) ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. The American Society for Testing Materials (ASTM) specifies the consistency of grease using a penetration test.

American wire gauge (AWG) A method used to measure wire diameter.

Ammeter An electrical test instrument used to measure amperes (unit of the amount of current flow).

Ampere hour A method used to rate battery capacity.

Ampere The unit of the amount of current flow. Named for André Ampère (1775–1836).

Ampere-turns The unit of measurement for electrical magnetic field strength.

Amplitude The difference between the highest and lowest level of a waveform.

Anaerobic sealers Anaerobic sealers cure in the absence of air. They are used as thread lockers (such as Loctite®), and they are used to seal rigid machined joints between cast parts.

Analog display An analog display uses a needle to show the values, such as engine RPM.

Analog-to-digital (AD) converter An electronic circuit that converts analog signals into digital signals that can then be used by a computer.

Anchor eyes One end of the web usually has a notch where the wheel cylinder touches the shoe, while the other end commonly has a flat or curved surface where the shoe meets an anchor or adjusting link. The upper ends of the webs on dual-servo brake shoes have semicircular cutouts called anchor eyes.

Anchor plate The support for the anchor pin on a drum brake backing plate.

Annulus gear The outer ring gear has teeth on the inside that mesh with the teeth of the planet pinion gears. The ring gear is also called the annulus gear or internal gear because the gear teeth are on the inside (rather than the outside) portion of the gear.

Anode The positive electrode; the electrode toward which electrons flow.

ANSI American National Standards Institute, an organization that publishes safety standards for safety glasses and other personal protective equipment.

Anti-dive A term used to describe the geometry of the suspension that controls the movement of the vehicle during braking. It is normal for a vehicle to nose-dive slightly during braking and is designed into most vehicles.

Antidrainback valve Many oil filters are equipped with an antidrainback valve that prevents oil from draining out of the filter when the engine is shut off.

Antifriction bearings Bearings that use steel balls or rollers to reduce friction.

Antiknock index (AKI) The octane rating posted on a gas pump, which is the average of the RON and MON octane ratings.

Antilock brake system (ABS) A system that is capable of pulsing the wheel brakes if lockup is detected to help the driver maintain control of the vehicle.

Antirattle clips Metal clips used to eliminate or dampen noise in a brake system.

Antiseize compound Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend Antiseize compound.

Anti-squat A term used to describe the geometry of the suspension that controls the movement of the vehicle body during acceleration. 100% anti-squat means that the body remains level during acceleration. Less than 100% indicates that the body ``squats down,” or lowers in the rear during acceleration.

API gravity The density or specific gravity of diesel fuel is measured in units of API gravity. API gravity is an arbitrary scale expressing the gravity or density of liquid petroleum products devised jointly by the American Petroleum Institute and the National Bureau of Standards.

Application cables The application cables use the force passed through the linkage to apply the rear-wheel brake assembly.

Application Programming Interface (API) A pass-through device or API serves as a connection point that makes all the hardware look the same, and allows the computer with the reprogramming software to communicate with the vehicles control module through the data link connector (DLC).

Apply devices Apply devices or holding devices are the mechanical or hydraulic assemblies that provide the force to hold or drive members of a planetary gear set.

Appointment Log The appointment log is created by the service consultant to record all the vehicles that are scheduled to come in on a particular day.

Appointment An arrangement to provide services at a particular place and time.

Apprentice program An apprentice program involves a beginning service technician working at a shop or dealership during the day and attending training classes in the evening. The key advantage to this type of program is that money is being earned due to full-time employment and getting on-the-job training (OJT) during the day.

Aqueous-based solutions Because of environmental concerns, most chemical cleaning is now performed using water-based solutions (also called aqueous-based solutions). Most aqueous-type chemicals are silicate–based and are mixed with water.

Arithmetic average roughness height (RA) The usual method of expressing surface finish is by the arithmetic average roughness height (RA), that is, the average of the distances of all peaks and valleys from the mean (average) line. Surface finish is measured using a machine with a diamond stylus.

Armature The rotating unit inside a DC generator or starter, consisting of a series of coils of insulating wire wound around a laminated iron core.

Arming sensor A sensor used in an air bag circuit that is most sensitive and completes the circuit first of two sensors that are needed to deploy an air bag.

Armor The fiber facing is protected around the combustion chamber with a metal armor (also called a fire ring).

Armored brake line Steel brake line that has wire wrapped around it to provide protection against stones and other debris.

Articulation test A test specified by some vehicle manufacturers that tests the amount of force necessary to move the inner tie rod end in the ball socket assembly. The usual specification for this test is greater than 1 lb. (.5 Kg.) and less than 6 lbs. (2.7 Kg.) of force.

Asbestos Asbestos is the term used to describe naturally occurring silicate minerals that consist of long fibers.

Assembly lube Lubricant that is designed to remain on the parts and not drip or run is called assembly lube.

Association des Constructeurs Européens d’ Automobiles (ACEA) The Association des Constructeurs Européens d’Automobiles (ACEA) rates the oil according to specific criteria.

ASTM American Society for Testing Materials.

Asymmetrical If the specifications vary, the camshaft is called asymmetrical.

Atmospheric pressure Pressure exerted by the atmosphere on all things based on the weight of the air (14.7 pounds per square inch at sea level).

Auto link A type of automotive fuse.

Automated manual transmission (AMT) Another term used to describe a dual-clutch automatic transmission/transaxle.

Automatic air-conditioning system A system that uses sensors and actuators to maintain a preset temperature inside a vehicle.

Automatic climate control system A system that controls the temperature and blower motor operation to control the climate inside the vehicle automatically depending on the preset temperature selected by the driver or passenger.

Automatic emergency braking (AEB) Automatic emergency braking automatically applies the brakes to avoid a collision.

Automatic headlights Automatic headlights automatically turn on the headlights when the light sensor detects low ambient light level.

Automatic level control (ALC) The automatic level control (ALC) system automatically adjusts the rear height of the vehicle in response to changes in vehicle loading and unloading.

Automatic reversal systems (ARS) Public Law 110-189, also known as the Cameron Gulbransen Kids Transportation Safety Act, mandated the use of power window automatic reversal systems (ARS). The automatic reversal system is designed to prevent windows from causing injury when they are closing.

Automatic shutdown (ASD) relay Many Chrysler group products use an automatic shutdown (ASD) relay to power the ignition coil. The ASD relay does not supply voltage to the coil unless the engine is cranking and the computer senses a crankshaft sensor signal.

Automatic temperature control (ATC) system Automatic air-conditioning systems are usually called automatic temperature control (ATC) systems.

Automatic transmission fluid (ATF) Fluid used in vehicles with self-shifting or automatic transmissions. automatic transmission fluid (ATF) is another important fluid that should be checked regularly.

Aviation tin snips Cutters designed to cut sheet metal.

Axial load A force in line (same axis) as the centerline of the bearing or shaft.

Axis All gear teeth lie parallel to the centerline, or axis, of the gear.

Axle ratio The gear ratio of the final drive (differential) is called the axle ratio.

Axle windup The movement of the rear axle on a rear-wheel-drive vehicle equipped with a leaf spring-type suspension during acceleration.

B20 A blend of 20% biodiesel with 80% petroleum diesel.

B5 A blend of 5% biodiesel with 95% petroleum diesel.

Babbitt Babbitt is the oldest automotive bearing material. Isaac Babbitt (1799–1862) first formulated this material in 1839. An excellent bearing material, it was originally made from a combination of lead, tin, and antimony.

Back clearance The space behind the ring is called the back clearance.

Back pressure The exhaust system’s resistance to flow. Measured in pounds per square inch (PSI).

Back pressure The exhaust system’s resistance to flow. Measured in pounds per square inch (psi).

Back spacing The distance between the back rim edge and the center section mounting pad of a wheel.

Back taper Back taper is an angle cut opposite to the chamfer so that spline or tooth narrows just behind the chamfered end.

Backfire A mistimed explosion in the cylinder. A backfire can take place with improper torch operation. The flame will go out with a loud snap or pop.

Backorder A backorder is for parts ordered from a supplier but not shipped due to them being out of stock.

Backup camera A camera mounts on the rear of the vehicle that is used to display what is behind a vehicle when the gear selector is placed in reverse.

Baffle A plate or shield used to direct the flow of a liquid or gas.

Balance valve In operation, the opening and closing of the exhaust port occurs many times per second. This sequence of events achieves a steady pressure as the valve balances both the spring pressure and the hydraulic pressure. Because of this action, this type of valve is sometimes called a balance valve.

Balancing bosses (pads) Many connecting rods are made with balancing bosses (pads) so that their weight can be adjusted to specifications.

Ball bearings An anti-friction bearing that uses steel balls between the inner and outer race to reduce friction.

Ball joints A ball and socket joint used in the front suspension to allow up and down and turn motion of the front wheel.

Ball socket assembly An inner tie rod end assembly that contains a ball and socket joint at the point where the assembly is threaded on to the end of the steering rack.

Bank The V-8 engine has four inline cylinders in each of the two blocks that are placed at a 90-degree angle to each other. Each group of four inline cylinders is called a bank.

Bar One bar is the pressure of the atmosphere at sea level, or about 14.7 PSI.

Barometric manifold absolute pressure (BMAP) sensor The barometric manifold absolute pressure (BMAP) sensor is actually a combination of a BARO and MAP sensor in the same housing.

Barometric pressure (BARO) sensor A sensor that measures both the barometric pressure and the absolute pressure in the intake manifold.

Barrel face ring A barrel face ring can replace the outer ring taper on some rings. Barrel faces are found on rectangular rings and on torsionally twisted rings

Barrier hoses A type of refrigerant hose that has a barrier material to precent the escape of the small molecules or refrigerant.

Base brakes Service brakes are the main driver-operated brakes of the vehicle. Service brakes are also called base brakes or foundation brakes.

Base The name for the section of a transistor that controls the current flow through the transistor.

Battery cables Cables that attach to the positive and negative terminals of the battery.

Battery control module (BCM) The battery control module (BCM) is responsible for controlling the operation of the high voltage battery based on the requests from the hybrid control module.

Battery Council International (BCI) Battery sizes are standardized by the Battery Council International (BCI).

Battery density Battery density refers to the amount of energy in kilowatt-hours (kWh) that a battery can store per kilo-gram of mass (kWh per kilograms) or volume (kWh per liter) of volume. The higher the number, the higher the energy density of the battery.

Battery electric vehicles (BEV) A battery electric vehicle (BEV), also called an electric vehicle (EV), uses a high-voltage battery pack to supply electrical energy to an electric motor(s) to propel the vehicle under all driving conditions.

Battery electrical drain test A test to determine if a component or circuit is draining the battery.

Battery Maintainer A battery maintainer is designed to hold the vehicle at a specific voltage throughout the duration of the repair.

Battery management system (BMS) The battery management system (BMS) is an electronic system that manages cells in a battery pack. The BMS monitors and controls the State of charge (SOC), State of health (SOH), State of function (SOF), Temperature and Load balancing/individual cell efficiency.

Bead The part of a tire that is made of wire that the body plies are wrapped around.

Beam-type torque wrench A type of wrench that displays the torque being applied to a fastener by the position of a deflective pointer and a scale, indicating the amount of torque.

Bearing crown The wall thickness of most bearings is largest in the center, called the bearing crown.

Bearing shell An engine bearing is called a bearing shell, which is a steel backing with a surface coating of bearing material. The steel provides support needed for the shaft load.

Bearing splitter A two-part steel device used between a bearing and a gear or other component, which is used to remove the bearing using a hydraulic press.

Bearingized A hard surface created inside a wheel cylinder or master cylinder by forcing a hardened steel ball through the bore.

Bedded-in Some manufacturers recommend that their replacement brake pads be bedded-in or burnished before returning the vehicle to the owner.

Bedplate S A bedplate is a structural member that attaches to the bottom of the block and supports the crankshaft. The oil pan is mounted under the bedplate, which in most cases is also part of the structure and support for the block assembly.

Beehive hold-down A type of hold-down spring used on drum brakes and shaped like a beehive.

Bell housing A bell-shape housing attached between the engine and the transmission.

Bellmouth When an open edge of a brake drum friction surface has a larger diameter than the closed edge, the drum is suffering from bellmouth distortion.

Belt Fabric or woven steel material over the body plies of a tire, and just under the tread area, to help keep the tread from squirming.

Bench grinder An electric motor with a grinding stone and/or wire brush attached at both ends of the armature and mounted on a bench.

Bench testing A test of a component such as a starter before being installed in the vehicle.

Bench vise A bench vise is used to hold components so that work can be performed on the unit.

Bend To shape and/or force into a curve or angle.

BEV Battery electric vehicle.

Bevel gear differential The bevel gear differential uses two bevel gears or spider gears attached to the output shaft of the transmission.

Bevel gear The teeth of a bevel gear are cut at an angle to the outside gear surface. Simple bevel gears have straight-cut teeth similar to those on a spur gear.

Bias voltage In electrical terms, bias is the voltage applied to a device or component to establish the reference point for operation.

Billet A billet crankshaft is machined from a solid piece of forged steel called a billet.

Biodiesel A renewable fuel manufactured from vegetable oils, animal fats, or recycled restaurant grease.

Bipolar transistor A type of transistor that has a base, emitter and collector.

BJI Abbreviation for ball-joint inclination.

Bleed holes In series flow systems, bleed holes or steam slits in the gasket, block, and head perform the function of letting out the steam.

Bleeder valve A threaded valve used to bleed air from a brake hydraulic system.

Blind spot monitor A blind spot monitor is an option that may include more than monitoring the front, rear and sides of the vehicle. It can include cross traffic alert, which can sound an alarm when backing out of a parking space when traffic is approaching from either side.

Block deck The cylinder head is fastened to the top surface of the block. This surface is called the block deck. The deck has a smooth surface to seal against the head gasket.

Block The foundation of any engine. All other parts are either directly or indirectly attached to the block of an engine.

Blocker ring In synchronized construction there are a number of design variations, all are similar and include a hub, a sliding sleeve, a blocker ring, (or stop ring or synchronizer ring), keys, and springs.

Blowby Blowby is the leakage of combustion gases past the rings and blows oil from the cylinder wall.

Bluetooth A short range wireless communication standard named after a Danish king that had a Bluetooth.

BNC connector Coaxial-type input connector. Named for its inventor, Neil Councilman.

Body control module (BCM) Many HVAC systems are controlled by the body control module (BCM).

Body ply A layer of cloth that gives a tire its strength.

Body The body of the vehicle is used to provide the support for the suspension and steering components as well as the powertrain.

Body-on-frame (BOF) vehicles A type of vehicle construction, often used with pickup trucks that use a separate frame and then the body is installed on top.

Bolt circle The diameter (in inches or millimeters) of a circle drawn through the center of the bolt holes in a wheel.

Bolts Most of the threaded fasteners used on vehicles are cap screws. They are called cap screws when they are threaded into a casting. Automotive service technicians usually refer to these fasteners as bolts.

Bonded linings Brake linings that are glued or bonded to the brake shoes.

Boost An increase in air pressure above atmospheric. Measured in pounds per square inch (psi).

Bore The inside diameter of the cylinder in an engine.

Bores The cylinder holes are called bores because they are made by a machining process called boring.

Bottom dead center (BDC) The lowest position in the cylinder that a piston can travel without reversing its direction.

Bound electrons electrons that are close to the nucleus of the atom.

Boundary lubrication When the oil film is thick enough to keep the surfaces from seizing, but can allow some contact to occur.

BOV Blow-off valve (BOV). Also called a dump valve or vent valve, the BOV features an adjustable spring design that keeps the valve closed until a sudden release of the throttle. The resulting pressure increase opens the valve and vents the pressurized air directly into the atmosphere.

Box-end wrench A double-ended tool with one end being like an open-end wrench or open-ended spanner, and the other end being like a box-end wrench or ring spanner. Both ends generally fit the same size of bolt. A box-end wrench is angled 15 degrees to allow it to clear nearby objects.

Boxer A type of engine design that is flat and has opposing cylinders. Called a boxer because the pistons on one side resemble a boxer during engine operation. Also called a *pancake engine.*

Braided ground straps Ground wires that are not insulated and braided to help increase flexibility and reduce RFI.

Brake assist system (BAS) Some vehicles are equipped with a brake assist system (BAS) that applies the brakes with maximum force if the system detects that the driver is making a panic stop.

Brake bleeding A process of removing air from the brake hydraulic system.

Brake block Brake pad material is pressed into a brake block before being heated to become a brake pad.

Brake fade A result of heat buildup. It is the reduction in braking force due to loss of friction between the brake shoes and the drum or between the disc brake pads and the rotor.

Brake fluid level sensor Since the late 1990s, master cylinders use a brake fluid level sensor or switch in the master cylinder reservoir. This sensor lights the red brake warning lamp (RBWL) on the dash if low brake fluid level is detected.

Brake fluid A non-petroleum-based fluid called polyglycol used in hydraulic brake systems.

Brake hardware kits Springs, clips, and other hardware items to replace the original items when the brake lining or pads are replaced.

Brake horsepower (bhp) The horsepower derived from a dynamometer is called brake horsepower (bhp). The horsepower is calculated from the torque readings at various engine speeds (in revolutions per minute or RPM). Horsepower is torque times RPM divided by 5252.

Brake pad The term used to describe the brake friction material used in disc brakes.

Brake pedal position (BPP) sensor An analog brake pedal position signal from the brake pedal-mounted brake pedal position (BPP) sensor. The BPP sensor outputs an analog signal, referenced to 5 volts, that increases or decreases with brake pedal depression.

Brake pipes Lines that carry brake fluid from the master cylinder to the wheel brakes.

Brake shoe holddowns Springs or clips used to hold brake shoes against the backing plate.

Brake shoe return springs While the return springs retract the brake shoes to their unapplied positions, the brake shoe holddowns keep the shoes securely against the support pads on the backing plate.

Brake shoes The part of the brake system upon which the brake lining is attached.

Brake tubing Pipes used to carry brake fluid from the master cylinder to the wheel brakes.

Brake Any device that is designed to slow or stop a mechanism or component.

Branches electrical parts of a parallel circuit.

Breaker bar (flex handle) A long-handled socket drive tool.

Breakout box (BOB) A piece of test equipment that installs between an electrical/electronic component, such as a controller, and the wiring harness.

Breather port Another name for the master cylinder replenishing port (rearward port).

Brinelling A type of mechanical failure used to describe a dent in metal such as what occurs when a shock load is applied to a bearing. Named after Johann A. Brinell, a Swedish engineer.

British thermal unit (BTU) The amount of heat required to raise 1 pound of water 1°F at sea level.

Bronze guides A type of replacement valve guide. Replacement valve guides can be installed to repair worn integral guides. Both cast-iron and bronze guides are available.

Brush-end housing The end of a starter or generator (alternator) where the brushes are located.

Brushes A copper or carbon conductor used to transfer electrical current from or to a revolving electrical part such as that used in an electrical motor or generator.

Bucket Overhead camshaft engines use several different types of valve opening designs. One type opens the valves directly with a bucket.

Bulb test A test to check the operation of certain circuits controlled by the ignition switch.

Bulkhead The panel between the engine compartment and the passenger compartment.

Bump cap A hat that is plastic and hard to protect the head from bumps.

Bump stop A rubber or urethane stop to limit upward suspension travel. Also called a strikeout bumper, suspension bumper, or compression bumper.

Burn kV The spark line voltage is called the burn kV.

Burnished Some manufacturers recommend that their replacement brake pads be bedded-in or burnished before returning the vehicle to the owner.

BUS A term used to describe a communication network.

Bypass valve (Engine Oil and Filters) Either the engine or the filter is provided with a bypass valve that will allow the oil to go around the filter element.

Bypass valve (Turbocharging and Supercharging) Many factory installed superchargers are equipped with a bypass valve that allows intake air to flow directly into the intake manifold, bypassing the supercharger. The computer controls the bypass valve actuator.

Bypass Allows a small part of the coolant to circulate within the engine during warm-up. It is a small passage that leads from the engine side of the thermostat to the inlet side of the water pump. It allows some coolant to bypass the thermostat even when the thermostat is open.

CA Cranking amperes. A battery rating.

Cabin filter A filter located in the air intake of the HVAC system.

Cage The support for rollers or ball bearings.

California Air Resources Board (CARB) A state of California agency which regulates the air quality standards for the state.

Calorie (c) Heat is measured in calories (c). The calorie is a metric unit that expresses the amount of heat needed to raise the temperature of one gram of water one degree Celsius.

Cam chucking Cam chucking is the movement of the camshaft lengthwise in the engine during operation.

Cam follower Overhead camshaft engines use several different types of valve opening designs. One type opens the valves directly with a bucket. One type uses a cam follower, also called a finger follower, that provides an opening ratio similar to that of a rocker arm.

Cam ground Aluminum pistons expand when they get hot. A method of expansion control was devised using a cam ground piston skirt.

Camber roll The camber angle of the front wheels due to caster.

Camber The inward or outward tilt of the wheels from true vertical as viewed from the front or rear of the vehicle. Positive camber means the top of the wheel is out from center of the vehicle more than the bottom of the wheel.

Cam-in-block design An engine where the crankshaft is located in the block rather than in the cylinder head.

Cam-in-block There are two basic areas where the camshaft can be located in an engine. In the engine block. This design is called the cam-in-block design. The camshaft is supported in the block by camshaft bearings and driven by the crankshaft with a gear or sprocket and chain drive. Engines with the cam located in the block are called pushrod or overhead valve (OHV) engines.

Campaign A recall where vehicle owners are contacted to return a vehicle to a dealer for corrective action.

Camshaft bearings There are two basic areas where the camshaft can be located in an engine. In the engine block. This design is called the cam-in-block design. The camshaft is supported in the block by camshaft bearings and driven by the crankshaft with a gear or sprocket and chain drive. Engines with the cam located in the block are called pushrod or overhead valve (OHV) engines.

Camshaft duration Camshaft duration is the number of degrees of crankshaft (not camshaft) rotation for which a valve is lifted off the seat.

Camshaft position (CMP) sensor To get a spark out of an ignition coil, the primary coil circuit must be turned on and off. This primary circuit current is controlled by a transistor (electronic switch) inside the ignition module or (igniter).There are various ways crankshaft position (CKP) sensors or camshaft position (CMP) sensors are used.

Camshaft A shaft with lobes which open valves when being rotated through a chain, belt, or gear from the crankshaft.

CAN Controller Area Network, a type of serial data transmission.

Cap screws Most of the threaded fasteners used on vehicles are cap screws. They are called cap screws when they are threaded into a casting. Automotive service technicians usually refer to these fasteners as bolts.

Capacitance Electrical capacitance is a term used to measure or describe how much charge can be stored in a capacitor (condenser) for a given voltage potential difference. Capacitance is measured in farads or smaller increments of farads such as microfarads.

Capillary action The movement of a liquid through tiny openings or small tubes.

Captive O-ring Captive O-rings use a larger-diameter cross section than standard O-rings placed positively in a shallow groove.

Carbohydrates All life-forms are able to collect, store, and use energy from their environment. In carbon-based biology, the basic energy storage compounds are in carbohydrates, where the carbon atoms are linked by single bonds into a chain.

Carbon dioxide (CO2) Carbon dioxide (CO2) is a colorless and odorless gas which is naturally occurring chemical compound.

Carbon footprint The carbon footprint includes energy-related emissions from human activities, including heat, light, power, refrigeration, and all transport-related emissions from vehicles, freight, and distribution.

Carbon monoxide (CO) A colorless, odorless, and highly poisonous gas. It is formed by the incomplete combustion of gasoline.

Carbon Most of the energy used in the world has been generated by burning organic fuel that contains carbon (abbreviated C). An economy that uses only carbon-based fuels is often referred to as a carbon-based society. Carbon is formed from materials that were once alive on the earth

Carburizing flame A reduction of an oxygen and fuel flame which leads to an excess of fuel (acetylene) gas that results in a carburizing flame. The high acetylene or carburizing flame is the one most commonly used by automotive technicians to heat parts or to solder. More acetylene is burned than oxygen, so the inner cone has a feather. The inner cone is also white. The envelope around the carburizing flame has the same look as the neutral flame and the temperature is about 5700° F (3154° C).

Carcass ply Plies of fabric in a tire that covers the entire tire from bead to bead.

Cardan joints A term used to describe U-joints, also called crossyoke joints. Cardan is named for a sixteenth-century Italian mathematician who worked with objects that moved freely in any direction.

Case hardening To improve wear resistance, some manufacturers harden the crankshaft journals. Methods used to harden the crankshaft journals includes Case hardening, where only the outer portion of the surface is hardened. Case hardening involves heating the crankshaft and adding carbon to the journals, where it causes the outer surface to become harder than the rest of the crankshaft.

Caster The forward or backward tilt of an imaginary line drawn through the steering axis as viewed from the side of the vehicle. Positive caster is where an imaginary line would contact the road surface in front of the contact path of the tire.

Cast-iron guides A type of replacement valve guide. Replacement valve guides can be installed to repair worn integral guides. Both cast-iron and bronze guides are available.

CAT III An electrical measurement equipment rating created by the International Electrotechnical Commission (IEC). CAT III indicates the lowest level of instrument protection that should be in place when performing electrical measurements on hybrid or electric vehicles.

Catalysts A catalyst is a chemical that helps start a chemical reaction, but does not enter into the chemical reaction.

Catalytic converter An emission control device located in the exhaust system that changes HC and CO into harmless H2O and CO2. If a three-way catalyst NOx is also divided into harmless separate nitrogen (N2) and Oxygen (O2).

Catalytic cracking Breaking hydrocarbon chains using heat in the presence of a catalyst.

Category three (CAT III) See CAT III.

Cathode ray tube (CRT) An analog scope uses a cathode ray tube (CRT), similar to some television screens, to display voltage patterns.

Cathode The negative electrode.

Caustic material Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the caustic action will be.

Caustic materials pH value, measured on a scale from 1 to 14, indicates the amount of chemical activity in the soap. Pure water is neutral; on the pH scale, water is pH 7. Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the alkaline action will be.

Cavitate Cavitation occurs when the pump tries to pull oil faster than it can flow from the pan to the pickup. When it cannot get enough oil, it will pull air. This puts air pockets or cavities in the oil stream. A pump is cavitating when it is pulling air or vapors.

CBV Compressor bypass valve (CBV). This type of relief valve routes the pressurized air to the inlet side of the turbocharger for reuse and is quiet during operation.

CCA Cold Cranking Amps. A rating of a battery tested at zero degrees F.

Cells A group of negative and positive plates to form a cell capable of producing 2.1 volts.

Celsius (centigrade) The Celsius scale was devised by taking the freezing point and the boiling point of water and dividing it into 100 equal parts.

CEMF Counter electromotive force.

Center bolt A bolt used to hold the leaves of a leaf spring together in the center. Also called a*centering pin.*

Center link The center part of a parallelogram-type steering linkage.

Center section The section of a wheel that attaches to the hub. Also called the spider.

Center support bearing A bearing used to support the center of a long drive shaft on a rear-wheel-drive vehicle. Also called a *steady bearing.*

Center take-off rack A type of rack-and-pinion steering gear that attaches the tie rods to the center of the rack instead of at the ends of the rack.

Central processing unit A control unit (computer) that processes data from sensors and then applies actuators.

Centrifugal pump A rotodynamic pump that uses a rotating impeller to increase the velocity of a fluid.

Ceramic Brake pads and linings that use synthetic material, such as aramid fibers, instead of steel are usually referred to as: 1. non-asbestos 2. non-asbestos organic (NAO) and 3. non-asbestos synthetic (NAS). These friction materials are often called ceramic in the American aftermarket because they include ceramic fibers, which are usually potassium titanite.

Cerium Since the early 1990s, many converters also contain cerium, an element that can store oxygen. The purpose of the cerium is to provide oxygen to the oxidation bed of the converter when the exhaust is rich and lacks enough oxygen for proper oxidation.

Cetane number The cetane number for diesel fuel is the opposite of the octane number for gasoline. The cetane number is a measure of the ease with which the fuel can be ignited.

CFR Code of Federal Regulations.

Channel A term used to describe a wheel brake being controlled by the antilock brake system controller.

Chapman strut A MacPherson strut-type of suspension used at the rear of the vehicle.

Charge density The more air and fuel that can be packed in a cylinder, the greater the density of the air-fuel charge.

Charge Policy A store's policy that out outlines credit purchases, refunds, and invoicing.

Charging voltage test an electrical test using a voltmeter and an ammeter to test the condition of the charging circuit.

Chart A chart is used to represent data, such as numbers or specifications, along with another variable, such as model or year of vehicle.

Chassis The frame, suspension, steering and machinery of a motor vehicle.

Cheater bar A pipe or other object used to lengthen the handle of a ratchet or breaker bar. Not recommended to be used as the extra force can cause the socket or ratchet to break.

Check balls Check balls are used in the valve body to allow hydraulic circuits to share a common passage. The check balls in these valves are usually made of steel, but they can be nylon, rubber, or some composite material as well.

Check valve A check valve contains a spring-type metallic disc or reed that closes under exhaust back pressure. Check valves are located between the air manifold and the switching valve(s). If exhaust pressure exceeds injection pressure or if the air pump fails, the check valve spring closes the valve to prevent reverse exhaust flow.

Chill spots Hard spots on a brake rotor or brake drum.

Chisel A sharpened tool used with a hammer to separate two pieces of an assembly.

CHMSL Centrally High Mounted Stop Light; the third brake light.

Christmas tree clips Plastic clips used to hold interior panels in place. The end that goes into a hole in the steel door panel is tapered and looks like a Christmas tree.

Circuit breakers A mechanical unit that opens an electrical circuit in the event of excessive current flow.

Circuit A circuit is the path that electrons travel from a power source, through a resistance, and back to the power source.

Clamping diode A diode installed in a circuit with the cathode toward the positive. The diode becomes forwarded biased when the circuit is turned off thereby reducing the high voltage surge created by the current flowing through a coil.

Clamping force Clamping force is the amount of force exerted on a gasket.

Clamps Clamps are U-bolts that come in different sizes that correspond to the pipe diameter that secure the slip joint connections that are attached to some exhaust system components. Clamps may also be used to attach hangers in some applications.

Class 2 A type of BUS communication used in General Motors vehicles.

Claw poles The magnetic points of a generator (alternator) rotor.

Clean Air Act A government action in 1990 to improve air quality.

Clicker-type torque wrench A clicker-type torque wrench is first set to the specified torque and then it "clicks" when the set torque value has been reached.

Clock generator A crystal that determines the speed of computer circuits.

Clock time The time charged to complete a service procedure, which is determined by the actual time spent.

Clock-in A method of payment that technicians may use and is the actual time spent on the repair as a basis for payment. Being paid for the actual time spent is often called straight time or clock time.

Clockspring A flat ribbon of wire used under the steering wire to transfer airbag electrical signals. May also carry horn and steering wheel control circuits depending on make and model of vehicle.

Closed loop As soon as the oxygen sensor (O2S) is capable of supplying rich and lean signals, PCM adjustments can be made to fine-tune the correct air-fuel mixture. This checking and adjusting of the PCM is called closed-loop operation.

Cloud point Cloud point is the low-temperature point when the waxes present in most diesel fuels tend to form crystals that can clog the fuel filter.

Cluster gears All manual transmissions/transaxles use a countershaft (also called a lay shaft or cluster shaft) to provide the other set of gears necessary to achieve the changes in gear ratios. The gears on the countershaft are called cluster gears or counter gears

Cluster shaft All manual transmissions/transaxles use a countershaft (also called a lay shaft or cluster shaft) to provide the other set of gears necessary to achieve the changes in gear ratios. The gears on the countershaft are called cluster gears or counter gears

Clutch cooling flow solenoid (CCFS) The solenoid that controls hydraulic oil for cooling of clutches of a dual clutch automatic transmission.

Clutch disc A clutch assembly consists of a clutch disc that is splined to the input shaft of the transmission/transaxle. When the driver depresses the clutch pedal, a throw-out bearing (release bearing) is forced against the fingers of the pressure plate.

Clutch drum The pressure plate and clutch assembly components fit into either a clutch drum (retainer) or a machined bore in the transmission case.

Clutch fork A lever that is pulled or pushed by a cable or hydraulic actuator on one end and pushes on the release bearing on the other end.

Clutch pack The multiple-plate clutch consists of plates, a piston, drum (retainer), and snap ring. Hydraulic pressure acts upon the clutch piston which moves in the drum. The piston movement compresses the plates together to provide either a holding or driving function. When the pressure is released, the piston returns to an unapplied position via a return spring assembly. This entire assembly is commonly known as a clutch pack.

Clutch pedal position switch A clutch pedal position switch is used to signal the starter circuit that the clutch is disengaged which prevents starter operation unless the clutch pedal is depressed.

Clutch pressure cut (CPCUT) The safety valve that controls pressure-dumping in the hydraulic system in a dual clutch automatic transmission.

Clutch shift pressure solenoid Controls hydraulic pressure for odd clutch or shifting in a dual clutch automatic transmission.

Clutch Any device that is made to couple one mechanism with another to cause each to rotate at the same speed.

Coach A role played by a mentor.

Coast (or concave) side While decelerating, the drive pinion contacts the ring teeth on its coast, or concave side.

Coast-down stall When an engine stalls coming to a stop this called a coastdown stall.

Coefficient of friction A measure of the amount of friction usually measured from 0 to 1. A low number (0.3) indicates low friction and a high number (0.9) indicates high friction.

Coil spring clutch A coil spring style of pressure plate uses coil springs and three or four release levers. A coil-spring-style pressure plate is also called the lever style .

Coil springs Coil springs are made of special round spring steel wrapped in a helix shape.

Coil A coil provides the magnetic pull to a movable armature (arm).

Coil-on-plug (COP) ignition (also coil-byplug, coil-near-plug,coil-over-plug) COP ignition Coil-on-plug ignition. This term describes ignition systems where each spark plug has its own coil assembly mounted directly over top of it. Also known as coil-over-plug, coil-by-plug, or coil-near-plug ignition.

Cold chisel A type of chisel used to remove rivets or to break off fasteners.

Cold Filter Plugging Point Cold Filter Plugging Point (CFPP) is the lowest temperature at that a specified volume of diesel type of fuel can pass through a standardized filtration device in a specified time when cooled under certain conditions.

Cold solder joint A type of solder joint that was not heated to high enough temperature to create a good electrical connection. Often a dull gray appearance rather than shiny for a good solder connection.

Collapsible column A steering column which collapses in the event of a front impact to the vehicle to help prevent injury to the driver.

Collector The name of one section of a transistor.

Column-mounted electric power steering (C-EPS) Column mounted. Column-mounted electric power steering (C-EPS) has sensors and the assist motor located inside the vehicle so they are not exposed to the heat and outside elements as is the rack-mounted system.

Combination circuit Another name for a series-parallel electrical circuit.

Combination valve A valve used in the brake system that performs more than one function, such as a pressure differential switch, metering valve, and/or proportioning valve.

Combination wrench A wrench that is open ended at one end and has a box end at the other end.

Combo Charging System (CCS) The SAE Combo Charging System (CCS) is a DC Fast Charging (DCFC) connector standard used by BMW, Ford, GM, VW, and other vehicle makers.

Combustion chamber The space left within the cylinder when the piston is at the top of its combustion chamber.

Combustion The rapid burning of the air-fuel mixture in the engine cylinders, creating heat and pressure.

Comfort zone The temperature range where humans feel comfortable, usually between 68°F and 78°F (20°C and 26°C).

Commission pay Income to a service technician determined by the number of hours that a flat-rate manual states in the time it should take multiplied by the hourly rate of the technician.

Communication The exchanging of information from one person to another. Communication may be verbal, non-verbal, or written.

Commutator segments The ends of the copper armature windings are soldered to commutator segments. The electrical current that passes through the field coils is then passed to the commutator of the armature by brushes that can move over the segments of the rotating armature.

Commutator-end housing The end of a starter motor that contains the commutator and brushes. Also called the brush end housing.

Compacted graphite iron (CGI) Compacted graphite iron (CGI) has increased strength, ductility, toughness, and stiffness compared to gray iron. If no magnesium is added, the iron will form gray iron when cooled, with the graphite present in flake form. If a very small amount of magnesium is added, more and more of the sulfur and oxygen form in the molten solution, and the shape of the graphite begins to change to compacted graphite forms. It has higher strength, stiffness, and toughness than gray iron.

Companion cylinder The cylinder that fires at the same time in a wastespark- type ignition system.

Companion flange The part that attaches to the driveshaft at the differential assembly.

Compensating port The port located in the master cylinder that allows excess fluid to return to the reservoir. See also vent port.

Complete circuit A type of electrical circuit that has continuity and current would flow if connected to power and ground.

Component identification (CID) The global (generic) data is used by most state emission programs. Global OBD-II displays often use hexadecimal numbers. Hexadecimal coding is also used to identify tests (test identification [TID] and component identification [CID]).

Composite camshaft Composite camshafts use a lightweight tubular shaft with hardened steel lobes press-fitted over the shaft.

Composite headlights A type of headlights that uses a separate, replaceable bulb.

Composite leaf spring A leaf spring made from a composite material, which usually includes fiberglass and epoxy resin.

Composite rotors Composite rotors use a steel center section with a cast-iron wear surface. These composite rotors are lighter in weight than conventional cast-iron rotors.

Compound circuit Another name for a series-parallel electrical circuit.

Comprehensive component monitor (CCM) Comprehensive component monitor (CCM). This monitor watches the sensors and actuators in the OBD-II system. Sensor values are constantly compared with known-good values stored in the PCM's memory.

Compressed natural gas (CNG) Another alternative fuel that is often used in fleet vehicles is compressed natural gas (CNG), and vehicles using this fuel are often referred to as natural gas vehicles (NGVs).

Compression ratio (CR) The ratio of the volume in the engine cylinder with the piston at bottom dead center (BDC) to the volume at top dead center (TDC).

Compression rings Piston rings are classified into two types,.one type is two compression rings, located toward the top of the piston'

Compression spring A spring which is part of a starter drive that acts on the starter pinion gear.

Compression test Can be used to test the condition of valves and piston rings.

Compressor speed sensor The air conditioning (A/C) compressor speed sensor, also called a lock or belt lock sensor, is used so the ECM will know if the compressor is running, and by comparing the compressor and engine speed signals, the ECM can determine if the compressor clutch or drive belt is slipping excessively.

Concentric clutch A clutch design where both plates share the same vertical plane provides a shorter assembly.

Concentric Perfectly round the relationship of two round parts on the same center.

Condenser An A/C system component located in front of the radiator in most vehicles that removes heat from the refrigerant and causes it to change from a gas to a liquid.

Conduction Conduction is the process of the heat traveling from a hotter part to a colder part of the same object or by direct contact.

Conductor A material that conducts electricity and heat. A metal that contains fewer than four electrons in its atom's outer shell.

Cone (inner ring) The inner race of a wheel bearing. Also a tapered metal cone with a hole in the center used to center a hubless brake drum or rotor on a brake lathe.

Conformability The ability of bearing materials to creep or flow slightly to match shaft variations is called conformability

Conicity A fault in a tire that causes it to be shaped like a cone and causes a pull.

Connecting rod bearing journal The crankshaft changes the up-and-down (reciprocating) motion of the pistons into rotary motion. The connecting rod is connected to a part of the crankshaft called a crank throw, crankpin, or connecting rod bearing journal.

Connecting rod Any rod connecting two moving parts in a mechanism such as piston which is attached to a crankshaft with a connecting rod.

Constant-mesh gear With constant-mesh gears, the shift linkage moves the 5-reverse synchronizer sleeve away from the fifth speed gear and toward the reverse speed gear when reverse is selected.

Constrained layer shims (CLS) Many original equipment brake pads use constrained layer shims (CLS) on the back of the brake pads. These shims are constructed with dampening material between two layers of steel.

Constructeurs Européens d' Automobiles (ACEA) Association des Constructeurs European d'Automobiles represents most of the Western European automobile and heavy-duty truck market. The organization uses different engines for testing than those used by API and SAE, and the requirements necessary to meet the ACEA standards are different yet generally correspond with most API ratings.

Continuity Instrument setup to check wiring, circuits, connectors, or switches for breaks (open circuit) or short circuits (closed circuit).

Continuously variable transmission (CVT) A transmission that uses two variable-width pulleys and a belt to change ratios from the lowest to the highest in a continuous, stepless manner instead of a group of fixed ratios.

Control arms A suspension link that connects a knuckle or wheel flange to the body or frame of the vehicle.

Control cables Control cables attach to the parking brake pedal, lever, or handle inside the vehicle.

Control module An electronic device used to control the operation of activities.

Controller A term that is usually used to refer to a computer or an electronic control unit (ECU).

Convection The movement of heat from the friction surface of a brake drum or rotor to the cooler part of the drum or rotor.

Conventional theory The theory that electricity flows from positive (+) to negative (−).

Coolant recovery system When the system cools, the pressure in the cooling system is reduced and a partial vacuum forms. This pulls the coolant from the plastic container back into the cooling system, keeping the system full.

Coolant The liquid mixture in the engine cooling system.

Cooling fins Heat is transferred through the tube wall and soldered joint to cooling fins. The fins are exposed to the air that flows through the radiator, which removes heat from the radiator and carries it away.

Cooling jacket Cylinders are surrounded by cooling passages. These coolant passages around the cylinders are often called the cooling jacket.

Cooling load The removal of heat to provide a comfortable environment.

Cooperative education Cooperative education programs are formal programs of study at a high school or college where the student attends classes at the school, and also works at a local shop or dealership.

Copper Copper is a soft metal with very high thermal and electrical conductivity and is used in most brake lining/pads.

Copper-lead alloy Copper-lead alloy is a stronger and more expensive bearing material than babbitt. It is used for intermediate- and high-speed applications. Tin, in small quantities, is often alloyed with the copper-lead bearings. This bearing material is most easily damaged by corrosion from acid accumulation in the engine oil. Also known as Trimetal.

Core charge An amount of money paid when a rebuildable part is purchased and refunded when the worn or defective part is returned to the parts store.

Core plugs Openings in the block are plugged with core plugs. Core plugs are also called freeze plugs or frost plugs.

Core tubes Are made from 0.0045 to 0.012 inch (0.1 to 0.3 mm) sheet brass or aluminum, using the thinnest possible materials for each application. The metal is rolled into round tubes and the joints are sealed with a locking seam.

Corrected torque This is a calculated number determined by the actual torque multiplied by the correction factor. There are subtle differences between each of the testing standards. The result after the correction factor has been applied is called corrected torque.

Correction factor A correction factor is a value that is multiplied to the data values so that engine performance can be compared, regardless of weather conditions.

Corrosion resistance By-products of combustion form acids in the oil. The bearings' ability to resist attack from these acids is called corrosion resistance.

Cotter pins A soft metal pin that is used to keep parts from loosening.

Coulomb A measurement of electrons. A coulomb is 6.28 x 101 (6.28 billion billion) electrons.

Counselor A Counselor is concerned about, but not trained to offer advice on personal life decisions.

Counter electromotive force (CEMF) A voltage produced by a rotating coil such as a starter motor where the armature is being moved through a magnetic field.

Counter gears All manual transmissions/transaxles use a countershaft (also called a lay shaft or cluster shaft) to provide the other set of gears necessary to achieve the changes in gear ratios. The gears on the countershaft are called cluster gears or counter gears

Countershaft All manual transmissions/transaxles use a countershaft (also called a lay shaft or cluster shaft) to provide the other set of gears necessary to achieve the changes in gear ratios. The gears on the countershaft are called cluster gears or counter gears

Counterweights Crankshafts are balanced by counterweights, which are cast, forged, or machined as part of the crankshaft. A crankshaft that has counterweights on both sides of each connecting rod journal is called fully counterweighted.

Country of origin The first number of the vehicle identification number (VIN), which identifies where the vehicle was assembled.

Coupling phase When the speed ratio is 90° or more, fluid flow in the torque converter is mostly rotary flow and the angle of flow from turbine to stator increases. This is called the coupling phase.

Courtesy lights General term used to describe all interior lights.

Cow Catcher A large spring seat used on many General Motors MacPherson strut units. If the coil spring breaks, the cow catcher is designed to prevent one end of the spring from moving outward and cutting a tire.

CPA Connector Position Assurance. A clip used to help hold the two parts of electrical connector together.

CPU Central Processor Unit.

Cracking A refinery process in which hydrocarbons with high boiling points are broken into hydrocarbons with low boiling points.

Cradle A structural support for the engine and transaxle on a front-wheel-drive vehicle.

Crank throw The crankshaft changes the up-and-down (reciprocating) motion of the pistons into rotary motion. The connecting rod is connected to a part of the crankshaft called a crank throw, crankpin, or connecting rod bearing journal.

Cranking vacuum test Measuring the amount of manifold vacuum during cranking is a quick and easy test to determine if the piston rings and valves are properly sealing.

Crankpin The crankshaft changes the up-and-down (reciprocating) motion of the pistons into rotary motion. The connecting rod is connected to a part of the crankshaft called a crank throw, crankpin, or connecting rod bearing journal.

Crankpins The rod bearing journals, also called crankpins, are offset from the centerline of the crank.

Crankshaft centerline The connecting rods and their bearings are attached to a bearing journal on the crank throw. The crank throw is offset from the crankshaft centerline. The distance between the centerline of the connecting rod bearing journal and the centerline of the crankshaft main bearing journal determines the stroke of the engine.

Crankshaft Position (CKP) sensor To get a spark out of an ignition coil, the primary coil circuit must be turned on and off. This primary circuit current is controlled by a transistor (electronic switch) inside the ignition module or (igniter).There are various ways crankshaft position (CKP) sensors or camshaft position (CMP) sensors are used.

Crankshaft Any shaft driven by a crank.

Creep Slight movement of the vehicle when the engine is at idle speed and the brakes are released is called creep.

Creeper A small platform mounted on short casters designed for a service technician to lie down and maneuver under a vehicle.

Crest The outside diameter of a bolt measured across the threads.

Crimp-and-seal connectors A type of electrical connector that has glue inside which provides a weather-proof seal after it is heated.

Critical thinking The process of analyzing and evaluating information and making a conclusion is called critical thinking.

Crosshatch finish The hone is stroked up and down in the cylinder as it rotates to produce a crosshatch finish on the cylinder wall which aides in proper ring break-in

Cross-steer linkage A type of steering linkage commonly used on light and medium trucks.

Cross-traffic alert A driver alert system that sounds an alarm when backing out of a parking space and traffic is approaching from either side.

Crowfoot socket A type of socket that slips onto the side of the bolt or nut. Used where direct access from the top is restricted.

Crown The tooth root is the depression lying between two teeth, and the crown is the very top of each tooth.

Cruise control A system that maintains the desired vehicle speed. Also called speed control.

Crush When the bearing is installed, each end of the bearing shell is slightly above the parting surface. When the bearing cap is tightened, the ends of the two bearing shells touch and are forced together. This force is called bearing crush. Crush holds the bearing in place and keeps the bearing from turning when the engine runs.

Cubic feet per minute (cfm) The cfm rating is the volume a vacuum pump can pump.

Cup (outer ring) Rubber seals that have a lip that forces outward when pressure is applied.

Cup design A design of an oxygen sensor that uses a shape like a cup or thimble.

Cuppy tire wear Scalloped tire wear usually on the inside or outside edges caused by defective or worn shock absorbers or other faults in the suspension system.

Cushion spring In the space between the friction surfaces of a clutch disc which is a wavy spring steel material.

Custom bending Used in exhaust system fabrication when there is no program card or existing pipe. Applications for which custom may be necessary include installing other than the original.

Customer pay (CP) Customer pay (CP) means that the customer will be paying for the service work at a dealership rather than the warranty.

Customer satisfaction survey A customer satisfaction survey is a study of a person's perceived satisfaction with a product or service. A completed survey provides answers for a list of questions that a company has concerning their products or service.

Customer Satisfaction Customer satisfaction is defined as the customer's overall feeling of satisfaction with an interaction with the store. Customer satisfaction recognizes the difference between customer expectations and customer perceptions. Satisfaction may develop quickly or may be refined over time.

CV joint boot The covering over a constant velocity joint made from rubber, thermoplastic, or urethane.

Cycle A cycle is a complete series of events that continually repeats. Most automobile engines use a four-stroke cycle.

Cylinder head temperature (CHT) Some vehicles are equipped with cylinder head temperature (CHT) sensors.

Cylinder leakage test A test that involves injecting air under pressure into the cylinders one at a time. The amount and location of any escaping air helps the technician determine the condition of the engine. The air is injected into the cylinder through a cylinder leakage gauge into the spark plug hole.

Cylinder A piston chamber in a internal combustion engine.

Damper drive A compressor-drive pulley with dampers/cushions to remove pulsations and no clutch.

Darlington pair Two transistors electrically connected to form an amplifier. This permits a very small current flow to control a large current flow. Named for Sidney Darlington, a physicist at Bell Laboratories from 1929 to 1971.

Data link connector (DLC) A multi-pin diagnostic connection port for vehicles used to interface a scan tool with control modules.

Daytime running lights (DRLs) Lights that are located in the front of the vehicle and come on whenever the ignition is on. In some vehicles, the vehicle has to be moving before they come on. Used as a safety device on many vehicles and required in many countries such as Canada since 1990.

DC coupling A signal transmission that passes both AC and DC signal components to the meter. (Also see AC coupling.)

DCFC (DC Fast Charge) Level 3 chargers are often called a DCFC (DC Fast Charge) or DC Quick Charge (DCQC).

Dead-blow hammer A type of hammer that has lead shot (small pellets) inside a steel housing, which is then covered with a plastic covering. Used to apply a blunt force to an object.

Deceleration sensors A sensor mounted to the body frame of a vehicle that detects and measures the deceleration of the vehicle. Used to control the activation of the airbags and vehicle stability systems.

Decibel (dB) A unit of the magnitude of sound.

Decimal point Decimals are used to represent fractions of a unit by using a dot called a decimal point to indicate that the number is a decimal.

Decking the block The block deck must be resurfaced in a surfacing machine that can control the amount of metal removed when it is necessary to match the size of the combustion chambers. This procedure is called decking the block.

Deep cycling The full discharge and then the full recharge of a battery.

Default gear A default (or limp-in) gear is the forward speed that is used if there is a failure in the electronic or computer system. If neither solenoid is engaged, then either second or third gear is actuated, depending on the exact make and model of the transmission or transaxle.

Default position The actuator is a DC electric motor and is often called a servomotor. The throttle plate is held in a default position by a spring inside the throttle body assembly.

Degrees A degree is 1/360th of a circle.

Delta pressure feedback EGR (DPFE) sensor Most Fords use an EGR monitor test sensor called a delta pressure feedback EGR (DPFE) sensor. This sensor measures the pressure differential between two sides of a metered orifice positioned just below the EGR valve's exhaust side. Pressure between the orifice and the EGR valve decreases when the EGR opens because it becomes exposed to the lower pressure in the intake. The DPFE sensor recognizes this pressure drop, compares it to the relatively higher pressure on the exhaust side of the orifice, and signals the value of the pressure difference to the PCM.

Delta pressure method Changing inflation pressure (usually requires lowering the inflation pressure by 5 to 10 PSI). This method is called the delta pressure method. The term delta refers to a change and is named for the Greek letter delta (Δ).

Delta winding A type of stator winding where all three coils are connected in a triangle shape. Named for the triangle-shape Greek capital letter.

Demand delivery system (DDS) Given the experience with both ERFS and MRFS, a need was recognized to develop new returnless technologies that could combine the speed control and constant injector pressure attributes of ERFS together with the cost savings, simplicity, and reliability of MRFS. This new technology also needed to address pulsation dampening/hammering and fuel transient response. Therefore, the demand delivery system (DDS) technology was developed.

Department of Transportation (DOT) The statutes pertaining to automotive brake systems are part of the Federal Motor Vehicle Safety Standards (FMVSS) established by the United States Department of Transportation (DOT).

Desiccant An ingredient, such as silica gel used to remove moisture from air. Used in electronic systems that uses air shocks or springs.

Despiking diode Another name of clamping diode.

Destination charging Hotels and motels often provide charging stations known as destination charging. Hotels are adding chargers to their properties to help attract EV drivers traveling on long trips.

Detonation A violent explosion in the combustion chamber created by uncontrolled burning of the air-fuel mixture; often causes a loud, audible knock. Also known as *spark knock* or *ping*.

DEX-COOL DEX-COOL, developed by Havoline, is just one brand of OAT coolant, which has been used in General Motors vehicles since 1996. DEX-COOL uses ethylhexanoic acid (2-EH) as a corrosive inhibitor. 2-EH is prone to damage plastics, such as Nylon 6.6 used in intake manifold gaskets and radiators

Diagnostic executive On OBD-II systems, the powertrain control module (PCM) incorporates a special segment of software. On Ford and GM systems, this software is called the diagnostic executive.

Diagnostic trouble codes (DTC) An alphanumeric or numeric sequence indicating a fault in a vehicle operating system. Each sequence corresponds to a specific malfunction.

Diagonal pliers Pliers designed to cut wire and to remove cotter keys. Also called *side cuts* or *dike pliers*.

Diagram A diagram is a graphic design that explains or shows the arrangement of parts.

Die grinder A handheld air-operated tool used with a grinding stone or a wire brush.

Die A die is used to cut threads on round rods or studs.

Dielectric Insulating materials are commonly called a dielectric. These substances are a poor conductors of electricity and can include air, mica, ceramic, glass, paper, plastic, or any similar nonconductive materials.

Diesel exhaust fluid (DEF) Urea also called Adblue used in some diesel engines' exhaust system to reduce emissions.

Diesel exhaust particulate filter (DPF) Diesel exhaust particulate filters (DPFs) are used in all light-duty diesel vehicles, since 2007, to meet the exhaust emissions standards.

Diesel oxidation catalyst (DOC) Diesel oxidation catalysts (DOC) are used in all light-duty diesel engines, since 2007. They consist of a flow-through honeycomb-style substrate structure that is wash coated with a layer of catalyst materials, similar to those used in a gasoline engine catalytic converter.

Diesohol Standard #2 diesel fuel combined with up to 15% ethanol.

Diff An abbreviation or slang for differential.

Differential case The ring gear is attached to a differential case that also contains small beveled spider gears or pinion gears.

Differential pressure sensor (DPS) Differential pressure sensors are used to monitor the soot loading of a particulate filter. The DPF differential pressure sensor (DPS) has two pressure sample lines. One line is attached before the DPF and the other is located after the DPF

Digital computer A computer that uses on and off signals only. Uses an A to D converter to change analog signals to digital before processing.

Digital display A digital display uses numbers to indicate values, such as vehicle speed'

Digital EGR valve General Motors used a digital EGR valve design on some engines. Unlike vacuum-operated EGR valves, the digital EGR valve consists of three solenoids controlled by the powertrain control module (PCM). Each solenoid controls a different size orifice in the base–small, medium, and large.

Digital multimeter (DMM) A digital multimeter is capable of measuring electrical current, resistance, and voltage.

Digital storage oscilloscope (DSO) A digital scope takes samples of the signals that can be stopped or stored and is, therefore, called a digital storage oscilloscope, or DSO.

Diode An electrical device that allows current to flow in one direction only.

Dipstick The oil level indicator which is commonly called a dipstick.

Direct drive A drive train that rotates the output shaft at the same speed as the input shaft. A direct drive has a gear ratio of 1:1.

Direct injection (DI) In a direct injection (abbreviated DI) diesel engine, fuel is injected directly into the cylinder.

Direct shift gearbox (DSG) Another term used to describe a dual-clutch automatic transmission/transaxle.

Direct-drive electric power steering (D-EPS) The rack-mounted system has the assist motor attached to the rack and is often called a rack-and pinion electric power steering (R-EPS) system. Another design has the assist motor surrounding the rack and this style is called a direct-drive electric power steering (D-EPS) system.

Disc brakes A type of wheel brake that squeezes two brake pads on both sides of a rotor or disc.

Disc thickness variation (DTV) A variation in the thickness of the rotor, commonly called disc thickness variation (DTV) can cause brake pedal pulsation during braking.

Discharge air temperature (DAT) sensor The discharge air temperature (DAT) sensor is located at the outlet of the vents. The purpose of this sensor is to inform the controller of the actual temperature at the discharge ducts.

Discharge line The line that connects the compressor discharge port to the condenser.

Discharge stroke The compressor piston movement that pumps refrigerant out of the cylinder.

Discs (disks) Another name for brake rotors. Also spelled disks. See brake rotor.

Displacement The total volume displaced or swept by the cylinders in an internal combustion engine.

Distillation the process of purification through evaporation and then condensation of the desired liquid.

Distortion The act of twisting or altering something out of its true, natural, or original state. The head should be checked in five planes. Checking the cylinder head gasket surface with a precision straightedge in five planes checks the head for warpage, distortion, bend, and twist.

Division A specific segment of a waveform, as defined by the grid on the display.

DMM Digital multimeter. A digital multimeter is capable of measuring electrical current, resistance, and voltage.

Dog Tracking A term used to describe the condition where the rear wheels do not follow directly behind the front wheels. Named for way many species of dogs run with their rear paws offset toward one side so their rear paws will not hit their front paws while running.

Doping The adding of impurities to pure silicon or germanium to form either P or N type material.

DOT 3 Rating of the most commonly specified brake fluid.

DOT 4 A brake fluid rating for polyglycol.

DOT 5.1 The highest rated polyglycol brake fluid.

DOT 5 Silicone brake fluid rating.

DOT tire code The Department of Transportation tire code. The first two letters identify the manufacturer and location. The last three or four numbers are the build date code.

Double flare A tubing end made such that the flare area has two wall thickness'.

Double knock If the piston pin is loose in the piston or in the connecting rod, it makes a sound while the engine is running. This is often described as a double knock.

Double overhead camshaft (DOHC) An engine design with two camshafts above each line of cylinders one for the exhaust valves and one for the intake valves.

Double roller chain In camshaft chain drives, if two chains are used side by side, this type of chain is called a double roller chain.

Double-Cardan joints Two Cardan-style U-joints are joined together.

Double-cut file A file that has two rows of teeth that cut at an opposite angle.

Double-trailing brake The least powerful non-servo drum brake is the double-trailing brake. This design has two trailing shoes and does not use any self energization. Both shoes have the same size and shaped linings that are applied with equal force by a pair of single-piston wheel cylinders.

DPDT Double-pole, double-throw switch.

DPST Double pole, single throw switch.

Drift A mild pull that does not cause a force on the steering wheel that the driver must counteract (also known as lead). Also refers to a tapered tool used to center a component in a bolt hole prior to installing the bolt.

Drive (or convex) side While a vehicle accelerates, the drive pinion contacts the ring teeth on its drive, or convex side.

Drive cycle A drive pattern is called a drive cycle. The drive cycle is different for each vehicle manufacturer but a universal drive cycle may work in many cases. in many cases, performing a universal drive cycle will reset most monitors in most vehicles.

Drive gear A drive gear is the source of power or rotation. Gear ratio is expressed as the number of rotations the drive gear must make in order to rotate the driven gear through one revolution.

Drive pinion gear The driveshaft applies torque to the drive pinion gear that meshes below the center line of a ring gear.

Drive plate The drive plate is attached to the compressor shaft. The drive plate is also called an armature or disc, and the pulley is also called a rotor.

Drive shaft A shaft that transfers engine torque from the output of the transmission to the rear axle (differential) assembly.

Drive size The size in fractions of an inch of the square drive for sockets.

Drive-by-wire Another term for electronic throttle control. See *ETC*.

Drive-end (DE) housing The end of a starter motor that has the drive pinion gear.

Drive-end housing 60 A starter consists of the main structural support called the field housing, one end of which is called a commutator-end (or brush-end) housing and the other end a drive-end housing. The drive-end housing contains the drive pinion gear, which meshes with the engine flywheel gear teeth to start the engine.

Driveline angles The angles of the driveshaft at the front and rear, which are equal, plus or minus 0.5 degrees.

Driven gear A driven gear is turned by the drive gear.

Driver selector switch The driver selector switch is a two- or three-mode switch, usually located in the center console, and is an input to the suspension control module.

Driveshaft runout A measurement of the amount a driveshaft is from perfectly round when rotated.

Driveshaft Driveshaft is the term used by the Society of Automotive Engineers (SAE) to describe the shaft between the transmission and the rear axle assembly on a rear-wheel-drive vehicle. General Motors and some other manufacturers use the term propeller shaft or prop shaft to describe this same part. The SAE term will be used throughout this textbook.

Drum brakes A type of wheel brake that uses expanding brake shoes inside a brake drum.

Dry bulb temperature Dry bulb temperature is the temperature of a room where the thermometer is shielded from moisture.

Dry cylinder sleeve The cast-iron cylinder sleeves are either cast into the aluminum block during manufacturing or pressed into the aluminum block. These sleeves are not in contact with the coolant passages and are called dry cylinder sleeves.

Dry park test A test of steering and/or suspension components. With the wheels in the straight ahead position and the vehicle on flat level ground, have an assistant turn the steering wheel while looking and touching all steering and suspension components looking for any looseness.

Dry sump In a dry sump system, the oil pan is shallow and the oil is pumped into a remote reservoir. In this reservoir, the oil is cooled and any trapped air is allowed to escape before being pumped back to the engine. A dry sump system uses an externally mounted oil reservoir.

Dual cell A design of a wide-band oxygen sensor that uses two cells.

Dual inline pins (DIP) A type of electronic chip that has two parallel lines of pins.

Dual overhead camshaft (DOHC) An engine design with two camshafts above each line of cylinders one for the exhaust valves and one for the intake valves.

Dual-diaphragm vacuum booster Dual-diaphragm or tandem-diaphragm vacuum boost are designed to increase the total area without increasing the physical diameter of the booster.

Dual-position actuator A dual-position actuator is able to move either open or closed. An example of this type of actuator is the recirculation door, which can be either open or closed.

Dual-servo brake A drum brake design where the primary (forward facing) brake shoe exerts force against the secondary (rearward facing) brake shoe during braking while the vehicle is traveling forward.

Dual-stage airbags Airbags that can deploy either with minimum force or full force or both together based on the information sent to the airbag controller regarding the forces involved in the collision.

Dual-zone Dual-zone air distribution allows the driver and passenger to select different temperature settings.

Ductile iron Ductile iron is used as a piston ring material in some automotive engines, which is very flexible and can be twisted without breaking.

Dump valve Blow-off valve (BOV). Also called a dump valve or vent valve, the BOV features an adjustable spring design that keeps the valve closed until a sudden release of the throttle. The resulting pressure increase opens the valve and vents the pressurized air directly into the atmosphere.

Duo-Servo Brand name of a Bendix dual-servo drum brake.

Durometer The hardness rating of rubber products named for an instrument used to measure hardness that was developed about 1890.

Duty cycle Refers to the percentage of on-time of the signal during one complete cycle.

DVOM Digital volt-ohm-milliammeter.

Dwell section Dwell is the amount of time that the current is charging the coil from the transistor-on point to the transistor-off point.

Dwell The amount of time, recorded on a dwell meter in degrees, that voltage passes through a closed switch.

Dye-penetrant testing Dye-penetrant testing is often used on pistons and other parts constructed of aluminum or other nonmagnetic material.

Dynamic compression test A running compression test, also called a dynamic compression test, is done with the engine running rather than during engine cranking as is done in a regular compression test.

Dynamic rear proportioning (DRP) Electronic brake proportioning (EBP) in the ABS is accomplished by monitoring brake switch input and front- and rear-wheel speeds, and reducing pressure to the rear brakes as needed using the ABS solenoids when there is a difference in wheel deceleration rates.

Dynamic seals Seals used between two surfaces where there is movement.

Dynamic voltage Voltage measured with the circuit energized and current flowing through the circuit.

Dynamometer (dyno or dyn) A dynamometer (often abbreviated as dyno or dyn) places a load on the engine and measures the amount of twisting force the engine crankshaft places against the load.

E10 A fuel blend of 10% ethanol and 90% gasoline.

E2PROM Electronically erasable programmable read only memory. A type of memory that can be electronically erased and reprogrammed.

E85 A fuel blend of 85% ethanol and 15% gasoline.

Easy out A tool used to extract a broken bolt.

ECA Electronic Control Module. The name used by Ford to describe the computer used to control spark and fuel on older model vehicles.

Eccentric cam An offset bolt and washer used to change an alignment angle.

Eccentric distortion A fault with brake drums where the geometric centerline of the drum is different from the centerline of the axle.

ECM Electronic control module on a vehicle.

ECU Electronic control unit on a vehicle.

Edge codes After January 1, 2014, all brake shoes and pads were required to have manufacturer's edge codes.

EDR Event data recorder. The hardware and software used to record vehicle information before, during and after an airbag deployment.

EEPROM Electronically Erasable Programmable Read Only Memory

EGR valve position (EVP) sensor A linear potentiometer on the top of the EGR valve stem indicates valve position to the PCM. This is called an EGR valve position (EVP) sensor.

EGR Exhaust gas recirculation. An emission control device to reduce NOx (oxides of nitrogen).

Elastic limit The limit of movement of brake shoes due to the metal not being able to return to its original dimensions.

Elastomer Another term for rubber.

Electric Adjustable Pedals (EAP) Adjustable pedals, also called electric adjustable pedals (EAP), place the brake pedal and the accelerator pedal on movable brackets that are motor operated.

Electric auxiliary pump An electric auxiliary pump is used to maintain fluid pressure in the transmission during internal combustion engine (ICE) idle stop.

Electric parking brake (EPB) Electric parking brake (EPB) systems are available using two different designs including the following: 1. A cable-pulling type that uses an electric motor to pull the parking brake cable rather than a mechanical handle or foot pedal and 2. A more advanced unit uses a computer-controlled motor attached to the brake caliper to activate it.

Electric power steering (EPS) A type of power steering that uses an electric motor to provide the steering assist.

Electric power-assisted steering (EPAS) A term commonly used to describe an electric power steering system.

Electric vehicle (EV) A term used to describe battery-powered vehicles.

Electrical Distribution System (EDS) The Electrical Distribution System (EDS) is to provide the electrical conduction path through the battery pack.

Electrical load Applying a load to a component such as a battery to measure its performance.

Electrical potential Another term to describe voltage.

Electricity The movement of free electrons from one atom to another.

Electrochemistry The term used to describe the chemical reaction that occurs inside a battery to produce electricity.

Electro-hydraulic power steering (EHPS) The electro-hydraulic power steering (EHPS) module controls the power steering motor, which has the function of providing hydraulic power to the brake booster and the steering gear

Electrolysis (Cooling System Operation and Diagnosis) Chemical decomposition produced by passing an electric current through a liquid. Electrolysis requires the use of an outside voltage source. The source is usually due to a poor electrical ground connection.

Electrolysis (Fule Cells and Advanced Technology) The chemical reaction in a fuel cell is the opposite of electrolysis. Electrolysis is the process in which electrical current is passed through water in order to break it into its components, hydrogen and oxygen. While energy is required to bring about electrolysis, this same energy can be retrieved by allowing hydrogen and oxygen to reunite in a fuel cell.

Electrolyte Any substance which, in solution, is separated into ions and is made capable of conducting an electric current. The acid solution of a lead-acid battery.

Electromagnet An electromagnet consists of a soft iron core surrounded by a coil of wire. Electrical current flowing through the coiled wire creates a magnetic field around the core.

Electromagnetic interference (EMI) An undesirable electronic signal. It is caused by a magnetic field building up and collapsing, creating unwanted electrical interference on a nearby circuit.

Electromagnetic parking sensors (EPS) Electromagnetic parking sensors (EPS) detect when a vehicle is moving slowly and towards an object

Electromotive force (EMF) The force (pressure) that can move electrons through a conductor.

Electron theory The theory that electricity flows from negative (−) to positive (+).

Electronic air control (EAC) The idle speed on newer vehicles is controlled by the electric throttle control (ETC) system.

Electronic brake control module (EBCM) The antilock brake system (ABS) control module. Also sontrols electronic suspension on some models.

Electronic brake proportioning The control of the rear brakes during heavy braking is controlled by the ABS controller instead of using a proportioning valve.

Electronic control unit (ECU) The ECM, which may also be referred to as the electronic control unit (ECU), is a small computer that receives input in the form of electrical signals from the sensors and switches and provides output electrical signals to the system actuators.

Electronic evaporator dryer (EED) An electrical control that will run the HVAC blower after the vehicle has been shut off. Its purpose is to dry the evaporator fins.

Electronic ignition system (EIS) Electronic ignition (EI) is the term specified by the SAE for an ignition system that does not use a distributor.

electronic leak detector Electronic leak detector meeting SAE J1628 is the most used method that experts and vehicle manufacturers recommend to find refrigerant leaks. Detector devices that are the most sensitive are capable of finding smaller leaks.

Electronic pressure control Electronic pressure control (EPC) is a type of electronic pressure regulation.

Electronic returnless fuel system (ERFS) A fuel delivery system that does not return fuel to the tank.

Electronic spark timing (EST) The computer controls spark timing advance.

Electronic stability control (ESC) Electronic stability control (ESC) is a system designed to help drivers to maintain control of their vehicles in situations where the vehicle is beginning to lose control.

Electronic throttle control (ETC) A system that moves the throttle plate using an electric motor instead of a mechanical linkage from the accelerator pedal.

Electronic vacuum regulator valve (EVRV) In some GM vehicles the PCM pulses the solenoid to control the vacuum that regulates the operation of the EGR valve. This called an electronic vacuum regulator valve (EVRV) by General Motors Corporation

Electronically controlled clutch assembly An electronically controlled clutch assembly is actuated by the vehicle's computer based on inputs from the ABS wheel speed sensors. If a wheel starts to spin, the computer can pulse the clutch on and off as necessary to control the amount of wheel slippage.

Electroplating The overplated bearing is a premium bearing. It is also the most expensive because the overplating layer, from 0.0005 to 0.001 inch (0.0125 to 0.025 mm) thick, is put on the bearing with an electroplating process.

Embeddability The bearings must be capable of embedding these particles into the bearing surface so that they will not score the shaft. To fully embed the particle, the bearing material gradually works across the particle, completely covering it. The bearing property that allows it to do this is called embeddability.

Embittered coolant This coolant has a small amount of a substance that makes it taste bitter and, therefore, not appealing to animals. The embittering agent used in ethylene glycol (EG) antifreeze is usually denatonium benzoate.

Emitter The name of one section of a transistor. The arrow used on a symbol for a transistor is on the emitter and the arrow points toward the negative section of the transistor.

Enable criteria A trip is defined as a key-on condition that contains the necessary conditions for a particular test to be performed, followed by a key-off. These conditions are called the enable criteria.

End cap An end cap is a rack or counter at the end of a store aisle used to display promotional or sale items. It is perceived to give a brand a competitive advantage.

Energy carrier Any medium that is utilized to store or transport energy. Hydrogen is an energy carrier because energy must be used to generate hydrogen gas that is used as a fuel.

Energy Capacity for performing work.

Engine coolant temperature (ECT) Computer-equipped vehicles use an engine coolant temperature (ECT) sensor. When the engine is cold, the fuel mixture must be richer to prevent stalling and engine stumble.

Engine fuel temperature (EFT) Some vehicles, such as many Ford vehicles that are equipped with an electronic returnless type of fuel injection, use an engine fuel temperature (EFT) sensor to give the PCM information regarding the temperature and, therefore, the density of the fuel.

Engine mapping A computer program that uses engine test data to determine the best fuel-air ratio and spark advance to use at each speed of the engine for best performance.

Engine stand A floor mounted-frame usually equipped with casters on which an engine can be attached and rotated.

Engine stop/start (ESS) With stop-start mechanism, the engine is stopped to reduce the fuel consumption when the vehicle is stopped at traffic signals or in stop and go traffic conditions.

Enhanced Flooded Batteries (EFB) Enhanced Flooded Battery (EFB) is a flooded battery (NOT an absorbed glass mat battery) that is optimized to work with stop/start vehicle systems.

Entrepreneur A person who owns a business.

EPA Environmental Protection Agency.

EPM Electrical Power Management. A General Motors term used to describe a charging system control sensor and the control of the generator(alternator) output based on the needs of the vehicle.

Equalizer A bracket used in a parking brake cable system to balance the force and transmit an equal amount to each rear brake assembly.

ESD Electrostatic discharge. Another term for ESD is static electricity.

Estimate The estimate is the suggested service cost to the customer which is determined by the service consultant.

Ethanol An octane enhancer added, at a rate of up to 10 percent, to gasoline; will increase the octane rating of the fuel by 2.5 to 3.0. Ethanol is a fuel oxygenate.

Ethics A set of principles that govern the conduct of an individual or group.

Ethyl alcohol Ethanol is also called ethyl alcohol or grain alcohol, because it is usually made from grain and is the type of alcohol found in alcoholic drinks, such as beer, wine, and distilled spirits like whiskey. Ethanol is composed of two carbon atoms and six hydrogen atoms with one added oxygen atom.

Ethylene glycol-based coolant Ethylene glycol is an organic compound used in antifreeze. All manufacturers recommend the use of ethylene glycol-based coolant.

EV Range The size or capacity of the battery pack used determines how far that the vehicle can travel without using the ICE, commonly called the EV range.

EV Electric vehicle. A term used to describe battery-powered vehicles.

EVA Abbreviation for electronic vibration analyzer. An EVA measures vibration frequency.

Evacuation To pump a vacuum into an A/C system to remove contaminated refrigerant and water.

Evaporative control (EVAP) system The purpose of the evaporative emission control system is to trap and hold gasoline vapors, also called volatile organic compounds (VOCs).

Evaporative cooling The process of cooling a surface using the evaporation of water.

Evaporator temperature (EVT) sensor A sensor used in automatic temperature control systems used to measure the temperature of the evaporator.

Exhaust gas recirculation (EGR) The process of passing a small, measured amount of exhaust gas back into the engine to reduce combustion temperatures and formation of NOx (oxides of nitrogen).

Exhaust manifold Exhaust manifolds collect exhaust gases from the cylinders and allows the exhaust gases to move to the exhaust pipe. The exhaust manifold bolts directly to the cylinder head and mates with the cylinder head exhaust ports.

Exhaust side electrode Exhaust-side electrode is exposed to the exhaust stream.

Exhaust valve A valve through which burned gases from a cylinder escape into the exhaust manifold. The exhaust valve opens, and the piston forces the residual burned gases out of the exhaust valve.

Expansion plugs Core holes left in the external block wall are machined and sealed with soft core plugs or expansion plugs (also called freeze plugs or Welsh plugs).

Exponentially weighted moving average (EWMA) monitor The exponentially weighted moving average (EWMA) monitor is a mathematical method used to determine performance.

Extended range electric vehicle.(EREV) A term used to describe an electric vehicle that has gasoline engine also that can be used to propel the vehicle.

Extension housing The rear of the transmission usually includes a separate casting called the extension housing.

Extension A socket wrench tool used between a ratchet or breaker bar and a socket.

External combustion engine An external combustion engine burns fuel outside of the engine itself, such as a steam engine.

External gears Spur and helical gears have gear teeth on their outside circumference and, for this reason, are called external gears. This type of gear is the most commonly used in manual transmissions and transaxles.

External trigger When using an oscilloscope connecting when the scope is to be triggered or started is connected to another circuit when the one being measured.

Eye Contact The action of looking directly into one another person's eyes. Eye contact is always important when we are communicating with others. In our culture, eye contact conveys sincerity and interest.

Eye wash station A water fountain designed to rinse the eyes with a large volume of water.

Fahrenheit A temperature scale developed by Gabriel Fahrenheit (1686-1736), a German physicist.

Fail safe position This partially open position, also called the neutral position or the fail safe position, is about 16% to 20% open.

False air Airflow sensors and mass airflow (MAF) sensors are designed to measure all the air entering the engine. If an air inlet hose was loose or had a hole, extra air could enter the engine without being measured. This extra air is often called false air.

False lean If an oxygen sensor reads low as a result of a factor besides a lean mixture, it is often called a false lean indication.

False rich An oxygen sensor reading that is high could be due to other things besides a rich air-fuel mixture. When the O2S reads high as a result of other factors besides a rich mixture, it is often called a false rich indication.

Farads A unit of capacitance named for Michael Faraday (1791–1867), an English physicist. A Farad is the capacity to store 1 coulomb of electrons at 1 volt of potential difference.

Fatigue life The length of time before fatigue will cause failure is called the fatigue life of the bearing.

Federal Motor Vehicle Safety Standards (FMVSS) The statutes pertaining to automotive brake systems are part of the Federal Motor Vehicle Safety Standards (FMVSS) established by the United States Department of Transportation (DOT).

Federal tax A payroll deduction.

Federal Test Procedure (FTP) In 1999, the EPA requested that states adopt OBD-II systems testing for 1996 and newer vehicles. The OBD-II system is designed to illuminate the MIL and store trouble codes any time a malfunction exists that causes the vehicle emissions to exceed 1 1/2 times the Federal Test Procedure (FTP) limits.

Feeler gauge A set of precision thickness steel blades used to measure a gap. Also called a *thickness gauge*.

FET Field effect transistor.

FFV Flex-fuel vehicle. Flex-fuel vehicles are capable of running on straight gasoline or gasoline/ethanol blends.

Fiber-reinforced matrix (FRM) Fiber-reinforced matrix (FRM) is used to strengthen cylinder walls in some Honda/Acura engines. FRM is a ceramic material similar to that used to construct the insulators of spark plugs. The lightweight material has excellent wear resistance and good heat transfer properties, making it ideal for use as a cylinder material. FRM inserts are placed in the mold and the engine block is cast over them.

FICA A payroll deduction (Federal Insurance Contribution Act, also known as Social Security).

Field coils Coils or wire wound around metal pole shoes to form the electromagnetic field inside an electric motor.

Field housing The part of a starter that supports the field coils.

Field poles The magnets used as field coils in a starter motor.

FIFO (first-in-first-out) Stock Rotation A type of stock rotation that places the first products into inventory to be purchased first and prevents older stock from getting an aged appearance.

Fifth gear In fifth gear, the shift linkage centers the 3–4 synchronizer sleeve and moves the fifth synchronizer sleeve toward the fifth speed gear. Note that on the T5 transmission the synchronizer assembly locks the fifth speed gear to the countershaft. The speed gear drives a fixed gear on the output shaft.

Files A metal smoothing tool.

Filler port A term sometimes used to identify the replenishing port (rear port) of a master cylinder.

Final drive assembly Most transaxles use speed gears and synchronizers on both the input and output shafts. The differential assembly is also called a final drive assembly.

Finger design A design of an oxygen sensor that uses a shape like a cup or thimble.

Finger follower Overhead camshaft engines use several different types of valve opening designs. One type opens the valves directly with a bucket. One type uses a cam follower, also called a finger follower, that provides an opening ratio similar to that of a rocker arm.

Fire blankets A fire-proof wool blanket used to cover a person who is on fire and smother the fire.

Fire ring The fiber facing is protected around the combustion chamber with a metal armor (also called a fire ring).

Firing line The leftmost vertical (upward) line is called the firing line. The height of the firing line should be between 5,000 and 15,000 volts (5 and 15 kV) with not more than a 3 kV difference between the highest and the lowest cylinder's firing line.

First gear In first gear, the shift linkage slides the 1–2 synchronizer sleeve rearward toward the first speed gear. The synchronizer assembly locks the speed gear to the output shaft.

First-class lever A type of lever where the fulcrum is between the weight and the force.

Fitting wrench A wrench that is used to remove the fitting holding a brake line or other line. Also called a *line wrench* or *flare-nut wrench*.

Five Basic Needs All customers have the five basic needs that need met when making a purchase: Service, Price, Quality, Action, and Appreciation.

Five-wheel alignment An alignment that not only includes the four wheels that are on the ground, but also includes the steering wheel.

Fixed brake caliper A type of disc brake caliper that has pistons on both sides of the rotor.

Fixed joint A type of CV joint used at the wheel end of the drive axle shaft.

Flare When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine flare.

Flare-nut wrench A type of wrench used to remove brake lines.

Flashback A flashback is a rapid high-pressure flame in the hose, which can occur if there are not any check valves or the check valves fails to operate due to improper installation.

Flat rate Pay based on the amount of time published in a labor guide rather than using the actual amount of time spent on the repair.

Flathead A design where the valves are located in the engine block is called flathead design because the cylinder head simply covers the combustion chamber and includes a hole for the spark plug.

Flat-link type The silent chain type (also known as a flat-link type, or Morse type for its original manufacturer) operates quietly but tends to stretch with use. The metal links themselves do not "stretch" but, instead, the pin bushings at each joint wear, which causes the chain to become longer.

Flat-tip (straight blade) screwdriver A screwdriver used to remove and insert screws that have a single slot.

Flex Fuels The 15% gasoline in the E85 blend helps the engine start, especially in cold weather. Vehicles equipped with this capability are commonly referred to as alternative-fuel vehicles (AFVs), Flex Fuels, and flexible fuel vehicles (FFVs).

Flexible brake hoses Brake hoses between the body or frame of a vehicle and the caliper or axle.

Flexible coupling A part of the steering mechanism between the steering column and the steering gear or rack and pinion assembly. Also called a *rag joint* or *steering coupling disc.* The purpose of the flexible coupling is to keep noise vibration and harshness from being transmitted from the road and steering to the steering wheel.

Floating caliper A type of caliper used with disc brakes which moves slightly to assure equal pad pressure on both sides of the rotor.

Floating position The intermediate position between drive and coast, when neither the ring gear nor the pinion is driving each other, is called the "floating" position.

Flooded lead acid (FLA) Conventional batteries use a liquid electrolyte and are called flooded lead acid (FLA) batteries. In this design, vents are used to allow the gases (hydrogen and oxygen) to escape

Floor jack A hydraulic jack mounted on casters or steel wheels and used to lift a vehicle.

Flow Control Valve A valve that regulates and controls the flow of power steering pump hydraulic fluids to the steering gear or rack and pinion assembly. The flow control valve is usually part of the power steering pump assembly.

Flushing To clean a system by pumping a liquid through it.

Flux density The density of the magnetic lines of force around a magnet or other object.

Flux lines becomes. The magnetic lines of force, also called magnetic flux or flux lines, form a magnetic field. The terms magnetic field, lines of force, flux, and flux lines are used interchangeably.

Flying web The flange between the splayed crankpin journals is sometimes called a flying web.

FM Frequency modulation.

Fogging oil When assembling an engine, the parts should be coated with a light oil film to keep them from rusting. This type of oil is commonly referred to as fogging oil.

Footnote A footnote is used to provide additional information for multiple applications. The footnotes themselves are important and should be referenced systematically in order to define parts.

Force motors Force motors is a type of electronic pressure regulation.

Force The amount of effort measured in pounds or Newtons.

Forced induction systems Forced induction systems use an air pump to pack a denser air-fuel charge into the cylinders. Because the density of the air-fuel charge is greater, the following occurs.

Formal evaluation The mentor and/or service manager may or may not conduct a written evaluation on a regular basis. If a written evaluation is performed, this is called a formal evaluation.

Formed in place gaskets (FIPG) Formed in place gaskets (FIPG) are commonly used because they can be applied at the engine plant using a robot. The sealing material is extruded and placed onto the sealing surface, the two parts being sealed are placed together, and the fasteners tightened.

Forward bias Current flow in normal direction.

Foundation brakes Service brakes are the main driver-operated brakes of the vehicle. Service brakes are also called base brakes or foundation brakes.

Four-stroke cycle An internal combustion engine design where four strokes of the piston (two crankshaft revolutions) are required to complete one cycle of events. The four strokes include intake, compression, power, and exhaust.

Fourth gear In fourth gear, the shift linkage moves the 3–4 synchronizer sleeve forward, away from the third speed gear and toward the input shaft drive gear. The synchronizer assembly locks the input shaft drive gear to the output shaft.

Four-wheel alignment A wheel alignment that checks and adjusts, if necessary, the angles of all four wheels.

Fractional Specifications are often published in fractional or decimal degrees, or in degrees and minutes. There are 60 minutes (written as 60') in 1 degree.

Fractions A measurement in parts of an inch, such as ½, ¼, and 1/8.

Frames Frame construction usually consists of channel-shaped steel beams welded and/or fastened together.

Free electrons The outer electrons in an atom that has fewer than four electrons in it outer orbit.

Free rotators A type of valve retainer that allows the valve to be free to rotate when the valve is opening or closing.

Freewheeling engine A freewheeling engine is one that causes no internal damage if the camshaft drive belt breaks when the engine is running.

Freewheeling An engine that is designed not to have the pistons hitting the valves if the timing belt or chain breaks, is called freewheeling.

Freeze plugs Core holes left in the external block wall are machined and sealed with soft core plugs or expansion plugs (also called freeze plugs or Welsh plugs).

Freeze-frame A freeze-frame is a snapshot of important engine data at the time the DTC was set.

Frequency The number of times a waveform repeats in one second, measured in Hertz (Hz), frequency band.

Freshening A term used to describe the process of engine repair that usually includes only replacing the piston rings and rod bearings.

Fretting Expansion/contraction rate difference between the cast-iron head and the aluminum intake manifold can cause the intake manifold gasket to be damaged by the relative motion of the head and intake manifold. This type of failure is called fretting.

Fretting Fretting is a condition that can destroy intake manifold gaskets, caused by the unequal expansion and contraction of two different engine materials.

Front bearing retainer The throw-out bearing is often supported and rides on the transmission/transaxle front bearing retainer (also called the quill).

Front bearing retainers At the front of the transmission (toward the engine) is the front bearing retainer (sometimes called the quill) that supports the clutch throw-out (release) bearing and usually houses the front grease seal.

Front steer A construction design of a vehicle that places the steering gear and steering linkage in front of the center line of the front wheels. Also called forward steer.

Front/Rear split master cylinders Front/rear split master cylinders use two separate pressure-building sections. One section operates the front brakes and the other section operates the rear brakes on vehicles equipped with a front/rear-split system.

Frost plugs Openings in the block are plugged with core plugs. Core plugs are also called freeze plugs or frost plugs.

FTD Fischer-Tropsch diesel process. See *Fischer-Tropsch*.

Fuel cell An electrochemical device that converts the energy stored in hydrogen gas into electricity, water, and heat.

Fuel compensation sensor A sensor used in flex-fuel vehicles that provides information to the PCM on the ethanol content and temperature of the fuel as it is flowing through the fuel delivery system.

Fuel rail A port fuel-injection system uses a pipe or tubes to deliver fuel from the fuel line to the intended fuel injectors. This pipe or tube is called the fuel rail.

Fuel tank pressure (FTP) A fuel tank pressure (FTP) sensor then monitors the rate with which vacuum increases in the system. The monitor uses this information to determine the purge volume flow rate.

Fuel trim A computer function that adjusts fuel delivery during closed-loop operation to bring the air-fuel mixture to as close to 14.7:1 as possible.

Fuel-cell hybrid vehicle (FCHV) A fuel-cell vehicle (FCV) uses the fuel cell as its only source of power, whereas a fuel-cell hybrid vehicle (FCHV) also has an electrical storage device that can be used to power the vehicle.

Fuel-cell stack A collection of individual fuel cells, which are stacked end-to-end into one compact package.

Fuel-cell vehicle (FCV) A fuel-cell vehicle (FCV) uses the fuel cell as its only source of power, whereas a fuel-cell hybrid vehicle (FCHV) also has an electrical storage device that can be used to power the vehicle.

Fulcrum A pivot point of a lever.

Full frame A frame of a vehicle that extends the entire length and width of the vehicle.

Full round bearing Overhead camshaft bearings may be one of two sleeve-type bushings, depending on the design of the bearing supports. They are full round bearings or split-type (half-shell) bearings.

Full-floating A type of axle assembly where the weight of the vehicle is supported by the axle housing and not on the axle itself.

Fully counterweighted Crankshafts are balanced by counterweights, which are cast, forged, or machined as part of the crankshaft. A crankshaft that has counterweights on both sides of each connecting rod journal is called fully counterweighted.

Functionality OBD II also requires that inputs from powertrain components to the PCM be tested for rationality, and that outputs to powertrain components from the PCM be tested for functionality. Both inputs and outputs are to be checked electrically.

Fungible All gasoline is said to be fungible, meaning that it is capable of being interchanged because each grade is created to specification, so there is no reason to keep the different gasoline brands separated except for grade.

Fuse link A safety device used on a solvent washer which would melt and cause the lid to close in the event of a fire. A type of fuse used to control the maximum current in a circuit.

Fuses An electrical safety unit constructed of a fine tin conductor that will melt and open the electrical circuit if excessive current flows through the fuse.

Fusible link A type of fuse that will melt and open the protected circuit in the event of a short circuit, which could cause excessive current flow through the fusible link. Most fusible links are actually wires that are four gauge sizes smaller than the wire of the circuits being protected.

Gallery Oil from the oil pump first flows through the oil filter, and then goes through a drilled hole that intersects with a drilled main oil gallery, or longitudinal header. This is a long hole drilled from the front of the block to the back.

Galvanic activity Galvanic activity is the flow of an electrical current as a result of two different metals in a liquid, which acts like a battery. Galvanic activity does not require an outside source of voltage.

Garter spring A spring used in a seal to help keep the lip of the seal in contact with the moving part.

Gas fade A type of brake fade where the lining materials are heated enough to emit gas. The gas between the pads and the rotor result in a loss of braking force.

Gasoline direct-injection (GDI) A fuel injection system design in which gasoline is injected directly into the combustion chamber.

Gasoline Refined petroleum product that is used primarily as a gasoline engine.

Gassing The release of hydrogen and oxygen gas from the plates of a battery during charging or discharging.

Gauss gauge A Gauss gauge is a handheld meter that responds to weak magnetic fields. It is used to observe this pulsing magnetic field, which is indicated on the gauge as needle movement.

GC-LB A grease rating for GC is the highest rating for wheel bearing grease and LB is the highest rating for chassis grease. A GC-LB grease, therefore, can be used.

Gear reduction A type of gear arrangement where the driven gear speed is slower than drive gear speed which provides gear reduction.

Gel battery A lead-acid battery with silica added to the electrolyte to make it leakproof and spill proof.

Geometric centerline A type of wheel alignment where all four wheels are aligned parallel to the centerline of the vehicle.

Germanium A semiconductor used in early diodes.

Gerotor A type of positive displacement oil pump uses an inner and an outer rotor. The term is derived from two words: "generated rotor," or gerotor. The inner rotor has one fewer tooth than the outer rotor and both rotate.

Girdle The extra bolts on the main bearing cap help to support the crankshaft when there are high combustion pressures and mechanical loads, especially during high engine speed operation. Many engines use a girdle, which ties all of the main bearing caps together to add strength to the lower part of the block.

Global positioning system (GPS) A government program of 24 satellites that transmit signals that are used by receivers to deter-mine their location.

Global warming potential (GWP) The amount that refrigerants are expected to affect the temperature of planet Earth.

Global warming The increase in average temperature for planet Earth.

Glow plug A glow plug is a heating element that uses 12 volts from the battery and aids in the starting of a cold engine by providing heat to help the fuel to ignite.

GMLAN GM local area network. A type of serial data transmission by General Motors.

GMM Graphing Multimeter.

Grade The strength rating of a bolt.

Grain alcohol Ethanol is also called ethyl alcohol or grain alcohol, because it is usually made from grain and is the type of alcohol found in alcoholic drinks, such as beer, wine, and distilled spirits like whiskey. Ethanol is composed of two carbon atoms and six hydrogen atoms with one added oxygen atom.

Graph A graph is a visual display of information. Graphs are commonly used in the automotive service industry to illustrate trends or specifications along with time or some other variable.

Graticule The series of squares on the face of a scope. Usually 8 by 10 on a screen.

Gravity bleeding Removing air from a hydraulic brake system by opening the bleeder valve and allowing the brake fluid to flow downward and out the bleeder taking any trapped air with it.

Grease fitting A metal replaceable fitting shaped to hold the end of a grease gun in place and equipped with a spring-loaded valve.

Grease seal A seal used to prevent grease from escaping and to prevent dirt and moisture from entering.

Grease Oil with thickener.

Green tire An uncured assembled tire. After the green tire is placed in a mold under heat and pressure, the rubber changes chemically and comes out of the mold formed and cured.

Greenhouse effect Gases in our atmosphere that, if in too great a concentration, can prevent heat from escaping the surface, leading to an increase in the temperature on earth. In a nursery greenhouse, the glass panes are painted white to reflect the heat back into the greenhouse.

Greenhouse gases (GHG) Greenhouse gases (GHG) are those gases in our atmosphere that, if in too great a concentration, can prevent heat from escaping the surface, leading to an increase in the temperature on earth. In a nursery greenhouse, the glass panes are painted white to reflect the heat back into the greenhouse.

Greenhouse gases (GHGs) A layer of gases that traps heat at the Earth's surface and lower atmosphere, and it is increasing the temperature of our living area.

Grid The lead-alloy framework (support) for the active materials of an automotive battery.

Grooves Piston ring grooves are located between the piston head and skirt. The width of the grooves, the width of the lands between the ring grooves, and the number of rings are major factors in determining minimum piston height.

Gross axle weight rating (GAWR) A rating of the load capacity of a vehicle and included on placards on the vehicle and in the owner's manual.

Gross vehicle weight rating (GVWR) The total weight of the vehicle including the maximum cargo.

Gross Gross earnings are the total amount you earned during the pay period.

Ground brushes The brushes in a starter motor that carry current to the housing of the starter or ground.

Grounded A defective component or circuit that is shorted to ground is commonly called grounded.

Groundout Groundout is a vibrating metal A/C line that contacts another surface which produces noise.

Guess-O-Meter (GOM) The dash display that shows the miles per kWh is often called a Guess-O-Meter (GOM) because it is often not accurate.

Guobiao (GB or GB/T) The Chinese national standard. BYD and other Chinese companies use this standard connector, as well as Mahindra and Tata electric vehicles.

GVW Abbreviation for gross vehicle weight. GVW is the weight of the vehicle plus the weight of all passengers and cargo up to the limit specified by the manufacturer.

Hacksaw A saw that uses a replaceable blade and is used to cut a variety of materials depending on the type of blade used.

Half shaft Drive axles on a front-wheel drive vehicle or from a stationary differential to the drive wheels.

Half-shell bearing Modern automotive engines use precision insert-type bearing shells, sometimes called half-shell bearings. The bearing is manufactured to very close tolerance so that it will fit correctly in each application.

Hall-effect switch A semiconductor moving relative to a magnetic field, creating a variable voltage output. Used to determine position. A type of electromagnetic sensor used in electronic ignition and other systems. Named for Edwin H. Hall, who discovered the Hall effect in 1879.

Handwheel position sensor A sensor that detects the direction and speed of rotation of the steering wheel.

Hangers The muffler and tailpipe are supported with brackets, called hangers, which help to isolate the exhaust noise from the rest of the vehicle.

Hard spots Formed in brake drums or rotors due to high heat.

Hazard warning A sticker or decal warning that a hazard is close.

Hazardous waste material Hazardous waste materials are chemicals, or components, that the shop no longer needs that pose a danger to the environment and people if they are disposed of in ordinary garbage cans or sewers.

Head-up display (HUD) The head-up display (HUD), also called a heads-up display, is a supplemental display that projects the vehicle speed and sometimes other data, such as turn-signal information, onto the windshield.

Heat checking A lesser form of drum and rotor cracking is called heat checking, which consists of many small, interlaced cracks on the friction surface.

Heat dams Most pistons have horizontal separation slots that act as heat dams. These slots reduce heat transfer from the hot piston head to the lower skirt. This, in turn, keeps the skirt temperature lower to reduce skirt expansion.

Heat of compression Heat is always generated when air is compressed. The diesel engine requires compression ratios of 16:1 and higher. Incoming air is compressed until its temperature reaches about 1,000°F (540°C).

Heat shield Heat shields are used to protect the underbody of the vehicle from excessive heat created by the exhaust system. Heat shields are usually riveted or screwed into the bottom of the vehicle floor pan above the exhaust system.

Heat shrink tubing A type of rubber tubing that shrinks to about half of its original diameter when heated. Used over a splice during a wire repair.

Heat sink Usually, a metallic-finned unit used to keep electronic components cool.

Heat Molecules in a substance tend to vibrate rapidly in all directions, and this disorganized energy is called heat.

Heated rear window defogger An electrically heated rear window defogger system uses an electrical grid baked on the glass that warms the glass to about 85°F (29°C) and clears it of fog or frost.

Heated seats Heated seats use electric heating elements in the seat bottom, as well as in the seat back, in many vehicles. The heating element is designed to warm the seat and/ or back of the seat to about 100°F (38°C) or close to normal body temperature (98.6°F [37°C]).

Heated steering wheel A heated steering wheel usually consists of the following components: 1. Steering wheel with a built-in heater in the rim. 2. Heated steering wheel control switch 3. Heated steering wheel control module.

Heater core A cooling system component that is responsible for transferring heat from the engine coolant to the passenger compartment.

Heating load The term used when added heat is needed.

Heating, ventilation, and air-conditioning system (HVAC) Driver and passenger comfort is the primary purpose of the heating, ventilation, and air-conditioning system, often abbreviated HVAC

Heel Each slanted ring gear tooth has two ends. Its toe is closest to the ring gear center; its heel, closest to the outside circumference

Height sensor A height sensor determines the vertical relationship between the suspension component and the body of a vehicle.

Height-sensing proportioning valve A valve connected to the rear suspension that limits the brake pressure sent to the rear brakes if the rear of the vehicle is high (unloaded).

Helical gear A helical gear, although similar to a spur gear, has its teeth cut at an angle to the axis of the gear.

Helical insert A steel insert used to repair damaged threads.

Heli-Coil® A brand name for a helical insert.

Helmholtz resonator A tube that is shaped and designed to dampen out certain resonant frequencies that can occur at specific engine speeds. Helmholtz resonator, named for the discoverer of the relationship between shape and value of frequency, Herman L. F. von Helmholtz (1821–1894) of the University of Hönizsberg in East Prussia.

HEPA vacuum High efficiency particulate air filter vacuum used to clean brake dust.

Hertz A unit of measurement of frequency. One Hertz is one cycle per second, abbreviated Hz. Named for Heinrich R. Hertz, a 19th century German physicist.

HEV Hybrid electric vehicle. Describes any vehicle that uses more than one source of propulsion, such as internal combustion engine (ICE) and electric motor(s).

High voltage (HV) High voltage (HV) circuits that if touched with an unprotected hand could cause serious burns or even death.

High-flotation tires High-flotation tires for light trucks are designed to give improved off-road performance on sand, mud, and soft soil and still provide acceptable hard-road surface performance.

High-impedance test meter Digital multimeter (DMM) and digital voltohm-meter (DVOM) are terms commonly used for electronic high-impedance test meters.

High-intensity discharge (HID) A type of headlight that uses high voltage to create an arc inside the arc tube assembly which then produces a blue-white light.

High-pressure common rail (HPCR) Newer diesel engines use a fuel delivery system referred to as a high-pressure common rail (HPCR) design. Diesel fuel under high pressure, over 20,000 PSI (138,000 kPa), is applied to the injectors, which are opened by a solenoid controlled by the computer.

HO2S The four-wire sensor is a heated O2S (HO2S) that uses an O2S signal wire and signal ground. The other two wires are the power and ground for the heater.

Hold-in winding One of two electromagnetic windings inside a solenoid; used to hold the movable core into the solenoid.

Holding devices Apply devices or holding devices are the mechanical or hydraulic assemblies that provide the force to hold or drive members of a planetary gear set.

Holding fixture A holding fixture allows the unit to be rotated yet properly supported during disassembly and reassembly.

Hole theory A theory which states that as an electron flows from negative (-) to positive (+), it leaves behind a hole. According to the hole theory, the hole would move from positive (+) to negative (-).

Homogeneous charge compression ignition (HCCI) A low-temperature combustion process that involves air–fuel mixtures being burned without the use of spark ignition.

Homogeneous mode A mode of operation in a gasoline direct injection system where the air- fuel mixture is the same throughout the cylinder.

Hooke's Law The force characteristics of a spring discovered by Robert Hooke (1635-1703). An English physicist. Hooke's Law states "the deflection (movement or deformation) of a spring is directly proportional to the applied force."

Horns An electromechanical device that creates a loud sound when activated.

Horsepower A unit of power; 33,000 foot-pounds per minute. One horsepower equals 746 W.

Hotchkiss drive A type of power transmission for a front engine, rear-drive vehicle where the engine torque reaction is controlled by the suspension as compared to the use of torque arm or frame-mounted differential.

Housekeeping Housekeeping is the responsibility of all personnel to keep all areas of the business clean and orderly. Lost sales can result from a disorderly and sloppy appearance. Counter tops, shelves, and displays should all be neat and clean. Good housekeeping leads to a safe, clean, and productive environment.

Housing expense Includes rent or mortgage payment, plus heat, light, and other utility expenses.

HTHS ACEA oil also requires low levels of sulfated ash, phosphorous, and sulfur, abbreviated SAPS, and has a high-temperature/ high-shear rate viscosity, abbreviated HTHS

Hub (Crankshafts, Balance Shafts, and Bearings) This damper or balancer usually consists of a cast-iron inertia ring mounted to a cast-iron hub with an elastomer sleeve.

Hub (Manual Transmissions/Transaxles) In synchronizer construction there are a number of design variations. All are similar and include a hub, a sliding sleeve, a blocker ring, (or stop ring or synchronizer ring), keys, and springs.

Human-machine interface (HMI) A human-machine interface (HMI) is the user interface that connects an operator to the controller for a vehicle.

Hunting gear sets Hunting gear sets are gear sets with final drive ratios expressible in a fraction that cannot be reduced to any lower terms

Hybrid electric vehicle (HEV) Hybrid electric vehicles (HEV) are vehicles that have two sources of propulsion either with an electric motor supplied energy from the high-voltage battery or an internal combustion engine (ICE).

Hybrid organic acid technology (HOAT) A type of coolant that has organic acids and either no phosphates and some silicates, or no silicates and some phosphates. Coolants can be green, orange, yellow, gold, pink, red, or blue.

Hydraulic electronic unit injection (HEUI) Ford 7.3, 6.0, and 6.4 liter (and Navistar) diesels use a system called a hydraulic electronic unit injection system, or HEUI system. The components used include: 1. High-pressure engine oil pump and reservoir 2. Pressure regulator for the engine oil and 3. Passages in the cylinder head for flow of fuel to the injectors. The engine oil is pressurized to provide an opening pressure strong enough to overcome the fuel pressure when the solenoid is commanded to open by the PCM.

Hydraulic impulse storage accumulator A hydraulic impulse storage accumulator is used to provide fluid pressure as the internal combustion engine (ICE) restarts after the idle stop mode.

Hydraulic lash adjusters (HLA) Overhead camshaft engines use several different types of valve opening designs. Some newer engines have the hydraulic adjustment in the rocker arm and are commonly called hydraulic lash adjusters (HLA).

Hydraulic press A piece of shop equipment usually mounted on the floor, which uses a hydraulic cylinder to remove and install pressed-on components, such as bearings.

Hydraulic valve lifter Valve train clearance is also called valve lash, which is needed to help compensate for thermal expansion and wear. Valve train clearance must not be excessive, or it causes noise or results in premature failure. One method commonly used to make the necessary valve clearance adjustments involves a lifter with an automatic hydraulic adjustment built into the lifter body, called a hydraulic valve lifter.

Hydrocarbons (HC) Any of a number of compounds of carbon and hydrogen used as fuel, such as gasoline. High levels of hydrocarbons in tailpipe emissions are a result of unburned fuel. When combined with NOx and sunlight, they form smog.

Hydrocracking A refinery process that converts hydrocarbons with a high boiling point into ones with low boiling points.

Hydrodynamic lubrication A wedge-shaped oil film is built up between the moving block and the surface. High oil pressure created between the crankshaft journal and the bearing created by the rotation of the oil film.

Hydrokinetic pump The word hydro means liquid and the term kinetic refers to motion, so the term hydrokinetic pump means that this design of pump rapidly moves the fuel to create pressure. This design of pump is a nonpositive displacement pump design.

Hydrometer An instrument used to measure the specific gravity of a liquid. A battery hydrometer is calibrated to read the expected specific gravity of battery electrolyte.

Hydroplaning Condition that occurs when driving too fast on wet roads where the water on the road gets trapped between the tire and the road forcing the tire onto a layer of water and off the road surface. All traction between the tire and the road is lost.

Hydroseal The cold soak tank is used to remove grease and carbon. The disassembled parts are placed in the tank so that they are completely covered with the chemical cleaning solution. Usually, there will be a layer of water over the chemical to prevent evaporation of the chemical. This water layer is called a hydroseal.

Hygrometer Relative humidity is commonly measured with a hygrometer or a psychrometer. A hygrometer depends on a sensitive element that expands and contracts, based on the humidity. Hygrometers typically resemble a clock, with the scale reading from 0% to 100% relative humidity.

Hygroscopic Ability of brake fluid to absorb moisture from the air.

Hypereutectic A standard cast aluminum piston contains about 9% to 12% silicon and is called a eutectic piston. To add strength, the silicon content is increased to about 16%, and the resulting piston is called a hypereutectic piston.

Hypoid gear set A ring gear and pinion gear set that meshes together below the center line of the ring gear. This type of gear set allows the drive shaft to be lower in the vehicle, yet requires special hypoid gear lubricant.

Hypothesis Proposed explanation made on the basis of limited evidence as a starting point for further investigation. Use the explanation (hypothesis) to test to see if it matches the existing problem.

H-block The H-block design is a type of TXV that uses four passages and controls the refrigerant flow using opposing pressures.

Identifier A tester used to determine what the correct refrigerant is for the system being service.

Idle speed control (ISC) motor Idle airflow in a TBI system travels through a passage around the throttle and is controlled by a stepper motor. In some applications, an externally mounted permanent magnet motor, called the idle speed control (ISC) motor.

Idle stop Idle stop means that the engine is not running, but could start at any time if the computer detects the need to charge the hybrid batteries, or any other issue that requires the gasoline engine to start and run.

Idle vacuum test An engine in proper condition should idle with a steady vacuum between 17 and 21 inch Hg

IEC International Electrotechnical Commission.

Igniter The negative terminal is attached to an ignition control module (ICM or igniter), which opens and closes the primary ignition circuit by opening or closing the ground return path of the circuit.

Ignition coil An electrical device consists of two separate coils of wire: a primary and a secondary winding. The purpose of an ignition is to produce a high-voltage (20,000 to 40,000 V), low-amperage (about 80 mA) current necessary for spark ignition.

Ignition control module (ICM) The ignition system includes the ignition coil(s), after coil which creates a high voltage spark by stepping up battery voltage using an ignition control module (ICM).

Ignition timing The exact point of ignition in relation to piston position.

Impact wrench An air-operated hand tool used to install and remove threaded fasteners.

Impedance The resistance of a coil of wire, measured in ohms.

Impeller The mechanism in a water pump that rotates to produce coolant flow.

Impulse Item An impulse item is a product that the customer buys to fill a want rather than a need.

Impurities Doping elements.

Incentive pay The hourly rate can vary greatly depending on the experience of the technician and type of work being performed. Most experienced service technicians are paid by a method called flat-rate. The flat-rate method of pay is also called incentive or commission pay. “Flat-rate” means that the technician is paid a set amount of time (flat-rate) for every service operation. The amount of time allocated is published in a flat-rate manual.

Inches of mercury (In. Hg) A measurement of vacuum; pressure below atmospheric pressure.

Inches of mercury (inch Hg) Unit of measure used to measure a vacuum.

Inclinometer An instrument used to measure angles. Normally used to measure driveshaft angles.

Included angle SAI angle added to the camber angle of the same wheel. Includes starter motor, starter solenoid/relay, battery, neutral safety switch, ignition including co-solvents, in unleaded gasoline is limited by law to 5 percent.

Independent suspension A suspension system that allows a wheel to move up and down without undue effect on the opposite side.

Indicator ball joints A type of ball joint that shows when the joint is worn enough to require replacement.

Indirect injection (IDI) In an indirect injection (abbreviated IDI) diesel engine, fuel is injected into a small prechamber, which is connected to the cylinder by a narrow opening. The initial combustion takes place in this prechamber. This has the effect of slowing the rate of combustion, which tends to reduce noise

Inductive ammeter A type of ammeter that is used a Hall Effect senor in a clamp that is used around a conductor carrying a current.

Inductive reactance An opposing current created in a conductor whenever there is a charging current flow in a conductor.

Inert The recirculated exhaust gas is inert (chemically inactive) and does not enter into the combustion process.

Inertia ring Harmful crankshaft twisting vibrations are dampened with a torsional vibration damper. It is also called a harmonic balancer. This damper or balancer usually consists of a cast-iron inertia ring mounted to a cast-iron hub with an elastomer sleeve.

Inertia switch The inertia switch is installed in the rear of the vehicle between the electric fuel pump and its power supply. With any sudden impact, such as a jolt from another vehicle in a parking lot, the inertia switch opens and shuts off power to the fuel pump.

Inertia Energy in a moving object.

Inflator module The part of an airbag that contains the airbag itself, plus the unit that is used to inflate the airbag.

Informal evaluation In many cases, a beginning technician's activities are simply observed and noted, which is a type of informal evaluation. Both are usually done and both can influence the technician's pay.

Infrared (IR) sensors A type of sensor used in many automatic air-conditioning systems that are used to detect the temperature of the passenger areas.

Initial timing If the engine is equipped with a distributor, it may be possible to adjust the base or the initial timing. The initial timing is usually set to fire the spark plug between zero degrees (top dead center or TDC) or slightly before TDC (BTDC).

Injection pump A diesel engine uses a fuel system with a precision injection pump and individual fuel injectors. The pump delivers fuel to the injectors at a high pressure and at timed intervals.

Inline engine Early engines used four or six cylinders arranged inline. These are called inline engines and are still produced today.

Inline filters A filter that can be installed into a refrigerant line that is designed to trap foreign particles.

Inner liner The inner layer of rubber inside a tire.

Inorganic additive technology (IAT) Inorganic additive technology (IAT) is conventional coolant that has been used for over 50 years. Most conventional green antifreeze contains inorganic salts.

Input conditioning What the computer does to the input signals to make them useful; usually includes an analog to digital converter and other electronic circuits that eliminate electrical noise.

Input member The drive member of a planetary gear set is called the input member.

Input shaft The input shaft is splined to the clutch disc and is also referred to as the main gear, clutch gear, or main drive pinion assembly. The main shaft, also called the output shaft, is splined at the end and transmits engine torque to the drive shaft (propeller shaft) through a yoke and universal shaft.

Input speed sensor (ISS) The sensor that measures the speed of the input shaft which is the same or almost the same as the engine speed. This is also called turbine speed sensor (TSS) because it is used to determine the speed of the turbine shaft.

Input Information on data from sensors to an electronic controller is called input. Sensors and switches provide the input signals.

Insert seats An insert seat fits into a machined recess in the steel or aluminum cylinder head. Insert seats are used in all aluminum head engines and in applications for which corrosion and wear resistance are critical.

Inside air Inside air is usually called recirculation

Installed height Valve stem height is the distance the valve stem is above the spring seat. Valve stem height is a different measurement from installed height.

Instrument panel (IP) All vehicles are equipped with war warning lights on the instrument panel (IP) and they are often confusing to drivers. Symbols are used instead of words because they are universal in a global vehicle market.

Instrument panel cluster (IPC) Vehicle information is displayed on the instrument panel cluster (IPC).

Insulated brushes Brushes used in a starter motor that connect to battery power through the solenoid.

Insulator A material that does not readily conduct electricity and heat. A nonmetal material that contains more than four electrons in its atom's outer shell.

Insulators Thin strips of plastic or hard rubber used to separate the leaves of a leaf spring.

Intake manifold All engines, both gasoline and diesel engines, draw air from the atmosphere. It requires about 9,000 gallons of air for each gallon of gasoline used. The air must be drawn where deep water in the road cannot be drawn into the engine. The air is then filtered by a replaceable air filter. After the air is filtered, it passes through a throttle valve and then into the engine through an intake manifold.

Intake valve A valve in the cylinder head of an internal-combustion engine that opens at the proper moment to allow a mixture of fuel and air to be drawn into the cylinder. The intake valve is open and the piston inside the cylinder travels downward, drawing a mixture of air and fuel into the cylinder.

Integral accumulator Piston-type accumulators look and function much like servo pistons. In fact, some piston-type accumulators share a bore with one of the transmission servos. This common bore design is known as an integral accumulator.

Integral reservoir A type of power steering pump that includes the pump inside the fluid reservoir.

Integral seat The valve face closes against a valve seat to seal the combustion chamber. The seat is generally formed as part of the cast-iron head of automotive engines, called an integral seat.

Integral sensors A term used to describe a crash sensor that is built into the airbag control module.

Integrally molded Disc brake pads where the friction material is molded and locked into holes in the steel backing plate.

Integrated circuit (IC) An electronic circuit that contains many circuits all in one chip.

Intelligent Speed Advice (ISA) Intelligent Speed Advice (ISA) uses a sign recognition camera or a navigation system (GPS) to determine the speed limit, which is used to warn the driver of the posted speed limit.

Interaxle differential (center differential) All-the-time four-wheel-drive, all-wheel-drive, and full-time four-wheel-drive systems use an interaxle differential (center differential) to prevent driveline harshness and vibration, commonly referred to as driveline windup.

Intercooler Power can be increased by cooling the compressed air after it leaves the turbocharger. The power can be increased about 1% per 10°F by which the air is cooled. A typical cooling device is called an intercooler.

Interference engine An interference engine, however, causes some of the valves that are open to hit the pistons, causing major engine damage.

Interference fit A method of retaining the piston pin in the connecting rod is to make the connecting rod hole slightly smaller than the piston pin. The pin is installed by heating the rod to expand the hole or by pressing the pin into the rod. This retaining method securely holds the pin. This press or shrink fit is called an interference fit.

Intermediate lever A lever used as part of the parking brake cable system.

Intermediate oscillations After the spark has stopped, some energy remains in the coil. This remaining energy dissipates in the coil windings and the entire secondary circuit. The intermediate oscillations are also called the “ringing” of the coil as it is pulsed.

Internal combustion engine (ICE) If engine combustion occurs within the power chamber, the engine is called an internal combustion engine.

Internal combustion engine All gasoline and diesel engines are called internal combustion engines and are designed to compress an ignitable mixture. This mixture is ignited by using a spark (gasoline) or by heat of compression (diesel).

Internal gear The outer ring gear has teeth on the inside that mesh with the teeth of the planet pinion gears. The ring gear is also called the annulus gear or internal gear because the gear teeth are on the inside (rather than the outside) portion of the gear.

Internal ring gears Gears having teeth along the inside circumference are called internal ring gears. The teeth of an internal ring gear may be spur or helical teeth.

International Lubricant Standardization and Approval Committee (ILSAC) Responsible for development of the ILSAC standard for motor oil performance.

In-vehicle temperature sensor A thermistor used to measure the temperature of the interior of a vehicle and used in automatic air-conditioning systems.

Inventory Discrepancy Form After a physical inventory has been completed, the discrepancies must be recorded and logged into the computer system. The cause of the discrepancy needs to be identified (wrong stock number, stolen, transfers to other stores, incorrect part numbers or quantities of parts picked off the shelf. The parts specialist will need to take action to eliminate discrepancies by using an inventory discrepancy form.

Inverter An electronic device used to convert DC (direct current) into AC (alternating current).

Invoice The invoice lists all parts by names and is used to track inventory and purchases for billing purposes.

IOD Ignition off draw. A Chrysler term used to describe battery electrical drain or parasitic draw.

Ion An atom with an excess or deficiency of electrons forming either a negative or a positive charged particle.

Iridium spark plugs Iridium is a white precious metal and is the most corrosion-resistant metal known. Most iridium spark plugs use a small amount of iridium welded onto the tip of a small center electrode 0.0015 to 0.002 inches (0.4 to 0.6 mm) in diameter.

Irradiance The term used to define the amount of solar radiation is irradiance. The solar irradiance at the earth’s surface varies greatly depending on factors such as: Latitude, Time of day, Time of year, Cloud cover, and Haze.

IRS Independent rear suspension.

ISO International Standards Organization.

Jack stands A metal device with an adjustable vertical support that is designed to support a vehicle after it has been raised off the ground. Also called a safety stand.

Jam nut A second nut used to prevent the first nut from loosening.

Job shadowing Job Shadowing is a career exploration activity that offers the Student Technician to spend time with a working Technician in an area of interest. A great way to see what it is really like to work as a service technician is to follow a professional around for a day or more. Job shadowing is usually arranged through an automotive program, and the shop or dealership has agreed to allow someone into the shop area to observe.

Jobber parts Jobber parts (or aftermarket parts) are not made by the original manufacturer of the vehicle. The aftermarket industry makes up about 80% of the parts used in vehicle repair.

Jobber Most aftermarket parts are sold at automotive parts stores or jobbers. A jobber or parts retailer usually gets parts from a large regional warehouse distributor.

Jumper cables Heavy-gauge (4 to 00) electrical cables with large clamps, used to connect a vehicle that has a discharged battery to a vehicle that has a good battery.

Junction The point where two types of materials join.

JWL Japan Wheel Light Metal Standard Mark.

KAM Keep alive memory.

Kelvin (K) A temperature scale where absolute zero is zero degrees. Nothing is colder than absolute zero.

Key fob A decorative unit attached to keys. Often includes a remote control to unlock/lock vehicles.

Keys In synchronized construction there are a number of design variations, all are similar and include a hub, a sliding sleeve, a blocker ring, (or stop ring or synchronizer ring), keys, and springs.

Kickback The movement of the steering wheel when the front wheels strike a curb or bump.

Kilo (k) Means 1,000; abbreviated k or K.

Kilowatt-hour (kWh) kWh is a unit of energy. Battery capacity is measured in kilowatt-hours (kWh). A kilowatt is 1,000 watts and a watt is a volt times an ampere, which is a measurement of electrical power. The higher the kWh rating of the battery, the more electrical energy it can store.

Kinetic energy The energy in any moving object. The amount of energy depends on the weight (mass) of the object and the speed of the object.

Kingpin Used on an I-beam or twin I-beam front suspension, A kingpin steering knuckle keeps the wheel rigid in relation to the I-beam during up-and-down wheel movement, but rotates around the steering axis to turn the wheels left and right.

Kingpins Kingpins allow the front wheels to rotate for steering. Kingpins are hardened steel pins that attach the steering knuckle to the front axle.

Kirchhoff’s current law A law that states: “The current flowing into any junction of an electrical circuit is equal to the current flowing out of that junction.” Lightemitting - Light-emitting diode (LED) trouble lights are excellent to use because they are shock resistant, long lasting, and do not represent a fire hazard.

Kirchhoff’s voltage law A law about electrical circuits that states: “The voltage around any closed circuit is equal to the sum (total) of the resistances.”

Knock sensor (KS) A sensor that can detect engine spark knock.

KPI Steering axis inclination (SAI) is also known as kingpin inclination (KPI) and is the imaginary line drawn through the kingpin as viewed from the front.

kWh/100 mi The EPA also expresses an EV’s energy consumption in terms of the number of kilowatts per hour needed to run the vehicle for 100 miles shortened to kWh/100 mi. For example, a Tesla Model 3 usually uses about 28 kW per 100 miles.

Labor guides A guide that shows the estimated labor times for each service or procedure.

Labyrinth seal A water seal formed by the curved area at the lip of the backing plate and the notch in the brake drum.

Ladder frame A steel frame for a vehicle that uses cross braces along the length, similar to the rungs of a ladder.

Lands Piston ring grooves are located between the piston head and skirt. The width of the grooves, the width of the lands between the ring grooves, and the number of rings are major factors in determining minimum piston height.

Lane departure warning system (LDWS) The lane departure warning system (LDWS) uses cameras to detect if the vehicle is crossing over lane marking lines on the pavement.

Lane keep assist (LKA) A lane keep assist (LKA) will warn the driver if the vehicle is moving out of the lane of traffic, but when no response, to also automatically use the electric power steering system to steer the vehicle back into the lane.

Lane-departure warning Lane-departure warning, also called Lane-keeping Assist often uses a small vibration in the seat to warn the driver that the vehicle is close to the center line, and can often actually steer the vehicle back into the lane

Lap On nonhunting and partially nonhunting gears, manufacturers lap the contacting gear teeth to decrease wear. For this reason, these gear sets are marked to ensure proper alignment during assembly procedures.

Lapelletier gear set The Lapelletier gear set is constructed by connecting a planetary gear set in front of a Ravigneaux gear set.

Lash The valve clearance or lash must be set on a solid lifter engine, so that the valves can positively seat.

Latent heat Heat that causes a change in state without a change in temperature.

Lateral acceleration sensor The function of the lateral acceleration sensor is to provide the suspension control module with feedback regarding vehicle cornering forces.

Lateral accelerometer sensor A sensor used in many vehicles equipped with electronic suspension and/or traction control systems used to detect sideways movement of the vehicle.

Lateral links Suspension arms that control the side-to-side movement of the wheels and vehicle. Also called transverse links.

Lateral runout (LRO) Lateral runout, often abbreviated LRO, is side-to-side wobble of the rotor as it rotates on the spindle.

Lateral runout A possible problem that tires can cause is a type of vibration called shimmy, which is the rapid back-and-forth motion transmitted through the steering linkage to the steering wheel. Excessive lateral runout is usually noticeable by the driver of the vehicle as a side-to-side vibration, especially at low speeds between 5 and 45 mph (8 and 72 km/h).

Lay shaft All manual transmissions/transaxles use a countershaft (also called a lay shaft or cluster shaft) to provide the other set of gears necessary to achieve the changes in gear ratios. The gears on the countershaft are called cluster gears or counter gears.

Lead A lead or drift is a mild pull that does not cause a force on the steering wheel that the driver must counteract.

Leading shoe The forward facing brake shoe on a leading/trailing type of drum brake.

Leading-trailing brakes A type of drum brake design which anchors the bottom of both shoes to the backing plate.

Leaf mark Washington State legislation mandates that all brake pads and shoes manufactured after January 1, 2015, are required to have a leaf mark icon indicating the level of compliance with state friction material content legislation.

Leaf springs Leaf springs are constructed of one or more strips of long, narrow spring steel. These metal strips, called leaves, are assembled with plastic or synthetic rubber insulators between the leaves, allowing for freedom of movement during spring operation.

Leak detection pump (LDP) Many vehicles use a vacuum operated leak detection pump (LDP) as part of the evaporative control system diagnosis equipment.

Lean indicator If O2 is high, the exhaust is lean, so O2 is called the "lean indicator"

LED test light An LED test light uses a light-emitting diode (LED), instead of a standard automotive bulb, for a visual indication of voltage.

Ledges Also called shoe pads, where the brake lining controls the backing plate.

Left-hand rule A method of determining the direction of magnetic lines of force around a conductor. The left-hand rule is used with the electron flow theory (- flowing to +).

Leg Another name for the branches of a parallel circuit.

Lenz's law The relative motion between a conductor and a magnetic field is opposed by the magnetic field of the current it has induced.

Lever style (pressure plate) Coil spring style. This style of pressure plate uses coil springs and three or four release arms. A coil-spring-style pressure plate is also called the lever style because it uses levers to compress the coil springs

Leverage The ability of a lever or other mechanical device used to increase force.

Leyden jar A device first used to store an electrical charge. The first type of capacitor.

Lift pump The diesel fuel is usually drawn from the fuel tank by a separate pump, called a lift pump, and delivers the fuel to the injection pump.

Light-emitting diode (LED) A high-efficiency light source that uses very little electricity and produces very little heat.

Lightly Loaded Vehicle Weight (LLVW) The actual performance tests are made with the vehicle loaded to both the manufacturer's specified gross vehicle weight rating (GVWR) and the lightly loaded vehicle weight (LLVW), with certain applied brake forces. There are precise instructions for every step of the test, including the number of times the tests must be repeated, the sequence of the testing, and the allowable stopping distance for the particular type of vehicle.

Light-off converter (LOC) Some vehicles have used a small, quick heating oxidation converter, called a preconverter or a pup (mini) converter, that connects directly to the exhaust manifold outlet. These have a small catalyst surface area close to the engine that heats up rapidly to start the oxidation process more quickly during cold engine warm-up. For this reason, they were often called light-off converters (LOCs).

Light-off temperature The catalytic converter does not work when cold, so it must be heated to its light-off temperature of close to 500°F (260°C) before it starts working at 50% effectiveness. When fully effective, the converter reaches a temperature range of 900°F to 1,600°F (482°C to 871°C). In spite of the intense heat, however, catalytic reactions do not generate a flame associated with a simple burning reaction.

Light-off time (LOT) The time it takes for an oxygen sensor to be start to work.

Limp-in gear A default (or limp-in) gear is the forward speed that is used if there is a failure in the electronic or computer system. If neither solenoid is engaged, then either second or third gear is actuated, depending on the exact make and model of the transmission or transaxle.

Line pressure solenoid (LPS) The solenoid that controls the line pressure to the transmission hydraulic system.

Linear EGR valve Most General Motors and many other vehicles use a linear EGR valve that contains a pulse-width modulated solenoid to precisely regulate exhaust gas flow and a feedback potentiometer that signals the PCM regarding the actual position of the valve.

Lining fade A condition where the brake lining overheats, reducing the coefficient of friction.

Lining table The part of a drum brake shoe where the lining is attached.

Lip seal A type of seal used on A/C compressors. The lip of the seal is made from Teflon and rides against a perfectly smooth portion of the drive shaft.

Liquid crystal display (LCD) A display that uses liquid crystals to display waveorms and text on its screen.

Liquid line The line that connects the condenser outlet to the receiver–drier inlet or orifice tube and the receiver–drier outlet to the TXV.

Liquified petroleum gas (LPG) Another term for propane.

Listening To make an effort to hear someone. Good listening requires that we focus our attention on those speaking to us.

Lithium iron phosphate (LiFePO4) Lithium iron phosphate (LiFePO4) is a type of battery chemistry that is stable at higher temperatures and does not contain cobalt, which is in limited supply world-wide.

Lithium-based brake grease Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend Lithium-based brake grease.

Live axle If engine torque is applied to the rear axle to drive the vehicle, the axle is referred to as a live axle.

Load Index An abbreviated method that uses a number to indicate the load carrying capabilities of a tire.

Load test A type of battery test where an electrical load is applied to the battery and the voltage is monitored to determine the condition of a battery.

Load A term used to describe a device when an electrical current is flowing through it.

Load-carrying ball joint If the coil spring is attached to the top of the upper control arm, then the upper ball joint is carrying the weight of the vehicle and is called the load-carrying ball joint.

Loaded calipers Loaded calipers are remanufactured calipers that include (come loaded with) the correct replacement friction pads and all the necessary hardware.

Lobe centers Separation between the centerlines of the intake and exhaust lobes, measured in degrees.

Lobe displacement angle (LDA) Another camshaft specification that creates some confusion is the angle of the centerlines of the intake and exhaust lobes. This separation between the centerlines of the intake and exhaust lobes is called lobe displacement angle (LDA).

Lobe lift The lobe lift of the cam is usually expressed in decimal inches and represents the distance that the valve lifter or follower is moved.

Lobe separation Another camshaft specification that creates some confusion is the angle of the centerlines of the intake and exhaust lobes. This separation between the centerlines of the intake and exhaust lobes is called lobe separation.

Lobe spread Another camshaft specification that creates some confusion is the angle of the centerlines of the intake and exhaust lobes. This separation between the centerlines of the intake and exhaust lobes is called lobe spread.

Lobe Camshafts have eccentric shapes called lobes that open the valve against the force of the valve springs.

Lock plate A plate located in the steering column that is used to lock the steering wheel when the key is removed from the ignition.

Lock ring Full-floating piston pins use some type of lock ring to retain the piston pin. There are two common types of lock rings: 1. Internal snap ring and 2. Spiral lock ring.

Lock tang A mechanical tab that is used to secure a terminal into a connector. This lock tang must be depressed to be able to remove the terminal from the connector.

Locking pliers Pliers that can be used to grasp an object and then be locked into position. Often called by a popular brand name VISE-GRIPS®.

Locks The valve keepers (also called locks) secure the spring retainer to the stem of the valve.

Locksmith ID In order to obtain module reprograming information or to replace a module, the shop or service technician must be a registered vehicle security professional and have a locksmith ID number. The National Automotive Service Task Force (NASTF), in conjunction with automotive manufacturers, insurance industry, independent repair, and law enforcement communities, has developed this system to allow the aftermarket repair industry to access to this sensitive data.

Logic probe A type of tester that can detect either power or ground. Most testers can detect voltage but most of the others can not detect if a ground is present without further testing.

Long block The replacement assembly is called a long block when the reconditioned assembly includes the heads and valve train.

Loss Leader A loss leader is a product that is sold for less than the usual or expected price in an effort to entice customers to visit the parts store to purchase the item.

Lost Sales Report A lost sales report will show new part numbers that the store does not stock along with older part numbers that are increasingly in demand. Some part numbers will have an instant demand, such as those found in some of the newer vehicles. Other parts will grow in demand, but more slowly.

Low range A low range may be selected to deliver high torque at low speeds to the drive wheels. Low range usually provides a 2:1 to 3:1 gear reduction. High range (usually 1:1) simply transfers engine torque at the same speed as the output shaft of the transmission.

Low-drag caliper A type of disc brake caliper where the piston retracts more than usual, reducing the brake drag between the pad and the rotor.

Low-grade heat Heat is generated by the fuel cell during normal operation. Excess heat can lead to a breakdown of the polymer electrolyte membrane, so a liquid cooling system must be utilized to remove waste heat from the fuel-cell stack. One of the major challenges for engineers in this regard is the fact that the heat generated by the fuel cell is classified as low-grade heat.

LP-gas Propane is the most widely used of all of the alternative fuels. Propane is normally a gas but is easily compressed into a liquid and stored in inexpensive containers. When sold as a fuel, it is also known as liquefied petroleum gas (LPG) or LP-gas because the propane is often mixed with about 10% of other gases.

LRR Low-rolling-resistance (LRR) tires reduce rolling resistance, which is the power-robbing friction between the tire and crown.

Lube oil The ATF returns to the transmission/transaxle to passages that lubricate the internal moving parts. This returned fluid is called lube oil.

Lug nuts Nuts used on wheel studs to attach wheels to hubs.

Lugging Never lug any engine. Lugging means increasing the throttle opening without increasing engine speed (RPM).

M85 Internal combustion engine fuel containing 85% methanol and 15% gasoline.

Magnetic flux The lines of force produced in a magnetic field.

Magnetic induction The transfer of the magnetic lines of force to another nearby metal object or coil of wire.

Magnetic sensor A magnetic sensor uses the changing strength of the magnetic field surrounding a coil of wire to signal the module and computer.

Magnetism A form of energy that is recognized by the attraction it exerts on other materials.

Magneto-rheological (MR) MR fluid shocks use a working fluid inside the shock that can change viscosity rapidly depending on electric current sent to an electromagnetic coil in each device. The fluid is called magneto-rheological (Mr) and is used in monotube-type shock absorbers.

Main drive pinion assembly The input shaft is splined to the clutch disc and is also referred to as the main gear, clutch gear, or main drive pinion assembly. The main shaft, also called the output shaft, is splined at the end and transmits engine torque to the drive shaft (propeller shaft) through a yoke and universal shaft.

Main gear The input shaft is splined to the clutch disc and is also referred to as the main gear, clutch gear, or main drive pinion assembly. The main shaft, also called the output shaft, is splined at the end and transmits engine torque to the drive shaft (propeller shaft) through a yoke and universal shaft.

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Major splice A place in a tire where the tread rubber and one or more body plies are spliced during tire construction.

Major thrust surface The side of an engine cylinder that receives the greatest thrust or force from the piston during the power stroke.

Malfunction indicator lamp (MIL) This amber, dashboard warning light may be labeled check engine or service engine soon.

Manifold absolute pressure (MAP) sensor Sensor used to measure the pressure inside the intake manifold compared to a perfect vacuum.

Manual valve The manual valve is the primary flow-directing valve in an automatic transmission. This valve connects to a shift lever in the transmission, which in turn connects to the gear selector lever through a mechanical linkage. The driver controls manual valve position through the gear selector and shift linkage.

Manufacturer's suggested retail price (MSRP) The Monroney label is the sticker on the vehicle that lists the manufacturer's suggested retail price, usually abbreviated MSRP. The law that requires this label on all vehicles is called the Monroney Law, named for the congressman who sponsored the bill, Almer S. Monroney (1902–1980), a U.S. farm representative from Oklahoma from 1939 to 1951 and a U.S. Senator from 1951 to 1969.

Marcel spring The torsional dampers are either coil springs or are made of rubber. In the space between the friction surfaces is a wavy spring steel material called a cushioning spring or marcel spring.

Mass airflow (MAF) sensor Unlike the air vane sensor, the MAF sensor takes into account relative humidity, altitude, and temperature of the air. The denser the air, the greater the cooling effect on the hot film sensor and the greater the amount of fuel required for proper combustion.

Mass The weight of an object. A measure of the amount of material contained in an object. Gravity acts on a mass to give it weight.

Master cylinder The part of the brake hydraulic system where the pressure is generated.

Match mounting Mount the tires on the rim with the valve stem matched to (lined up next to) the mark on the tire or with the major splice. This is called match mounting.

MCA Marine cranking amps. A battery specification.

Mechanical advantage The use of levers, such as a brake pedal to increase the force applied by the driver.

Mechanical fade Braking reduction caused by the heat expansion of the brake drum away from the brake lining.

Mechanical force A mechanical force involves contact with another object. The pressure developed within the combustion chamber is applied to the head of a piston to produce a usable mechanical force, which is converted into useful mechanical power.

Mechanical power Mechanical power. Power is the rate at which work is done. The pressure developed within the combustion chamber is applied to the head of a piston to produce a usable mechanical force, which is converted into useful mechanical power.

Mechanical refrigeration A cooling process that involves pumping a chemical with a very low boiling point through a series of heat exchangers.

Mechanical returnless fuel system (MRFS) A returnless fuel delivery system design that uses a mechanical pressure regulator located in the fuel tank.

Medium hybrid A hybrid electric vehicle design that utilizes "medium" voltage levels (between 50 and 200 volts). Medium hybrids use regenerative braking and idle stop but are not capable of starting the vehicle from a stop using electric mode.

Mega (M) Million. Used when writing larger numbers or measuring large amount of resistance.

Membrane electrode assembly (MEA) The part of the PEM fuel cell that contains the membrane, catalyst coatings, and electrodes.

Memory steer Memory steer is a lead or pull of a vehicle caused by faults in the steering or suspension system. If after making a turn, the vehicle tends to pull in the same direction as the last turn, then the vehicle has memory steer.

Mentor An experienced technician who offers to help a beginning technician learn all aspects of the trade.

Mercury A heavy metal.

Mesh spring A spring used behind the starter pinion on a starter drive to force the drive pinion into mesh with the ring gear on the engine.

Metal Inert Gas (MIG) Is an arc welding process that uses a continuous solid wire electrode heated and fed into the weld pool from a welding gun. The two base materials are melted together forming a joint. The gun uses a shielding gas around the electrode to protect the weld pool from oxidation. The MIG welder is currently used for welding panels and structural components together. MIG welding can repair high-strength steel without harming or weakening it.

Meter accuracy The accuracy of a meter measured in percent.

Meter resolution The specification of meter that indicates how small or fine a measurement the meter can detect and display.

Metering valve (Hold-off valve) A valve installed between the master cylinder and front disc brakes which prevents operation of front disc brakes until 75-125 psi is applied to overcome rear drum brake return spring pressure.

Metric bolts Bolts manufactured and sized in the metric system of measurement.

Metric wire gauge The metric method for measuring wire size in the square millimeters. This is the measure of the core of the wire and does not include the insulation.

Micro-hybrid drive A term used to describe Belt Alternator Starter (BAS) and other mild hybrid systems.

Microinches (μin) The smoothness of the rotor is called rotor finish or surface finish. Surface finish is measured in units called microinches, abbreviated μin..

Micron A unit of length equal to one millionth of a meter. One micron is equal to 0.000039 inch.

Mild hybrid A hybrid electric vehicle design that utilizes regenerative braking and idle stop but cannot propel the vehicle in electric-only mode. Also called an assist hybrid and typically operates below 50 volts.

Miles per hour (MPH) Level 2 charging adds about 25 miles of Range Per Hour (RPH), labeled as miles per hour (MPH) on the dash display of a Nissan Leaf.

Milli (m) One thousandth of a volt or ampere.

Millimeters of mercury (Mm Hg) A metric measure of vacuum.

Mineral oil Mineral oil is used in R-12 refrigerant systems.

Minutes There are 60 minutes (written as 60') in 1 degree.

Miscible Oils must be miscible, meaning they are capable of mixing with other oils (brands and viscosities, for example) without causing any problems, such as sludge

Mode door A flap valve that moves to divert airflow to the floor, instrument panel, or windshield outlets.

Mode select switch A switch used to select ride comfort settings on a vehicle equipped with electronic suspension.

Mode shift Either two-wheel drive or four-wheel drive may be selected. Many transfer cases also have a neutral position. The mode shift is achieved by the use of a floor-mounted lever to engage and disengage a clutch inside the transfer case.

Model year (MY) The year of a vehicle, which may be different from the calendar year when it is sold.

Modified X A method of tire rotation.

Modulation The combination of these two frequencies is referred to as modulation.

Mold-bonded lining A design of disc brake pads where the lining material is molded into holes in the steel backing plate.

Molybdenum disulfide (MOS2) grease Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend Molybdenum disulfide (MOS2) grease.

Momentary switch A type of switch that toggles between on and off.

Mono leaf A leaf spring that uses only one leaf.

Monoblock Blocks are often of the monoblock design, which means that the cylinder, water jacket, main bearing supports (saddles), and oil passages are all cast as one structure for strength and quietness.

Moon roof A moon roof is made of a tinted glass panel that can be either tilted open or completely retracted to operate as an open window in the roof. Most new cars have moon roofs.

Morse type The silent chain type (also known as a flat-link type, or Morse type for its original manufacturer) operates quietly but tends to stretch with use. The metal links themselves do not "stretch" but, instead, the pin bushings at each joint wear, which causes the chain to become longer.

MOSFET Metal oxide semiconductor field-effect transistor; a type of transistor.

MPGe To help consumers compare the energy consumption of electric vehicles with those that run on fossil fuel, the EPA created a miles-per-gallon measurement, called MPGe. This is calculated based on a conversion factor of 33.705 kilowatt-hours of electricity equaling one gallon of gasoline. Therefore, a battery that has a capacity of 100 kWh is equal to the energy of about three gallons of gasoline.

MSI Steering axis inclination (SAI) is also called MacPherson strut inclination (MSI) on a vehicle equipped with McPherson struts.

Mu (μ) The Greek letter that represents the coefficient of friction.

Muffler A muffler is used in the exhaust stream to help quiet the sound of engine combustion.

Mufflers A device that quiets compressor pumping sounds.

Multigroove adjustable pliers Pliers that are capable of grasping a wide range of object sizes; also called water pump pliers or by a popular brand name of Channel Locks®.

Multilayered steel (MLS) gaskets The multilayered steel (MLS) gaskets are constructed in the following manner: 1. Three to five layers of stainless steel sheet are separated by elastomer (rubber) material. 2. The elastomer material is between the layers of the sheet metal and on both surfaces. 3. The multiple layers of metal provide a spring like effect to the gasket, which allows it to keep the combustion chamber sealed.

Multiple-plate clutch The multiple-plate clutch consists of plates, a piston, drum (retainer), and snap ring. Hydraulic pressure acts upon the clutch piston which moves in the drum. The piston movement compresses the plates together to provide either a holding or driving function. When the pressure is released, the piston returns to an unapplied position via a return spring assembly. This entire assembly is commonly known as a clutch pack.

Multiplexing A process of sending multiple signals of information at the same time over a signal wire.

Mutual induction The generation of an electric current due to a changing magnetic field of an adjacent coil.

N.C. Normally closed.

N.O. Normally open.

NASTF The NASTF is a cooperative effort of the automotive service industry, the tool industry, and the original equipment manufacturers to ensure that automotive professionals employed outside of the OEMs have all the information, training, and tools they need to diagnose and repair modern automobiles.

National Lubricating Grease Institute (NLGI) Usually associated with grease. The higher the NLGI number, the firmer the grease. #000 is very fluid whereas #5 is very firm. The consistency most recommended is NLGI #2 (soft).

Natural frequency The frequency where the brake pads tend to vibrate.

Naturally (normally) aspirated An engine that uses atmospheric pressure for its intake charge is called a naturally (normally) aspirated engine.

Naturally aspirated If atmospheric air pressure is used to force the air-fuel mixture into the cylinders, the engine is called naturally aspirated.

Needle rollers A needle bearing is a type of roller bearing that uses smaller rollers called needle rollers. The clearance between the diameter of the straight roller is manufactured into the bearing to provide the proper radial clearance and is not adjustable.

Needle-nose pliers Pliers that are equipped with pointed jaws, which allow use in restricted areas or for small parts.

Negative temperature coefficient (NTC) Usually used in reference to a temperature sensor(coolant or air temperature). As the temperature increases, the resistance of the sensor decreases.

Nernst cell Another name for a conventional oxygen sensor. The Nernst cell is named for Walther Nernst, 1864–1941, a German physicist known for his work in electrochemistry.

Net The paycheck you receive will be for an amount called net earnings and taxes and other deductions will have been taken out from your gross pay.

Network A communications system used to link multiple computers or modules.

Neutral charge An atom that has the same number electrons as protons.

Neutral flame The neutral flame is generally used for welding and burns about one part oxygen to one part acetylene. Adjust the torch until the inner cone is blunt and the feathery edges have disappeared. A typical neutral flame burns at 5900° F (3260° C).

Neutral position This partially open position, also called the neutral position or the fail safe position, is about 16% to 20% open.

Neutral run-up test A test used to help determine the source of a vibration. Engine speed is increased and vibration is measured with the transmission in neutral.

Neutral safety switch An electrical switch that allows the starter to be energized only if the gear selector is in neutral or park.

Neutral In neutral, all of the synchronizer sleeves are centered on their hubs

Newton's laws of motion Newton's first law of motion states that an object at rest tends to stay at rest and an object in motion tends to stay in motion unless acted on by an outside force.

NGV Natural gas vehicle.

Nibs Small V-shaped notches on the side of brake shoes where they rest against the backing plate.

Nickel, cobalt, and aluminum (NCA) Nickel, cobalt, aluminum (NCA) cathode material results in a long battery life and faster charging capability compared to some other types of battery chemistry.

Nickel, manganese, and cobalt (NMC) A NMC battery uses a combination of nickel, manganese and cobalt (NMC) for the cathode material. This cathode material results in slightly lower energy, but is less volatile and can withstand variation in temperature.

Nickel-metal hydride (NiMH) A battery design used for the high-voltage batteries in most hybrid electric vehicles.

Night vision Night vision systems use a camera that is capable of observing objects in the dark to assist the driver while driving at night. The primary night-viewing illumination devices are the headlights.

The night vision option uses a HUD to improve the vision of the driver beyond the scope of the headlights.

NiMH Nickel-metal hydride. A battery design used for the high-voltage batteries in most hybrid electric vehicles.

Nitriding To improve wear resistance, some manufacturers harden the crankshaft journals. Methods used to harden the crankshaft journals includes: Nitriding, where the crankshaft is heated to about 1,000°F (540°C) in a furnace filled with ammonia gas, and then allowed to cool.

Nitrogen oxides (NOx) Nitrogen (N2) and oxygen (O2) molecules are separated into individual atoms of nitrogen and oxygen during the combustion process. These molecules then bond to form NOx (NO, NO2). When combustion flame front temperatures exceed 2,500°F (1,370°C), NOx is formed inside the cylinder, which is then discharged into the atmosphere from the tailpipe.

Nitrogen (N_2) Nitrogen gas is used to inflate tires and is used to prevent moisture and oxygen inside a tire where it can increase the chances of rust or corrosion.

NLGI National Lubricating Grease Institute. Usually associated with grease. The higher the NLGI number, the firmer the grease. #000 is very fluid whereas #5 is very firm. The consistency most recommended is NLGI #2 (soft).

Node A module and computer that is part of a communications network.

Noid light Designed to electrically replace the injector in the circuit and to flash if the injector circuit is working correctly.

Noise-reducing tire The purpose of a noise reducing tire is to eliminate noise in the 130 to 240 Hz range that would be normally covered up by normal engine noise in a vehicle with an internal combustion engine. The noise reduction is accomplished by adding acoustical foam to the inside of a tire.

Non-asbestos organic (NAO) Brake pads and linings that use synthetic material, such as aramid fibers, instead of steel are usually referred to as: 1. non-asbestos 2. non-asbestos organic (NAO) and 3. non-asbestos synthetic (NAS). These friction materials are often called ceramic in the American aftermarket because they include ceramic fibers, which are usually potassium titanite.

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Non-condensable gas (NCG) Gases, such as air in an A/C system, that do not readily change to a liquid state as the refrigerant does.

Non-condensable gases (NCG) Gases, such as air in an A/C system, that do not readily change to a liquid state as the refrigerant does.

Nonhunting gear sets Nonhunting gear sets are gear sets with final drive ratios expressible as a whole number

Non-hygroscopic Brake fluid, such as DOT 5 that does not absorb moisture from the air.

Non-load-carrying ball joint If the coil spring is attached to the top of the upper control arm, then the upper ball joint is carrying the weight of the vehicle and is called the load-carrying ball joint.

Non-methane organic gases (NMOG) Non-methane organic gases (NMOG) and NOx are combined under one limit, meaning that the HC and NOx have to be both controlled to meet these standards.

Nonprincipal end The nonprincipal end of the engine is opposite the principal end and is generally referred to as the front of the engine, where the accessory belts are used.

Non-servo brakes A drum brake design where the primary lining (forward facing) does not control or transmit a force to the secondary (rearward facing) brake shoe.

Non-Verbal Communications Not involving or using words to communicate. Examples of are hand gestures, head nodding, and body position.

Nonvolatile RAM Nonvolatile RAM memory can retain its information even when the battery is disconnected.

Nonvolatile random access memory (NVRAM) Nonvolatile RAM memory can retain its information even when the battery is disconnected. One use for this type of RAM is the storage of odometer information.

No-retorque-type gaskets No-retorque-type gaskets, mean the cylinder head bolts do not have to be retorqued after the engine has run. New gaskets do not contain asbestos.

Normal operating temperature Normal operating temperature is the temperature at which the upper radiator hose is hot and pressurized.

NPN transistor A type of transistor that has the P-type material in the base and the N-type material is used for the emitter and collector.

NTC Negative temperature coefficient. Usually used in reference to a temperature sensor (coolant or air temperature). As the temperature increases, the resistance of the sensor decreases.

N-type material Silicon or germanium doped with phosphorus, arsenic, or antimony.

Nut splitter A hand tool designed to break a nut that is rusted onto a bolt or stud.

NVH Abbreviation for noise, vibration and harshness.

OAD Overrunning alternator dampener.

OAP Overrunning alternator pulley

OBD-II The engine, as well as the engine management systems can test itself, for proper operation and alert the driver if a fault is detected. The warning lamp is called the malfunction indicator light (MIL) and is labeled “Check Engine” or “Service Engine Soon.” The on-board diagnostic system is currently in the second generation and is called OBD-II.

Occupant detection system (ODS) An airbag system that includes a sensor in the passenger seat used to detect whether or not a passenger is seated in the passenger side and the weight range of that passenger.

Occupational Safety and Health Administration (OSHA) OSHA is the main federal agency responsible for enforcement of workplace safety and health legislation.

Octane rating The measurement of a gasoline’s ability to resist engine knock. The higher the octane rating, the less prone the gasoline is to cause engine knock (detonation).

OEM (Original Equipment Manufacturers) OEM (Original Equipment Manufacturer) parts are manufactured by the same company that produced the original part used in assembly of the vehicle.

Offset The distance the center section (mounting pad) is offset from the centerline of the wheel.

Ohm’s Law An electrical law that requires 1 volt to push 1 ampere through 1 ohm of resistance.

Ohmmeter An electrical test instrument used to measure ohms (unit of electrical resistance).

Ohms The unit of electrical resistance. Named for George Simon Ohm.

Oil control ring Piston rings are classified into two types, one type is one oil control ring, located below the compression rings.

Oil control valve (OCV) The camshaft position actuator oil control valve (OCV) directs oil from the oil feed in the head to the appropriate camshaft position actuator oil passages.

Oil filter An engine-driven oil pump forces the oil under pressure through an oil filter, then to passages in the block and head called oil galleries, and then to all of the moving parts.

Oil gallery plugs After oil holes are drilled, the unneeded open ends may be capped by pipe plugs, steel balls, or cup-type soft plugs, often called oil gallery plugs.

Oil gallery An oil pump which is driven by the engine, forces the oil through the oil filter and then into passages in the crankshaft and block.

Oil pan All engines need a supply of lubricating oil to reduce friction and help to cool the engine. Most engines are equipped with an oil pan, also called an oil sump, containing 3 to 7 quarts (liters) of oil.

Oil pump An engine-driven oil pump forces the oil under pressure through an oil filter, then to passages in the block and head called oil galleries, and then to all of the moving parts.

Oil sump An engine-driven oil pump forces the oil under pressure through an oil filter, then to passages in the block and head called oil galleries, and then to all of the moving parts.

oil trap Many A/C compressors use an oil trap to help the oil in the compressor this method is not as efficient as it has been in the past when used with older systems.

OL Overload or over limit.

On-board diagnosis (OBD) During the 1980s, most manufacturers began equipping their vehicles with full-function control systems capable of alerting the driver of a malfunction and of allowing the technician to retrieve codes that identify circuit faults. These early diagnostic systems were meant to reduce emissions and speed up vehicle repair. The automotive industry calls these systems On-Board Diagnostics (OBDs).

Onboard refueling vapor recovery (ORVR) Onboard refueling vapor recovery (ORVR) systems have been developed to reduce evaporative emissions during refueling. These systems add components to the filler neck and the tank.

One-pedal driving One pedal driving means that for normal driving, the driver only needs to use the accelerator pedal to accelerate and deaccelerate.

Oneway clutch Another common type of automatic transmission device is the one-way clutch (OWC), or overrunning clutch. Like a transmission band, a one-way clutch is always a holding device. One-way clutches are either roller or sprag clutches, although the roller clutch is more common.

One-way valve A one-way valve allows fluid to flow in one direction.

OnStar OnStar does not display the location of the vehicle to the driver unless the vehicle is also equipped with a navigation system. Unlike most navigation systems, the OnStar system requires a monthly fee. The driver interface unit is a group of three buttons mounted on the inside rearview mirror and a hands-free cellular telephone.

On-the-job training (OJT) Training that occurs in the actual work environment. For Technicians training occurs while working on the vehicle.

Op-amps Used in circuits to control and simplify digital signals.

Open circuit voltage Voltage measured without the circuit in operation.

Open circuit Any circuit that is not complete and in which no current flows.

Open loop When the PCM alone is determining the amount of fuel needed, it is called open-loop operation.

Open-end wrench A wrench with jaws having a fixed width of opening at one or both ends of the handle. An open-end wrench can be easily placed on a bolt or nut with an angle of 15 degrees, which allows the wrench to be flipped over and used again to continue to rotate the fastener.

Opposite-phase steering A type of four-wheel steering when the front wheels and rear wheels are steered in the opposite direction.

Organic acid technology (OAT) Antifreeze coolant contains ethylene glycol, but does not contain silicates or phosphates. This type of coolant is usually orange in color and was first developed by Havoline (called DEX-COOL) and used in General Motors vehicles starting in 1996.

Original equipment (OE) Parts at a new vehicle dealership come either directly from the vehicle manufacturer or a regional dealership. Original equipment parts, abbreviated OE, are generally of the highest quality because they have to meet performance and durability standards not required of replacement parts manufacturers.

Oscilloscope A visual display of electrical waves on a fluorescent screen or cathode ray tube.

OSHA Occupational Safety and Health Administration. OSHA is the main federal agency responsible for enforcement of workplace safety and health legislation.

Out-of-round A fault with a brake drum, which is not perfectly round.

Output drivers There are two basic types of output drivers. They are Low-side drivers and High-side drivers.

Output member The drive member of a planetary gear set is called the input member, the held member, the reaction member, and the driven member, the output member.

Output shaft The input shaft is splined to the clutch disc and is also referred to as the main gear, clutch gear, or main drive pinion assembly. The main shaft, also called the output shaft, is splined at the end and transmits engine torque to the drive shaft (propeller shaft) through a yoke and universal shaft.

Output speed sensor (OSS) This speed sensor, also called the vehicle speed (VS) sensor, is used by the PCM for speedometer and cruise control operation as well as for transmission/transaxle operation and shift-related fault detection.

Outside air temperature (OAT) sensor The outside air temperature (OAT) sensor, also called the ambient temperature sensor, measures outside air temperature and is often mounted at the radiator shroud or in the area behind the front grill.

Outside air Outside air is often called fresh air.

Outside Purchase An outside purchase happens when a part is a non-stocking part and ordered from an outside supplier.

over the air (OTA) The process of updating electronic modules using cellular or Wi-Fi system.

Overcenter adjustment Gear mesh preload is a measurement of how much turning force must be applied to the input shaft to overcome the resistance of the sector gear and move it. Gear mesh preload is usually measured in a 90-degree turn across the center of the input shaft movement. General Motors calls this adjustment the overcenter adjustment.

Overdrive In a transmission or drive axle, when the input shaft turns slower than the output shaft. A gear ratio of 0.87:1 is considered to be an overdrive gear ratio because only 0.87 turns of the input shaft will result in 1 full turn of the output shaft.

Overhead camshaft (OHC) Newer engine designs feature overhead camshafts (OHC), called single overhead camshaft (SOHC) designs and engines that use two overhead camshafts per bank of cylinders called double overhead camshaft (DOHC) designs. The placement of the camshaft results in better flow of intake air into and exhaust out of the engine.

Overhead valve (OHV) By the 1950s, most engine designs placed the valves in the cylinder head. This is called an overhead valve or OHV design.

Overlay Corrosion results in bearing journal wear as the bearing is eroded by the acids. Many of the copper-lead bearings have an overlay, or third layer, of metal. This overlay is usually of babbitt. Babbitt-overlayed bearings have high fatigue strength, good conformity, good embeddability, and good corrosion resistance.

Overrunning clutch A mechanical coupling device that allows torque to be transmitted in one direction of rotation, but freewheels when turned in the opposite direction. Also known as a *one-way clutch*.

Oversize (OS) stems Some domestic vehicle manufacturers that have integral valve guides in their engines recommend reaming worn valve guides and installing new valves with oversize (OS) stems. When a valve guide is worn, the valve stem is also likely to be worn. In this case, new valves are required. If new valves are used, they can just as well have oversize stems.

Oversteering Oversteering is when the rear of the vehicle tends to move outward or breaks loose, resulting in the vehicle spinning out of control. This condition is also called loose. If the condition is detected during a left turn, the ESC system would apply the right front brake to bring the vehicle back under control.

Over-travel spring A spring used as part of the self-adjusting components that allow normal operation even if the star wheel adjuster does not move.

Owner's manual The owner's manual is the instructional booklet that comes with every new vehicle and includes important information.

Oxides of nitrogen (NOx) A primary emission produced in the combustion chamber under high temperatures when nitrogen combines with oxygen. Oxides of nitrogen contribute to the formation of smog (ground level ozone [O3]) when combined with HC and sunlight.

Oxidizing flame The oxidizing flame is used for brazing and is obtained by opening the oxygen valve slightly more than the neutral flame. The inner cone gets shorter and pointed and it becomes somewhat purple in color. Flame temperature is about 6300° F (3482° C).

Oxygen (O2) Oxygen (O2) is an element that composes 21% of air.

Oxygen sensors (O2S) Automotive computer systems use a sensor in the exhaust system to measure the oxygen content of the exhaust. These sensors are called oxygen sensors (O2S).

Oxygen storage capacity (OSC) The converters used on these vehicles have oxygen storage capacity (OSC), due mostly to the cerium coating in the catalyst rather than the precious metals used. The converter stores, then releases, the oxygen during normal reduction and oxidation of the exhaust gases, smoothing out the variations in oxygen being released.

Oxygenated fuels Fuels such as ETBE or MTBE that contain extra oxygen molecules to promote cleaner burning. Oxygenated fuels are used as gasoline additives to reduce CO emissions.

Ozone (Health and Environmental Concerns) Ozone is composed of three atoms of oxygen and is abbreviated O3. In high concentrations it can be a lung and respiratory irritant.

Ozone (Vehicle Emissions Standards and Testing) Oxygen rich (O3) gas created by sunlight reaction with un-burned hydrocarbons (HC) and oxides of nitrogen (NOx); also called smog.

Ozone depletion potential (ODP) The amount of effect that certain chemicals have on the ozone layer.

Ozone-depleting substances (ODS) Depletion of the earth's upper ozone layer due to the release of man-made chemicals threatens human health and damages plant life. Certain manmade chemicals used in refrigeration, air conditioning, fire and explosion prevention, and as solvents can trigger reactions in the atmosphere that destroy the ozone layer. Ozone-depleting substances (ODS) include chlorofluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs), halons and methyl bromide.

Pacific fuse element A type of automotive fuse.

Pad wear indicators A metal strap or notch in the disc brake pad to indicate that the pads are worn to the point of needing replacement.

PAG (polyalkylene glycol) PAG (polyalkylene glycol) oils are used in most R-134a refrigerant systems.

Paired cylinder Each end of the secondary winding is connected to a cylinder exactly opposite the other in the firing order, which is called a companion (paired) cylinder. This means that both spark plugs fire at the same time

Pal nut Jam nuts screw on top of a regular nut and jam against the regular nut to prevent loosening. A jam nut is so called because of its intended use, rather than a special design.Some jam nuts are thinner than a standard nut. Jam nuts are also called pal nuts .

Palladium The converter substrate contains small amounts of rhodium, palladium, and platinum. These elements act as catalysts. As mentioned, a catalyst is an element that starts a chemical reaction without becoming a part of, or being consumed in, the process.

Pancake An engine arranged for compactness by stacking cylinders one above another horizontally or side by side. This style of engine is used in Porsche and Subaru engines, and is often called a boxer engine.

Panhard rod A horizontal steel rod or bar attached to the rear axle housing at one end and the frame at the other to keep the center of the body directly above the center of the rear axle during cornering and suspension motions. Also called a *track rod.*

Paper test Hold a piece of paper or a 3 × 5 index card (even a dollar bill works) within 1 inch (2.5 cm) of the tailpipe with the engine running at idle. The paper should blow out evenly without "puffing." If the paper is drawn toward the tailpipe at times, the exhaust valves in one or more cylinders could be burned.

Parallel circuit An electrical circuit with more than one path from the power side to the ground side. Has more than one branch or leg.

Parallel clutch A clutch design used in a dual clutch automatic where the clutches rearranged side-by-side.

Parallel flow system In the parallel flow system, coolant flows into the block under pressure and then crosses the head gasket to the head through main coolant passages beside each cylinder.

Parallelism A measurement of a brake rotor to determine that both sides of the rotors are perfectly parallel.

Parallelogram linkage A geometric box shape where opposite sides are parallel (equal distance apart). A type of steering linkage used with a conventional steering gear that uses a pitman arm, center link, idler arm and tie rods.

Parameter identification (PID) When using a scan tool, powertrain data is listed using an ID and its current value or status. The specific piece of data is called the parameter identification (PID).

Parasitic load test An electrical test that measures how much current (amperes) is draining from the battery with the ignition off and all electrical loads off.

Parking assist systems The parking-assist system is used to help drivers avoid contact with another object while moving slowly. When backing up at speed of less than 5 MPH (8 km/h), the system constantly monitors for objects located around the vehicle.

Partially nonhunting gear sets Partially nonhunting gear sets are gear sets with final drive ratios expressible as a reducible fraction not equaling a whole number.

Particulate matter (PM) Also called soot and an emission from diesel engines.

Partitions Separations between the cells of a battery. Partitions are made of the same material as that of the outside case of the battery.

Parts Bulletins Parts Bulletins inform the parts store personnel about technical changes to the part.

Parts counter person A parts counter person often learns job skills by on-the-job training. A good parts counter person must be able to greet and easily talk to customers and technicians. A parts counter person must also have computer skills and the willingness to help others

Part-time employment Employment that is less than forty hours per week.

Pascal's law A law of hydraulics named for the person who developed it, Blaise Pascal (1632–1662)

PASS A word used to help remember how to use a fire extinguisher; pull pin, aim, squeeze the lever, and sweep the nozzle from side to side.

Passenger presence system (PPS) An airbag system that includes a sensor in the passenger seat used to detect whether or not a passenger is seated in the passenger side and the weight range of that passenger.

Passivation Passivation is a chemical reaction that takes place between coolant additives and the metal that it protects.

Passive balancing Passive balancing is achieved by having energy drawn from the most charged cell and dissipated as heat, usually through resistors. Passive balancing allows the stack to act as if every cell has the same capacity as the weakest cell. Using a relatively low current, it drains a small amount of energy from high SOC cells during the charging cycle so that all cells charge to their maximum state-of-charge (SOC).

Passive entry, passive starting (PEPS) A remote fob that allows entry to the vehicle is within a certain distance of the vehicle and allows the starting.

Passive wheel speed sensor A passive wheel speed sensor generates its own output signal and can operate without an outside voltage being applied. Passive wheel speed sensors are often called variable reluctance (VR)–type sensor, which uses a magnetic core surrounded by coil windings.

Pass-through device A pass-through device or API serves as a connection point that makes all the hardware look the same, and allows the computer with the reprogramming software to communicate with the vehicles control module through the data link connector (DLC).

Pattern bending Means measuring and comparing the old exhaust pipe to make a new one. This may be necessary when making a pipe for an older or low production vehicle for which no program card exists.

Pawl A lever for engaging in a notch. Used to rotate the notched star wheel on self-adjusting brakes.

PCV valve Regulates the flow of gases created in the crankcase of a running engine, which are routed back into the intake manifold. The engine will then draw these gases into the combustion chamber where they are burned to help prevent the release of the gases into the atmosphere.

Peak inverse voltage (PIV) The rating of resistance to reverse-bias voltage. Also called peak reverse voltage (PRV).

Peak reverse voltage (PRV) The rating of resistance to reverse-bias voltage is called the peak inverse voltage (PIV) rating, or the peak reverse voltage (PRV) rating.

Peak-and-hold A method for regulating the current flow through electronic fuel injectors. Supplies higher current necessary to energize the injector, then drops to a lower level just enough to keep the injector energized.

Pedal free play Pedal free play is the distance the brake pedal travels before the primary piston in the master cylinder moves.

Pedal height Proper brake pedal height is important for the proper operation of the stop (brake) light switch. If the pedal is not correct, the pushrod may be in too far forward, preventing the master cylinder cups from uncovering the compensation port. If the pedal is too high, the free play is excessive.

Pedal ratio The mechanical advantage of the brake pedal due to the location of the fulcrum and the length of the pedal arm.

Peltier Effect A French scientist Peltier found that electrons moving through a solid can carry heat from one side of the material to the other side. This effect is called the Peltier effect.

Pending code Any code(s) that are displayed when the MIL is not on is called a pending code.

Penetrating oil A thin oil that is designed to penetrate through rust and provide lubrication for the threads of a fastener.

Penetration test The American Society for Testing Materials (ASTM) specifies the consistency of grease using a penetration test. The National Lubricating Grease Institute (NLGI) uses the penetration test as a guide to assign the grease a number. Low numbers are very fluid and higher numbers are more firm or hard.

Percentage Percentage is the relationship of a value or number out of 100.

Perimeter frame A steel structure for a vehicle that supports the body of the vehicle under the sides, as well as the front and rear.

Peripheral pump A turbine pump is the most common because it tends to be less noisy. Sometimes called turbine, peripheral, and side-channel, these units use an impeller that accelerates the fuel particles before actually discharging them into a tract where they generate pressure via pulse exchange.

Permanently Engaged (PE) Starter A permanently engaged starter delivers the quickest and quietest restart times of all starter motor-based systems. In this system, the starter and flywheel gears are permanently connected, so there are no concerns with gear engagement and disengagement.

Permeability The measure of how well a material conducts magnetic lines of force.

Personal protective equipment (PPE) Personal protective equipment that can include gloves, safety glasses, and other items.

pH A measure of the acidity or alkalinity of a material. A pH of 7 is neutral, higher than 7 is alkaline, and lower than 7 is acidic.

Phone as a Key (PAAK) Many hybrid electric and electric vehicles, as well as some regular (ICE) vehicles can be controlled using a smart phone application (app). This control of the vehicle, including remote start from the smart phone, is referred to as Phone as a Key (PAAK).

Phosphate hybrid organic acid technology (PHOAT) Phosphate hybrid organic acid technology (PHOAT) is used in Mazda-based Fords (2008+), same as Mazda FL-22, and is ethylene glycol based. This coolant is available in a 55% coolant/45% water premix.

Photodiodes A type of diode used as a sun-load sensor. Connected in reverse bias, the current flow is proportional to the sun load.

Photoelectricity When certain metals are exposed to light, some of the light energy is transferred to the free electrons of the metal. This excess energy breaks the electrons loose from the surface of the metal. They can then be collected and made to flow in a conductor which is called photoelectricity.

Photons Light is emitted form an LED by the release of energy in the form of photons.

Photoresistor A semiconductor that changes in resistance with the presence or absence of light. Dark is high resistance and light is low resistance.

Phototransistor An electronic device that can detect light and turn on or off. Used in some suspension height sensors.

Piezoelectricity The principle by which certain crystals become electrically charged when pressure is applied.

Piezoresistivity There are four resistors attached to the silicon wafer, which changes in resistance when strain is applied to the wafer. This change in resistance due to strain is called piezoresistivity. The resistors are electrically connected to a Wheatstone bridge circuit and then to a differential amplifier, which creates a voltage in proportion to the vacuum applied.

Pillars The roof of a vehicle is supported by pillars and they are labeled A, B, C, and D from the front to the rear of the vehicle. All vehicles have an A pillar at the windshield but many, such as a hardtop, do not have a B pillar. Station wagons and sport utility vehicles (SUVs) often have a D pillar at the rear of the vehicle.

Pilot bearing A pilot bearing (or bushing) that supports the front of the transmission input shaft.

Pin bushings The small roller bearings used in a universal joint.

Pinch bolt A bolt used to retain a ball joint in some designs of suspensions.

Ping Secondary rapid burning of the last 3 to 5% of the air-fuel mixture in the combustion chamber causes a second flame front that collides with the first flame front causing a knock noise. Also called *detonation* or *spark knock*.

Pinion gear A small gear on the end of the starter drive which rotates the engine flywheel ring gear for starting.

Pinion shaft A pinion shaft passes through the two pinion gears in the case. In mesh with the pinion gears are two side gears that are splined to the inner ends of the axles.

Pinion-mounted electric power steering system (P-EPS) While not directly mounted on the column itself, another type of electric power steering is the pinion-mounted electric power steering system (P-EPS) system. This system has the assist motor connected to the pinion shaft of the rack and-pinion steering gear.

Pin-slider caliper A disc brake caliper design that uses guide pins and is able to move slightly during a brake application.

Pipe adapter A pipe adapter is used to connect non-standard exhaust components to existing OEM components like the one used to connect to the catalytic converter to the existing exhaust systems or connecting one size pipe to another.

Piston compressors A piston compressors is a positive-displacement compressor that uses pistons driven by a crankshaft. Most older automotive compressors used a crankshaft, similar to a small gasoline engine, and a reciprocating-piston type. Newer piston compressors use a swash or wobble plate.

Piston pin The piston is attached to the connecting rod with a piston pin, also called a wrist pin. The piston pin is allowed to have a rocking movement because of a swivel joint at the piston end of the connecting rod.

Piston ring compressor The piston ring compressor is then put on the piston to hold the rings in their grooves.

Piston ring expander Installing the compression rings requires the use of a piston ring expander tool that will only open the ring gap enough to slip the ring on the piston.

Piston rings Piston rings seal the small space between the piston and cylinder wall, keeping the pressure above the piston.

Piston stops Metal tangs next to drum brake wheel cylinders used to prevent cylinder pistons from coming out of their bores when the brake lining is removed.

Piston stroke A piston stroke is a oneway piston movement either from top to bottom or bottom to top of the cylinder. During one stroke, the crankshaft rotates 180 degrees (1/2 revolution).

Piston A solid cylinder or disk that fits snugly into a larger cylinder and moves under fluid pressure. The piston forms a movable bottom to the combustion chamber.

Pitch The pitch of a threaded fastener refers to the number of threads per inch.

Pitman arm A short lever arm that is splined to the steering gear cross shaft. It transmits the steering force from the cross shaft to the steering linkage.

Pitman shaft As the steering wheel is turned, the movement is transmitted through the steering gear to an arm attached to the bottom end of the pitman shaft. This arm is called the pitman arm. Whenever the steering wheel is turned, the pitman arm moves.

Placard cold inflation pressure The term placard cold inflation pressure is used in service information to indicate the specified tire inflation pressure.

Plain bearing Most engine bearings are one of two types which are plain bearing and sleeve bearing.

Planar In 1998, Bosch introduced a wide-band oxygen sensor that is flat and thin (1.5 mm or 0.006 inch), known as a planar design, and not in the shape of a thimble, as previously constructed. Now several manufacturers produce a similar planar design wide-band oxygen sensor. Its thin design makes it easier to heat than older styles of oxygen sensors and, as a result, it can achieve closed loop in less than 10 seconds.

Planet carrier The part of a planetary gearset that houses the planet pinions.

Planet pinions The planet pinion gears rotate around the sun gear, like the planets around the sun, and are attached by a planet carrier.

Plateau honing This plateau surface is achieved by first using a coarse honing stone followed by a smooth stone to achieve the desired surface. The process of using a course and fine stone is called plateau honing.

Platform The platform of a vehicle includes the basic structure (frame and/or major body panels), as well as, the basic steering and suspension components. One platform may be the basis for several different brand vehicles.

Platinum spark plugs Platinum spark plugs have a small amount of the precious metal platinum welded onto the end of the center electrode, as well as on the ground or side electrode.

Platinum The converter substrate contains small amounts of rhodium, palladium, and platinum. These elements act as catalysts. As mentioned, a catalyst is an element that starts a chemical reaction without becoming a part of, or being consumed in, the process.

Plenum A chamber, located between the throttle body and the runners of the intake manifold, used to distribute the intake charge more evenly and efficiently.

Plug-in hybrid electric vehicle (PHEV) A plug-in hybrid electric vehicle (PHEV) is a vehicle that is designed to be plugged into an electrical outlet at night to charge the batteries.

Plunge joint An inner constant velocity joint that is able to move in and out and transmit torque while the vehicle suspension moves up and down over bumps.

Ply steer A term used to describe why a tire can cause a pulling condition based on the angle of the cords of the belt layers.

PNP transistor A type of transistor that used N-type material for the base and P-type material for the emitter and collector.

POE (polyol ester) POE (polyol ester) (ester) oils are used in a few R-134a systems, and either ester or PAG oils are used in R-12 systems that have been retrofitted to R-134a.

Point of purchase (POP) Displays are also often built near the cash register as a point of purchase (POP) display, so that customers notice the product when they pay.

Polarity The condition of being positive or negative in relation to a magnetic pole.

Pole shoes The metal part of the field coils in a starter motor.

Pole The point where magnetic lines of force enter or leave a magnet.

Poles The point where magnetic lines of force enter or leave a magnet.

Polyalphaolefin (PAO) Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend Polyalphaolefin (PAO).

Polyglycol A term used to describe brake fluid.

Polymer electrolyte fuel cell (PEFC) Another term for Proton Exchange Membrane fuel cell. See *PEM*.

Pop rivet A type of fastener that uses a rivet gun to pull out the rivet until the end deforms and thereby creating a light clamping form.

Poppet valve Automotive engine valves are of a poppet valve design. The term poppet refers to the shape of the valve and their operation in automotive engines.

Porous lead Lead with many small holes to make a surface porous for use in battery negative plates; the chemical symbol for lead is Pb.

Porsche Doppelkupplung (PDK) Another term used to describe a dual-clutch automatic transmission/transaxle used in Porsche vehicles.

Port fuel-injection A port fuel-injection design uses a nozzle for each cylinder and the fuel is squirted into the intake manifold about 2 to 3 inches (70 to 100 mm) from the intake valve.

Port The part of the intake or exhaust system passage that is cast in the cylinder head is called a port.

Portable crane A piece of shop equipment that is used to lift and move heavy pieces of equipment, such as an engine.

Porting (relieving) Redirecting flow that is large enough to handle the flow is called porting or relieving.

Positive crankcase ventilation (PCV) System used to prevent corrosive blow-by gases (by-products of combustion) in the crankcase from entering the atmosphere.

Positive displacement pumps A type of pump where everything that enters the pumps, leaves the pump.

Positive displacement The roots supercharger was patented in 1860 as a type of water pump to be used in mines. Later, it was used to move air and is used today on two-stroke-cycle Detroit diesel engines and other supercharged engines. The roots-type supercharger is called a positive displacement design, because all of the air that enters is forced through the unit.

Positive rotators A type of rotator that causes the valve to rotate in a controlled manner as it is opened.

Positive slip Traction control allows an ABS to control wheel spin during acceleration. When tires lose traction during acceleration, it is called positive slip.

Positive temperature coefficient (PTC) Usually used in reference to a conductor or electronic circuit breaker. As the temperature increases, the electrical resistance also increases.

Positive twist ring A positive twist ring gives the same wall contact as the taper face ring. It also provides a line contact seal on the bottom side of the groove. Sometimes, a twist and a taper face are used on the same compression ring.

Potential energy the energy possessed by a body by virtue of its position relative to others, stresses within itself, electric charge, and other factors. Potential energy if it is capable of being changed to useful energy, such as the potential energy stored in a battery or a vehicle at the top of a hill.

Potentiometer A 3-terminal variable resistor that varies the voltage drop in a circuit.

Pouch cell Pouch design HV battery uses laminated architecture in a bag referred to as pouch cell. It is light and cost-effective, but exposure to humidity and high temperature can shorten its life.

Pour point Oil must not be too thick at low temperatures to allow the engine to start. The lowest temperature at which oil will pour is called its pour point.

Power balance test The purpose of a cylinder power balance test is to determine if all cylinders are contributing power equally. It determines this by shorting out one cylinder at a time.

Power bleeding Also called pressure bleeding.

Power chamber The enclosure of a vacuum brake booster assembly which is separated into the vacuum side and the atmospheric air pressure side by a flexible diaphragm.

Power path The path electricity travels between the source, usually the battery, and the load.

Power source In electrical terms the battery or generator (alternator).

Power steering control module (PSCM) The power steering control module (PSCM) and the power steering motor are serviced as an assembly and are serviced separately from the steering column assembly

Power steering pressure (PSP) A pressure switch, known as the power steering pressure (PSP) switch, transmits an electronic signal to the powertrain control module (PCM) when the pressure in the system is high enough to increase the load on the engine. In response to the PSP switch signal, the PCM increases the engine idle speed to prevent stalling.

Power windows Most power window systems use permanent magnet (PM) electric motors. It is possible to run a PM motor in the reverse direction by reversing the polarity of the two wires going to the motor.

Power The rate of doing work, measured in horsepower as kilowatts. In electrical terms, is amperes x volts (Power = $I \times E$).

Powertrain control module (PCM) The on-board computer that controls both the engine management and transmission functions of the vehicle.

Powertrain mounts A part of the vehicle that holds the engine in place to the frame. Broken powertrain mounts can cause stress on the exhaust system to wear and even cause components to break.

PPE Personal protective equipment, which can include gloves, safety glasses, and other items.

PPO Vegetable oil is a triglyceride with a glycerin component joining three hydrocarbon chains of 16 to 18 carbon atoms each, called straight vegetable oil (SVO). Other terms used when describing vegetable oil include: 1. Pure plant oil (PPO)—a term most often used in Europe to describe SVO. 2. Waste vegetable oil (WVO)—this oil could include animal or fish oils from cooking. 3. Used cooking oil (UCO)—a term used when the oil may or may not be pure vegetable oil

Prealignment checks As part of the prealignment checks check all the tires for proper inflation pressures. Tires should be approximately the same size and tread depth, and the recommended size for the vehicle. Check the wheel bearings for proper adjustment.

Precision insert-type bearing shells Modern automotive engines use precision insert-type bearing shells, sometimes called half-shell bearings. The bearing is manufactured to very close tolerance so that it will fit correctly in each application.

Preconverter Some vehicles have used a small, quick heating oxidation converter, called a preconverter or a pup (mini) converter, that connects directly to the exhaust manifold outlet.

Preloaded clutch Preloaded clutches use two mechanisms to accomplish this action. First, a coil, Belleville, or leaf spring applies a force against the two side gears. Second, a multidisc clutch pack or cones lie behind one or both of the side gears. Vehicle manufacturers refer to these differentials using various brand names, such as Positive Traction, Sure-Grip, Anti-Spin, and Traction-Lok.

Pressure bleeding A method used to bleed air out of a brake hydraulic system using compressed air above the master cylinder reservoir.

Pressure control solenoids Pressure control solenoids is a type of electronic pressure regulation.

Pressure control valve (PCV) A fuel pump and a low-cost, high-performance bypass regulator are used within the appropriate fuel sender. They supply a pressure somewhat higher than the required rail set pressure to accommodate dynamic line and filter pressure losses. Electronic pump speed control is accomplished using a smart regulator as an integral flow sensor. A pressure control valve (PCV) may also be used and can readily reconfigure an existing design fuel sender into a returnless sender.

Pressure control Pressure control (PC) is a type of electronic pressure regulation.

Pressure decay stage A stage during ABS operation where the pressure of the brake fluid at a wheel brake is reduced.

Pressure differential A difference in pressure from one brake circuit to another.

Pressure dump stage The fluid is usually routed into a spring-loaded or pressurized storage reservoir (called an accumulator) so it can be reused as needed. Releasing pressure in the brake circuit allows the brake to loosen its grip so the wheel can speed up and regain traction. This is called: pressure reduction stage, pressure release stage, pressure decay stage, or pressure dump stage.

Pressure feedback EGR (PFE) sensor Some later-model Ford EGR systems, however, use a feedback signal provided by an EGR exhaust back pressure sensor that converts the exhaust back pressure to a voltage signal. This sensor is called a pressure feedback EGR (PFE) sensor.

Pressure holding stage A stage during ABS operation where the pressure of the brake fluid at a wheel brake is held at the correct level.

Pressure increase stage A stage during ABS operation where the pressure of the brake fluid at a wheel brake is increasing due to a driver brake application.

Pressure plate A clutch assembly consists of a clutch disc that is splined to the input shaft of the transmission/transaxle. When the driver depresses the clutch pedal, a throw-out bearing (release bearing) is forced against the fingers of the pressure plate.

Pressure reduction stage The fluid is usually routed into a spring-loaded or pressurized storage reservoir (called an accumulator) so it can be reused as needed. Releasing pressure in the brake circuit allows the brake to loosen its grip so the wheel can speed up and regain traction. This is called: pressure reduction stage, pressure release stage, pressure decay stage, or pressure dump stage.

Pressure regulating valve A valve that limits the pressure of the oil pump.

Pressure regulator valve Transmission oil pumps are capable of creating an excessive amount of pressure quickly; therefore, every transmission uses a pressure regulator valve, or pressure control valve, to control hydraulic pressure.

Pressure release stage The release and isolation solenoids are then closed and the additional solenoid energized, so pressure can be reapplied to the brake from the master cylinder or accumulator to reapply the brake. This is called the pressure increase stage.

Pressure transducer A pressure transducer can be used in the low- and/or high-pressure refrigerant line. The transducer converts the system pressure into an electrical signal that allows the ECM to monitor pressure.

Pressure vent valve (PVV) A valve located in the fuel tank to prevent over-pressure due to the thermal expansion of the fuel.

Pressure A force applied to a surface divided by its area.

Pressure-relief valve To handle the excess pressure in a power steering system, a pressure-relief passage runs from a point near the pressure hose fitting to the spring end of the modulator valve.

Pretensioners An explosive devices used to remove the slack from a safety belt when an airbag is deployed.

Prevailing torque nut A special design of nut fastener that is deformed slightly or has other properties that permit the nut to remain attached to the fastener without loosening.

Preventative maintenance (PM) Preventative maintenance (PM) means periodic service work performed on a vehicle that will help keep it functioning correctly for a long time.

Primary ignition circuit The ignition components that regulate the current in the coil primary winding by turning it on and off are known collectively as the primary ignition circuit.

Primary oil pressure (POP) The fluid pressure applied to the primary pulley in a CVT transmission/transaxle.

Primary pressure sensor (PPS) The sensor used to measure the fluid pressure applied to the primary pulley in a CVT transmission/transaxle.

Primary shoe A brake shoe installed facing the front of the vehicle.

Primary vibration When pistons move up and down in the cylinders, they create a primary vibration, which is a strong low-frequency vibration.

Principal end The end of the engine that the flywheel is attached to.

Program card A program card lists the length and diameter of the pipe, the distance between the center of the bends, and the rotation and depth of the bends in degrees. There may also be remarks that describe bending instructions for peculiar applications. Using this information, the technician can make a pipe identical to the one which was originally installed by the vehicle manufacturer. The number of the program card is found by looking up the make, model, year and engine in the card catalog. There are separate cards for each pipe in the exhaust system.

Programmable Controller Interface (PCI) A type of network communications protocol used in Chrysler brand vehicles.

PROM Programmable read-only memory.

Propagation Sound is the movement of air that the ear interprets as sound. Sound travels through the air, which is called propagation.

Propane Propane is the most widely used of all of the alternative fuels. Propane is normally a gas but is easily compressed into a liquid and stored in inexpensive containers. When sold as a fuel, it is also known as liquefied petroleum gas (LPG) or LP-gas because the propane is often mixed with about 10% of other gases, such as butane, propylene, butylene, and mercaptan to give the colorless and odorless propane a smell.

Propeller shaft A term used by many manufacturers for a drive shaft.

Proportioning Valve A proportioning valve improves brake balance during hard stops by limiting hydraulic pressure to the rear brakes.

Protection A circuit breaker or fuse used to open the circuit if excessive current flows though the circuit.

Proton exchange membrane (PEM) The Proton Exchange Membrane fuel cell is also known as a Polymer Electrolyte Fuel Cell (PEFC). The PEM fuel cell is known for its lightweight and compact design, as well as its ability to operate at ambient temperatures.

PTC circuit protection Positive temperature coefficient (PTC) circuit protectors are solid-state (without moving parts). Like all other circuit-protection devices, PTCs are installed in series in the circuit being protected.

P-type material Silicon or germanium doped with boron or indium.

Public Charging Stations (PCS) Public Charging Stations (PCS) are available at many locations and most commercial level 2 charging stations.

Pull chain A type of chain used in a CVT transmission/transaxle that is made up of links and link pins, much like a silent chain. The ends of the link pins contact the pulley sides. This style is also called a luk chain drive.

Pull Vehicle tends to go left or right while traveling on a straight, level road.

Pull-in winding One of two electromagnetic windings inside a solenoid used to move a movable core.

Pulse train A DC voltage that turns on and off in a series of pulses.

Pulse width The amount of “on” time of an electronic fuel injector.

Pulse wipers Windshield wipers that operate intermittingly. Also called delay wipers.

Pulse-width modulation The amount of time the current is on compared to the amount of time it is off is called pulse width, and the control of a solenoid using this pulsing-on-and-off method is called pulse-width modulation.

Pump cell A pump cell is the area above the Nernst cell which is another zirconia layer with two electrodes. The two cells share a common ground, which is called the reference.

Pump-up The job of the hydraulic lifter is to take up all clearance in the valve train. Occasionally, engines are run at excessive speeds. This tends to throw the valve open, causing valve float. During valve float, clearance exists in the valve train. The hydraulic lifter takes up this clearance as it is designed to do. When this occurs, it keeps the valve from closing on the seat, a process called pump-up. Pump-up does not occur when the engine is operated in the speed range for which it is designed.

Punch A hand tool designed to be used with a hammer to drive out pins.

Pup (mini) converter Some vehicles have used a small, quick heating oxidation converter, called a preconverter or a pup (mini) converter, that connects directly to the exhaust manifold outlet.

Purchase Order (PO) A purchase order (PO) is used to enable a store or business to purchase parts. It describes the component and the quantity being purchased along with billing information.

Purge valve The canister purge valve, also called the canister purge (CANP) solenoid, is normally closed and is pulsed open by the PCM during purging. The purge valve is connected to intake manifold vacuum using a rubber hose to draw gasoline vapors from the charcoal canister into the engine when the purge valve is commanded open.

Push belt A type of belt used in a CVT transmission/transaxle that is made of about 400 wedge-shaped segments that are held together by two steel bands. Each band is made from multiple layers to allow flexibility. The segment sides contact the pulley sides. A push-belt is often called the Van Doorne design.

Pushrod engine An overhead valve engine (OHV engine) is a pushrod engine and is also known as a reciprocating piston engine.

Putty knife The scraper most frequently used is a putty knife, or a plastic card. The broad blade of the putty knife helps avoid scratching the surface as it is used to clean the parts.

PWM Pulse-width modulation. The control of a device by varying the on-time of the current flowing through the device.

Pyrolytic A pyrolytic (high-temperature) oven cleans engine parts by decomposing dirt, grease, and gaskets with heat in a manner similar to that of a self-cleaning oven.

Quench area The squish area can also be the quench area where the air-fuel mixture is cooled by the cylinder head. The quench area is the flat area of the combustion chamber that is above the flat area of the piston. As the piston moves upward on the compression stroke, the air-fuel mixture is forced from this area as the piston gets near the top.

Quill The transmission front bearing retainer has a long, hollow tube extending toward the engine. The release bearing sleeve slides on the outer surface of this tube, which is commonly called the quill, quill shaft, or candlestick

Ra Roughness average; a measurement of surface finish. The lower the number, the smoother the surface.

Rack support A spring-loaded unit that is used to hold the rack part of a rack and pinion steering gear assembly in proper position.

Rack-and-pinion electric power steering (R-EPS) The rack-mounted system has the assist motor attached to the rack and is often called a rack-and pinion electric power steering (R-EPS) system.

Rack-and-pinion The term rack and pinion is a description of the basic design of this type of steering gear. The rack-and-pinion steering gear is widely used because it is light in weight and takes less space than a conventional steering gear. The input gear of a rack-and-pinion steering gear is a pinion gear that receives rotary input from the steering shaft. the rack is a rod with gear teeth machined into one side. The pinion gear teeth mesh with the teeth on the rack so that when the pinion gear turns, it pushes the rack from side to side.

Radial force variation (RFV) The out-of-round runout of a wheel or tire which can cause a tramp-type (up and down) vibration if excessive.

Radial load The load applied to a bearing 90 degrees from the axis. The weight of the vehicle applies a radial load to the wheel bearing.

Radial runout A measure of the amount a tire or wheel is out of round. Excessive radial runout can cause a tramp-type vibration.

Radiation Radiation is a method of energy transfer where heat is transmitted through the air.

Radiator A cooling system component used to dissipate heat from the coolant to the surrounding air.

Radio choke A small coil of wire installed in the power lead, leading to a pulsing unit such as an IVR to prevent radio interference.

Radio frequency (RF) Frequency, also known as radio frequency (RF), is the number of times a particular waveform repeats itself in a given amount of time and is measured in hertz (Hz).

Radio frequency identification (RFID) Most security systems today use a Radio Frequency Identification (RFID) security system which has two main component which is a key fob and/or a transponder key.

Radius rod A suspension component to control longitudinal (front-to-back) support and is usually attached with rubber bushings to the frame at one end and the axle or control arm at the other end. Also see strut rod.

Rain-sense wipers Windshield wiper that use an electronic sensor to detect the presence of rain on the windshield and start operating automatically if the wiper switch is in the Auto position.

RAM Random access memory.

Ramp Valve trains using solid lifters must run with some clearance to ensure positive valve closure, regardless of the engine temperature. This clearance is matched by a gradual rise in the cam contour, called a ramp

Range anxiety Range anxiety is a feeling many drivers' experience when driving an electric vehicle because they fear running out of electric battery energy before they reach their destination.

Range per hour (RPH) Level 2 charging adds about 25 miles of Range Per Hour (RPH), labeled as miles per hour (MPH) on the dash display of a Nissan Leaf.

Range shift Range shift allows low range to be selected to deliver high torque at low speeds to the drive wheels. Low range usually provides a 2:1 to 3:1 gear reduction. High range (usually 1:1) simply transfers engine torque at the same speed as the output shaft of the transmission.

Ratchet A handle used to rotate a socket, which is reversible and allows the socket to be rotated in one direction and then free movement in the opposite direction of rotation.

Ratio control motor A stepper motor that changes the position of the upper end of the pulley ratio link in a CVT transmission/transaxle. The stepper motor controls the hydraulic ratio valve through the link, which in turn, controls fluid flow to the piston.

Rationality Rationality checks refer to a PCM comparison of input values to values from other sensors to determine if they make sense and are normal (rational).

Ravigneaux gear set The Ravigneaux system has the following: 1. Two sun gears. 2. Two planet pinion sets, one longer than the other, supported in one carrier. 3. A single ring gear

RBS (rubber-bonded socket) Because there is no sliding friction inside the tie rod end, no lubrication was needed. This type of tie rod end is called RBS (rubber-bonded socket).

RCRA Resource Conservation and Recovery Act.

Reaction member The drive member of a planetary gear set is called the input member, the held member, the reaction member, and the driven member, the output member.

Reaction pads All braking force is transferred through the caliper to the mount. The places where the caliper contacts the caliper mount are called the abutments, reaction pads, or ways.

Real-time dampening (RTD) A brand name for a General Motor vehicle electronic suspension system.

Rear cross-traffic warning (RCTW) A rear cross-traffic warning system sounds an audible warning when a vehicle is crossing at the rear while backing. Some vehicles are capable of automatically braking to avoid a collision.

Rear end A differential is also called a rear end or abbreviated simply as a diff. Whenever any vehicle makes a turn, the outside wheel must travel a greater distance than the inside wheel.

Rear steer A construction design of a vehicle that places the steering gear and steering linkage behind the centerline of the front wheels.

Rebound clips Clips used around the leaves of a leaf spring.

Rebuilding A complete engine reconditioning job is called rebuilding. Sometimes, this type of reconditioning is called a major overhaul.

Rebuilt A remanufactured component (also called rebuilt) has been used on a vehicle until the component wore out or failed. A remanufacturer totally disassembles the component, cleans, machines, and performs all the necessary steps to restore the part to a "like new" look and function.

Recall A notification to the owner of a vehicle that a safety issue needs to be corrected.

Recirculation Inside air usually called recirculation.

Reclaimed refrigerant Reclaimed refrigerant is refrigerant that has been sent out to an EPA-certified reclamation facility where it has been processed and certified as if it were new refrigerant.

Recombinant battery A battery design that does not release gasses during normal operation. AGM batteries are known as recombinant batteries.

Recovery The act of removing refrigerant from a system so that it can be recycled for reuse.

recovery, recycling, and recharging (RRR) Most refrigerant recovery units are made as part of the recovery, recycling, and recharging (RRR) machine and contain two service hoses (a low and high side) that are connected to the system service ports.

Rectifier bridge A group of six diodes, three positive (+) and three negative (-) commonly used in alternators.

Recycled refrigerant Recycled refrigerant is refrigerant that that has been processed at a service facility (shop or dealership) by using recycling equipment that is SAE certified.

Recycling The act of using portable equipment to clean debris, oil, water, and noncondensable gases from refrigerant so it can be reused in a system.

Red brake warning lamp (RBWL) The red brake warning lamp (RBWL) lights whenever a hydraulic system failure occurs or low brake fluid level has been detected. The red brake warning lamp lights when the ignition is turned on as a bulb check, then goes out, unless a hydraulic fault has been detected.

Red brake warning lamp The dash-mounted warning lamp that lights if a hydraulic system fault is detected.

Reed valve The typical valve used in compressors is the reed valve: a one-way, flap-type check valve that is built into the valve plate that seals one or more cylinders.

Reference electrode Ambient-side electrode is exposed to outside (ambient) air and is the signal electrode, also called the reference electrode.

Reference Material Reference Materials provide information to the parts specialist and include new item bulletins, product information bulletins, catalog errors, and parts specifications.

Reference A reference is someone who is willing to tell a possible employer about you, including your skills and talents, as well as your truthfulness and work habits.

Refractometer A device used to measure battery state of charge by allowing light to pass through an electrolyte sample.

Regeneration A process of taking the kinetic energy of a moving vehicle and converting it to electrical energy and storing it in a battery.

Reid vapor pressure (RVP) A method of determining vapor pressure of gasoline and other petroleum products. Widely used in the petroleum industry as an indicator of the volatility of gasoline.

Relative compression test Relative compression test uses the starter motor current to determine the compression values of all cylinders. the advantage of a relative compression test is that no pressure sensors are needed to check each individual cylinder and all cylinders can be tested at the same time.

Relative humidity (RH) sensor A few vehicles use a relative humidity (RH) sensor to determine the level of in-vehicle humidity. High RH increases the cooling load. A relative humidity sensor uses the capacitance change of a polymer thin film capacitor to detect the relative amount of moisture in the air.

Relative humidity Relative humidity is the percentage of how much moisture is present in the air compared to how much moisture the air is capable of holding at that temperature.

Relay An electromagnetic switch that uses a movable arm.

Release bearing A clutch assembly consists of a clutch disc that is splined to the input shaft of the transmission/transaxle. When the driver depresses the clutch pedal, a throw-out bearing (release bearing) is forced against the fingers of the pressure plate.

Reluctance The resistance to the movement of magnetic lines of force.

Remote keyless entry (RKE) While the remote keyless entry (RKE) part of the key fob has a battery to power the transmitter, the RFID chip part of the key fob does not require a battery to function.

Remote reservoir A type of power steering pump where the fluid is in a reservoir separate from the pump.

Remote start A remote start is the ability to start the engine of the vehicle from a distance by using a remote control.

Remove and inspect (R & I) R & I is often used to indicate remove and inspect to check a component for damage.

Remove and replace (R & R) Parts replacement is often called R & R, meaning remove and replace.

Removers This term is used to describe hand tools, which are designed to remove broken studs, bolts, and other fasteners.

Renewal parts Parts manufactured to be sold for use after the vehicle is made are often referred to as aftermarket parts or renewal parts.

Repair order (RO) A work order, also called a repair order or RO contains all vehicle and customer information plus what service work is requested by the customer.

Repair order log A repair order log (or daily work control log) is used to track the repair and completion process or the lead time for each repair order. It provides an overview of all the vehicles that are in the shop on a given day.

Replenishing port The Society of Automotive Engineers (SAE) term for the rearward low-pressure master cylinder port. Also called inlet port, bypass port, filler port or breather port.

Reserve capacity The number of minutes a battery can produce 25 A and still maintain a battery voltage of 1.75 V per cell (10.5 V for a 12 V battery).

Residual magnetism Magnetism remaining after the magnetizing force is removed.

Residual or rest pressure Residual or rest pressure prevents vapor lock and hot-start problems on these systems.

Resistance The opposition to current flow measured in ohms.

Resonate When back-and-forth deflections occur at the same vibration frequency (number of vibrations per second) as that of another engine part, the parts will vibrate together. When this happens, the parts are said to resonate.

Resonator The resonator is similar to a muffler and is usually connected in the exhaust stream before the muffler. The resonator helps to quiet the sound of combustion before the exhaust gases reach the muffler.

Restricted exhaust In a vacuum a needle that drops to near zero when the engine is accelerated rapidly and then rises slightly to a reading below normal indicates an exhaust restriction.

Resume A statement of your background and experience submitted to a potential employer.

Retainer plate-type axle Rear axle bearings are either sealed or lubricated by the rear-end lubricant. The rear axle must be removed from the vehicle to replace the rear axle bearing. There are two basic types of axle retaining methods named retainer plate-type or C-lock.

Retainer The valve keepers (also called locks) secure the spring retainer to the stem of the valve.

Return path (ground) A return path (ground) for the electrical current from the load back to the power source so that there is a complete circuit.

Return policies Return policies vary by store. For example, for some companies, electrical and electronic parts are sometimes not returnable for reimbursement.

Returnability The ability of the steering wheel to return to the straight ahead position after making a turn.

Reverse bias Current flow in the opposite direction from normal.

Reverse cooling The coolant flows from the radiator to the cylinder head(s) before flowing to the engine block.

Reverse twist ring A reverse twist ring is produced by chamfering the ring's lower inner corner. This seals the lower outer section of the ring and piston ring groove, thus improving oil control.

Reverse There are two common reverse gear designs used on transmissions a Sliding gear and Constant-mesh gear.

Rheostat A two-terminal variable resistor.

Rhodium The converter substrate contains small amounts of rhodium, palladium, and platinum. These elements act as catalysts. As mentioned, a catalyst is an element that starts a chemical reaction without becoming a part of, or being consumed in, the process.

Rich indicator If CO is high, the exhaust is rich, so CO is called the "rich indicator"

Ride height The height of the vehicle. Also called the trim height.

Right-to-know laws Laws that state that employees have a right to know when the materials they use at work are hazardous.

Rim width The width of a wheel measured between bead sections.

Ring (annulus) gear The outermost member of the gear set is the ring gear, the internal type with teeth inside. the ring gear is sometimes called an annulus or internal gear. the pinion gears are in simultaneous mesh with both the sun gear and the ring gear.

Ring gap The piston ring gap allows some leakage past the top compression ring. This leakage is useful in providing pressure on the second ring to develop a dynamic sealing force. The amount of piston ring gap is critical.

Ring gear runout Use a dial indicator to check ring gear runout If any of the visual measurement tests indicate a problem or a noise analysis indicates a bearing problem, the axle assembly should be disassembled for further analysis and service.

Ring gear The large gear inside a differential assembly, which meshes with the drive pinion gear.

Riveted linings Brake lining that is held to the brake shoe using rivets.

Road crown A roadway where the center is higher than the outside edges. Road crown is designed into many roads to drain water off the road surface.

Role model A role played by a mentor.

Roller bearings Antifriction bearings that use hardened steel rollers between the inner and outer races.

Roller cell In the roller cell or vane pump, the impeller draws fuel into the pump, and then pushes it out through the fuel line to the injection system.

Roller chain type A roller chain is a type of camshaft chain that is noisy, but operates with less friction and stretches less than the silent type of chain.

Rolling circumference The distance a tire travels when rotated one revolution.

ROM Read-only memory.

Root cause The root cause is the true cause of a failure, which may not be noticed at first.

Root The tooth root is the depression lying between two teeth, and the crown is the very top of each tooth.

Root-mean-square (RMS) A method of displaying variable voltage signals on a digital meter.

Roots supercharger The roots supercharger was patented in 1860 as a type of water pump to be used in mines. Later, it was used to move air and is used today on two-stroke-cycle Detroit diesel engines and other supercharged engines. The roots-type supercharger is called a positive displacement design, because all of the air that enters is forced through the unit.

Rosin-core solder A type of solder for use in electrical repairs. Inside the center of the solder is a rosin that acts as a flux to clean and help the solder flow.

Rotary control valve A power steering valve that operates by rotating an inner valve inside an outer valve to control the amount of steering assist.

Rotary engine A rotary engine has a rotating combustion chamber and has a triangular-shaped rotor turning in a housing. The housing is in the shape of a geometric figure called a two lobed epitrochoid. A seal on each corner, or apex, of the rotor is in constant contact with the housing, so the rotor must turn with an eccentric motion.

Rotary flow Rotary flow is created by the rotation of the torque converter and causes the oil (ATF) to flow around the circumference of the torque converter.

Rotary vane pump The pump consists of a central impeller disk, several rollers or vanes that ride in notches in the impeller, and a pump housing that is offset from the impeller centerline.

Rotor The rotating part of a generator where the magnetic field is created.

RPO (regular production option) The RPO (regular production option) code will tell the technician the type of suspension used.

RTV Room-temperature vulcanization.

Rubber band effect A condition that affect some CVT units where the vehicle speed slowly catches up to the engine speed, and is most noticeable only during periods of rapid acceleration.

Rubber-coated metal (RCM) gaskets A type of gasket.

Run-flat tires Tires specially designed to operate for reasonable distances and speeds without air inside to support the weight of the vehicle. Run-flat tires usually require the use of special rims designed to prevent the flat tire from coming off the wheel.

Running compression test A running compression test, also called a dynamic compression test, is done with the engine running rather than during engine cranking as is done in a regular compression test.

RVP Reid vapor pressure. A measure of the volatility at exactly 100 degrees F.

RVS Remote Vehicle Start. A general Motor's term for the system that allows the driver to start the engine using a remote control.

Rzeppa joint The Rzeppa joint transfers torque through six round balls that are held in position midway between the two shafts.

R-744 Refrigerant that is carbon dioxide (CO2)

Saddles The first step in determining the condition of the main bearing bores is to determine if the bore alignment in the block is straight. These bores are called the saddles.

SAE J2534 version 5.0 The SAE J2534 version 5.00 is the newest standard and includes all the changes required in the previous updates and serves to improve the communication through the J1962 connector.

SAE J2534 SAE J2534 is a standard for communications between a computer and a vehicle. The original standard was introduced in February of 2002, and was identified as version 02.02.

SAE J2534-1 The SAE J2534 standard was updated in December of 2004. The new standard was identified as version 04.04 or more commonly as SAE J2534-1. The changes in the second version of the standard supported specific requirements of Ford and Chrysler that were not addressed in the first standard that related to J1850 class 2 communication protocols.

SAE J2534-2 An updated SAE J2534 standard referred to as SAE J2534-2. The updates addressed issues related to single wire CAN Bus communication and issues related to the GM UART communication protocol.

SAE Society of Automotive Engineers.

Safety stands A metal device with an adjustable vertical support that is designed to support a vehicle after it has been raised off the ground. Also called a *jack stand*.

Safety switch A switch on the clutch pedal that prevents starter operation unless the clutch pedal is depressed.

SAI Steering axis inclination (SAI) is the inward tilt of the steering axis.

Sales Objections Sales Objections are when a customer has a problem with the price or item.

Same-phase steering A type of four-wheel steering system where the front and rear wheels are steered in the same direction. Same-phase steering improves steering response, especially during rapid-lane-change-type maneuvers.

SAPS ACEA oil also requires low levels of sulfated ash, phosphorous, and sulfur, abbreviated SAPS, and has a high-temperature/ high-shear rate viscosity, abbreviated HTHS

SAR Supplemental Air Restraints. Another term used to describe an airbag system.

Saturation The point of maximum magnetic field strength of a coil.

Scan tool Electronic hand-held testers, called scan tools, are needed to access (retrieve) stored diagnostic trouble codes (DTCs) and view sensor and system data.

Schmitt trigger A Schmitt trigger inside the sensor itself converts an analog signal into a digital signal.

Schrader valve A type of valve used in tires, air-conditioning, and fuel injection systems. Invented in 1844 by August Schrader.

Scientific method The scientific method is a series of steps taken to solve a problem. These steps help eliminate errors and to achieve an accurate result.

Scientific notation Scientific notation is written as a number multiplied by the number of zeros to the right or left of the decimal point

Score resistance Bearings have a characteristic called score resistance. It prevents the bearing materials from seizing to the shaft during oil film breakdown.

Scoring Grooves worn into the drum or disc braking surface.

SCR Silicon Controller Rectifier

Scraper ring A scraper ring does a good job of oil control and is usually recommended for use at the second compression ring.

Scratch cut Turn the drum by hand before turning on the lathe to be sure everything is clean. Advance the tool bit manually until it just contacts the drum. This is called a scratch cut.

Screwdriver A hand tool designed to remove or insert screws.

Scroll compressor A compressor design that uses two meshed scrolls to pump refrigerant.

Scroll A smoothly curved passage that changes the fluid flow direction with minimum loss in velocity.

Scrub radius Refers to where an imaginary line drawn through the steering axis intersects the ground compared to the centerline of the tire. *Zero* scrub radius means the line intersects at the center line of the tire. *Positive* scrub radius means that the line intersects below the road surface. *Negative* scrub radius means the line intersects above the road surface. It is also called *steering offset* by some vehicle manufacturers.

SDARS Satellite Digital Audio Radio Services. Another term used to describe satellite radio.

SDS All hazardous materials must be properly labeled, and information about each hazardous material must be posted on safety data sheets (SDS), formally called material safety data sheets (MSDS) available from the manufacturer.

Seal cartridge A compressor shaft seal that keeps refrigerant from leaking.

Seal driver A hand tool used with a mallet or hammer to seat seals into a seal groove.

Seal puller A hand tool designed to remove seals.

Seal seat A gasket or rubber O-ring is used so that the seal seat makes a gas-tight seal at the housing, and the seat has an extremely smooth sealing face.

Sealed lead–acid (SLA) A type of battery usually an absorbed glass mat (AGM) design that is not vented to thee outside and therefore can used in the interior or a vehicle.

Seasonal Item A seasonal item is something that may not normally be stocked during certain times of the year. Some seasonal items are stocked throughout the entire year but not in large quantities.

Second gear In second gear, the shift linkage slides the 1–2 synchronizer sleeve forward, away from the first speed gear and toward the second speed gear. The synchronizer assembly releases first gear, then locks the second speed gear to the output shaft.

Secondary air injection (SAI) The secondary air-injection (SAI) system provides the air necessary for the oxidizing process either at the exhaust manifold or inside the catalytic converter.

Secondary ignition circuit The components necessary to create and distribute the high voltage produced in the secondary windings of the coil are called the secondary ignition circuit.

Secondary oil pressure (SOP) The fluid pressure applied to the secondary pulley of a CVT transmission/transaxle. The pressure measured is called the secondary oil pressure (SOP).

Secondary pressure sensor (SPS) A pressure transducer used to monitor secondary pulley pressure. The pressure measured is called the secondary oil pressure (SOP).

Secondary shoe The brake shoe installed facing the rear of the vehicle.

Secondary vibration Four-cylinder engines, however, suffer from a vibration at twice engine speed. This is called a secondary vibration, which is a weak high-frequency vibration caused by a slight difference in the inertia of the pistons at top dead center, compared to bottom dead center.

Second-class lever A second-class lever increases the force applied to it and passes it along in the same direction.

Section 609 (clean air act) The Clean Air Act of 1990 specified that the production of R-12 refrigerant ceased at the end of 1995. Section 609 of the Clean Air Act required the following: 1. All technicians who service or repair automotive air-conditioning systems shall be properly trained and certified. 2. Recovery and recycling equipment must be properly approved. 3.Each shop that performs automotive air-conditioning service should comply to the Environmental Protection Agency (EPA).

Sector gear A section of a gear inside a steering gear that is attached to the sector shaft. Also called the pitman shaft.

Sector shaft The output shaft of a conventional steering gear. It is a part of the sector shaft in a section of a gear that meshes with the worm gear and is rotated by the driver when the steering wheel is turned. It is also called a *pitman shaft.*

Sediment chamber A space below the cell plates of some batteries to permit the accumulation of sediment deposits flaking from the battery plates. A sediment chamber keeps the sediment from shorting the battery plates.

Select low principle Some four-wheel ABS have a separate wheel speed sensor for each front wheel but use a common speed sensor for both rear wheels. These are called "three-channel" systems. The rear wheel speed sensor is mounted in either the differential or the transmission. The sensor reads the combined or average speed of both rear wheels. This type of setup saves the cost for an additional sensor and reduces the complexity of the system by allowing both rear wheels to be controlled at the same time which is called the select low principle.

Selectable ride (SR) A brand name for a General Motor vehicle electronic suspension system.

Selective catalytic reduction (SCR) A type of exhaust emission system that uses urea injection to reduce oxides of nitrogen emissions from diesel engines.

Self-aligning spacer (SAS) A double cone used to spread the force of the retaining nut on the spindle of a brake lathe.

Self-energizing action A brake shoe, that when applied, develops a wedging action that assists the braking force applied by the wheel cylinder.

Self-induction The generation of an electric current in the wires of a coil created when the current if first connected or disconnected.

Self-parking Several vehicle manufacturers offer a self-parking feature that uses the electric power steering to steer the vehicle. The driver has control of the brakes.

Self-propelled vehicle Self-propelled vehicles are vehicles that moved under their own power.

Self-tapping screw A screw that has a tapered tip which allows the screw to form threads in the metal.

Semiconductor A material that is neither a conductor nor an insulator; has exactly four electrons in the atom's outer shell.

Semi-independent suspension A type of rear suspension that allows some transfer of motion to the opposite side.

Semimetallic The term semimetallic refers to brake lining material that uses metal, rather than asbestos, in its formulation. It still uses resins and binders and is, therefore, not 100% metal, but rather semimetallic. Semimetallic pads are commonly called "semi-mets."

Semi-trailing arm A type of rear suspension that controls both side-to-side and front-to-rear motion.

Separator plate The separator plate, also called a spacer plate, provides rigidity and contains calibrated holes and openings that help manage fluid flow.

Sequential fuel injection (SFI) A fuel injection system in which injectors are pulsed individually in sequence with the firing order.

Sequestration The process of storing carbon dioxide under-ground is called sequestration.

Serial communications interface (SCI) A type of serial data transmission used by Chrysler.

Serial data Data that is transmitted by a series of rapidly changing voltage signals.

Series circuit An electrical circuit that provides only one path for current to flow.

Series flow system In the series flow system, the coolant flows around all the cylinders on each bank. The coolant then enters the rear of the heads. In the heads, the coolant flows forward to a crossover passage on the intake manifold outlet at the highest point in the engine cooling passage. This is usually located at the front of the engine. The outlet is either on the heads or in the intake manifold.

Series-parallel circuits Any type of circuit containing resistances in both series and parallel in one circuit.

Series-parallel flow system Some engines use a combination of the series and parallel flow system.

Serpentine (Poly V) A serpentine (or Poly V) is a single continuous belt used to drive multiple peripheral devices in an automotive engine, such as an alternator, power steering pump, and/or water pump. Serpentine (or Poly V) belts are to be replaced every four to seven years.

Service advisor A person who talks to the customer about a vehicle service and completes the work order.

Service bay A work area for a vehicle, with or without a lift. Also called a *stall*.

Service brakes The main driver-operated vehicle brakes.

Service consultant A service advisor, also called a service writer or service consultant, is the person at the dealership or shop designated to communicate the needs of the customer and accurately complete a work order.

Service History Documentation of a vehicle's past service, maintenance, and repairs.

Service information Includes service manuals, owner's manuals, CD ROM discs, Internet sites, or other sources where vehicle information is found.

Service manager The person in charge of a shop or dealer service department.

Service Pricing Menu A Service Pricing Menu provides a quick reference for the service consultant to identify and accurately quote the cost for the most common repairs that the shop performs.

Service writer A service advisor, also called a service writer or service consultant, is the person at the dealership or shop designated to communicate the needs of the customer and accurately complete a work order.

Servo A band is applied by using a hydraulically operated piston that travels inside a machined cylinder bore. This piston and cylinder assembly is known as a servo.

Servomotor The actuator in an electronic throttle control (ETC) system.

Setback The amount the front wheels are set back from true parallel with the rear wheels. Positive setback means the right front wheel is set back farther than the left. Setback can be measured as an angle formed by a line perpendicular (90°) to the front axles.

Shackles one end of the leaf spring is attached to the frame with movable mounting hangers called shackles.

Shift cooling multiplex solenoid (SHCMS) Controls position of gearshift forks as well as cooling of clutch in a dual clutch automatic transmission/transaxle.

Shimmy A vibration that results in a rapid back and forth motion of the steering wheel. A bent wheel or a wheel assembly that is not correctly dynamically balanced are common causes of shimmy.

Shock absorbers A suspension component that links and controls the action and reaction of the springs.

Shoe anchors A round part at the top of most backing plates used to prevent the brake shoes from rotating with the drum during a brake application.

Shoe contact areas Raised areas on the backing plate of a drum brake where the brake shoes contact.

Shoe rim Another name for the lining table where the brake lining is attached to the brake shoe.

Shoe support pads Six areas on the backing plate of a drum brake where the lining makes contact.

Shoe web The support under the shoe table on a drum brake shoe.

Shop Foreman A journeyman service technician who helps solve technical problems and helps service technicians.

Shop supervisor A person at a shop that supervises the service technicians and often diagnoses vehicle problems Signal electrode - This electrode is exposed to outside (ambient) air and is the signal electrode, also called the reference electrode or ambient air electrode.

Short block The quickest way to get a vehicle back in service is to exchange the faulty engine for a different one. In an older vehicle, the engine may be replaced with a used engine from a salvage yard. In some cases, only a reconditioned block, including the crankshaft, rods, and pistons, is used. This replacement assembly is called a short block.

Short circuit A circuit in which current flows, but bypasses some or all the resistance in the circuit. A connection that results in a "copper-to-copper" connection.

Short/long arm (SLA) The two main links in a short/long-arm (SLA) suspension are the upper control arm and the lower control arm. The upper control arm is shorter than the lower one.

Shorted a condition of being shorted such as a short circuit.

Short-to-ground A short circuit in which the current bypasses some or all the resistance of the circuit and flows to ground. Because ground is usually steel in automotive electricity, a short-to-ground (grounded) is a "copper-to-steel" connection.

Short-to-voltage A circuit in which current flows, but bypasses some or all the resistance in the circuit. A connection that results in a "copper-to-copper" connection.

Shunt A device used to divert or bypass part of the current from the main circuit.

Siamese port On some older engines, two cylinders share the same port because of the restricted space available. Shared ports are called Siamese ports.

Side clearance The space in the ring groove above the ring is called the side clearance

Side gears The gears inside a differential that attach to the axles.

Side-channel pump A turbine pump is the most common because it tends to be less noisy. Sometimes called turbine, peripheral, and side-channel, these units use an impeller that accelerates the fuel particles before actually discharging them into a tract where they generate pressure via pulse exchange.

Sidewall The side of a tire.

Sight glass A window in the liquid line or receiver–drier that allows observation of refrigerant flow used in older R-12 systems.

Signal electrode This electrode is exposed to outside (ambient) air and is the signal electrode, also called the reference electrode or ambient air electrode.

Significant new alternatives policy (SNAP) An EPA process for determining acceptable replacement refrigerants for R-12.

Silent chain type The silent chain type (also known as a flat-link type, or Morse type for its original manufacturer) operates quietly but tends to stretch with use. The metal links themselves do not "stretch" but, instead, the pin bushings at each joint wear, which causes the chain to become longer.

Silicon A semiconductor material.

Silicone brake fluid A type of brake fluid that is purple and does not absorb moisture.

Silicone coupling A type of thermostatic fan that is mounted between the drive pulley and the fan.

Silicone grease Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend Silicone grease.

Simpson gear set the Simpson gear set consists of two simple planetary gear sets that share a common sun gear. This combination is capable of providing three forward gears, as well as neutral and reverse.

Sine with dwell (SWD) test The standardized test used to determine if an electronic stability control system functions okay is called the sine with dwell (SWD) test.

Single cell A type of wide-band oxygen sensor that uses one cell using four wires; two for the heater and two cell wires.

Single overhead camshaft (SOHC) Newer engine designs feature overhead camshafts (OHC), called single overhead camshaft (SOHC) designs and engines that use two overhead camshafts per bank of cylinders called double overhead camshaft (DOHC) designs.

Single stroke bleeding method A method of manual brake bleeding where the brake pedal is depressed one time, held until the bleeder is closed and the released.

Single-cut file A file that has just one row of cutting teeth.

SIR Supplemental Inflatable restraints. Another term for air bags.

Skewed A skewed thermostat works, but not within the correct temperature range. Therefore, the engine could overheat or operate cooler than normal, or even do both.

Skirt Piston ring grooves are located between the piston head and skirt. The width of the grooves, the width of the lands between the ring grooves, and the number of rings are major factors in determining minimum piston height. The outside diameter of the lands is about 0.02 to 0.04 inch (0.5 to 1 mm) smaller than the skirt diameter.

SLA Abbreviation for short/long arm suspension.

Sleep mode Is when the vehicle is stopped, the sensor "goes to sleep" to help improve battery life. In this mode, the transmitter still will broadcast tire inflation information every hour or every six hours, depending on the sensor.

Sleeve bearing Most engine bearings are one of two types which are plain bearing and sleeve bearing.

Sleeve The bore of the barrel (sleeve) is threaded and a spindle screws into the bore. The thimble rotates over the sleeve on a screw that has 40 threads per inch.

SLI SLI means starting, lighting, and ignition, and describes the use of a typical automotive battery.

Sliding caliper A type of disc brake caliper that is free to move within a limited range.

Sliding reverse gear With a sliding reverse gear design, such as on the Borg Warner T5, the shift linkage slides the reverse idler gear on its shaft until it engages the reverse gears on the countershaft and output shaft gear. Both gears are fixed to their respective shafts.

Sliding sleeve In synchronized construction there are a number of design variations, all are similar and include a hub, a sliding sleeve, a blocker ring, (or stop ring or synchronizer ring), keys, and springs.

Slip joint hand tool which has two positions allowing the use of two different ranges of sizes.

Slip-joint pliers A hand tool which has two positions allowing the use of two different ranges of sizes.

Slipper skirt A slipper skirt design piston is shorter on the two sides that are not thrust surfaces.

Slip-ring-end (SRE) housing The rear housing, or the slip-ring-end (SRE) housing, usually contains either a roller bearing or ball bearing support for the rotor and mounting for the brushes, diodes, and internal voltage regulator (if so equipped).

Slope The ratio of front to rear brake pressure by a proportioning valve.

Slugging Charging liquid into a compressor which can cause severe damage.

Small-hole gauge A handheld measuring tool that is adjustable to fit inside small holes. A micrometer is then used to measure the gauge to determine the inside diameter of the hole. Also called a *split-ball gauge*.

Smart control head HVAC control heads that have the ability to process data.

Smart motor HVAC door motors that have the ability to process data.

Smog pump The SAI pump, also called an AIR pump, a smog pump, or thermactor pump, is mounted at the front of the engine and can be driven by a belt from the crankshaft pulley. It pulls fresh air in through an external filter and pumps the air under slight pressure to each exhaust port through connecting hoses or a manifold.

Smog The term used to describe a combination of *smoke* and *fog.* Formed by NOx and HC with sunlight.

Smoke machine Vacuum (air) leaks can cause a variety of driveability problems and are often difficult to locate. one good method is to use a machine that generates a stream of smoke. Connecting the outlet of the smoke machine to the hose that was removed from the vacuum brake booster allows smoke to enter the intake manifold. Any vacuum leaks will be spotted by observing smoke coming out of the leak.

Snap ring A spring steel clip that is used to retain an object in a bore by being inserted into a groove.

Snap-ring pliers A hand tool, which is designed to install or remove snap rings.

Society of Automotive Engineers (SAE) A professional organization made up of automotive engineers and designers that establishes standards and conducts testing for many automotive-related functions.

Socket adapter An adapter that allows the use of one size of driver (ratchet or breaker bar) to rotate another drive size of socket.

Socket A tool that fits over the head of a bolt or nut and is rotated by a ratchet or breaker bar.

Soft core plugs Core holes left in the external block wall are machined and sealed with soft core plugs or expansion plugs (also called freeze plugs or Welsh plugs).

Soft skill In any career, including being a service technician, requires people, communication, and teamwork skills, often called soft skills.

Solenoid controlled damper a shock absorber that is electronically controlled by a solenoid.

Solenoid An electromagnetic device that uses a moveable core which can be connected to linkage to move a valve or other device.

Solid axle A solid supporting axle for both front or both rear wheels. Also referred to as a straight axle or nonindependent axle.

Solid valve lifter Valve train clearance is also called valve lash, which is needed to help compensate for thermal expansion and wear. Valve train clearance must not be excessive, or it causes noise or results in premature failure. One method commonly used to make the necessary valve clearance adjustments involves a solid valve lifter, which can be adjusted mechanically at the rocker arm or by changing shims on certain overhead camshaft engines.

Solvent Usually colorless liquids that are used to remove grease and oil.

Soot Particulate matter emitted by diesel engines.

Space frame A type of vehicle construction that uses the structure of the body to support the engine and drive train, as well as the steering and suspension. The outside body panels are nonstructural.

Spalling A term used to describe a type of mechanical failure caused by metal fatigue. Metal cracks then break out into small chips, slabs or scales of metal. This process of breaking up is called spalling.

Spark ignition direct injection (SIDI) In a gasoline direct injection (GDI) system the fuel is squired directly into the combustion chamber. General Motors refers to this as a spark ignition direct-injection(SIDI) system.

Spark knock Secondary rapid burning of the last 3 to 5% of the air-fuel mixture in the combustion chamber. Causes a second flame front that collides with the first flame front causing a knock noise.

Spark line The spark line is a short horizontal line immediately after the firing line.

Spark tester If the engine is equipped with a separate ignition coil, remove the coil wire from the center of the distributor cap, install a spark tester, and crank the engine. See the Tech Tip "Always Use a Spark Tester." A good coil and ignition system should produce a blue spark at the spark tester.

SPDT Single pole, double throw. A type of electrical switch.

Speakers A device consisting of a magnet, coil of wire and a cone which reproduces sounds from the electrical signals sent to the speakers from a radio or amplifier.

Special Order A special order is placed whenever a customer purchases a part that is not normally kept in stock.

Specific energy A fuel cell is a hydrogen powered battery. Hydrogen is an excellent fuel because it has a very high specific energy when compared to an equivalent amount of fossil fuel.

Specific gravity The ratio of the weight of a given volume of a liquid divided by the weight of an equal volume of water.

Speed density Engines that do not use an airflow meter or sensor rely on calculating the amount of air entering the engine by using the MAP sensor and engine speed as the major factors. The method of calculating the amount of fuel needed by the engine is called speed density.

Speed nuts Also called Tinnerman nuts. Used to keep the brake drum on at the assembly plant. Can be removed and discarded when servicing drum brakes for the first time.

Speed rating A letter on most tires that indicates the maximum speed at which the tire is designed to perform.

Spider gears Another name for the pinion gear used in a differential.

Spider Center part of a wheel. Also known as the center section.

Spike protection resistor A resistor usually between 300 and 500 ohms that is connected in a circuit in parallel with the load to help reduce a voltage spike caused when a current following through a coil is turned off.

Spindle The part of a micrometer that moves and contacts the object being measured.

Spit hole Some connecting rods have a spit hole that bleeds some of the oil from the connecting rod journal.

Splay angle The angle between the crankpins on the crankshaft throws is called a splay angle

Splice pack A central point where many serial data lines jam together, often abbreviated SP.

Spline bind A condition where the splines on the yoke of a driveshaft bind and then release as a vehicle is first accelerated after a stop.

Spline phaser A type of variable valve timing actuator that uses a piston inside the cam phaser and rides along the helical splines, which compresses a coil spring. This movement causes the cam phaser gear and the camshaft to move in an opposite direction.

Split point The pressure point where reduction of pressure to the rear brake begins in a proportioning valve.

Split-ball gauge A small-hole gauge (also called a split-ball gauge) is used with a micrometer to measure the inside diameter of small holes, such as a valve guide in a cylinder head.

Split-type (half-shell) bearing Overhead camshaft bearings may be one of two sleeve-type bushings, depending on the design of the bearing supports. They are full round bearings or split-type (half-shell) bearings.

Spoke angle The angle of the steering wheel.

Sponge lead Lead with many small holes used to make a surface porous or sponge-like for use in battery negative plates; the chemical symbol for lead is Pb.

Spontaneous combustion A condition that can cause some materials, such as oily rags to catch fire without a source of ignition.

Sprags A one-way sprag clutch that consists of a hub and a drum separated by a number of figure-eight shaped metal pieces called sprags.

Spread The bearing shell has a slightly larger arc than the bearing housing. This difference, called bearing spread, makes the shell 0.005 to 0.02 inch (0.125 to 0.5 mm) wider than the housing bore. Spread holds the bearing shell in the housing while the engine is being assembled.

Spring pocket Also called a spring seat.

Spring rate The spring rate is the amount of weight it takes to compress a spring a certain distance, such as 200 pounds per inch.

Springs Used as a buffer between the suspension and the frame or body and used to absorb wheel movement plus support the weight of the vehicle.

SPST Single pole, single throw. A type of electrical switch.

Spun bearing Bearing shells that do not have enough crush may rotate with the shaft. The result is called a spun bearing.

Spur gear A spur gear consists of a gear blank with straight-cut teeth around its entire circumference. All gear teeth lie parallel to the centerline, or axis, of the gear. The teeth are shaped so they can mesh without slippage with a second spur gear's teeth positioned along a parallel axis.

Squib The heating element of an inflator module which starts the chemical reaction to create the gas which inflates an air bag.

Squish area This is an area of the combustion chamber where the piston nearly contacts the cylinder head. When the piston is moving upward toward the cylinder head, the air fuel mixture is rapidly pushed out of the squish area, causing turbulence. Turbulence helps mix the air and fuel, thereby ensuring a more uniform and complete combustion.

SRS Supplemental Restraint System. Another term for an airbag system.

Stabilitrak The General Motors version of ESC is called the vehicle stability enhancement system (VSES) and includes an additional level of vehicle control to the EBCM. VSES is also known as Stabilitrak.

Stabilizer bar A hardened steel bar connected to the frame and both lower control arms to prevent excessive body roll. Also called an *anti-sway* or *anti-roll bar.*

Stall speed Stall speed is the engine speed when the engine drives the impeller at the maximum speed possible without moving the turbine.

Stall A work order, also called a repair order or RO, is assigned to a technician who is best qualified to perform the work. The technician gets the keys and drives the vehicle to an assigned service bay (also called a stall), performs the proper diagnosis, gets the necessary parts from the parts department, and completes the repair.

Standard Corporate Protocol (SCP) A network communications protocol used by Ford.

Starter drive A term used to describe the starter motor drive pinion gear with overrunning clutch.

Starter solenoid A type of starter motor that uses a solenoid to activate the starter drive.

State of health (SOH) A signal sent by modules to all of the other modules in the network indicating that it is well and able to transmit.

State tax A typical payroll deduction.

State-of-charge (SOC) The state-of-charge (SOC) is the percentage of the available capacity that can be stored in a battery. A battery that has a state of charge of 100% is fully charged.

Static electricity An electrical charge that builds up in insulators and then discharges to conductors.

Static seal A seal used between two surfaces that are not moving.

Stator A name for three interconnected stationary windings inside an alternator. A rotating rotor provides a moving magnetic field and induces a current in the windings of the stator.

Steam slits In series flow systems, bleed holes or steam slits in the gasket, block, and head perform the function of letting out the steam.

Steering angle sensor (SAS) The steering angle sensor (SAS) is usually located at the base of the steering column inside the vehicle and monitors the driver's steering input from straight ahead. It also monitors how fast the driver is turning the wheel and reports this information to body control module (BCM) in most applications.

Steering dampener A steering dampener is used on many pickup trucks, sport-utility vehicles (SUVs), and many luxury vehicles designed with a high-positive-caster setting. The dampener helps prevent steering wheel kickback when the front tires hit a bump or hole in the road and also helps reduce steering wheel shimmy that may result from the high-caster setting.

Steering knuckle The inner portion of the spindle that pivots on the king pin or ball joints.

Steering offset *Scrub radius is also called steering offset by some vehicle manufacturers.*

Steering position sensor (SPS) The PSCM uses the steering position sensor (SPS) to determine the steering system on-center position.

Steering shaft torque sensor The PSCM uses the steering shaft torque sensor as a main input for determining steering direction and the amount of assist needed.

Steering shaft The part of the steering that connects the steering wheel to the steering gear assembly.

Steering stops Steering stops are the projections or built-up areas on the control arms of the front suspension designed to limit the steering movement at full lock.

Steering wheel controls Steering wheel controls are steering wheels that include buttons to allow the driver to control certain audio, vehicle information, and HVAC functions. The purpose of having steering wheel controls is to allow the driver to keep their hands on the wheel and their eyes on the road at all times.

Steering wheel position sensor A sensor that determines in which direction and how fast the steering wheel is being turned.

Stellite An alloy of nickel, chromium, and tungsten, Stellite® is nonmagnetic. Some valves use this product only on the tip of the valve to help reduce wear in places where the rocker arm contacts the valve stem on engines that do not use a roller rocker arm.

Stepper motor A motor that moves a specified amount of rotation.

Stochiometric ratio Engines consume about 15 times more air than gasoline, this ratio of air to fuel is called the stochiometric ratio. This ratio, which is 14.7:1 for gasoline, is the ratio where all the fuel is consumed in the combustion process and all the available oxygen is used.

Stock Order A stock order is used to order more parts from the supplier on a routine basis.

Stocking fee If a customer returns a part, a stocking fee may be charged based on the original purchase price.

Stoichiometric An air-fuel ratio of exactly 14.7:1. At this specific rate, all the gasoline is fully oxidized by all the available oxygen.

Stone wheel A grinding stone attached to a grinder used for cleaning, sharpening, or other similar operations.

Stop ring In synchronized construction there are a number of design variations, all are similar and include a hub, a sliding sleeve, a blocker ring, (or stop ring or synchronizer ring), keys, and springs.

Storage mode New tire-pressure warning sensors (transmitters) are shipped in storage mode. This mode prevents the battery from becoming discharged while in storage.

Straddle-mounted pinion The final drive pinion uses two opposed taper roller bearings to support a straddle-mounted pinion, but the distance between them is smaller than in the overhung design. Most noticeably, a third smaller bearing attaches to a stemlike machined pilot protruding from the gear-end of the drive pinion shaft.

Straight cut aviation snips A tin snip that is designed with curved jaws that allow a straight cut through sheet metal.

Straight time The amount of time actually spent performing a service operation.

Straightedge A straightedge is a precision-ground metal measuring gauge that is used to check the flatness of engine components when used with a feeler gauge.

Strategy-based diagnosis When diagnosing a heating and air air-conditioning system problem, most vehicle manufacturers recommend that the following steps be performed. By following the same steps each time an air air-conditioning issues is found is called strategy-based diagnosis.

Stratified mode Stratified catalyst heating mode. In this mode, there are two injections: The first injection is on the compression stroke just before combustion and the second injection is after combustion occurs to heat the exhaust. This mode is used to quickly warm the catalytic converter and to burn the sulfur from the NOx catalyst.

Stratosphere The earth's upper atmosphere. Most of the earth's ozone is located in the stratosphere.

Stress riser A nick or rust area in a spring that could cause the spring to break.

Stroke The stroke of an engine is the distance the piston travels from top dead center (TDC) to bottom dead center (BDC).

Strong hybrid Another term for "full hybrid." See *Full hybrid*.

Strut rod Suspension member used to control forward/backward support to the control arms. Also called *tension* or *compression rod* (TC rod) or *drag rod.*

Strut suspension A type of suspension system that uses struts.

Struts A structural part of a suspension that includes the shock absorber.

Stub shaft A short shaft which is part of the steering gear and attaches to the steering shaft assembly.

Stub-type frame A type of vehicle frame that only supports the front suspension and engine.

Stud removal tool A hand tool used with a breaker bar or ratchet to remove what is left of a broken stud.

Stud remover A stud removal tool grips the part of the stub above the surface and uses a cam or wedge to grip the stud as it is being rotated by a ratchet or breaker bar.

Stud A short rod with threads on both ends.

Subscription-Based Electronic Information Retrieval Systems A digital online parts catalog that allows Parts Specialists to quickly retrieve OEM and aftermarket parts information.

Suction line The line that connects the evaporator outlet to the compressor suction port.

Suction stroke The line that connects the evaporator outlet to the compressor suction port.

Sump The term sump is used to describe a location where oil is stored or held.

Sun gear The center member of a planetary gearset. The other members (planet carrier and ring) rotate around the sun gear, thus the term "planetary."

Sun load sensor A sensor that detects the amount of sunlight and radiant heat entering the vehicle.

Sun roof A sun roof is basically any kind of panel on the roof of a car that permits light, air, or both to come into a vehicle, but only if the panel is opened.

Sun shades Sun shades are fabric or screen-like material installed on the inside of the vehicle that can be raised, lowered, or moved to block the rays of the sun from entering the interior of the vehicle.

Supercharger A supercharger is an engine-driven air pump that supplies more than the normal amount of air into the intake manifold, and boosts engine torque and power. A supercharger provides an instantaneous increase in power without any delay.

Superheat The heat that warms the refrigerant is referred to as superheat. Superheat is usually measured as the actual temperature difference between the boiling point of the refrigerant at the inlet and at the outlet of the evaporator.

Supersession Bulletin A Supersession Bulletin alerts the parts specialist of a superseded part.

Supplemental brake assist (SBA) Supplemental brake assist (SBA) is a motor-driven vacuum pump that can supplement engine vacuum to the vacuum brake booster.

Suppression diode A diode installed in the reverse bias direction and used to reduce the voltage spike that is created when a circuit that contains a coil is opened and the coil discharges.

Surface finish All crankshaft journals are ground to a very smooth finish. Surface finish is measured in micro inches; and the smaller the number, the smoother the surface.

Surface-to-volume ratio This ratio is an important design consideration for combustion chambers. A typical surface to-volume ratio is 7.5:1, which means the surface area of the combustion chamber divided by the volume is 7.5.

Surge tank A reservoir mounted at the highest point in the cooling system.

SVO Vegetable oil is a triglyceride with a glycerin component joining three hydrocarbon chains of 16 to 18 carbon atoms each, called straight vegetable oil (SVO). Other terms used when describing vegetable oil include: 1. Pure plant oil (PPO)—a term most often used in Europe to describe SVO. 2. Waste vegetable oil (WVO)—this oil could include animal or fish oils from cooking. 3. Used cooking oil (UCO)—a term used when the oil may or may not be pure vegetable oil

SVR Sealed Valve Regulated. A term used to describe a type of battery that is valve regulated lead acid or sealed lead acid.

SWCAN An abbreviation for single wire CAN (Controller Area Network).

Swept area The amount of brake drum or rotor friction surface that moves past the brake linings every time the drum or rotor completes a rotation.

Switching The turning on and off of the primary circuit is called switching.

Symmetrical If the lift is the same, the cam is called symmetrical.

Synchromesh transmission fluid (STF) Manual transmission fluid (sometimes called synchromesh transmission fluid, or STF) can be defined as an ATF-like fluid that contains special friction modifiers that are intended for specific manual transmissions.

Synchronizer assemblies The real "shifting" in a synchromesh transmission takes place in the synchronizer assemblies, not the gears. Most synchronizer assemblies ride on the output shaft between two gears. A synchronizer assembly is named for the gears on either side of it, which are the two speeds that it engages.

Synchronizer keys Small, spring-loaded detent keys, also called synchronizer keys or struts, ride in slots on the outer sleeve. The stop ring has slots to match these keys. This allows the stop ring to rotate slightly, relative to the sleeve, before the keys hit the sides of their slots and stop the stop ring.

Synchronizer ring In synchronized construction there are a number of design variations, all are similar and include a hub, a sliding sleeve, a blocker ring, (or stop ring or synchronizer ring), keys, and springs.

Synthetic grease Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend Synthetic grease.

Synthetic retainers A type of retention method for holding together parts of a universal joint.

System main relays (SMRs) System Main Relays (SMRs) are heavy duty relays that control the high voltage circuit between the battery and the other components of the high voltage system. SMRs are often referred to as contactors. Depending on the design of the battery control system, the battery will contain one to three SMRs.

Tag number Sometimes the vehicle identification number (VIN) is needed to obtain the correct parts, but more often the transmission/transaxle identification number, also called the tag number.

Tail Pipe The tail pipe is the last pipe in the exhaust system and it carries the exhaust fumes out from under the vehicle and into the atmosphere.

Tandem Solenoid (TS) Starter has two solenoids allows the starter to engage the flywheel of the engine when it is still moving, such as when the vehicle is coasting to a stop. A tandem solenoid starter design is also able to start the engine within 0.5 and 1.5 seconds, compared to about 3 seconds for a conventional starter.

Tandem-diaphragm vacuum booster Dual-diaphragm or tandem-diaphragm vacuum boost are designed to increase the total area without increasing the physical diameter of the booster.

Tap test The simple tap test involves tapping (not pounding) on the catalytic converter using a rubber mallet. If the substrate inside the converter is broken, the converter rattles when hit. If the converter rattles, a replacement converter is required.

Tap A metal cutting tool used to create threads in metal after a hole of the proper size has been drilled.

Taper face ring A taper face ring contacts the cylinder wall at the lower edge of the piston ring.

Tapered roller bearings A type of antifriction bearing that uses tapered rollers between the inner and outer races.

Task manager On OBD-II systems, the powertrain control module (PCM) incorporates a special segment of software. On Ford and GM systems, this software is called the diagnostic executive. On Chrysler systems, it is called the task manager.

Teacher A role played by a mentor.

Team leader An experienced technician who helps advise a small group of technicians who are paid according to the total amount of work completed by all members of the team.

Technical service bulletin (TSB) When a problem has a correction, the vehicle manufacturer releases a technical service bulletin (TSB), which details the repair.

Technician (tech) An Automotive Technician is educated and trained to inspect vehicles, remove and install vehicle components, repair vehicles, and has advanced understanding and knowledge the various vehicle operations.

Telematics Telematics is an interconnected system that combines telecommunications (cellular systems) and GPS navigation satellite system technology. Telematics is a method of monitoring a vehicle by combining a GPS system with on-board diagnostic systems.

Telescoping steering column A steering column that can be adjusted toward and away from the driver.

Telltale light The ESC lamp, called a telltale light, is required to remain on for as long as the malfunction exists, whenever the ignition is in "On" ("Run") position. The ESC malfunction telltale will flash to indicate when the ESC system is operating to help restore vehicle stability.

Temperature Temperature is the measure of the level of energy. Temperature is measured in degrees.

Temperature-blend door A door in the A/C and heat system that mixes cold and hot air to get the desired temperature.

Tensile strength The maximum stress used under tension (lengthwise force) without causing failure.

Terminal The metal end of a wire which fits into a plastic connector and is the electrical connection part of a junction.

Terminating resistors Resistors placed at the end of a high-speed serial data circuit to help reduce electromagnetic interference.

Test identification (TID) The global (generic) data is used by most state emission programs. Global OBD-II displays often use hexadecimal numbers. Hexadecimal coding is also used to identify tests (test identification [TID] and component identification [CID]).

Test light A light used to test for voltage. Contains a light bulb with a ground wire at one end and a pointed tip at the other end.

Thermactor pump The SAI pump, also called an AIR pump, a smog pump, or thermactor pump, is mounted at the front of the engine and can be driven by a belt from the crankshaft pulley.

Thermistor A resistor that changes resistance with temperature. A positive-coefficient thermistor has increased resistance with an increase in temperature. A negative-coefficient thermistor has increased resistance with a decrease in temperature.

Thermocouple Two dissimilar metal when connected and heated creates a voltage. Used for measuring temperature.

Thermoelectricity The production of current flow created by heating the connection of two dissimilar metals.

Thermostat A device that controls the flow in a system such as the engine cooling system based on temperature.

Thermostatic spring A second type of thermal fan has a thermostatic spring added to the silicone coupling fan drive.

Thickness gauge A feeler gauge (also known as a thickness gauge) is an accurately manufactured strip of metal that is used to determine the gap or clearance between two components.

Thickness variation (TV) Lack of parallelism, also called thickness variation (TV), is a variation in the thickness of the rotor when it is measured at several places around its circumference.

Thimble design A typical zirconia oxygen sensor has the sensing element in the shape of a thimble; therefore, it is often referred to as one of the following: 1. Thimble design 2. Cup design and Finger design.

Thimble The part of a micrometer that is rotated to move the spindle.

Thin-film-transistor (TFT) Thin-film-transistor (TFT) liquid-crystal display (LCD) is a type of a liquid-crystal display that uses thin-film-transistor (TFT) technology This type of display has enhanced image qualities and contrast compared to simple light-driven LCDs.

Third gear In third gear, the shift linkage centers the 1–2 synchronizer sleeve and moves the 3–4 synchronizer sleeve back toward the third speed gear. The synchronizer assembly locks the third speed gear to the output shaft.

Third-class lever A type of lever where the fulcrum is located at the end of the lever and the force is applied to the middle of the lever.

Threaded insert A type of thread repair where the original threads are replaced by an insert that contains the same size threads as the original on the inside of the insert.

Three cs (concern, cause, correction) After the service work has been performed, the service technician should then fill out the work order and describe what work was performed. These are called the “three Cs.” Concern—Write on the work order what was done to confirm the customer’s concern. Cause—The service technician should write the cause of the problem. Correction—The service technician should write what was done to correct the problem.

Three-angle valve job A three-angle valve job means that the valve seats are ground three times.

(Three) 3-minute charge test A method used to test batteries. Not valid for all types of batteries.

Three-position actuator A three-position actuator is able to provide three air door positions, such as the bi-level door, which could allow defrost only, floor only, or a mixture of the two.

Three-way converter (TWC) In a three-way (catalytic) converter (TWC) all three exhaust emissions (NOx, HC, and CO) are converted to carbon dioxide (CO2) and water (H2O).

Threshold voltage Another name for barrier voltage or the voltage difference needed to forward bias a diode.

Throating angle A 60-degree stone or cutter to remove material right below the valve seat to increase flow in or out of the combustion chamber. This angle is called the throating angle.

Throttle position (TP) sensor Signals the computer as to the position of the throttle.

Throttle-body temperature (TBT) Some engines use a throttle-body temperature (TBT) sensor to sense the temperature of the air entering the engine, instead of an intake air temperature sensor.

Through bolts The bolts used to hold the parts of a starter motor together. The long bolts go though field housing and into the drive-end housing.

Throws The term used to describe the number of output circuits there are in a switch.

Thrust bearing A thrust bearing supports these loads and maintains the front-to-rear position of the crankshaft in the block.

Thrust line The direction the rear wheels are pointed as determined by the rear wheel toe.

Thrust plate Each camshaft must have some means to control the shaft end thrust. One method is to use a thrust plate between the camshaft drive gear or sprocket and a flange on the camshaft.

Tie rods A parallelogram-type linkage uses four tie rods, two inner and two outer (left and right).

Tilt steering column A type of steering column that can be moved upward or downward to fit the driver.

Time base The time defined per each horizontal division on the display.

Time-of-use (TOU) A time-of-use (TOU) electric rate plan is needed to achieve the largest savings for charging. A TOU plan offers lower electric rates during off-peak periods (usually 11 PM until 5 AM), with higher rates for using electricity during high-demand times. Because most EVs are parked at home overnight, TOU rates are a wise choice for most EV owners.

Tin snips A hand tool used to cut sheet metal, thin cardboard, or similar material.

Tinnerman nuts Used to keep the brake drums on at the assembly plant. Can be removed and discarded when servicing the drum brake for the first time.

Tire rotation A term used to describe moving wheel/tire assemblies from one position on a vehicle to another.

Tire slip The difference between the actual speed and the rate at which the tire tread moves across the road surface.

Tire-pressure monitoring system (TPMS) A tire-pressure monitoring system (TPMS) is a system that detects a tire that has low inflation pressure and warns the driver.

Toe The inward or outward angle of the front or rear wheels as viewed from overhead.

Tolerance adjustment An alignment method that involves loosening all suspension mounting fasteners and retightening.

Tone generator tester A type of tester used to find a shorted circuit that uses a tone generator. Headphones are used along with a probe to locate where the tone stops which indicates were in the circuit the fault is located.

TOOT Turning radius is also called toe-out on turns, abbreviated TOT or TOOT, and is determined by the angle of the steering knuckle arms.

Top dead center (TDC) The highest point in the cylinder that the piston can travel. The measurement from bottom dead center (BDC) to TDC determines the stroke length of the crankshaft.

Topping angle A part of the three-angle valve job that is the third angle and uses a 30-degree stone or cutter to smooth the transition between the valve seat and the cylinder head, again to increase flow in or out of the combustion chamber. This angle is called the topping angle.

Torque angle To have a more constant clamping load from bolt to bolt.

Torque arm An arm that attaches the rear differential assembly to the body of the vehicle.

Torque converter clutch (TCC) Lockup torque converters reduce slippage by using a torque converter clutch (TCC) to lock the impeller to the cover (shell).

Torque steer Torque steer occurs in front-wheel-drive vehicles when engine torque causes a front wheel to change its angle (toe) from straight ahead. The resulting pulling effect of the vehicle is most noticeable during rapid acceleration, especially whenever upshifting of the transmission creates a sudden change in torque.

Torque wrench A wrench that registers the amount of applied torque.

Torque A twisting force measured in pounds-feet (lb.-ft) or Newton-meters (N-m) which may result in motion.

Torque-to-yield (TTY) Many engines use a tightening procedure called the torque-to-yield (TTY) method. The purpose of the TTY procedure is to have a more constant clamping load from bolt to bolt.

Torsion bar A type of spring in the shape of a straight bar. One end is attached to the frame of the vehicle, and the opposite end is attached to a control arm of the suspension. When the wheels hit a bump, the bar twists and then untwists.

Torsional dampers Around the center hub of the clutch disc are torsional dampers that absorb the initial shock of engagement and help dampen engine-firing in pulses being transmitted into and through the transmission/transaxle.

Total circuit resistance The total resistance in a circuit.

Total Environmental Warming Impact (TEWI) The Total Environmental Warming Impact (TEWI) index rates the impact of various refrigerants along with the energy required to per-form the cooling operation.

Total indicator runout (TIR) In grinding a valve seat, the maximum acceptable variation is 0.002 inch and called the total indicator runout (TIR) of the valve seat.

Total toe The total (combined) toe of both wheels, either front or rear.

Touch screen A type of drive information screen that uses capacitive circuits to detect the presence of a finger pointing to an icon or symbol on the screen.

TPC Tire Performance Criteria.

Track rod A horizontal steel rod or bar attached to rear axle housing at one end and the frame at the other to keep the center of the rear axle centered on the body. Also known as a *panhard rod.*

Traction control (TC) The electromechanical parts used to control wheel slip during acceleration.

Trade number The number stamped on an automotive light bulb. All bulbs of the same trade number have the same candlepower and wattage, regardless of the manufacturer of the bulb.

Trailing arm A rear suspension arm that attaches to the frame or body in front of the rear axle.

Trailing shoe The rear facing drum brake shoe on a leading/trailing type of drum brake.

Trainee a person undergoing training for a particular job or profession.

Tramp An up and down vibration of a tire/wheel assembly usually due to out-of-round tire or out-of-balance condition.

Transaxle A front-wheel-drive vehicle uses a transaxle, which is a combination of a transmission and differential in one assembly. Drive axle shafts then transfer the engine torque to the front drive wheels from the output of the transaxle.

Transceiver A transceiver is inside the vehicle and receives the signal transmitted by the transponder in the key. A “transceiver” functions as both a reviewer and a transmitter.

Transducers An electrical device that changes a varying pressure into a variable voltage.

Transfer cable A transfer cable transmits force to an intermediate lever or equalizer to the application cables.

Transfer case There are many types of methods of powering all four wheels. Many include a transfer case to split engine torque to both the front and the rear wheels.

Transistor A semiconductor device that can operate as an amplifier or an electrical switch.

Transmission band A transmission band stops and holds one planetary gear set member so that another member can react against the held member and develop output motion.

Transmission case The center housing is usually referred to as the transmission case.

Transmission fluid temperature The transmission fluid temperature (TFT), also called transmission oil temperature (TOT), sensor is an important sensor for the proper operation of the automatic transmission.

Transmission range sensor (TRS) A multi-contact switch operated by the manual shift lever.

Transmission temperature sensor (TTS) A Negative Temperature Coefficient (NTC) thermistor used to measure temperature of the transaxle.

Transmitter ID A replacement TPMS transmitter has an 8-digit number, called the transmitter ID, on each valve/transmitter assembly.

Transponder The transponder is mounted in the key or the body of the key fob. A transponder has an antenna, which consists of a coil of wire, as well as a circuit board containing the processing electronics and data memory.

TREAD Act The Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act requires that all vehicles be equipped with a tire-pressure monitoring system that will warn the driver in the event of an underinflated tire.

Tread The rubber part of a tire that touches the road.

Trigger level The voltage level that a waveform must reach to start display.

Trigger slope The voltage direction that a waveform must have to start display. A positive slope requires the voltage to be increasing as it crosses the trigger level; a negative slope requires the voltage to be decreasing.

Trouble light A light used to help a service technician see while performing service work on a vehicle.

Troxler effect The Troxler effect is a visual effect where an image remains on the retina of the eye for a short time after the image has been removed. The effect was discovered in 1804 by Igney Paul Vital Troxler (1780 1866), a Swiss physician. Because of the Troxler effect, headlight glare can remain on the retina of the eye and create a blind spot.

Trunnions The four arms of a typical universal joint.

Trust The belief in another person’s reliability, ability, or confidence that the person will do and/or act based on their statements. All this conversation should be based on trust and the relationship you have built with the customer during his or her experience with you and the shop.

Tube-nut wrench Line wrenches are also called flare-nut wrenches, fitting wrenches, or tube-nut wrenches and are designed to grip almost all the way around a nut used to retain a fuel or refrigerant line, and yet be able to be installed over the line.

Tuftriding To improve wear resistance, some manufacturers harden the crankshaft journals. Methods used to harden the crankshaft journals includes Tuftriding, another variation of this process, involves heating the crankshaft in a molten cyanide salt bath. Tuftriding is a trade name of General Motors.

Turbine pump A turbine pump is the most common because it tends to be less noisy. Sometimes called turbine, peripheral, and side-channel, these units use an impeller that accelerates the fuel particles before actually discharging them into a tract where they generate pressure via pulse exchange.

Turbine The turbine is located on the engine side of the converter. The impeller vanes pick up fluid in the converter housing and direct it toward the turbine.

Turbo lag The delay between acceleration and turbo boost is called turbo lag

Turbocharger An exhaust-powered supercharger.

Turning torque The drive pinion nut is then tightened farther until the turning torque is within specifications.

Turns ratio The ratio between the number of turns used in the primary winding of the coil to the number of turns used in the secondary winding. In a typical ignition coil the ratio is 100:1.

Twin clutch transmission Another term used to describe a dual-clutch automatic transmission/transaxle.

Twin I-beam A twin I-beam front suspension was used for over 30 years on Ford pickup trucks and vans, beginning in the mid1960s. Strong steel twin beams that cross provide independent front suspension operation with the strength of a solid front axle.

Twist Form into a bent, curling, or distorted shape. The head should be checked in five planes. Checking the cylinder head gasket surface with a precision straightedge in five planes checks the head for warpage, distortion, bend, and twist.

Twisted pair A pair of wires that are twisted together from 9 to 16 turns per foot of length. Most are twisted once every inch (12 per foot) to help reduce electromagnetic interference from being induced in the wires as one wire would tend to cancel out any interference pickup up by the other wire.

UART-based protocol (UBP) Newer Fords use the CAN for scan tool diagnosis, but still retain SCP and UART-based protocol (UBP) for some modules.

UCO Vegetable oil is a triglyceride with a glycerin component joining three hydrocarbon chains of 16 to 18 carbon atoms each, called straight vegetable oil (SVO). Other terms used when describing vegetable oil include: 1. Pure plant oil (PPO)—a term most often used in Europe to describe SVO. 2. Waste vegetable oil (WVO)—this oil could include animal or fish oils from cooking. 3. Used cooking oil (UCO)—a term used when the oil may or may not be pure vegetable oil

U-joints Universal joints.

ULSD Ultra-Low-Sulfur Diesel. Diesel fuel with a maximum sulfur content of 15 parts per million.

Ultracapacitor Ultracapacitor cells are based on double-layer technology, in which two activated carbon electrodes are immersed in an organic electrolyte. The electrodes have a very large surface area and are separated by a membrane that allows ions to migrate, but prevents the electrodes from touching.

Ultrasonic cleaning Ultrasonic cleaning is used to clean small parts that must be absolutely clean, such as hydraulic lifters and diesel injectors.

Ultrasonic object sensors Ultrasonic object sensors built into the fender and front and rear bumper assembly. The ultrasonic proximity detectors are used to measure the distances to nearby objects. The sensors send out acoustic pulses and a control unit measures the return interval of each reflected signal, calculating object distances.

Ultraviolet (UV) radiation Ultraviolet (UV) radiation is divided into three. The designations include:

- Designation "A," abbreviated UVA, is not absorbed by the ozone layer and generally is not damaging to bio-logical organisms.
- Designation "B," abbreviated UVB, is only partially absorbed by the ozone layer and can cause damage to biological organisms.
- Designation "C," abbreviated UVC, is almost completely absorbed by the ozone layer and represents little, if any, health concerns.

UNC (Unified national Coarse) A type of thread used on fasteners.

Underground storage tank (UST) An underground storage tank system (UST) is a tank and any underground piping connected to the tank. Used oil must be stored in compliance with an existing underground storage tank (UST)

Understeering Understeering is when the front of the vehicle tends to continue straight ahead when turning, a condition that is also called plowing or tight. If this condition is detected during a right turn, the ESC system would apply the right rear wheel brake to bring the vehicle back under control.

UNF (Unified national Fine) Unified national fine.

Unibody Unit-body construction (sometimes called unibody) is a design that combines the body with the structure of the frame. The body is composed of many individual stamped-steel panels welded together. The strength of this type of construction lies in the shape of the assembly.

Unit-body Unit-body construction (sometimes called unibody) is a design that combines the body with the structure of the frame. The body is composed of many individual stamped-steel panels welded together. The strength of this type of construction lies in the shape of the assembly.

Universal joint A joint in a steering or drive shaft that allows torque to be transmitted at an angle.

Upselling Upselling refers to the attempt to increase sales up and beyond what the customer first wanted.

Urea A chemical used to reduce oxides of nitrogen emission on diesel engines that use an SCR emission control system.

Used oil Any petroleum-based or synthetic oil that has been used.

Utility knife A handheld knife that uses replaceable blades.

UTQGS Uniform Tire Quality Grading System.

Vacuum bleeding Using a vacuum source to draw air from a brake hydraulic system.

Vacuum servo A vacuum controlled parking brake release mechanism controlled by an electrical solenoid.

Vacuum test Vacuum is pressure below atmospheric pressure and is measured in inches (or millimeters) of mercury (Hg).

Vacuum Any pressure less than atmospheric pressure (14.7 psi).

Valence ring The outer most ring or orbit of electrons around a nucleus of an atom.

Valve (camshaft) overlap Is the number of degrees of crankshaft rotation during which both intake and exhaust valves are open.

Valve body A valve body is where most of the valves in a transmission are located, and is attached to the case with bolts. Valve bodies can be either cast aluminum or cast iron.

Valve duration Valve duration is the number of degrees by which the crankshaft rotates when the valve is off the valve seat.

Valve face The location on a valve where the valve rests on the valve seat of the cylinder head.

Valve float The job of the hydraulic lifter is to take up all clearance in the valve train. Occasionally, engines are run at excessive speeds. This tends to throw the valve open, causing valve float. During valve float, clearance exists in the valve train. The hydraulic lifter takes up this clearance as it is designed to do.

Valve guides The valve guide supports the valve stem so that the valve face will remain perfectly centered, or concentric, with the valve seat

Valve lash Valve train clearance is also called valve lash, which is needed to help compensate for thermal expansion and wear. Valve train clearance must not be excessive, or it causes noise or results in premature failure.

Valve seat inserts The valve guide supports the valve stem so that the valve face will remain perfectly centered, or concentric, with the valve seat. Removable or pressed-in valve guides and valve seat inserts are always used in aluminum heads.

Valve seat The place in the cylinder head where the valve rests when closed.

Valve spring inserts (VSI) Also called shims and are used to adjust the installed height of valve springs.

Valve spring surge The tendency of a valve spring to vibrate.

Valve spring Holds the valve against the seat.

Valve stem height Valve stem height is the distance the valve stem is above the spring seat. Valve stem height is a different measurement from installed height.

Vane compressor Vane compressor has vanes that contact the rotor housing at each end, and they slide to make a seal at each end as the rotor turns.

Vane phaser A vane phaser is an actuator used in most variable valve timing systems and uses a rotor with four vanes, which is connected to the end of the camshaft. The rotor is located inside the stator, which is bolted to the cam sprocket. The stator and rotor are not connected. Oil pressure is controlled on both sides of the vanes of the rotor, which creates a hydraulic link between the two parts. The oil control valve varies the balance of pressure on either side of the vanes and thereby controls the position of the camshaft. A return spring is used under the reluctor of the phaser to help return it to the home or zero degrees position.

Vapor lock At higher temperatures, liquid gasoline can easily vaporize, which can cause vapor lock. Vapor lock is a lean condition caused by vaporized fuel in the fuel system.

Variable force solenoids (VFS) Variable force solenoids (VFS) is a type of electronic pressure regulation.

Variable fuel sensor General Motors, Ford, Chrysler, Mazda, and Honda are a few of the manufacturers offering E85-compatible vehicles. E85- vehicles use fuel system parts designed to withstand the additional alcohol content, modified driveability programs that adjust fuel delivery and timing to compensate for the various percentages of ethanol fuel, and a fuel compensation sensor that measures both the percentage of ethanol blend and the temperature of the fuel. This sensor is also called a variable fuel sensor.

Variable rate springs A type of valve spring that provides a variable force depending on how much it is compressed.

Variable ratio A steering gear design that provides a variable steering gear ratio.

Variable valve timing (VVT) On newer engines, the camshaft can have the capability of a variable valve-timing feature that changes the camshaft specifications during different operating modes.

Variable valve timing and lift electronic control (VTEC) A valve train control system developed by Honda Motor Company to enhance engine output and efficiency over a wide RPM range.

Variable A variable is a measurement of something that changes, such as engine speed or time.

Variable-delay wipers Windshield wipers whose speed can be varied.

Variable-position actuator A variable-position actuator is capable of positioning a valve in any position.

Variators Two variable width pulleys to change the gear ratio in a continuously variable transmission.

Vehicle emissions control information (VECI) This sticker is located under the hood on all vehicles and includes emission-related information that is important to the service technician.

Vehicle identification number (VIN) Alphanumeric number identifying vehicle type, assembly plant, powertrain, etc.

Vehicle safety certification label A vehicle safety certification label is attached to the left side pillar post on the rearward-facing section of the left front door. This label shows the month and year of manufacture, the VIN, as well as the gross vehicle weight rating (GVWR), which is the maximum weight of a vehicle as specified by the OEM.

Vehicle speed (VS) sensor The vehicle speed (VS) sensor is used by the electronic brake control module (EBCM) to help control the suspension system

Vehicle stability enhancement system (VSES) A General Motors term used to describe one type of electronic stability control system.

Vent port The Society of Automotive Engineers (SAE) term for the front port of a master cylinder, also called the compensating port or bypass.

Vent valve Blow-off valve (BOV). Also called a dump valve or vent valve, the BOV features an adjustable spring design that keeps the valve closed until a sudden release of the throttle. The resulting pressure increase opens the valve and vents the pressurized air directly into the atmosphere.

V-FFV Virtual Flexible Fuel Vehicle. This fuel system design does not use a fuel compensation sensor and instead uses the vehicle's oxygen sensor to adjust for different fuel compositions.

Vibration damper A device designed to compensate for and reduce the effects of torsional vibration in the crankshaft of an engine. A vibration damper is also called a harmonic balancer.

Vibration order A description used to help define a vibration.

Virtual display A virtual display is a dash that allows the driver to select what data is being displayed. Many vehicles are equipped with an LCD dash display that can be changed to display various functions based on the driver's preference. This allows the dash display to be totally customized to what the driver wishes to see displayed.

Viscosity Resistance to flow of an oil. A high-viscosity oil is thicker than a low-viscosity oil.

Viscosity index (VI) An index of the change in viscosity between the cold and hot extremes.

Viscous coupling A type of device used to allow a limited difference in speed of two axles.

Vise-Grip A brand name for locking pliers.

Visual inspection A visual inspection of the under-hood items includes items that are part of the heating and air conditioning system.

Voice activation Most recent vehicles include voice commands, commonly called voice activation, that can be used to perform various functions or settings in the vehicle.

Voice inflection Voice inflection is a variation in the pitch, timing, or loudness of the voice. Pitch is made up of the highs and lows of your voice.

Voice recognition A system which uses a microphone and a speaker connected to an electronic module which can control the operation of electronic devices in a vehicle.

Volatile organic compounds (VOC) Volatile organic com-pounds (VOC) are gases emitted by paints, solvents, aerosol sprays, cleaners, glues, permanent markers, pesticides, and fuels.

Volatility A measurement of the tendency of a liquid to change to vapor. Volatility is measured using RVP, or Reid Vapor Pressure.

Voltage drop Voltage loss across a wire, connector, or any other conductor. Voltage drop equals resistance in ohms times current in amperes (Ohm's law).

Voltmeter An electrical test instrument used to measure volts (unit of electrical pressure). A voltmeter is connected in parallel with the unit or circuit being tested.

Volt Unit of electrical pressure.

Volumetric efficiency The ratio between the amount of air-fuel mixture that actually enters the cylinder and the amount that could enter under ideal conditions expressed in percent.

Vortex flow Vortex flow is the flow of the fluid from the impeller to the turbine and back to the impeller.

VRLA Valve-regulated lead–acid battery. A sealed battery that is both spill proof and leakproof. AGM and gelled electrolyte are both examples of VRLA batteries.

Wander A type of handling which requires constant steering wheel correction to keep the vehicle going straight.

Wankel engine The rotary engine is also a Wankel engine named after its inventor, Felix Heinrich Wankel (1902–1988), a German inventor.

Warehouse distributor A jobber or parts retailer usually gets parts from a large regional warehouse distributor. The warehouse distributor can either purchase parts directly from the manufacturer or from an even larger central warehouse.

Warpage Warpage is to bend out of shape. The head should be checked in five planes. Checking the cylinder head gasket surface with a precision straightedge in five planes checks the head for warpage, distortion, bend, and twist.

Warranties A guarantee that is issued to a customer by the manufacturer, promising to replace or repair a qualified item within a specified period of time.

Washcoat A substrate that is coated with a porous aluminum material called the washcoat, which makes the surface rough.

Washers Flat or shaped pieces of round metal with a hole in the center used between a nut and a part or casting.

Wastegate e. A wastegate is a valve similar to a door that can open and close. It is a bypass valve at the exhaust inlet to the turbine, which allows all of the exhaust into the turbine, or it can route part of the exhaust past the turbine to the exhaust system.

Waste-spark ignition Waste-spark ignition is another name for distributorless ignition system (DIS) or electronic ignition (EI). Waste-spark ignition was introduced in the mid-1980s and uses the onboard computer to fire the ignition coils.

Water (H2O) During combustion, the HC combines with the air to form water (H2O) and carbon dioxide (CO2), plus nitrogen (N2) and some other non-desirable gases.

Water fade A lack of braking caused by water getting between the friction material and the brake drum or rotor.

Water Jacket coolant is circulated by a water pump through passages in the cylinder block and head called water jackets.

Water pump pliers For gripping larger objects, a set of multigroove adjustable pliers is a commonly used tool of choice by many service technicians. Originally designed to remove the various size nuts holding rope seals used in water pumps, the name water pump pliers is also used.

Water pump A mechanical device responsible for circulating coolant through a liquid cooling system.

Water-fuel separator Between the fuel tank and the lift pump is a water-fuel separator. Water is heavier than diesel fuel and sinks to the bottom of the separator.

Watt's law The formula for Watts is the voltage times the amperes in the circuit that represents the electrical power in the circuit.

Watt An electrical unit of power; 1 watt equals current (amperes) x voltage (1/746 hp). Named after James Watt, a Scottish inventor.

Watts linkage An element used in the rear suspension of some vehicles to keep the rear axle centered under the body.

Ways Places where the disc brake caliper contacts on a sliding-type caliper design.

Wear bars *Wear indicators (wear bars) are strips of bald tread that show when the tread depth is down to 2/32 inch, which is the legal limit in many states.*

Weight bias The amount of weight on the front compared to the rear of a vehicle.

Weight The weight of an object is the force of gravity on the object and may be defined as the mass times the acceleration of gravity. Therefore, mass means the property of an object and weight is a force.

Weld pool An arc is struck between the end of a wire electrode and the workpiece, melting both to form a puddle of molten steel, called the weld pool.

Welsh plugs Core holes left in the external block wall are machined and sealed with soft core plugs or expansion plugs (also called freeze plugs or Welsh plugs).

Wet compression test If the compression test reading indicates low compression on one or more cylinders, add three squirts of oil to the cylinder and retest. This is called a wet compression test, when oil is used to help seal around the piston rings.

Wet cylinder sleeve Some engines have die-cast aluminum blocks with replaceable cast-iron cylinder sleeves. The sleeves are sealed at the block deck and at their base. Coolant flows around the cylinder sleeve, so this type of sleeve is called a wet cylinder sleeve.

Wet sump In most engines, oil is held in the oil pan and the oil pump draws the oil from the bottom. This type of system is called a wet sump oil system.

Wheel rate Similar to spring rate, but includes the ratio of wheel travel to spring travel to determine the force per inch rate.

Wheel speed sensors (WSS) The purpose and function of wheel speed sensors, abbreviated WSS, is to monitor the speed of the wheels.

WHMIS Workplace Hazardous Materials Information Systems.

Wide-band O2S Wide-band O2S sensors are used by most vehicle manufacturers to ensure that the exhaust emissions can meet the current standard. A wide-band oxygen sensor is capable of supplying air-fuel ratio information to the PCM. Compared with a conventional zirconia oxygen sensor, the wide-band oxygen sensor has the following features. 1. The ability to detect exhaust air-fuel ratio from as rich as 10:1 to as lean as 23:1 in some cases 2. Cold start activity within as little as 10 seconds

Windage tray Tray that is sometimes installed in engines to eliminate the oil churning problem.

Windshield wipers The assembly of motor, motor control, operating linkage plus the wiper arms and blades which are used to remove rain water from the windshield.

Wire brush wheel A wire brush wheel is often mounted on one end of a grinder and is used for cleaning parts and other similar operations.

Wiring schematic A drawing showing the wires and the components in a circuit using symbols to represent the components.

Witness mark Discoloration or scraping marks that show where two components have been touching or rubbing together.

Work hardened Bearing metals, like other metals, tend to fatigue and break after being flexed or bent a number of times. Flexing starts fatigue, which shows up as fine cracks in the bearing surface because the bearing material became work hardened.

Work light See Trouble Light.

Work order Contains all vehicle and customer information plus what service work is requested by the customer. Also called a *repair order*.

Work place charging (WPC) Work place charging (WPC) is very popular because the vehicle owner can charge their vehicle while at work and usually for free.

Work The transfer of energy from one physical system to another. Actually moving an object is work.

Worldwide harmonized Light vehicles Test Procedure (WLTP) In the United States the Environmental Protection Agency (EPA) estimates of electric vehicle range, while in Europe electric vehicle range uses the Worldwide harmonized Light vehicles Test Procedure (WLTP).

Worm gear A type of gear used in an older type of steering gear, which is attached to the steering shaft.

Worm holes Valve bodies have many fluid passages for the various transmission hydraulic circuits cast into them. These are sometimes called worm holes or worm tracks.

Worm tracks Valve bodies have many fluid passages for the various transmission hydraulic circuits cast into them. These are sometimes called worm holes or worm tracks.

WOW display A dash display when it first comes on and lights all possible segments. Can be used to test the dash display for missing lighted segments.

Wrench A hand tool used to grasp and rotate a threaded fastener.

Wrist pin The piston is attached to the connecting rod with a piston pin, also called a wrist pin. The piston pin is allowed to have a rocking movement because of a swivel joint at the piston end of the connecting rod.

Wrought alloys Aluminum and aluminum alloys that are mechanically shaped are called wrought alloys.

WVO Vegetable oil is a triglyceride with a glycerin component joining three hydrocarbon chains of 16 to 18 carbon atoms each, called straight vegetable oil (SVO). Other terms used when describing vegetable oil include: 1. Pure plant oil (PPO)—a term most often used in Europe to describe SVO. 2. Waste vegetable oil (WVO)—this oil could include animal or fish oils from cooking. 3. Used cooking oil (UCO)—a term used when the oil may or may not be pure vegetable oil

WWFC World Wide Fuel Charter. A fuel quality standard developed by vehicle and engine manufacturers in 2002.

Yaw rate sensor An input sensor usually located in the center of the vehicle that detects yaw as part of an electronic suspension system.

ZDDP The levels of phosphate and zinc found in engine oils are commonly referred to as zinc dialkyl dithiophosphate or (ZDDP or ZDP).

Zener diode A specially constructed (heavily doped) diode designed to operate with a reverse-bias current after a certain voltage has been reached. Named for Clarence Melvin Zener.

Zerk fitting A name for a chassis grease fitting, also known as an alemite fitting (named for Oscar U. Zerk).

Zero-emission vehicles (ZEVs) Electric vehicles that use battery power alone to propel the vehicle are called zero-emission vehicles (ZEVs).

Zirconia A zirconia oxygen sensor is made of zirconium dioxide (ZrO2), an electrically conductive material capable of generating a small voltage in the presence of oxygen.

ZrO2 A zirconia oxygen sensor is made of zirconium dioxide (ZrO2), an electrically conductive material capable of generating a small voltage in the presence of oxygen.

Zyglo To be seen, fluorescent penetrant requires a black light. It can be used on iron, steel, or aluminum parts. Cracks show up as bright lines when viewed with a black light. The method is commonly called Zyglo, a trademark of the Magnaflux Corporation.